QUEENSLAND GEOLOGY 12

Geology of the Auburn Arch, southern Connors Arch and adjacent parts of the Bowen Basin and Yarrol Province, central Queensland

2009

IW Withnall, LJ Hutton, RJ Bultitude,
FE von Gnielinski & IP Rienks

veryresourceful

Queensland Government

GEOLOGY OF THE AUBURN ARCH, SOUTHERN CONNORS ARCH AND ADJACENT PARTS OF THE BOWEN BASIN AND YARROL PROVINCE, CENTRAL QUEENSLAND

I.W. Withnall, L.J. Hutton, R.J. Bultitude, F.E. von Gnielinski & I.P. Rienks

Authors' address:

I.W. Withnall, L.J. Hutton, R.J. Bultitude, F.E. von Gnielinski
Geological Survey of Queensland
Mines and Energy
Department of Employment, Economic Development and Innovation
Block A, 80 Meiers Rd
Indooroopilly QLD 4068

I.P. Rienks
Queensland Department of Employment, Economic Development and Innovation
PO Box 1475
Coorparoo QLD 4151

ISSN 1035-4840
ISBN 978-1-921489-07-5

Issued: April, 2009

REFERENCE: WITHNALL, I.W., HUTTON, L.J., BULTITUDE, R.J., von GNIELINSKI, F.E. & RIENKS, I.P., 2009: Geology of the Auburn Arch, Southern Connors Arch and adjacent parts of the Bowen Basin and Yarrol Province, Central Queensland. *Queensland Geology*, **12**.

GEOLOGY OF THE AUBURN ARCH, SOUTHERN CONNORS ARCH AND ADJACENT PARTS OF THE BOWEN BASIN AND YARROL PROVINCE, CENTRAL QUEENSLAND

I.W. Withnall, L.J.Hutton, R.J. Bultitude, F.E. von Gnielinski & I.P. Rienks

CONTENTS

FIGURES

TABLES

MAPS(INCLUDED ON CD AS PDF FILES)

15. Rawbelle Special 1:100 000 Geology Map
17. Rookwood 1:100 000 Geology Map
18. Scoria 1:100 000 Geology Map
19. St Lawrence 1:100 000 Geology Map
20. Theodore 1:100 000 Geology Map

SUMMARY

This report describes the geology of part of central eastern Queensland from Mackay to Mundubbera covering twenty 1:100 000 map sheet areas with a total area of 27 500km^2. The major structural provinces within the area are the Connors and Auburn Arches and the Gogango Overfolded Zone, which are parts of the northern New England Orogen. A narrow strip of rocks of the Bowen Basin flank them on the eastern side and separate them from the Yarrol Province. They are flanked on the west by the main part of the Bowen Basin.

The Connors Arch in the north and Auburn Arch in the south both consist of early Carboniferous to Permian mafic to felsic volcanic and plutonic rocks that are herein interpreted to have formed an Andean volcanic arc west of a forearc basin represented by the Yarrol Province.

In the Auburn Arch, a metamorphic basement of unknown age is intruded by deformed early Carboniferous granitic rocks. The lower part of the overlying succession, the Torsdale Volcanics, consist mainly of felsic ignimbrite with SHRIMP dates in range 325–300Ma. These are overlain by the Camboon Volcanics, which pass upwards through a succession of alternating felsic ignimbrite and mafic lava packages into dominantly basaltic rocks. Unconformities marked by conglomerates that locally overlie small granitic bodies have been observed, but these may be local and/or diachronous and the dominantly mafic and felsic successions of the Torsdale and Camboon Volcanics may overlap in age. Numerous plutons ranging from gabbro to granite were emplaced synchronously with the volcanic rocks.

SHRIMP U-Pb zircon dating suggests at least three major magmatic episodes in the Connors Arch. An early Carboniferous (older than ~330Ma) mafic to felsic magmatic event is represented by volcanic and minor plutonic rocks. A late Carboniferous felsic magmatic event at around 310–320Ma is represented by extensive ignimbritic units and small granitic plutons. These are separated by a regional unconformity from a more heterogeneous assemblage of volcanic and sedimentary rocks that contain some local unconformities. SHRIMP U-Pb zircon ages range from 300 to 285Ma. Most of the plutonic rocks (gabbro to granite) of the Urannah Batholith were probably also emplaced during this interval. The oldest rocks in the interval (Leura Volcanics) show a complete range of compositions from basalt through andesite to rhyolite, but the younger rocks (Lizzie Creek Volcanic Group) tend more towards bimodality.

Most of the Yarrol Province lies outside the study area, but in the north-east, a succession of Late Devonian to early Carboniferous mafic to felsic volcanic and sedimentary rocks is the northern continuation of the Yarrol Province, and is herein referred to as the Campwyn Subprovince. Farther south, volcanic and sedimentary rocks ranging from the Late Devonian to early Permian comprise the Stoodleigh Subprovince. The Late Devonian to Carboniferous volcanic rocks in these subprovinces are more oceanic in geochemical affinities than those in the Connors and Auburn Arches and probably represent an intra-oceanic island arc. Along the eastern edge of the study area in the south, successions of mainly mafic volcanic and related clastic rocks assigned to the Nogo Subprovince may include some Late Devonian rocks, but most are probably early Permian.

The basal part of the Bowen Basin consists of shallow marine sedimentary rocks, but in many places, these are separated from the dominantly volcanic successions of the Connors and Auburn Arches by discontinuous sequences that contain fluviatile and lacustrine sedimentary rocks and bimodal volcanic rocks. These have been interpreted as the early extensional or rift phase in the formation of the Bowen Basin. Within the adjacent Yarrol Province, the Rookwood Volcanics, a sequence of mainly submarine basalt with MORB-like geochemical affinities was possibly erupted as part of this extensional phase. The overlying marine sediments of the Bowen Basin were deposited during the thermal sag phase of basin development. They are overlain by non-marine sedimentary rocks that include coal measures and represent a foreland basin succession formed during the onset of the Hunter-Bowen Orogeny. These rocks are overlain by Early Triassic redbed and sandstone units.

The eastern side of the Bowen Basin in the study area is strongly deformed in the Gogango Overfolded Zone (GOZ), a thrust belt that consists of strongly cleaved sedimentary and some volcanic rocks. It separates the Connors and Auburn Arches and continues south along the eastern side of the Auburn Arch, separating it from the Yarrol Province. The boundary between the GOZ and the Yarrol Province is a system of major thrust faults.

The northern termination of the thrust belt also marks the northern edge of the Marlborough Block, a belt of ultramafic and mafic rocks interleaved with deformed and metamorphosed sedimentary rocks that are probably part of the Yarrol Province. The mafic-ultramafic rocks probably formed in a Neoproterozoic oceanic spreading centre and later interacted with magmas of island arc composition in a supra-subduction zone in the Late Devonian. The ophiolite complex so-formed was emplaced into its current position as an out-of-sequence thrust sheet in the Late Permian.

Intruding the Auburn Arch and southern part of the GOZ is the Rawbelle Batholith that consists of granitoids that mostly have late Permian to Early Triassic ages and can be divided into two main geochemical suites. Two other suites of early Permian granitic rocks show probable S-type and I-type affinities respectively. Minor areas of Late Triassic felsic volcanic rocks and some granitic plutons crop out in the southern part of the study area.

The Surat and Mulgildie Basins formed in the Jurassic when sediments were deposited in fluvial, lacustrine and some coal swamp environments. In the Styx Basin, an Early Cretaceous coal-bearing sequence was deposited. Early Cretaceous ignimbritic volcanic rocks crop out on the coast near Mackay and are probably related to the Whitsunday

Province, a felsic-dominated large igneous province that is mainly preserved on islands offshore of central Queensland. Several plutons in the Urannah Batholith and adjacent area were emplaced in the Cretaceous and some subvolcanic intrusions and extrusive rocks of this age also occur farther south.

In the Eocene, several narrow, north-north-westerly trending basins developed as half grabens with faulted westerly margins developed in central Queensland. They were filled by fluvial to lacustrine sediments including oil shale. In the study area, the basins are the Biloela, Duaringa and Herbert Creek Basins. Deposition was followed by the development of a deep weathering profile over much of the area during the Oligocene.

Basalt lavas were erupted sporadically through the study area from the Late Cretaceous to the Oligocene. Some felsic rocks of probable Oligocene age also occur, particularly in the north, and include lavas and plugs as well as some high-level plutonic rocks near Mackay. Cainozoic sedimentary deposits are extensive and include high level alluvial fans and talus, flood plain alluvium, colluvial and residual deposits and various coastal deposits.

Keywords: Regional geology; stratigraphy; plutonic rocks; volcanic rocks; structural geology; geochemistry; tectonics; Auburn Arch; Connors Arch; Yarrol Province; Nogo Subprovince; Grantleigh Subprovince; Campwyn Subprovince; Stoodleigh Subprovince; Marlborough Block; Bowen Basin; Surat Basin; Mulgildie Basin; Biloela Basin; Duaringa Basin; Herbert Creek Basin; Ah Fat Granite Complex; Aisbetts Granodiorite; Aitken Creek Gabbro; Ametdale Volcanics; Back Creek Group; Banana Formation; Baralaba Coal Measures; Barfield Formation; Ben Mohr Igneous Complex; Berri Berri Granite; Biloela Formation; Blackwater Group; Blenheim Formation; Boam Creek Quartz Monzonite; Boolgal Granophyre; Boomer Formation; Bora Creek Quartz Monzodiorite; Broadlands Granite; Broadsound Range Volcanics; Buffel Formation; Bundarra Granodiorite; Burwood Complex; Cadarga Creek Granodiorite; Calen Coal Measures; Camboon Volcanics; Cameron Creek Granite; Camp Creek Granite; Campwyn Volcanics; Carinya Granite; Carmila beds; Carminya Granodiorite; Ceratodus Granite; Cerberus Dacite Member; Charon Point Rhyolite Member; Cheltenham Creek Granite; Cleethorpes Granodiorite; Clement Creek Quartz Monzodiorite; Clive Creek Volcanics; Clondalkin Granite; Cobweb Mountain Rhyolite; Collaroy Volcanics; Colodon Granite; Connors Volcanic Group; Coonambula Granodiorite; Coppermine Andesite; Copperville Granodiorite; Crystal Vale Monzogranite; Culcraigie Granite; Dacey Granite; Dawson Granite; Delubra Gabbro; Delusion Granodiorite; Dogherty Granite; Donore Granite Gneiss; Doraville Granodiorite; Doreen Granite; Duaringa Formation; Early Permian plutons; East Apple Granite; Eidsvold Complex; Epsom Granodiorite; Euroka Granite; Evandale Tonalite; Evergreen Formation; Exmoor Formation; Featherstone Granite; Finch Hatton Granite; Flat Range Granodiorite; Flat Top Diorite; Flat Top Formation; Fort Cooper Coal Measures; Gargett Granite; Gebbie Formation; Glandore Granodiorite; Glen View Quartz Monzodiorite; Glencoe Gabbro; Glenhalvern Granite; Glenleigh Granite; Glenprairie beds; Glissons Granodiorite; Goodedulla beds; Greencoat Quartz Monzonite; Greystone Granite; Gyranda Subgroup; Hainault Granodiorite; Harkness Granodiorite; Harrami Igneous Complex; Hazlewood Granite; Hefferon Creek Gabbro; Hildura Granodiorite; Horse Leucogneiss; Hutchinsons Granite; Hutton Sandstone; Impey Granodiorite; Injune Creek Group; J P Granite; Jack Shay Gabbro; Jan Mar Granite; Johnstone Creek Igneous Complex; Jonah Vale Granite; Kandoonan Granite; Kariboe Layered Gabbro; Keen Creek Granite; Kenmore Gabbro; Kildare Granodiorite; Kooingal Granite Complex; Kooyong Gabbro; Koumala Granite; Langdale Hill Rhyolite; Leura Volcanics; Lizzie Creek Volcanic Group; Lonesome Creek Quartz Monzonite; Lookerbie Igneous Complex; Lorray Formation; Lotus Creek Rhyolite; Lyndale Diorite; Macksford Volcanics; Magog Gabbro; Marlborough Metamorphics; Marvel Creek Gabbro; May Queen Gabbro; McKonkey Granodiorite; Mia Mia Igneous Complex; Moah Creek beds; Monkey Springs Granite; Montour Gabbro; Moocoorooba Granite; Moranbah Coal Measures; Morang Volcanics; Morrow Granite; Morugo Granite; Mount Appenben Granite; Mount Bassett Dolerite; Mount Benmore Volcanics; Mount Bridgeman Igneous Complex; Mount Buffalo Volcanics; Mount Chelona Granite; Mount Christian Granodiorite; Mount Clairvoyant Granite; Mount Cooper Volcanics; Mount Eagle Volcanics; Mount Jukes Intrusive Complex; Mount Rose Gabbro; Mount Saul Granite; Mount Scott Granite; Mount Shields Granodiorite; Mount Spencer Granodiorite; Mountain View Volcanics; Mulgildie Coal Measures; Munbura Diorite; Muncon Volcanics; Mungunal Granite; Narayen beds; Nine Mile Granite; Nob Creek Amphibolite; Nogo beds; Nulambie Granite; Og Syenite; Okangal Quartz Monzodiorite; Olympus Granite; Oxtrack Formation; Palms Lookout Granodiorite; Parraweena Gabbro; Pinedale Granite; Pisgah Igneous Complex; Plevna Oil Shale; Pollard Granodiorite; Precipice Sandstone; Princhester Serpentinite; Quaggy Mountain Quartz Gabbro; Racecourse Creek Gabbro; Rangal Coal Measures; Rannes beds; Ravenscraig Gabbro;Rawbelle Batholith; Rewan Group; Rockdale Granite; Rockhampton Group; Rockybar Granodiorite; Rookwood Volcanics; Ross Granite; Round Top Granite; Sambo Quartz Monzonite; Screaming Creek Gabbro; Shawlands Granodiorite Complex; South Creek Quartz Diorite; Stony Creek Granite; Strathdee Granodiorite; Styx Coal Measures; Sujeewong Gabbro; Swayneville Granite; Tally Ho Igneous Complex; Tanderra Volcanics; Tandora Granodiorite; Tartrus Rhyolite; Tecoma Granodiorite; Teemburra Igneous Complex; Telemark Granodiorite; Ten Mile Granite; The Pride Gabbro; Tindarra Granite; Tireen Granite; Tiverton Formation; Toobier Granite; Tooloombah Creek Granite; Torsdale Volcanics; Unnamed intrusions; Uruba Granite; Waitara Granite; Wathonga Granite; West Hill Granodiorite; Whelan Creek Volcanics; Whitehorse Mountain Granite; Whitsunday Volcanics; Widbury Granite; Wind Mill Diorite; Wingfield Granite; Wiseman Formation; Wongrabry beds; Woolein beds; Woolton Granite Complex; Wundaru Granodiorite; Yaparaba Volcanics; Yarravale Creek Granite; Yatton Limestone; Yerilla Metamorphics; Youlambie Conglomerate; Devonian; Carboniferous; Permian; Triassic; Jurassic; Cretaceous; Tertiary; Quaternary; Palaeogene; Neogene; Nebo; Mirani; Mount Bluffkin; Connors Range; Carmila; Mackay; Duaringa; Rookwood; Marlborough; Saint Lawrence; Bungaban; Cracow; Theodore; Banana; Mount Morgan; Auburn; Rawbelle; Scoria; Mundubbera; Eidsvold; SF5508; SF5512; SF5516, SF5613, SG5601, SG5605; 8654, 8655, 8752, 8753, 8754, 8755, 8850, 8851, 8852, 8853, 8946, 8947, 8948, 8949, 8950, 9046, 9047, 9048, 9146, 9147.

INTRODUCTION

The South Connors–Auburn–Gogango (SCAG) Project covers approximately 27 500km^2 of central eastern Queensland from Mackay to Mundubbera (Figure 1). The project commenced in 1996 as part of the Department of Mines and Energy's GEOMAP 2005 program, which was designed to focus on second-pass mapping to help establish the mineral resource potential of regions within the State (Day, 1995). The area of investigation was selected in consultation with the exploration industry, academia and government, as one of the priority areas for government geoscience mapping in Queensland (Hofmann, 1989). The project was designed to draw mineral exploration to this under-explored region by updating and adding value to the geoscientific knowledge base, and providing a reassessment of the mineral potential of the area. In addition to reducing the risk to explorers, the updated interpretations should improve land-use decision-making by ensuring that it takes account of mineral resource potential. Geological map data is also used as a basic layer by other scientific disciplines such as those mapping vegetation, soils, land zones and salinity hazards.

Because the traditional field mapping process is slow and expensive, the Department has made increasing use of new technologies involving remote sensing and data management (Day, 1995). For the SCAG Project, geological re-interpretation was aided by airborne radiometric and magnetic data from the Department's AIRDATA Project, which covered most of the project area, in addition to data acquired by Queensland Metals Corporation for its Fitzroy Project. These were integrated with new field observations, air-photo interpretation, gravity data, satellite imagery, geochemical data, petrologic data, and previous exploration and research data.

A four-week reconnaissance trip was carried out in October–November, 1996, to examine the entire area from Mackay to Mundubbera to collect data for logistical planning and to acquaint the team with the regional geology. A wide range of samples of granites, and some volcanic rocks were collected for geochemistry and U-Pb zircon dating by the SHRIMP method at the Australian National University.

Field work from June to October 1997 was focussed on the southern part of the project area that falls within the Duaringa, Rockhampton, Monto and Mundubbera 1:250 000 Sheet areas. A total of 70 man weeks were spent on geological mapping and about 12 man weeks on mineral occurrence mapping. The second major field season was carried out in September to early November 1998 in the northern part of the project area. It was delayed by budgetary problems and then dogged by unseasonably wet weather that made access to many areas difficult or impossible. A total of 40 man weeks was spent on geological mapping and about 8 man weeks on mineral occurrence mapping. Follow-up field work in both the southern and northern areas was done in 1999, a total of 40 man weeks being spent in February to early May and in August–September. Several man weeks were done in the Carmila–Nebo area in early 2000.

Responsibilities of individuals in the project are summarised by a plot of field observation sites in Figure 2. In more detail they are:

R.J. Bultitude — volcanic rocks and granitoids in the Auburn Arch and Rawbelle batholith in CRACOW and western RAWBELLE; volcanic rocks and granitoids in the Connors Arch mainly in NEBO and CARMILA

L.J. Hutton — volcanic rocks and granitoids in the Auburn Arch and Rawbelle batholith in THEODORE and western SCORIA; volcanic rocks and granitoids in the Connors Arch mainly in CONNORS RANGE and southern NEBO

I.P. Rienks — volcanic rocks and granitoids in the Auburn Arch and Rawbelle batholith in AUBURN and eastern BUNGABAN

F.E. von Gnielinski — volcanic rocks and granitoids in the eastern parts of RAWBELLE and SCORIA and western EIDSVOLD; granitoids of the Urannah Batholith and other rocks in MIRANI and MACKAY

I.W. Withnall — stratigraphy and structure of the Gogango Overfolded Zone and volcanic rocks and granitoids of the northern part of the Auburn Arch and southern Connors Arch in BANANA, MOUNT MORGAN, DUARINGA, ROOKWOOD, MOUNT BLUFFKIN and southern CONNORS RANGE. Rocks of the Yarrol province and Marlborough Block in MARLBOROUGH and SAINT LAWRENCE.

In addition J. Domagala and R. Barker from the Yarrol Project Team studied the Rookwood Volcanics in MOUNT MORGAN, RIDGELANDS AND ROOKWOOD and P.R. Blake briefly examined the Campwyn Volcanics in CARMILA and MACKAY. Data from various field notebooks held by GSQ or Geoscience Australia from the original first pass 1:250 000 mapping and also some university studies and exploration company mapping were also consulted and used in map compilation. In particular notebooks from mapping from Marlborough Mines by the late Dr J.F. Dear were used in the southern end of the Connors Arch. These are shown in Figure 2 as 'Legacy data'.

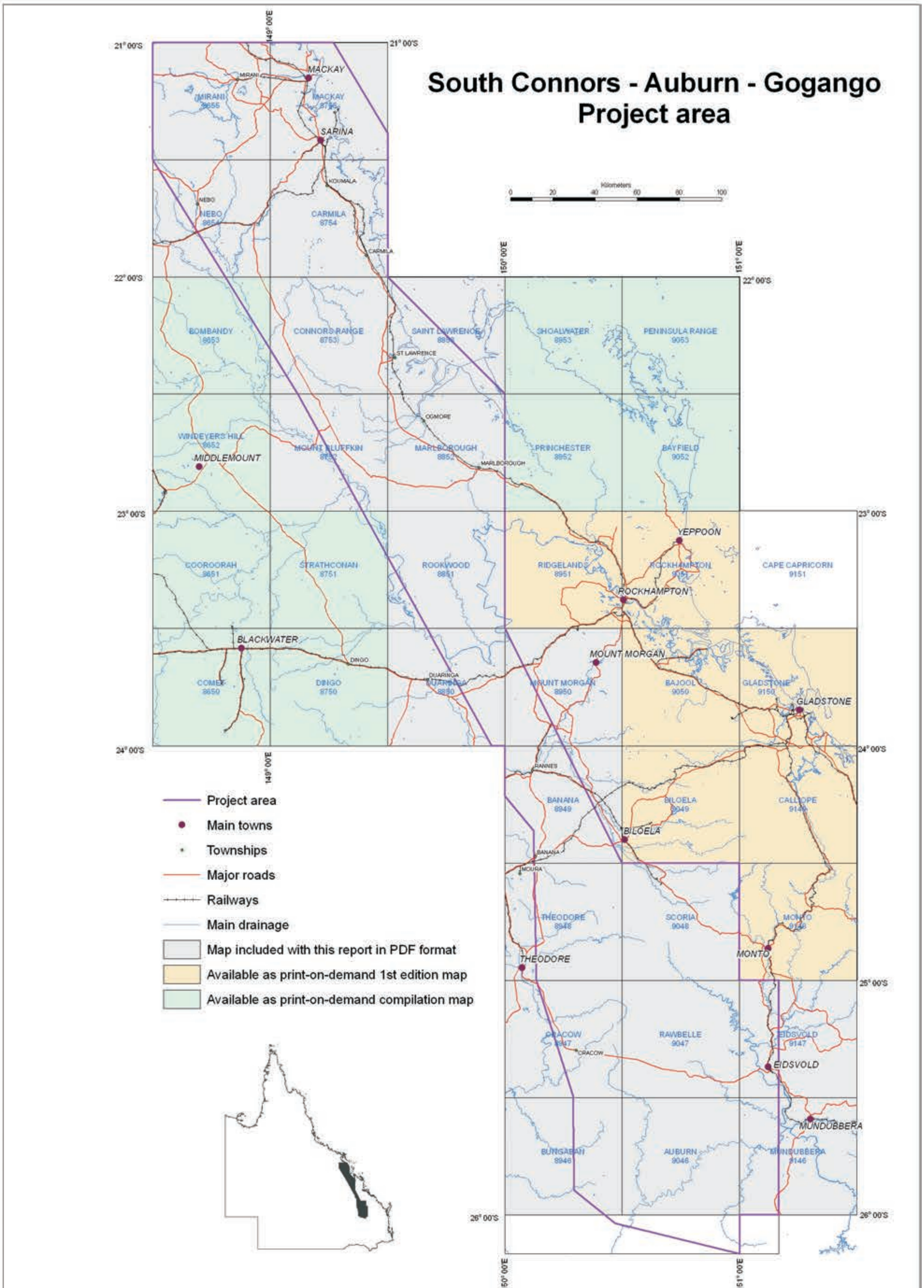

Figure 1. Location map showing the extent of the South Connors–Auburn–Gogango Project area and available maps

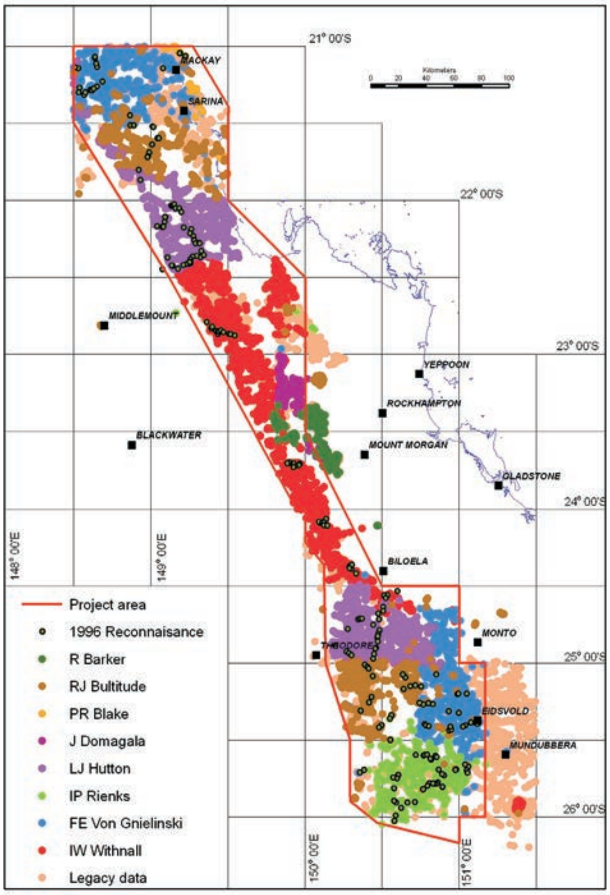

Figure 2. Distribution of field observation sites showing the areas of responsibility of contributors to the project

MACKAY was mapped in 1982 by W.F. Willmott, M.J. O'Flynn and J.E. Martin of the Urban & Environmental Geology Section of the GSQ, but although field compilation sheets were prepared, no published map or report was produced. Their compilation, with some follow-up fieldwork was used to compile the map in this report.

Project results were made available progressively throughout the term of the project (Withnall & others, 1998a,b; Hutton & others, 1999a,b; Withnall & others, 2000). Outputs comprise geological and mineral occurrence maps, reports and reviews, and digital data sets. Data from the investigation were captured into the Department's MERLIN corporate information system, and manipulated within a project GIS environment. In addition to supporting data storage and manipulation, MERLIN also facilitates the efficient production of digital and hard copy maps and reports. Copies of the 20 geological maps in pdf format are included with this report. They are also available from the Department as print-on-demand plots (see Figure 1). Mineral occurrence maps and reports were completed by Burrows (2004), Garrad & Withnall (2004a,b), Lam (1998, 2004, 2005), Lam & Jackson (1998) and Lam & von Gnielinski (2004).

A comprehensive GIS, the Central Queensland Region Geoscience Dataset (Yarrol–Connors–Auburn GIS), was released in 2005 and is available from the Department in ArcView and MapInfo formats. The presentation can also be viewed using the Geoviewer software provided in the DVD package. The GIS is an integrated digital geological information package for the Yarrol and South Connors–Auburn–Gogango Project areas and covers the area from Mackay in the north, to Mundubbera in the south. The 1:250 000 map sheets of Mackay, St Lawrence, Rockhampton, Duaringa, Mundubbera and Monto define the GIS boundaries. The GIS package includes information on geology of the area; solid geology based on tectonic setting; airborne magnetic and radiometric images; gravity images; Landsat images, geophysical interpretation; whole rock geochemical and geochronological data for igneous units; locations of historical exploration tenures, and the locations and descriptions of about 1600 mineral occurrences. In addition, more than 26 000 geological site observations are on the DVD.

Geochemical analysis was carried out on about 1100 samples (730 intrusive rocks and 375 volcanic and related rocks) from most of the named units and many unnamed units from the project area to assist in determining their genetic relationships and petrogenesis. Most analyses were done by x-ray fluorescence at the Queensland Government Chemical Laboratory, part of Queensland Health Scientific Services, but a selection of mafic rocks were submitted for more precise trace element analysis, particularly of the rare earth elements, by laser ablation mass spectrometry at PRISE in the Research School of Earth Sciences at the Australian National University. The analyses are stored in the Surface Geology System of the Department of Mines & Energy's Geoscience and Resource Database (GRDB) and also as a layer in the Yarrol-Connors-Auburn GIS. It should be noted that in some cases in these databases, samples of xenoliths and younger dykes are included with their host unit. In the preparation of the plots in this report, such samples were excluded along with some samples of altered rocks. The laser ablation analyses were used to construct multi-element plots and these were compared with modern basaltic suites using the database compiled from literature by Murray & Blake (2005, appendix 1).

In compilation of this report, each project team member was responsible for writing the description of the rock units within their area of responsibility. Assembly of the final report, in addition to summarising the geochemical data and compiling reviews from literature of geological units outside the original scope of the project, was done mainly by I.W. Withnall. The report was edited by C.G. Murray (manager of the Regional Geoscience Unit) and desktop publishing was done by S. Beeston.

Locations throughout the report are given in metres related to the Map Grid of Australia on the Geocentric Datum of Australia (GDA94) as appears on the accompanying 1:100 000 scale maps. Most references are given to the nearest 100m where they have been read from the maps, but some localities based on Global Positioning System (GPS) measurements are given to the nearest 10m. However, it should be noted that at the time of the fieldwork (1997–1999), the 'selective availability' of the GPS satellites was still in operation and the accuracy of the GPS measurements used herein was in many cases no better than 100m. Where the names of standard 1:100 000 sheet areas are given in the report, they are capitalised (*e.g.* AUBURN).

Throughout the report, Early, Middle and Late are used for subdivisions (epochs) of geological periods rather than Lower, Middle and Upper (which apply to rock series). Although Australian usage has recently adopted the international terms for subdivisions of the Carboniferous and Permian periods and the Cainozoic era (Gradstein & others, 2004; Heckel & Clayton, 2006), this report has retained the older terms, still in common usage in Australia at the time of writing. However, the adjectives 'early' and 'late' are not capitalised for the subdivisions of the Carboniferous and Permian, in recognition of their now informal status. The subdivisions early and late Carboniferous are used with a boundary between them at 325Ma as shown on the AGSO Phanerozoic Timescale (Jones, 1995). The early Carboniferous comprises the Tournaisian and Visean Stages and the late Carboniferous, the Namurian, Westphalian and Stephanian Stages. Early Permian corresponds with the Cisuralian (Asselian to Kungurian Stages) and late Permian the Guadalupian and Lopingian (Roadian to Changhsingian Stages). The boundary between the early and late Permian on the AGSO Timescale is at 270Ma. Tertiary (Palaeocene to Pliocene) and Quaternary (Pleistocene to Holcene) are retained as subdivisions of the Cainozoic. The term early Tertiary corresponds to the Palaeogene, and late Tertiary corresponds to the Miocene and Pliocene.

PREVIOUS REGIONAL INVESTIGATIONS

The first pass regional geological mapping of the 1:250 000 sheet area was carried out by mainly by joint parties of the then Bureau of Mineral Resources (now Geoscience Australia) and the Geological Survey of Queensland (GSQ) in the 1960s. In the south, Monto and Mundubbera 1:250 000 Sheet areas were mapped mainly by the GSQ in the late 1960s and early 1970s.

The sheet areas and the key references are tabulated below:

1:250 000 Sheet	**References**
Mackay (SF55-8)	Jensen & others (1966); Jensen, 1972
Saint Lawrence (SF55-12)	Malone & others (1969); Malone (1970)
Rockhampton (SF56-13	Kirkegaard & others (1970); Murray (1975)
Duaringa (SF55-16)	Malone & others (1969); Kirkegaard (1970)
Monto (SG56-01)	Dear & others (1971)
Mundubbera (SG56-05)	Whitaker & others (1974); Mollan & others (1972)

These publications all contain comprehensive summaries of previous work that are not repeated in this report. These and subsequent research will be referenced through this report where relevant. Webb & McDougall (1968) gave a geochronological framework. The main subsequent research by geologists from government, academia and industry has been either preparation of syntheses or research focussed on tectonics and structural geology. Some of the most important are by Day & others (1978), Murray (1986, 2007), Fergusson (1991), Fergusson & others (1994), Dear (1994), Allen & others (1994, 1998), Holcombe & others, (1997a,b) Fielding & others (1994, 1997a,b) and, Bryan & others (1997, 2000, 2001, 2003a, 2004b).

GEOLOGICAL SETTING

The SCAG Project area forms part of the northern New England Orogen. The major structural provinces within the study area are the Connors and Auburn Arches and the Gogango Overfolded Zone. They are flanked to the west by the Bowen Basin (Figure 3). A narrow strip of rocks of the Bowen Basin flank them on the eastern side and separate them from the Yarrol Province. A more detailed breakdown the geological provinces and subprovinces in the project area is shown in Figure 4.

In the north-eastern part of the study area, a succession of Late Devonian to early Carboniferous volcanic rocks is the northern continuation of the ***Yarrol Province***, and is herein referred to as the Campwyn Subprovince. Farther south, between Marlborough and Charon Point, volcanic and sedimentary rocks ranging from the Late Devonian to early Permian comprise the Stoodleigh Subprovince.

The ***Connors Arch*** in the north and ***Auburn Arch*** in the south both consist of late Palaeozoic granites and silicic volcanic rocks that have been regarded as representing a Late Devonian to early Carboniferous Andean volcanic arc west of the Yarrol Province. The latter has been interpreted as a forearc basin with a complementary accretionary complex in the Coastal Block (Day & others, 1978; Murray, 1986). This volcanic arc was named the Connors–Auburn Volcanic Arc, the main volcanic units being the Connors Volcanics in the north and the Torsdale beds in the south. The age of the volcanic arc was poorly constrained. It was based on the fact that the volcanic rocks are intruded by late Carboniferous granites (Webb & McDougall, 1968) (and hence must be older) and a single K–Ar age of 343Ma (Whitaker & others, 1974) from the Torsdale beds in the Auburn Arch. Volcanism was interpreted to have ceased during the late Carboniferous when voluminous granites were intruded. In the early Permian, a second arc, the Camboon Volcanic Arc was inferred to have developed on the site of the older arc, but no corresponding forearc or accretionary complex was identified. The main units recognised in the Camboon Volcanic Arc were the Camboon Volcanics and the Nogo and Narayen beds.

In the southern part of the Connors Arch, Dear (1994) described three sequences or cycles of largely felsic volcanic rocks within the Connors Volcanics. Cycle 1 was postulated to be Middle Devonian and Cycle 2 was correlated with the Torsdale beds and thought to be early Carboniferous. Cycle 3 was correlated with the Camboon Volcanics.

More recent work from both the Auburn and Connors Arches (Allen & others, 1994, 1998; Holcombe & others, 1997a,b) suggested that, although internal unconformities can be recognised, all of the volcanic rocks are broadly of late Carboniferous to early Permian age. Holcombe & others (1997b) postulated a magmatic episode spanning ~40my from ~320Ma and peaking at ~305Ma. They questioned the existence of any arc-type rocks that can be related to the interpreted fore-arc sequences in the Yarrol Province. This study has, however, identified some early Carboniferous rocks, particularly in the Connors Arch. In addition, Bryan & others (2004b) obtained early Carboniferous ages from ignimbrites in the Yarrol Province, but they argued that these were not subduction-related.

The basal part of the ***Bowen Basin*** flanks the Connors and Auburn Arches, both to the east and west. It generally consists of sandstone, mudstone and subordinate carbonates deposited in a shallow marine environment. However, in many places, these rocks are separated from the volcanic rocks of the Connors Arch and northern part of the Auburn Arch by local successions of fluviatile and lacustrine sedimentary rocks and bimodal volcanic rocks. These have been interpreted as the early extensional or rift phase in the formation of the Bowen Basin and include the Carmila and Goodedulla beds and Woolein Formation. Within the Yarrol Province, on the eastern side of the Gogango Overfolded Zone, a sequence of submarine volcanic rocks, the Rookwood Volcanics, was possibly erupted as part of this extensional phase. The overlying marine sediments were deposited during the thermal sag phase of basin development (Fielding & others, 1994, 1997a).

The **Gogango Overfolded Zone** (GOZ) partly separates the Connors and Auburn Arches and continues south along the eastern side of the Auburn Arch, separating it from the Yarrol Province. It is largely a belt of

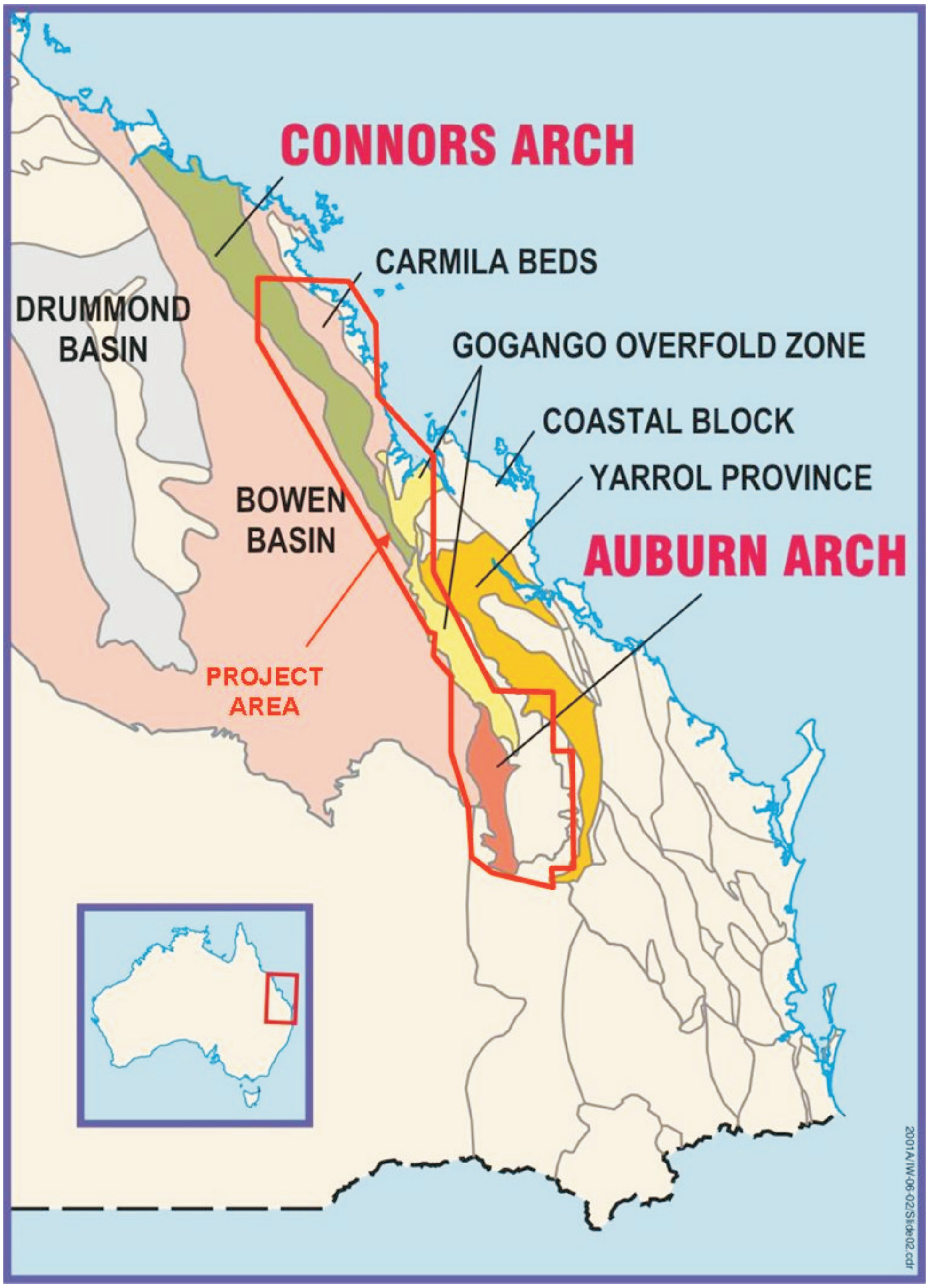

Figure 3. Location of the Connors and Auburn Arches and the "Gogango Overfolded Zone" with respect to adjoining structural units and the South Connors-Auburn-Gogango Project area

monotonous, strongly cleaved sandstone and mudstone with belts of deformed intermediate to felsic volcanic rocks up to 10km long. Day & others (1978) proposed that the Connors Arch formed the eastern margin of the Bowen Basin during the early Permian and that sedimentary rocks in the GOZ to the east formed in a separate deep-water basin, the Grantleigh Trough. Stratigraphic, sedimentological and structural studies in recent years (Fielding & others, 1994, 1997a,b; Fergusson, 1991; Fergusson & others, 1994) have led to the conclusion that the GOZ is simply a part of the Bowen Basin that was more intensely deformed by thrusting during the late Permian to Early Triassic Hunter–Bowen Orogeny. These results confirm earlier interpretations that the Bowen basin extended across the Connors Arch, probably beyond the present coastline (Malone, 1964).

Fergusson (1991) interpreted the Connors Arch, as now exposed, as a later structural feature, possibly the upper part of a passive-roof duplex or antiformal stack of fault bound slivers, that plunges southwards under the GOZ. The volcanic rocks are slivers of the underlying basement rocks that form the Connors and Auburn Arches. As discussed later in this report, the term **Gogango Thrust Zone** is probably more appropriate, as overturned folds are actually uncommon.

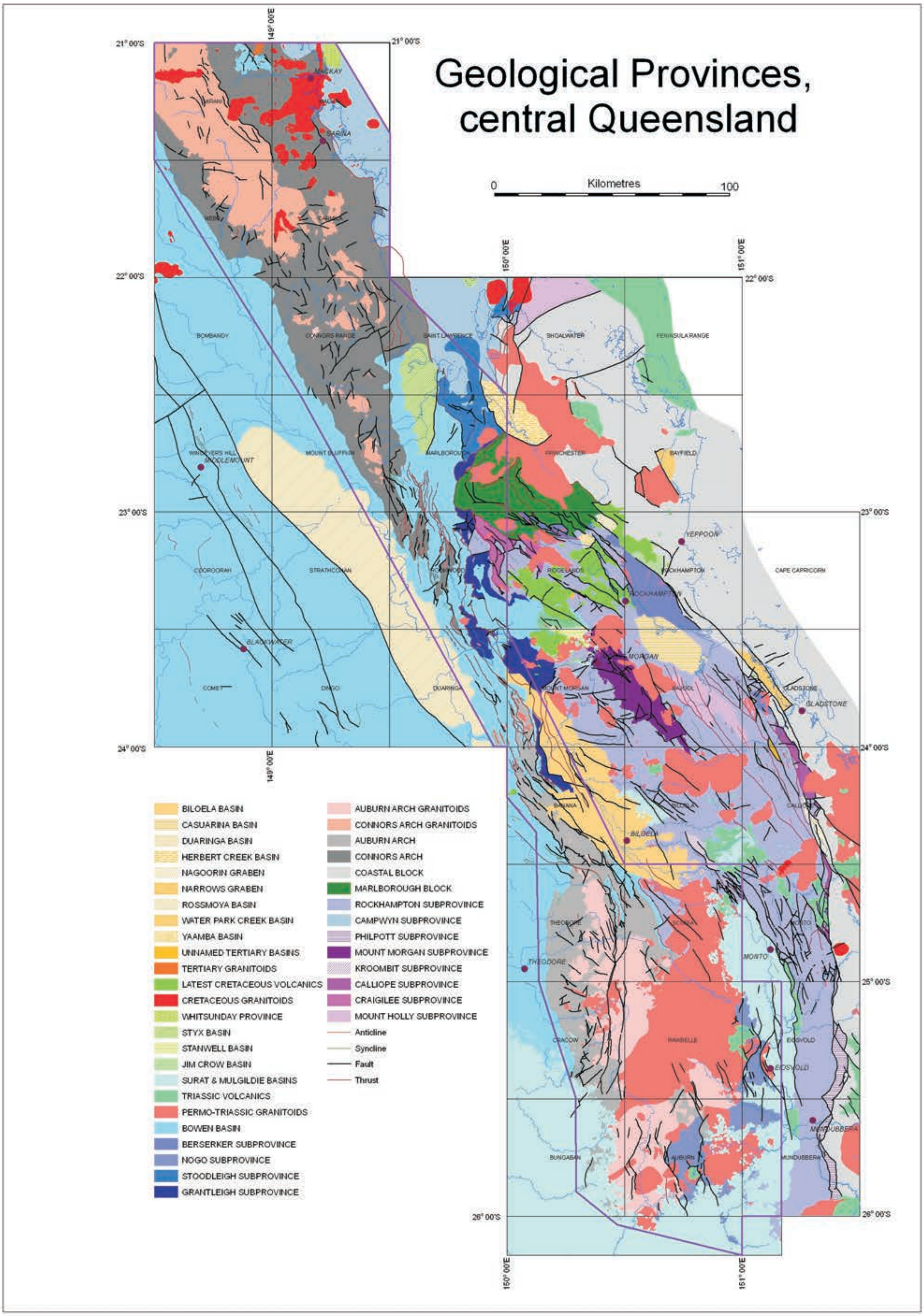

Figure 4. Geological provinces in central Queensland

The boundary between the Gogango Overfolded Zone and the Yarrol Province is a system of major thrust faults. Various segments separated by Tertiary basins are herein named the Develin, Comanche, Rannes and Grevillea Thrusts.

The northern termination of the thrust belt is probably a diffuse south-westerly continuation of the Stanage Fault, which is an approximate north-north-east trending oblique shear zone with dextral strike slip offset (Henderson & others, 1993; Leitch & others, 1994). It also marks the northern edge of the **Marlborough Block**, which is interpreted as an out-of-sequence thrust sheet of ultramafic and mafic rocks interleaved with deformed and metamorphosed sedimentary rocks that are probably part of the Yarrol Province.

Intruding the Auburn Arch and southern part of the GOZ is the ***Rawbelle Batholith*** (Whitaker & others, 1974) that consists of granitoids that have mostly given late Permian to Triassic ages. Withnall & others (1998a,b) extended the Rawbelle Batholith to encompass the late Carboniferous granitoids to the west. These are contiguous along the western margin of the "Rawbelle Batholith" (denotes older usage) as used by Whitaker & others (1974). The presently accepted definition of batholith refers to a spatially coherent granite mass, and is not intended as a stratigraphic term.

Granites of the ***Urannah Batholith*** intrude the northern part of the Connors Arch. In a study of the magmatic history of the northern New England Orogen, Allen & others (1998) identified several magmatic suites in the Urannah Batholith extending almost 400km from west of Carmila to about the latitude of Proserpine. Most of the granites in the Mackay 1:250 000 Sheet area are included in the Urannah Suite. SHRIMP U–Pb ages for the Urannah Suite are late Carboniferous (~308 and 304Ma; Allen & others, 1998), but K–Ar ages show a greater spread (Webb & McDougall, 1968). The Urannah Suite is intruded by dykes, one suite of which yield a zircon age of 283.9±5.2Ma (Allen & others, 1998).

Granites in the Saint Lawrence 1:250 000 Sheet area were included in the Saint Lawrence Suite (Allen & others, 1998). These rocks yielded late Carboniferous K–Ar ages (Webb & McDougall, 1968). Cretaceous granites intrude the Urannah Suite and adjacent volcanic and sedimentary rocks.

STRATIGRAPHY OF THE AUBURN ARCH

YERILLA METAMORPHICS

Introduction

The Yerilla Metamorphics crop out over ~120km^2 in southern RAWBELLE and northern AUBURN (Figure 5). Scattered areas of metamorphic rocks farther south, for example along the Auburn River, 10km north-east of Auburn homestead, have also been assigned to the Yerilla Metamorphics. The main outcrop area contains a very heterogeneous assemblage of rocks, indicating that the area is a metamorphic and plutonic igneous "complex" rather than a simple unit. Metasedimentary and mafic metavolcanic rocks are intruded by a variety of variably foliated granitoids that include orthogneiss and common pegmatite and aplite as well as a variety of younger granite, diorite and gabbro bodies and dolerite and rhyolite dykes. Outcrop is poor in much of the area, so it has not been possible to map out all of these different rock types, except for some areas that have a distinctive radiometric response and which have been assigned to the Horse Leucogneiss.

Type locality

The type locality is given at MGA 275800 7168450 in Cheltenham Creek near Yerilla homestead, from which the unit takes its name. Biotite schist and paragneiss are well exposed (Figure 6). The schist and gneiss shows millimetre to centimetre-scale compositional layering, and lenticular pegmatite pods are common; some of the layers show granitic segregations and grade into migmatite. The rocks are well foliated with biotite aligned parallel to the compositional layering and the foliation is deformed by generally open macroscopic folds.

Lithology

The metasedimentary part of the Yerilla Metamorphics is similar to the type locality and was probably originally a psammopelitic sequence. The more pelitic rocks generally contain muscovite in addition to biotite and locally porphyroblasts of cordierite were observed.

Fine-grained mafic rocks are also widespread and consist of variably foliated amphibolite. Many of the rocks are massive and may originally have been lavas. They consist of acicular green hornblende with interstitial plagioclase. Relict plagioclase phenocrysts to 2mm are preserved in some outcrops. The hornblende is

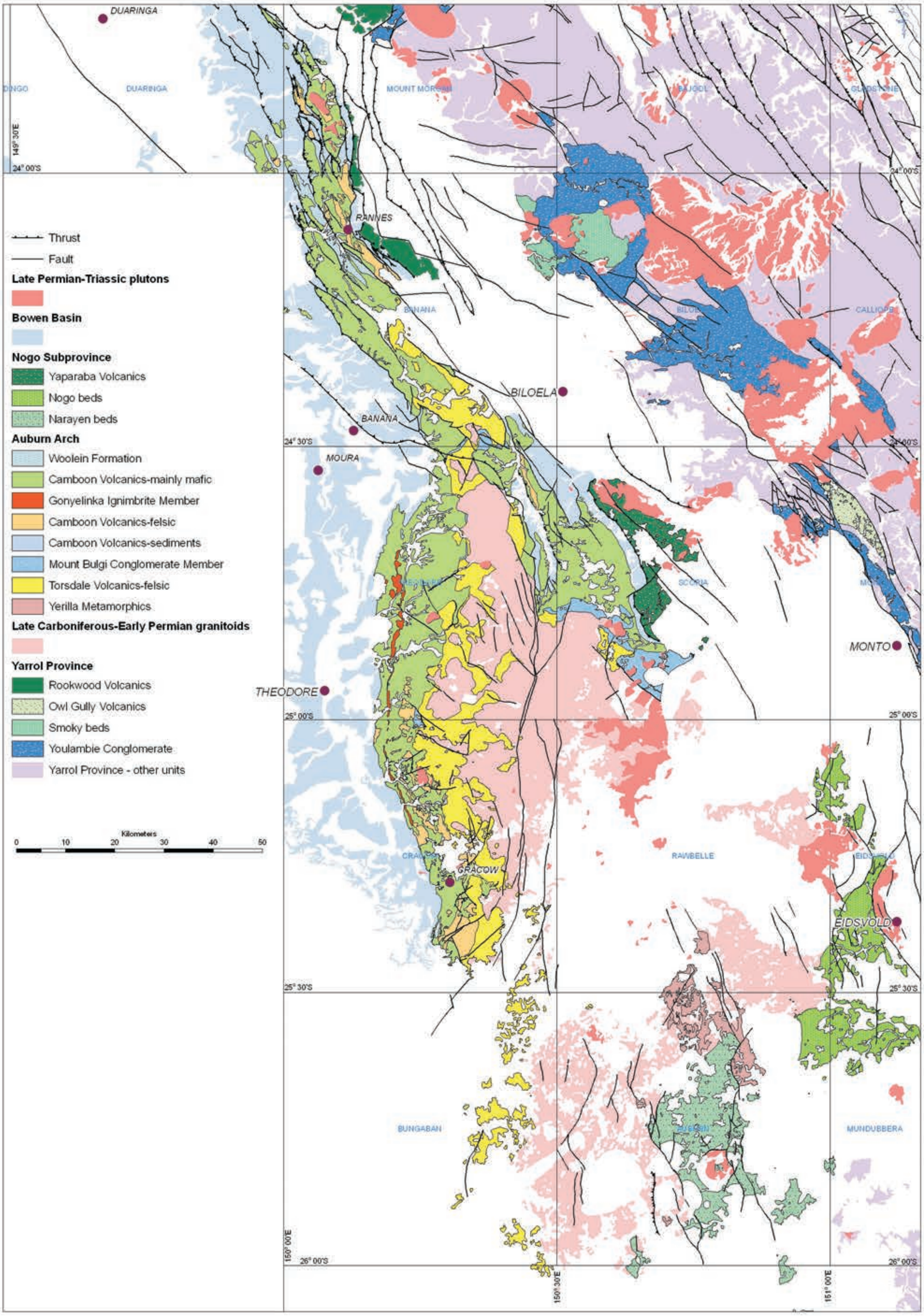

Figure 5. Generalised stratigraphy of the Auburn Arch

Figure 6. Outcrop of banded gneiss in the Yerilla Metamorphics at the type locality. MGA 275800 7168450 in Cheltenham Creek near Yerilla homestead (IRAU430).

commonly aligned and defines a foliation that is locally crenulated. Small flattened aggregates of quartz up to a few millimetres long may have been amygdales. Clastic rocks, probably originally volcaniclastic sandstone or conglomerate, are also present, but are often hard to recognise because metamorphic recrystallisation has masked the original fabric. Variations in the proportions of hornblende and plagioclase outline diffuse clastic fabrics in thin section.

In most of the outcrop area, the mafic rocks have not been mapped out. However, a belt of mafic rocks has been outlined as a subunit of the Yerilla Metamorphics in the eastern part of the outcrop area. The rocks were originally mapped as a hornfelsed part of the Narayen beds by Whitaker & others (1974), but are distinguished from that unit by the presence of a foliation. Outcrops near the Yerilla–Mundubbera road at MGA 283550 7167000 consist of abundant relict phenocrysts of plagioclase to 0.5mm and hornblende to 2mm in a fine-grained groundmass of acicular green hornblende, plagioclase and opaque oxides. The hornblende defines an anastomosing foliation that wraps around the phenocrysts. Other rocks are coarser-grained and may originally have been high-level intrusive rocks. They have a strong anastomosing foliation defined by acicular green hornblende to 0.5mm with interstitial granoblastic plagioclase. The foliation wraps around more equant hornblende crystals ~1mm across.

No detailed metamorphic studies have been done, but the presence of green hornblende and plagioclase assemblages in the amphibolites and the local migmatisation of the para-gneisses indicate that the rocks were metamorphosed in the amphibolite facies.

Geophysical response

On radiometric images, the Yerilla Metamorphics have low to moderate responses for potassium, thorium and uranium, resulting in greyish hues on composite images that contrast with the pale greenish response of the Horse Leucogneiss. Mapped areas of mafic rocks within the Yerilla Metamorphics have a low response in all channels.

The magnetic response of the unit is low in contrast with the more magnetic Carboniferous and Permo-Triassic plutons that surround it. This is consistent with magnetic susceptibility readings on the metamorphic rocks which show a strong mode for values <100 x 10^{-5} SI units with a tail of sporadic values extending to about 2000.

Relationships and age

The Yerilla Metamorphics are intruded by a variety of variably foliated granitoids that include orthogneiss and common pegmatite and aplite as well as a variety of younger granite, diorite and gabbro bodies and dolerite and rhyolite dykes. The foliated granitoids and orthogneiss include rocks that have been assigned to the Horse Leucogneiss where they are more abundant, and probably also rocks assigned to the Donore Orthogneiss. The latter units also include zones of metamorphic rocks like those in the Yerilla Metamorphics so that the distinction between these metamorphic assemblages is not altogether clear. The Yerilla Metamorphics have been intruded by the late Carboniferous Glissons Granodiorite and by the late Permian to

Triassic Pollard Granodiorite and Quaggy Mountain Gabbro. They are unconformably overlain by the early Permian Narayen beds.

The age of the Yerilla Metamorphics is unknown. They are intruded by orthogneiss similar to that mapped as Donore Orthogneiss and dated at 342.5±4.0Ma (see Appendix). This indicates that they are early Carboniferous or older.

The age of deformation and accompanying amphibolite facies metamorphism is also unknown. It clearly predates the early Permian Narayen beds and probably also the Torsdale Volcanics the oldest age of which is 325±4.0Ma (see Appendix). It is possible that the orthogneisses were intruded syn-tectonically and therefore that the metamorphism and deformation is early Carboniferous, although there is no evidence for deformation of this age elsewhere in central coastal Queensland. No studies have been done on the nature of the deformation fabrics and it is not known whether they were produced by contractional or extensional deformation.

UNNAMED METAMORPHIC ROCKS

Very poorly exposed metamorphic rocks of uncertain affinities crop out farther north in RAWBELLE and southern SCORIA. They are labelled **Pzm**, but may be equivalent to the Yerilla Metamorphics.

On southern Kooyong Station in SCORIA, dark grey to black banded gneiss is intruded by gneissic granite. Elsewhere, the gneissic granite occurs as hills surrounded by areas of low relief. In a pit along the road south of Kooyong homestead, fine to medium-grained meta-sediments occur with meta-conglomerate, possible migmatite, and some granitoids. The presence of abundant metamorphic biotite suggests that the rocks have attained upper greenschist to amphibolite grade metamorphism. South-east of Kooyong homestead, granofels consisting of andesine to labradorite (~45%), hornblende (~25%), pyroxene (~20%), quartz (~10%), opaques and epidote may be an orthoamphibolite.

Areas of deformed granitoids occur within poorly exposed metamorphics elsewhere in the southern part of SCORIA. These granites are typically greyish-pink, fine-grained foliated biotite granite/granitic gneiss forming small bodies only ~2–3km^2 in area. They commonly crop out as hills, surrounded by areas of very poor outcrop interpreted to be underlain by metamorphic rocks. Similar granitic gneiss occurs on a hill on northern Rossmore Station and beside Pinedale Road.

Slivers of gneissic rocks occur along the western margin of the Wingfield Granite. These commonly have vertical, strongly mylonitic (?) foliation with well-developed vertical stretching lineations suggesting that these packages of metamorphics may have been ductilely deformed by being ‘dragged up’ during intrusion of the Wingfield Granite.

TORSDALE VOLCANICS

Introduction

The Torsdale Volcanics are exposed as a north-trending belt in the central part of the Auburn Arch from near Woolein homestead in BANANA for ~160km to south of Cracow (Figures 5 and 7). In the northern part of this belt, the Camboon Volcanics flank the unit to both the west and east and Carboniferous granites intrude it. Farther south, in CRACOW and AUBURN, various Carboniferous and Permian to Triassic granitoids intrude the unit.

The unit was first recognised by Dear & others (1971) and named the “Torsdale beds”. Previously, the rocks had been included in the Permian “Camboon Andesite”, but dating of granites that intruded some of the volcanic rocks in the Theodore area (Webb & McDougall, 1968) gave late Carboniferous ages, and led to the recognition of an older volcanic sequence. We use the name Torsdale Volcanics because the unit is composed dominantly of thick successions of relatively massive volcanic rocks.

Type area

Although Dear & others (1971, page 36) mentioned a type area, they did not specify where it was. However, we infer from the context that it was near Torsdale homestead, from which the unit takes its name. It is difficult to define a type section in this area, because the base of the unit is not exposed, and many of the rocks are massive and structural data are absent. Therefore a more suitable type area is proposed here to the

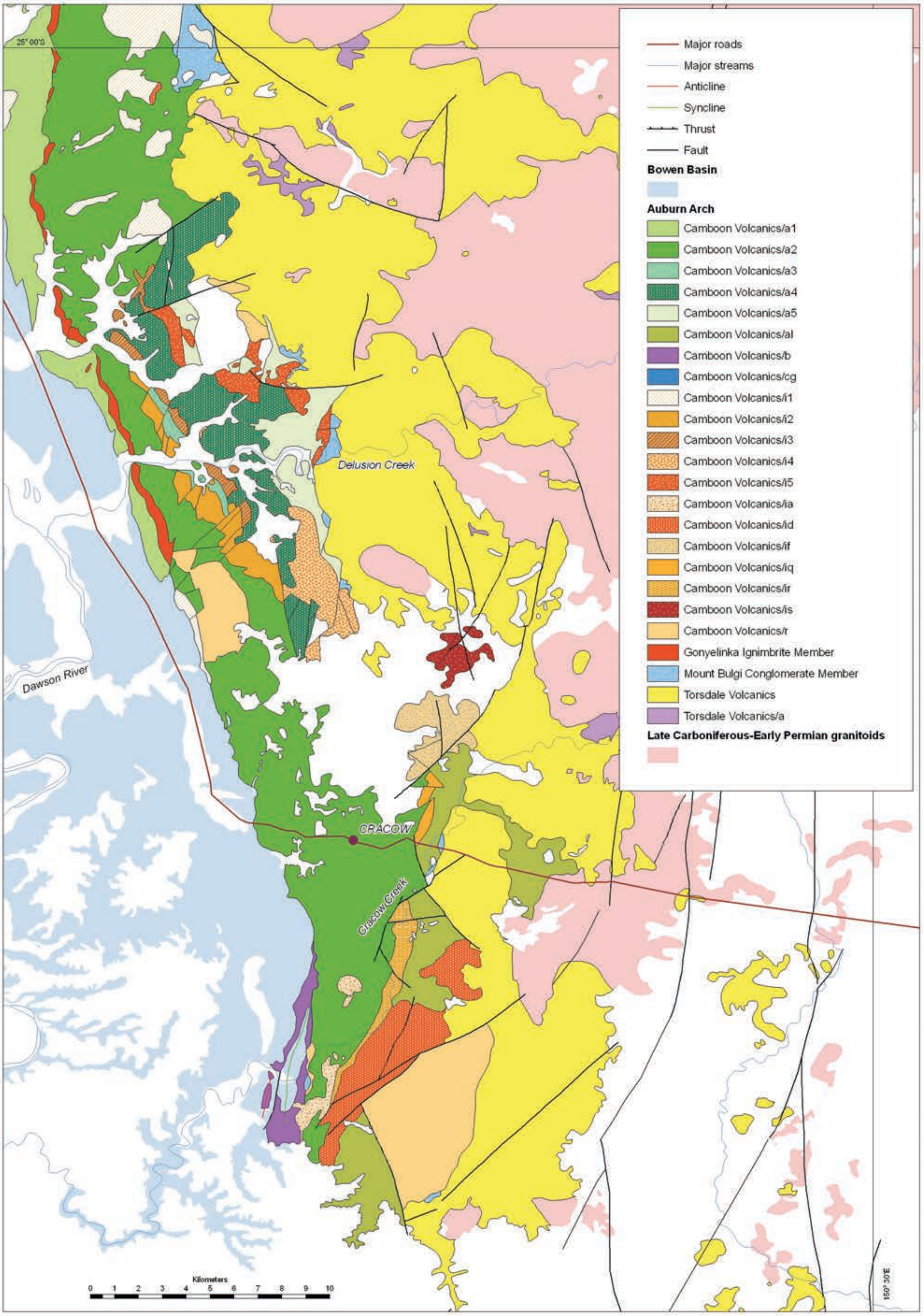

Figure 7. Volcanic stratigraphy of the Cracow area

north-west of Torsdale homestead in the Banana Range and north to the Dawson highway in southern BANANA. Typical felsic volcanic rocks, especially ignimbrite, as well as minor sandstone, conglomerate and mafic volcanic rocks are well exposed. Future detailed work may be able to define a type section here. A critical relationship exposed in this area is the base of the Mount Bulgi Conglomerate Member at MGA 232400 7291300. Here, the conglomerate unconformably overlies both the Torsdale Volcanics and leucogranite that intrudes them.

Lithology

As originally mapped, the Torsdale Volcanics include predominantly rhyolitic to dacitic ignimbrite, lava, and related epiclastic sediments. In the Cracow area and in the Banana Range west of Biloela, they are almost exclusively massive ignimbrite (much less altered than ignimbrites in the Camboon Volcanics) and are easily distinguished from the Camboon Volcanics. West of Torsdale homestead, a distinctive conglomerate, the Mount Bulgi Conglomerate Member, occurs at the base of the Camboon Volcanics. This conglomerate is derived mainly from the Torsdale Volcanics, but also includes clasts of granite that intrudes the Torsdale Volcanics.

Banana Range to Woolein area

In the Banana Range west of Biloela, the unit consists predominantly of crystal-rich ignimbrite and some spherulitic rhyolite lava. In most of the ignimbrite, the crystals are feldspar and some biotite or hornblende. Quartz is inconspicuous in many outcrops, although it is locally abundant as rounded, strongly embayed grains to 2mm. Most of the ignimbrite is lithic poor, but fiamme up to 2cm long are locally abundant. Where lithic clasts are present they are mainly aphyric rhyolite, but reworked volcaniclastic rocks and some fine-grained leucogranite are present in places. The groundmass is extremely fine-grained (<0.005mm) and vitroclastic textures are poorly preserved.

The more elevated terrain of the Banana Range may reflect the dominance of thick ignimbrite sheets. Rocks in the lowlands immediately to the north of the Banana Range are more diverse, and include crystal-rich rhyolitic ignimbrite and lava, polymictic conglomerate, volcaniclastic sandstone and siltstone, and possible andesitic rocks. The ignimbrites are superficially similar to those in the Banana Range, but they are probably thinner as can be observed in some of the road cuttings along the Dawson Highway. Vitroclastic textures are also better preserved.

Possible andesitic or basaltic rocks are most abundant in the east, to the north of Torsdale homestead. The rocks are represented by magenta hues on the composite radiometric images, contrasting with the usual white of the rhyolitic rocks. They are very poorly sorted, and consist of greyish-green, unbedded volcanic arenite and rudite consisting of greenish-grey to white feldspar crystal fragments in a very fine to fine-grained matrix. Lithic clasts are commonly difficult to distinguish from the matrix, but they are mostly porphyritic andesite. In a thin section of a rock from MGA 232230 7292420, they also include composite grains of plagioclase laths and some interstitial quartz-K-feldspar intergrowths, probably derived from quartz diorite intrusives. The matrix consists of fine lithic clasts and epidote, chlorite, saussuritised plagioclase, calcite and, in places, minor zeolite. Other outcrops within the “magenta zone” include interbedded volcaniclastic conglomerate, sandstone and breccia. The volcanic clasts are aphyric to porphyritic rhyolite and dacite, and range from rounded in the conglomerate beds to subangular in the breccias. At MGA 235380 7288350, the andesitic rocks are overlain by the Mount Bulgi Conglomerate Member, indicating that they are part of the Torsdale Volcanics rather than infolded Camboon Volcanics.

Trachyandesite, containing plagioclase and augite phenocrysts crops out at the foot of the Banana Range farther west, along the powerline at MGA 225250 7296100.

West of Torsdale Station, rhyolitic tuff and ignimbrite with possible interbedded fine-grained sandstone are interbedded with more massive rhyolitic ignimbrite. The massive ignimbrite is dark grey to black, moderately crystal-rich, and locally lithic-rich. A similar ignimbrite north of Brookleigh Station contains granite clasts.

Felsic volcanic rocks in a narrow strip up to 3km wide along the edge of the Biloela Basin, extending from the Biloela–Banana Road to near Woolein homestead, have been assigned to the Torsdale Volcanics. They include rhyolitic lava and ignimbrite and volcaniclastic sediments, and are locally relatively deformed. The effects of the deformation are mainly anastomosing fractures and some flattening (and less commonly stretching) of lithic clasts to produce characteristic “tombstone-style” outcrops (Figure 8b). In thin section, quartz crystal fragments are strained, and pressure shadows filled with fibrous quartz have formed adjacent to some feldspar clasts in the ignimbrites. Aligned flakes of very fine-grained muscovite or sericite are present in the matrix of poorly sorted sandstone.

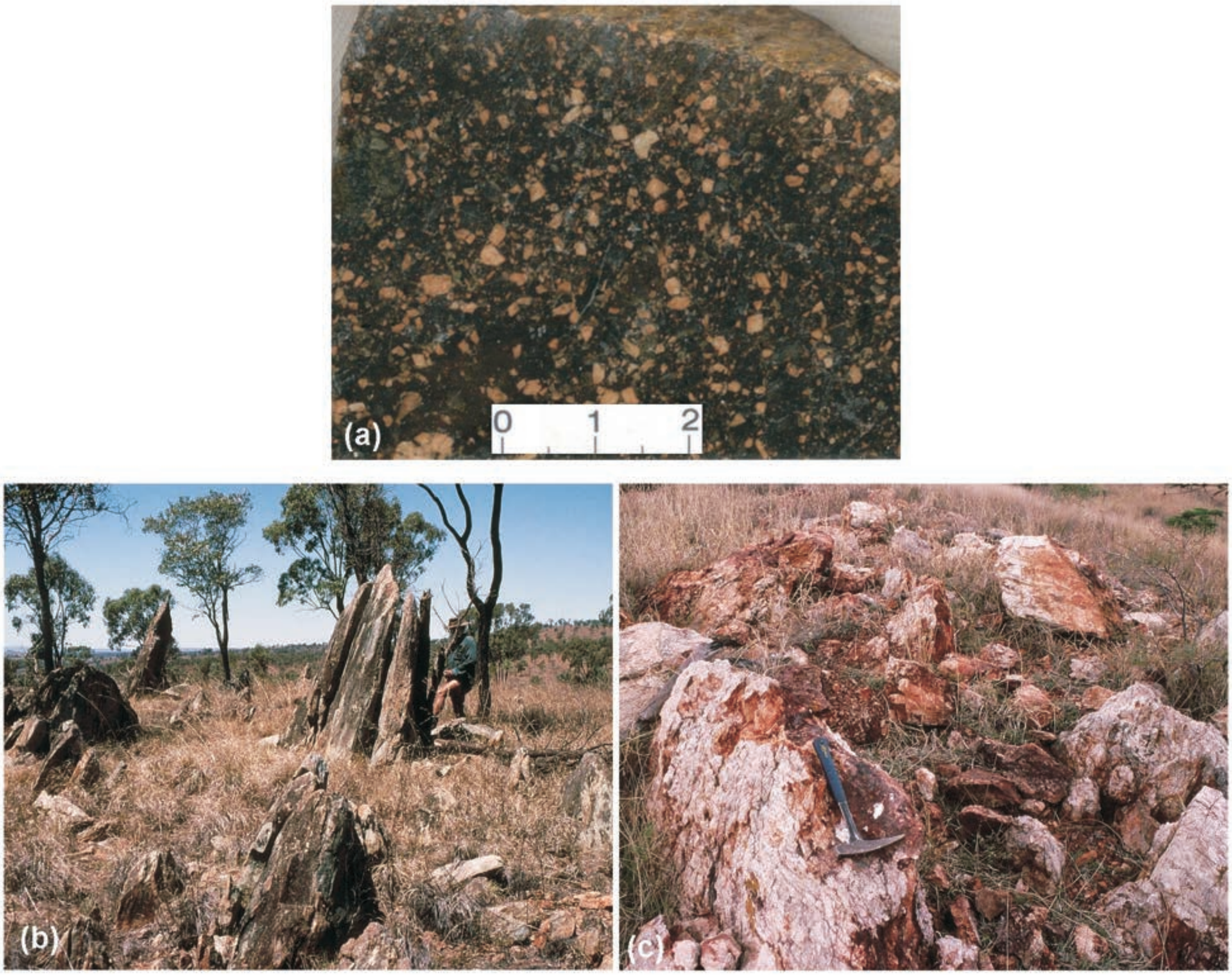

Figure 8. Torsdale Volcanics
(a) Scanned slab of crystal-rich rhyolitic ignimbrite. Cockatoo Creek at MGA 234585 7153726 (RSC218); scale is 2cm
(b) Deformed 'tombstone-style' outcrops of rhyolitic ignimbrite. North-east part of Greycliffe Station at MGA 222483 7305247 (IWGN155)
(c) Argillically altered rhyolite. Track to the communication towers on the Banana Range at MGA 227246 7296377 (IWGN225)

The ignimbrites are generally lithic-rich and crystal-rich. The lithic-rich ignimbrites locally pass into volcanic breccia (co-ignimbrite lags?). The lithic clasts are mainly aphyric to porphyritic rhyolite to andesite, and the crystal fragments are mostly feldspar. Some ignimbrite along the Belldeen–Greycliffe School road also contains fresh brown hornblende and sparse biotite crystals. The volcaniclastic sandstone is medium to very thick-bedded and interbedded with laminated siltstone. It consists mainly of felsic volcanic clasts (including rounded pebbles of rhyolite) and subordinate feldspar and quartz grains.

Theodore–Scoria area

East of Theodore, mafic rocks (such as andesitic lava, breccia and conglomerate) are common as well as the more typical felsic rocks. Distinguishing the Torsdale Volcanics from the Camboon Volcanics is therefore difficult, because as described below, the dominantly mafic Camboon Volcanics also contain some felsic volcanic rocks. During mapping of these areas, the Torsdale Volcanics were distinguished as those volcanic rocks and associated sedimentary rocks which pre-date the late Carboniferous granites. In many places adjacent to plutons, they have been at least slightly hornfelsed, and some form large septa or screens between plutons. However, another problem arises farther to the east, because granitoids there are known to be late Permian to Early Triassic and therefore would have intruded both units.

On northern Camboon Station, crystal-rich rhyolitic ignimbrite occurs between granite plutons, although it does not appear to be recrystallised. In the same area, andesitic rudite and andesitic conglomerate that resemble Camboon Volcanics were observed near a dam at MGA 228150 7232900. It was not possible to map a boundary between these rocks and the felsic ones, so they have been included in the Torsdale Volcanics. Dacitic volcanics ~4km west are mapped as Torsdale Volcanics as they appear to be recrystallised. Lithic-rich, quartz-poor mafic volcanic rocks in the north-west part of Brindabella Station appear to form a septum between granite bodies and are therefore also included in the Torsdale Volcanics.

South-east of Woolton Station adjacent to the Boam Creek Quartz Monzodiorite, hornfelsed siltstone, minor sandstone and possible volcanics are represented by a dark band on the composite radiometric image. To the south-west, andesite crops out, but it is unclear whether it is part of the Torsdale Volcanics or Camboon Volcanics. North-east of Woolton on the western part of Kandoona Station, hornfels and rhyolite are probably part of the Torsdale Volcanics.

East of Nulambie homestead, intermediate dykes and a granitoid body intrude a succession of massive volcanolithic conglomerate, dacitic to andesitic lava and volcaniclastics. Whether the granitoid is late Carboniferous to early Permian or younger is unclear but the intruded sequence is mapped as Camboon Volcanics. An extensive package of interbedded rhyolite and conglomerate on western and southern Parraweena Station is assigned to the Torsdale Volcanics.

Recrystallised rhyolite crops out south of Davey Creek on the southern part of Runaroo Station. This rock comprises phenocrysts of embayed quartz, feldspar and minor biotite and lithic clasts in a recrystallised mosaic of quartz, feldspar and biotite. Some phenocryst phases also show the effects of recrystallisation.

In the area around Rawbelle Station, quartz-phyric rhyolitic volcanics, siltstone, fine-grained sandstone, and minor conglomerate crop out with numerous small bodies of granite to diorite. Both the volcanics and sedimentary rocks are hornfelsed. Radiometric images of the area have a mottled pattern with pale areas interspersed with dark patches. This pattern may be due to small granite to diorite bodies.

Cracow area

In the Cracow area, the unit consists mainly of grey to dark grey, welded dacitic to rhyolitic ignimbrite. The ignimbrites are generally crystal-rich with up to ~50% plagioclase and K-feldspar crystal fragments. Quartz crystals up to 3mm (commonly embayed or fractured) are common (up to ~20%) in most of the rhyolitic compositions, but are rare or absent in the more silica-poor dacitic ignimbrites. Sparse altered biotite and hornblende crystals are also present. Lithic fragments are common and locally are the main component of the rocks. Most consist of various types of non-vesiculated rhyolite, dacite and andesite or basalt. The ignimbrites are also commonly characterised by a well-developed eutaxitic foliation and flattened fiamme. Minor rock types include rhyolite lava (which is concentrated at or near the contact with the overlying Camboon Volcanics), andesite lava, and volcanic breccia.

Rocks equated with the Torsdale Volcanics were observed adjacent to a gabbro body in the upper reaches of Mountain Creek north-east of Kilbeggan homestead. Main rock-types include hornfelsed crystal-lithic rhyolitic ignimbrite and hornfelsed arenite. Conspicuous metamorphic biotite and recrystallisation are the main macroscopic effects of hornfelsing.

Mount Misery

Mount Misery is an inlier of Torsdale Volcanics within the Jurassic Evergreen Formation in central BUNGABAN, ~65km south of Cracow. It was examined at MGA 231800 7135850 near the road to Geddesvale homestead. The outcrop consists of rounded boulders of massive, grey to greenish grey, quartz-feldspar-phyric rhyolite. The rock contains ~50% large fragmental feldspar and subordinate embayed quartz crystals up to 3mm across. Also present are altered biotite flakes to 2mm and remarkably fresh greenish brown hornblende to 1.5mm. The groundmass is a very fine-grained, granular quartz-feldspar mosaic, with sporadic patches with devitrification textures, such as microspherulites. Lithic clasts (or xenoliths) are common and are mostly aphyric andesite or hornblende microdiorite and aphyric to more coarsely porphyritic rhyolite similar to the host but lacking hornblende. Some could be fiamme, but none are particularly flattened. In outcrop, it is difficult to determine whether the rock is extrusive or intrusive. However, although no vitroclastic textures are preserved, the fragmental nature of the quartz and feldspar suggests that the rock is probably part of a thick recrystallised ignimbrite sheet.

Geophysical response

The felsic rocks of the Torsdale Volcanics are generally characterised by moderate to high responses in all three channels, resulting in light greyish to whitish hues on composite images.

In the magnetic data the response is moderate and similar to that in the southern part of the Camboon Volcanics, so that the units cannot be distinguished magnetically. Magnetic susceptibility values have a mean of 540 x 10^{-5} SI units, and a bimodal distribution showing a mode at about 20 and another at about 900 with sporadic values up to about 7000.

Environment of deposition

The abundance of ignimbrite indicates an exclusively non-marine, continental origin for the Torsdale Volcanics. The local sedimentary rocks were probably deposited in fluvial and lacustrine environments within the volcanic terrain.

The Torsdale Volcanics have been interpreted as being part of an early Carboniferous Andean volcanic arc (the Connors–Auburn Arc) by Day & others (1978). This arc was inferred to be complemented by the Yarrol Province, interpreted as an unstable forearc basin, and the accretionary complex of the Wandilla Terrane. However, Holcombe & others (1997b) argued that the magmatic rocks in the Auburn and Connors Arches are mostly late Carboniferous and that this model needs to be re-evaluated. They considered the Torsdale and Connors Volcanics, Auburn and Urannah Complexes and Camboon Volcanics to be part of a broad magmatic system, the Connors–Auburn Province that spanned ~40Ma from ~320Ma. They presented two interpretations based on whether the province is interpreted as a continental arc or a broader province associated with continental extension not necessarily associated with subduction.

Dating certainly indicates that the Torsdale Volcanics are late Carboniferous and that there is no clear evidence for any early Carboniferous volcanic rocks in the Auburn Arch. However, unpublished SHRIMP data from detrital zircons from the accretionary wedge indicates that arc-related volcanism persisted from the Devonian through to at least 315Ma (C.G. Murray, personal communication) overlapping with the Torsdale Volcanics. Early Carboniferous volcanic rocks have been identified in the Connors Arch where they appear to be quite extensive, and the presence of a now-obliterated older arc is not precluded in the Auburn Arch.

Geochemistry

Thirteen samples from the Torsdale Volcanics, mostly ignimbrites or other clastic rocks, were analysed for a range of major and trace elements. Using the total alkalis-silica plot (Figure 9a), the data demonstrate that, according to the classification of volcanic rocks by Le Bas & others (1986), most of the rocks are of rhyolitic rather than dacitic composition in terms of their SiO_2 content, although three samples are more mafic and range from basaltic trachyandesite to trachyandesite. The basaltic trachyandesite is from the “magenta zone” near Torsdale. The trachyandesite lava is from near the Banana Range.

It is possible that alteration processes, for example mobility of silica and alkalis during devitrification, have affected some of the rocks, leading to them being misclassified by the TAS plot. The plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) provides a method of classifying the original composition of altered volcanic rocks, because of the immobility of these elements. In unaltered volcanic rocks Zr/TiO_2shows a strong correlation with SiO_2. Poor precision in determining Nb does not affect the classification for subalkaline rocks, because most field boundaries are relatively flat. The plot gives a comparable classification to the TAS plot for the Torsdale Volcanics, although it does not distinguish between dacite and rhyodacite, which is included with rhyolite in more modern classification schemes such as that of Le Bas & others (1986). The clastic rock, a breccia, which is in the trachyandesite field in the TAS plot, falls in the rhyodacite-dacite field in Figure 9b suggesting that it has been depleted in silica.

The trachyandesite sample was submitted for precise trace element analysis by laser ablation mass spectrometry, and the data have been used to construct the multi-element and REE plots in Figures 9c & d. The multi-element plot shows a distinct Ta-Nb trough consistent with a strong subduction component. Both plots were compared with those from modern basaltic suites using the database compiled from literature by Murray & Blake (2005, appendix 1). The closest fit in terms of slope of the REE plot and actual normalised values was found to be from the Peteroa suite developed on thick crust in the Southern Volcanic Zone of the Andes (Tormey & others, 1995) and this is shown in Figures 9c & d. The multi-element plot also shows a very close fit. However, it should be noted that there is a slight Eu anomaly in the REE plot consistent with plagioclase fractionation, and therefore the andesite may not be directly comparable with the Andean Peteroa basalts.

Nevertheless, the steep slope is consistent with interpretations that the late Carboniferous volcanic rocks of the Auburn Arch represent a volcanic arc developed on thick crust on an Andean-type continental margin.

Relationships and age

The Torsdale Volcanics are intruded by numerous granites of the Rawbelle Batholith. Contacts are rarely exposed and hornfelsing of the massive felsic volcanic rocks, which make up most of the formation, is generally not extensive.

Some areas of granite have a radiometric signature similar to nearby rhyolitic ignimbrite. The similarity of the signatures suggests similar chemistry and the possibility that the rocks are co-magmatic. For example, south

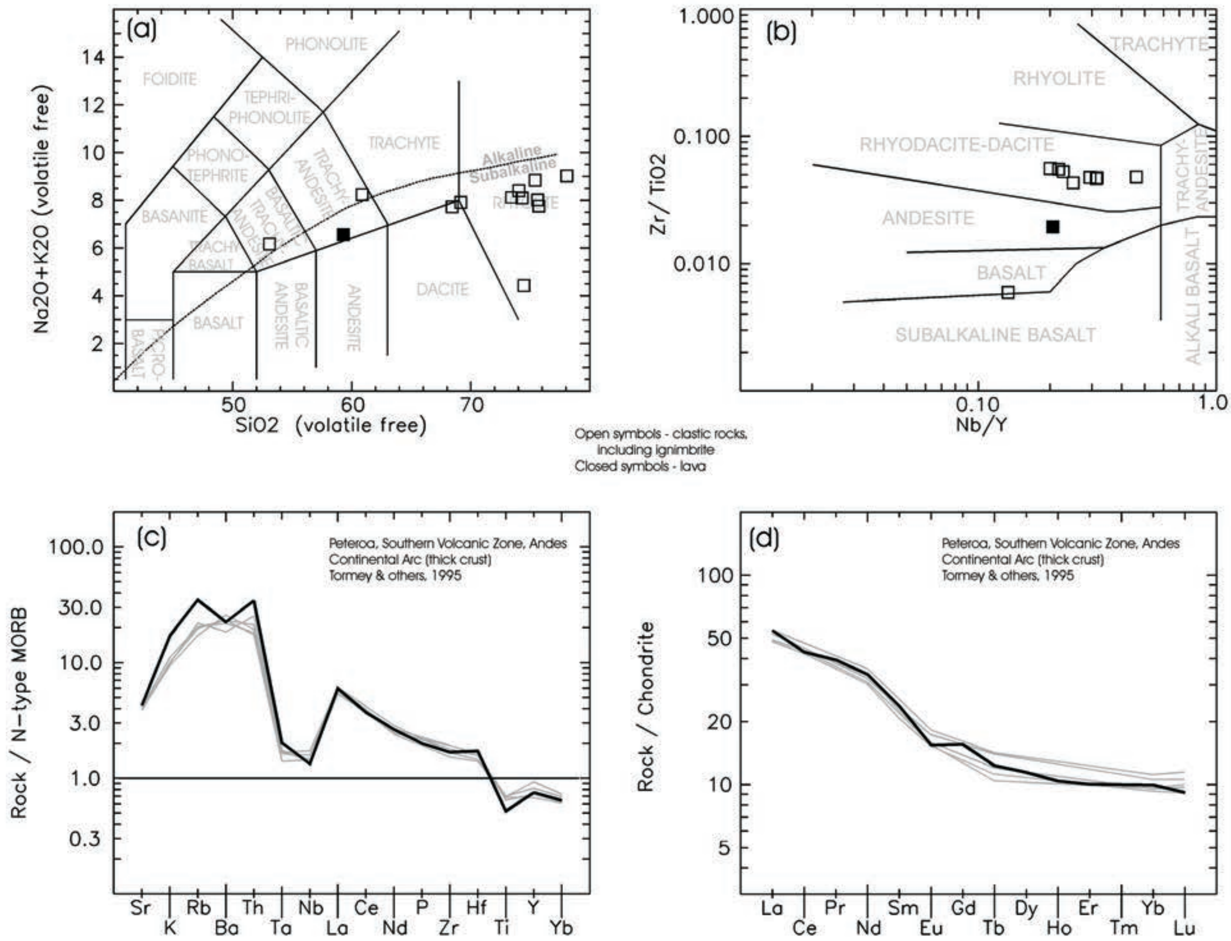

Figure 9. Geochemistry of the Carboniferous Torsdale Volcanics: (a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986) and Irvine & Baragar (1971); (b) Nb/Y vs Zr/TiO_2 showing the fields of Winchester & Floyd (1977); (c) N-MORB normalised multi-element plot (using values from Pearce, 1983) for a trachyandesite sample; (d) chondrite-normalised REE plot (using values from Sun & McDonough, 1989) for sample in (c). For comparison, the patterns of basalts from the modern Andean Peteroa suite are shown in grey.

of Torsdale homestead on western Timbuktu Station, medium to coarse-grained pink to red biotite granite has a radiometric signature similar to rhyolitic ignimbrite. Similarly, in the Banana Range and in the Brindabella Station area farther south, granites and rhyolitic volcanics have similar signatures.

The Camboon Volcanics overlie the Torsdale Volcanics, probably disconformably. Scattered lenses of polymictic pebble to boulder conglomerate crop out along the postulated unconformity, but they are best developed in the Banana Range, south-west of Biloela, where the Mount Bulgi Conglomerate Member has been mapped at the base of the Camboon Volcanics. The conglomerate consists mainly of clasts of felsic volcanic rocks from the Torsdale Volcanics, but also includes some of the granites that intrude them. North-west of Torsdale homestead, the conglomerate directly overlies one of these granites. This suggests a hiatus between the Torsdale Volcanics and Camboon Volcanics, long enough for the unroofing of the granites. The Torsdale Volcanics are also unconformably overlain by the Precipice Sandstone and Evergreen Formation to the south and south-west of Cracow.

Dear & others (1971) correlated the “Torsdale beds” with the partly volcaniclastic early Carboniferous Three Moon Conglomerate of the Yarrol Province. However, unlike the Torsdale Volcanics, the Three Moon Conglomerate has a low radiometric response and the volcanic rocks are of basaltic composition (Murray & Blake, 2005), suggesting that this correlation may not be valid. They also suggested that the unit could include younger rocks north-west of Torsdale homestead and near Mount Shaw homestead, and they correlated these with the early Permian Youlambie Conglomerate. This appears to have been on the basis of an occurrence of leaves of *Noeggerathiopsis hislopi* 8km north-west of Torsdale homestead. This site was not relocated, but its plotted position places it close to the boundary between the andesite assigned to the Torsdale Volcanics and the Mount Bulgi Conglomerate Member. The occurrence of these fossils is consistent with the SHRIMP age (IWGN145 — see below) for ignimbrite from this area. The age is close to the Carboniferous–Permian boundary.

Table 1: U-Pb SHRIMP ages for the Torsdale Volcanics

Sample	Locality	Rock type	Age (Ma)
IWGN145	Foot of Banana Range south of Dawson Highway (MGA 224434 7296173)	rhyolitic ignimbrite	Dominant younger group of 16 analyses has a weighted mean $^{206}Pb/^{238}U$ age of 298.2±5.1Ma (MSWD = 0.98). An older group of 9 analyses have a weighted mean $^{206}Pb/^{238}U$ age of 315±5.8Ma (MSWD= 0.78)
RSC157	Eidsvold Cracow road (MGA 234229 7198405)	rhyolitic ignimbrite	308±5.1Ma for 14 of 15 analyses (MSWD= 2.0)
RSC218A	Cockatoo Creek, near Taroom-Auburn road (MGA 234586 7153737)	rhyolitic ignimbrite	311.6±3.8Ma for 10 of 15 analyses (3 younger analyses are suspect; 2 older grains at 330–3358Ma)
IRAU613	Mount Misery (MGA 231806 7135837)	recrystallised rhyolitic ignimbrite(?)	314.9±2.9Ma for 14 of 18 analyses
LHT322	South of Glandore HS, adjacent to Glandore Granodiorite (MGA 238952 7244722)	recrystallised rhyolite	Dominant peak at 325±4.0Ma (Namurian) for 15 of 20 analyses (younger group indicate Pb loss?)

Whitaker & others (1974) reported a single K–Ar hornblende age of 343Ma (early Carboniferous) for the rhyolitic ignimbrite from the inlier at Mount Misery. This agreed with the correlation by Dear & others (1971) with the Three Moon Conglomerate. However, subsequent dating indicates that the unit, including the rocks at Mount Misery, is mainly late Carboniferous (Namurian) — see Table 1. The early Carboniferous age obtained has been much quoted in the literature, and the Mount Misery outcrop shows evidence of having been subsequently sampled for palaeomagnetism. Any conclusions resulting from such work might need to be modified. The older age obtained by the K–Ar dating may be due to excess argon in the hornblende.

In total five samples were selected for U-Pb zircon dating by the SHRIMP method at the Research School of Earth Sciences at the Australian National University. The results (see Appendix for details) as shown in Table 1.

The older age from near Glandore along with the ages of around 320Ma obtained from some of the granites suggest that there may be two successions, but it is impossible to separate them without much more dating. Jones & others (1996) reported a K–Ar hornblende date from the Torsdale Volcanics of 312±4Ma that agrees with the main group of dates reported here.

The youngest age of ~300Ma (sample IWGN145) is from a succession of ignimbrites, which form the northern part of the Banana Range north-west of Torsdale and are intruded by small granite plutons, one of which is unconformably overlain by the Mount Bulgi Conglomerate Member. This date is close to the age of rhyolite clasts as well as a rhyolitic ignimbrite in the Youlambie Conglomerate north-east of Biloela (see Appendix).

Dating of rocks mapped as Camboon Volcanics (see below) suggests that any break between them and the Torsdale Volcanics is likely to be short and that the units may actually have overlapped in age. Volcanism was thus essentially continuous. Breaks, such as at the base of the Mount Bulgi Conglomerate Member near Torsdale, may not be regionally significant and mapped contacts between the units are probably diachronous.

CAMBOON VOLCANICS

Introduction

The Camboon Volcanics overlie granites and volcanics along the western flank of the Auburn Arch, and also on the eastern side, south of Biloela (Figure 4). North-north-west of Biloela, they extend almost continuously as far north as the Capricorn Highway, as thrust slices interleaved with the overlying Woolein beds and Back Creek Group. The total exposed length of the outcrop area is almost 200km. North of the Capricorn Highway, a break in continuity of the Carboniferous to Permian volcanic rocks, extends for ~30km to the north-west, where thrust slices of volcanic rocks crop out west of Rookwood homestead. The latter have been assigned to the Leura and Mount Benmore Volcanics, and are considered the southernmost extent of the Connors Province.

The Camboon Volcanics are known to extend westwards beneath the Taroom Trough, and may be continuous with volcanic rocks intersected by petroleum wells in the Roma Shelf area to the west. These volcanics are generally collectively named the Combarngo Volcanics (Green & others, 1997).

The unit was first defined as the Camboon Andesite by Derrington & others (1959) and described in more detail by Dear & others (1971) and Whitaker & others (1974). Briggs & Waterhouse (1982) changed the name to Camboon Volcanics, recognising that the range of rock types is more diverse than implied by the lithological term “andesite”. Subsequent authors have mostly adopted this name.

Type area

Derrington & others (1959) gave the type area of the “Camboon Andesite” as “near Camboon homestead”. However, Dear & others (1971) quoted a personal communication from Derrington that indicated that the definition should have read “near Camboon Woolshed”, which was ~23km south-south-east of Theodore in northern CRACOW.

In view of the imprecise definition of the type area, we propose a type section for the Camboon Volcanics, along and adjacent to Delusion Creek in CRACOW from MGA 227800 7215500 (the basal conglomerate overlying the Torsdale Volcanics) to 219400 7214700 (the base of the overlying Oxtrack Formation). This area includes many of the informal subdivisions described below.

Lithology

The unit consists mainly of andesitic and basaltic lavas and volcaniclastics, but rhyolitic to dacitic lavas and volcaniclastics, including ignimbrite, and pebble to boulder conglomerate are also present.

Mount Bulgi Conglomerate Member

In THEODORE and southern BANANA, the base of the Camboon Volcanics is defined by a conglomerate in almost all sections visited (*e.g.* Figures 10a,b). Where this conglomerate is well developed, such as in the Torsdale area, it has been mapped out as the **Mount Bulgi Conglomerate Member** of the Camboon Volcanics. The conglomerate differs from most of those in the Torsdale Volcanics in that it contains granite clasts, although both Whitaker & others (1974) and Dear & others (1971) stated that granite clasts are present in conglomerates in both units. In the type area near Mount Bulgi, north-west of Torsdale homestead, the pebble to cobble conglomerate directly overlies a pink to orange biotite granite that intrudes the Torsdale Volcanics. Clasts of this granite are conspicuous near the base of the conglomerate unit (Figure 10b) but become less abundant and are rare up-section. Most of the clasts are aphyric to porphyritic felsic volcanic rocks. They are usually moderately well rounded and are supported by a matrix of very coarse-grained sandstone. Beds are very thick and poorly defined. Internal stratification is usually limited to grainsize variation.

The most northerly outcrops were observed north-east of Greycliffe homestead along Sellheim Creek and its tributaries, where discontinuous basal conglomerates up to 30m thick overlie the Torsdale Volcanics (Figure 10a). They contain only felsic volcanic clasts. To the south of the Torsdale area, conglomerate containing granite clasts is very well exposed in a tributary of William Creek on the northern part of Valencia Station.

In the Torsdale area, the Mount Bulgi Conglomerate Member contains a prominent columnar jointed rhyolite sheet that in fact forms Mount Bulgi. This may be a flow or possibly a sill. Rhyolitic rocks have been observed in other areas, for example on the western flank of the Banana Range. In the central part of SCORIA, extensive areas of felsic volcanics interbedded with conglomerate and volcanic conglomerate are assigned to the Mount Bulgi Conglomerate Member. Rhyolite on south-western Rawbelle Station, in the headwaters of One Mile Creek, has also been mapped within the Mount Bulgi Conglomerate Member.

In the Pump Creek area in south-west SCORIA, polymictic conglomerate crops out with rhyolitic to dacitic volcanics and minor siltstone to fine grained sandstone. Relationships are complex in this area as also noted by Dear & others (1971, pages 34–35). Near the Lone Hand gold mine, quartz-phyric rhyolitic volcanic rocks and volcanilithic conglomerate are intruded by aplite veins or dykes. Some of the conglomerates contain granite clasts and for this reason the area has been mapped as Mount Bulgi Conglomerate Member. However, the general predominance of rhyolite and the aplite veins and dykes are more characteristic of the Torsdale Volcanics and some of the rocks are intruded by the Glandore Granodiorite rather than overlying it. This would suggest that granite-bearing conglomerates are present in the Torsdale Volcanics and such clasts are not a reliable criteria to recognise the Mount Bulgi Conglomerate Member. Dear & others (1971) also commented that polymict conglomerates with granite boulders occur in both the Torsdale Volcanics and basal Camboon Volcanics in this area.

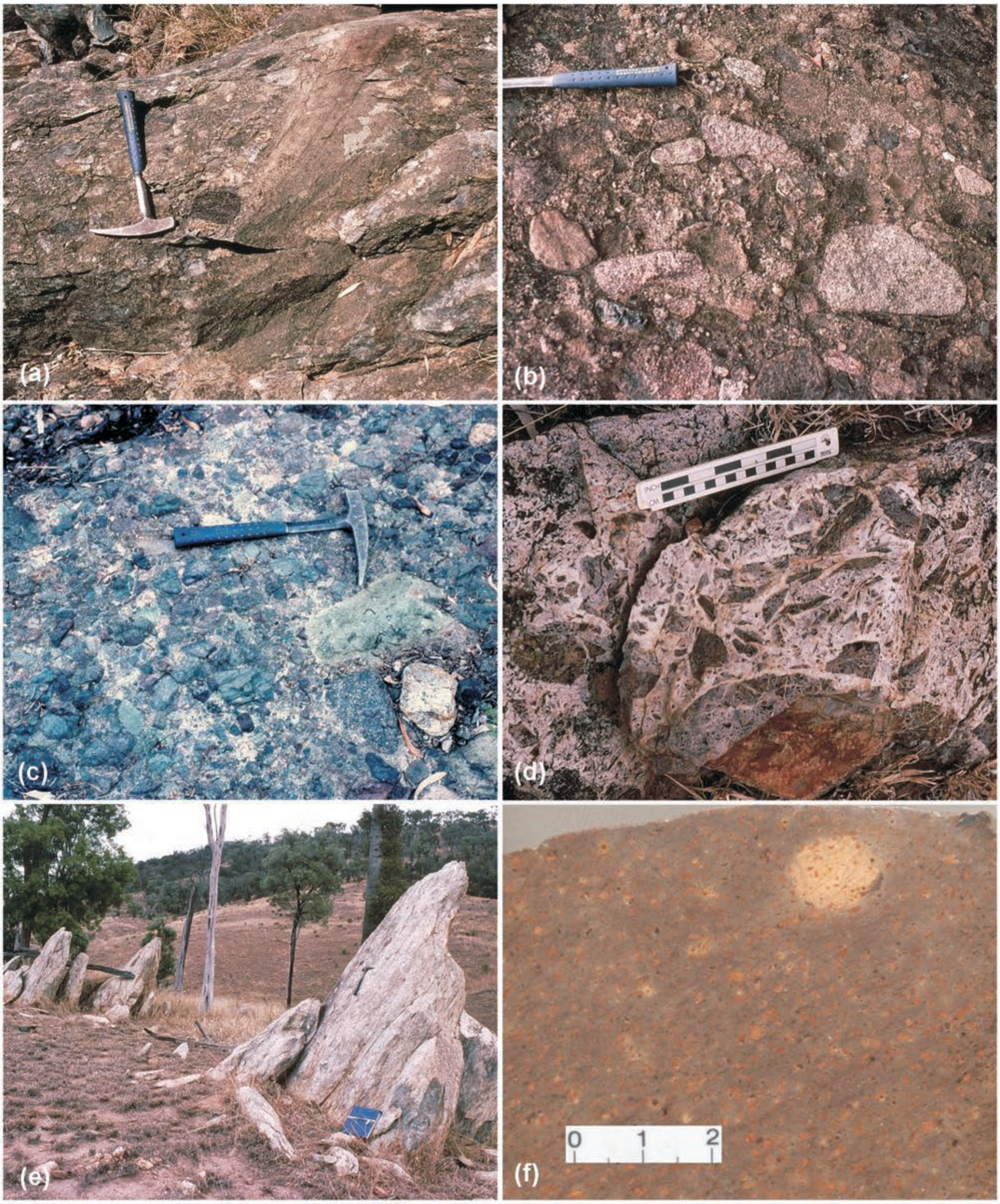

Figure 10. Camboon Volcanics
(a) Matrix-supported conglomerate and cross-bedded sandstone at the base of the Camboon Volcanics. North-east part of Greycliffe Station at MGA 222406 7304707 (IWGN160)
(b) Granite clasts in conglomerate of the Mount Bulgi Conglomerate Member. About 1km west of Mount Bulgi at MGA 232270 72911158 (IWGN246)
(c) Polymictic conglomerate consisting of a variety of aphyric to porphyritic mafic volcanic clasts in Cracow Creek at MGA 231937 7199227 (BB2957)
(d) Breccia of porphyritic rhyolite clasts with epithermal quartz infill. Stoney Creek track on Darling Plains Station at MGA 208819 7310926 (IWGN094)
(e) Deformed 'tombstone-style' outcrops of rhyolitic ignimbrite. Lakeview Station 12.5km south-west of Wowan at MGA 206786 734873 (IWGG809)
(f) Crystal-rich feldspar-phyric rhyolitic ignimbrite of the Gonyelinka Ignimbrite Member. Castle Creek Road near the intersection with Walloon Road, 14km east-north-east of Theodore at MGA 216821 7244807 (RSC143); scale is 2cm.

The thickness of the unit in most areas is not known, but appears to be variable, and in places is too thin to map out. In the Mount Bulgi area, where it is the most extensive, at least 250m underlies the rhyolite flow. The thickness of the rocks overlying the flow is difficult to estimate because of the shallow dips and apparent dip reversals.

Cracow area

This area is the southernmost exposed part of the Camboon Volcanics and extends from near Cracow Station in the south to about Mount Irving (Figure 7). The subdivisions recognised include mafic volcanics rocks (**CPvc$_{al}$, CPvc$_{a2}$** and **CPvc$_{b}$**), ignimbrites (**CPvc$_{id}$, CPvc$_{if}$, CPvc$_{iq}$, CPvc$_{ia}$, CPvc$_{ir}$** and **CPvc$_{is}$**), rhyolitic lava (**CPvc$_{r3}$** and **CPvc$_{r4}$**) and minor sedimentary rocks (**CPvc$_{s}$**).

CPvc$_{r3}$ crops out in the south of the area, and has been mapped over ~20km^2 abutting the Torsdale Volcanics. It could be part of that unit, although a thin polymictic conglomerate separates them in the south. The unit appears to consist mainly of almost aphyric, locally flow-banded and brecciated rhyolite containing sparse quartz and feldspar phenocrysts. Although interpreted as mainly lava, it possibly contains some volcaniclastic rocks, as “crystal tuff with quartz, feldspar and mafic phenocrysts” were described in R. Rollason’s field notes near the base of the unit in the south at MGA 231700 7184550. Some breccia in this area may be flow-foot breccia. The unit appears to be in faulted contact with other units in the Camboon Volcanics.

CPvc$_{al}$ is a somewhat heterogeneous unit, consisting of abundantly porphyritic (plagioclase-phyric) andesite that is locally extremely altered, andesitic volcaniclastic breccia, flow-banded rhyolite and densely welded, crystal-rich rhyolitic ignimbrite. It appears to overlie **CPvc$_{id}$**, and to the north abuts the Torsdale Volcanics. To the south, rocks assigned to **CPvc$_{al}$** appear to underlie **CPvc$_{id}$**.

It is overlain by several separate ignimbrite units that are from south to north **CPvc$_{id}$**, **CPvc$_{ir}$**, **CPvc$_{iq}$**, **CPvc$_{if}$**, and **CPvc$_{is}$**.

- **CPvc$_{id}$** consists of dark grey or brown, fine-grained, densely welded dacitic ignimbrite that ranges from crystal-poor to crystal-rich. Crystals are quartz and white feldspar, and scattered hornblende is present. It is generally lithics-poor, but dark green to brown, flattened rhyolite fragments up to 3cm are locally present.
- **CPvc$_{ir}$** is dark reddish brown to maroon, very fine-grained, densely welded, rheomorphic rhyodacitic (?) ignimbrite with crystals of plagioclase, biotite, hornblende andpyroxene,
- **CPvc$_{iq}$** is pale grey, rhyolitic ignimbrite with crystals of quartz, K-feldspar, plagioclase, biotite and hornblende,
- **CPvc$_{if}$** is purple, fine-grained, rhyodacitic (?) to dacitic (?) ignimbrite, characterised by the presence of abundant feldspar crystals and scarce or no quartz crystals
- **CPvc$_{is}$** is brown to red-brown rhyolitic ignimbrite.

The most extensive unit in the area is **CPvc$_{a2}$**, another relatively heterogeneous unit consisting of moderately porphyritic (plagioclase and hornblende (?)-phyric) andesite or basalt, volcaniclastic conglomerate and densely welded, crystal and lithics-poor dacitic (?) to rhyodacitic ignimbrite. The rocks are locally strongly altered and are host to the epithermal gold mineralisation at Cracow. It is generally the uppermost part of the Camboon Volcanics in this area and is overlain by either the Buffel Formation or Oxtrack Formation. An ignimbrite unit (**CPvc$_{ia}$**) mapped within it, is fine-grained, welded, lithics-poor, crystal-rich, dacitic (?) ignimbrite with abundant feldspar crystals

However, in the south near Cracow homestead, the uppermost part of the Camboon Volcanics is subunit **CPvc$_{b}$**, which was described briefly by Holcombe & Jell (1983). The most common rock type is a purplish to dark green, matrix-supported volcanic breccia that contains clasts from pebble to boulder size. Several distinct lava flows were also described, and consist of porphyritic olivine basalt with well-defined, amygdaloidal, flow-top breccias. The rocks are overlain by the Buffel Formation and underlain locally by flow-banded rhyolite lava (**CPvc$_{r5}$**) that forms a very prominent spur on the south-east side of Buffel Hill.

Mount Irving to Barfield

In this area, the Camboon Volcanics consist mainly of andesitic and basaltic lava flows and interlayered dacitic to rhyolitic ignimbrites. This has enabled the subdivision of the sequence into a series of subunits based on composition, whether dominantly andesite or basalt (**CPvc$_{a1}$** to **CPvc$_{a5}$**), ignimbrite (**CPvc$_{i1}$** to **CPvc$_{i5}$**) or felsic lava (**CPvc$_{r1}$** and **CPvc$_{r2}$**). Most of these subdivisions are recognised only in the central part of CRACOW (mainly in the catchment of Delusion Creek and southern Oxtrack Creek). They are based partly on the mapping of A. Jones as part of her PhD research as well as observations by R. Bultitude and P. Garrad (this project) and those of R. Rollason (as part of the first pass regional mapping of Whitaker & others (1974)). To the north, extending into THEODORE, only three main units are recognised — **$CPvc_{a1}$** and **$CPvc_{a2}$** and the Gonyalinka Ignimbrite Member, which separates the other two.

$CPvc_{cg}$ is the basal conglomerate to the Camboon Volcanics in this area. It is similar to the Mount Bulgi Conglomerate Member, described above, but because of its patchy distribution, this name has not been used. It consists of polymictic, pebble to boulder conglomerate, mainly derived from felsic volcanics of the Torsdale Volcanics, and locally contains granitoid clasts; some lithic sandstone is interbedded. It is overlain partly by **$Cpvc_{i5}$** and **$CPvc_{a5}$**.

Two small areas of felsic lava have been mapped near the base of the Camboon Volcanics in the catchment area of Oxtrack Creek. At MGA 224600 7220650, **$CPvc_{l1}$** is pale pink, slightly porphyritic rhyolite that contains phenocrysts of pink K-feldspar, sparse, altered biotite and rare quartz. It contains sparse pyrite cubes and is relatively extensively altered. It is tentatively interpreted as lava. **$CPvc_{l2}$** crops out at MGA 222800 7222550 and is a very thick unit of volcanic breccia, typical of those associated with rhyolite lava domes or flows. The breccia consists of unsorted, angular clasts of quartz-feldspar-phyric rhyolite up to 50cm across.

$CPvc_{i5}$ consists of dark reddish brown to purplish brown, very fine-grained, crystal-poor to moderately crystal-poor, lithics-poor to moderately lithics-poor, densely welded, dacitic to rhyolitic(?) ignimbrite with local columnar jointing; it is commonly extremely altered and ferruginised.

$CPvc_{a5}$ contains medium to dark grey, fine-grained aphyric to moderately plagioclase-phyric basalt to andesite with local, extensively altered, amygdaloidal and flow-margin breccia zones; poorly sorted, polymictic conglomerate and breccia composed mainly of mafic volcanic clasts is also present.

The overlying **$CPvc_{a4}$** includes pale grey or brownish to purplish grey plagioclase-phyric and locally hornblende-phyric andesite or basalt that is autobrecciated and amygdaloidal in places and also locally extremely altered. Some altered welded, rhyodacitic (?) ignimbrite also occurs within the mapped area.

To the south **$CPvc_{a4}$** and **$CPvc_{a5}$** are separated by an ignimbrite unit, **$CPvc_{i4,}$** consisting of grey to purplish grey, rhyodacitic ignimbrite (?), the base of which is defined by a conspicuous dip slope.

Another ignimbrite unit, **$CPvc_{i3}$**, which consists of pale purple to reddish brown, very fine-grained, densely welded, lithics-poor to moderately lithics-poor, moderately crystal-poor to crystal-rich, rhyodacitic to rhyolitic ignimbrite, overlies **$CPvc_{a4}$**. The unit is commonly extensively altered. Some flow-banded, autobrecciated rhyolite has also been recorded in **$CPvc_{i3}$**.

The overlying **$CPvc_{a3}$** was observed at MGA 221900 7214550 where it consists of massive, slightly plagioclase-phyric andesite or basalt. The exposure is capped by a thin reddish to purplish grey, crystal-poor, rhyolitic ignimbrite that may be part of the overlying unit **$CPvc_{i2}$** that elsewhere is purplish brown to purplish grey, very fine-grained, densely welded, lithics-poor to moderately lithics-poor, crystal-poor to moderately crystal-poor, dacitic to rhyolitic ignimbrite. It has a strong eutaxitic foliation and conspicuous flattened fiamme and is locally rheomorphic. The unit is extensively altered.

This unit is overlain by **$CPvc_{a2}$**, which extends into northern CRACOW and THEODORE, where it comprises the entire lower part of the Camboon Volcanics. It is possible that it includes equivalents of the subdivisions discussed above, but they have not been mapped out due to poor outcrop and the lack of distinctive ignimbrite units to provide markers in the succession. The unit, as mapped, overlies the basal conglomerate in THEODORE and northern CRACOW and is a sequence of dark grey, greenish to brownish grey or purple, fine to medium-grained, porphyritic andesite (locally amygdaloidal), minor polymictic granule to cobble conglomerate, andesitic tuff and rhyodacitic(?) ignimbrite. Typical basalt from the bank of Cattle Creek beside the Theodore–Walloon road comprises plagioclase and pyroxene phenocrysts in a groundmass of plagioclase, pyroxene, opaques and altered glass. Outcrop is poor with only isolated outcrops surrounded by thick black soils. The thickness of the sequence is unknown. Dips are shallow and the variation in orientation suggests that open folds are present.

Flat-lying dacitic ignimbrite mapped as Subunit **$CPvc_{i1}$** forms patchy outcrop areas within the area of **$CPvc_{a2}$** south-west of Woolton homestead in southern THEODORE and northern CRACOW. The ignimbrite is purplish grey to dark brownish purple, very fine-grained, densely welded, mostly lithics-free to -poor, fiamme-rich and moderately crystal-rich. Locally some outcrops are lithics-rich and/or crystal-poor. The crystals include plagioclase, pyroxene, iron oxide and amphibole in a devitrified glassy groundmass. The ignimbrite is extensively altered and includes minor volcanic breccia.

Towards the top of the Camboon Volcanics in THEODORE and northern to central CRACOW, a thick ignimbrite (Figures 5 and 7) forms a semi-continuous ridge. This unit is named the **Gonyelinka Ignimbrite Member**. The type section is along Lonesome Creek in Gonyelinka Gorge (MGA 218400 7253400 to 218000 7253400), where the unit comprises mainly oligoclase-albite phenocrysts, volcanic lithic fragments in an extremely fine-grained (glassy) matrix containing shards and fiamme. It is ~150m thick. The Gonyelinka Ignimbrite Member has been traced for ~55km, although it is locally discontinuous in CRACOW. It separates Subunits **$CPvc_{a1}$** and **$Cpvc_{a2}$**. Mount Tam, which lies to the east of the Gonyelinka Ignimbrite Member, is a very prominent hill made up of extensively silicified volcanic rock of unknown affinity. It intrudes rocks stratigraphically below the ignimbrite, and is surrounded by numerous trachytic (?) dykes, possibly similar in composition to the Gonyelinka Ignimbrite. It is possible that Mount Tam was a vent for the eruption of the ignimbrite.

A belt of basalt to basaltic andesite (**$CPvc_{a1}$**) conformably overlies the Gonyelinka Ignimbrite Member, and underlies the marine sequence of the Bowen Basin. These rocks may represent a more mafic sequence in the Camboon Volcanics. They have darker colours on the composite radiometric image. They appear to be less fractionated with higher *mg* values (Figure 11). Apart from lower SiO_2, they are higher in TiO_2, P_2O_5, Cr and Ni and depleted in Al_2O_3 with respect to volcanic rocks in unit **$CPvc_{a2}$** that underlie the ignimbrite unit. Similar rocks with a low radiometric response occur in the Prospect Creek area in the north-east part of THEODORE where the rocks also have a low aeromagnetic response.

Porphyritic andesite crops out in a north–south belt from ~1km east of Barfield homestead south for ~13km. These rocks are anomalously high in Rb and Th with respect to the remainder of the mafic volcanic rocks in the Camboon Volcanics. They also appear less altered and are interpreted as dykes.

At the extreme southern end of the area, felsic lava, assigned to **$CPvc_{r4}$** occurs within **$CPvc_{a2}$**. The lava is white to buff or purplish brown, fine-grained, and porphyritic with scattered quartz phenocrysts. It may be a rhyolite cryptodome and is commonly extensively altered.

An interesting feature of some of the Camboon Volcanics near the top of the unit in the Theodore area is the presence of native copper nuggets as float within the black soil plains. Resistant prehnitised boulders in the soil profile contain disseminated native copper. The largest recorded boulder weighed up to 1 tonne (Garrad & Withnall, 2004a). Large nuggets of native copper with cuprite and minor malachite and calcite commonly weighing up to 75kg have been reported from ~9.5km north-east of Theodore (Stevens, 1983). They occur in black soil over several hectares close to a vein of similar mineralisation. The nuggets appear to have been derived from the vein and concentrated as a lag deposit in the soil. A prehnite-native copper-cuprite association occurs in elongate north-south zones replacing parts of vesicular flow-tops in a 3km-wide strip to the north of Castle Creek (Heywood, 1974; Stevens, 1983).

The native copper mineralisation may be the result of epigenetic processes (water table fluctuations and water movement within the soil profile) concentrating the background copper values present in the andesite and basalt. Campe & Richards (1968) noted that the Camboon Volcanics contain an elevated background copper level of ~100ppm. They considered that during low grade metamorphism of primary pyroxene and hornblende to chlorite and epidote, the copper that could not be accommodated in this new assemblage, was liberated and mobilised as native copper. The deposits are not considered to be economic.

Barfield to Rannes

North from Barfield, the Camboon Volcanics have not been subdivided, and are mostly basaltic to andesitic lavas and volcaniclastic rocks, including poorly bedded epiclastic volcanic arenite and rudite, as well as probable primary pyroclastics. The rudites range from poorly-sorted breccias with subangular clasts in a sandy to silty matrix to moderately-sorted conglomerate with subrounded clasts. The extensive autoclastic brecciation evident in the Mount Benmore Volcanics was not observed in the Camboon Volcanics.

Alteration is relatively pervasive, and most outcrops are saussuritised or epidotised, chloritised and/or hematised to some extent. In the basalts and basaltic andesites, clinopyroxene phenocrysts are commonly preserved, but in the groundmass clinopyroxene is usually replaced by chlorite. In outcrop, the rocks are typically pale grey to green, and were described in the field as dacites. Geochemical studies however, show these rocks to be mostly basalt or basaltic-andesite in composition. The pale colour may be due to alteration.

Most of this alteration can be attributed to burial metamorphism. However, local zones of more intense silicic, propylitic and argillic alteration, brecciation and epithermal-style quartz veining (Figure 10d) through the area are associated with low-grade gold mineralisation that has been investigated by Placer and Queensland Metals Corporation. It is uncertain whether the timing of this alteration and mineralisation is related to the main phase of volcanism in the early Permian, or is a younger superimposed event. Potassic anomalies in the airborne radiometrics in this area are partly due to alteration, but also appear to include small rhyolite intrusions. These intrusions may be related to the mineralisation and alteration.

Strain increases eastwards towards the Gogango Overfolded Zone. The deformation was relatively heterogeneous, and relatively undeformed rocks are interspersed by foliated zones up to a few tens of metres across. The foliation is defined by flattening and alignment of lithic clasts in the volcaniclastics and a fracture cleavage or spaced, anastomosing shear planes in the lavas.

Prospect Creek to Rawbelle area

Camboon Volcanics crop out extensively in the Prospect Creek area in the north-eastern part of THEODORE and north-western part of SCORIA. These rocks flank the eastern side of the belt of Torsdale Volcanics and Carboniferous granitoids, and are folded with the overlying Back Creek Group in the Prospect Creek Anticline. Farther east they occur with the Back Creek Group in a complex zone of thrusting and folding between the Drumberle and Grevillea Thrusts.

In this area, the unit again mostly comprises aphyric to porphyritic basalt to andesite lava and volcaniclastic rudite and arenite. The lavas contain phenocrysts of plagioclase and locally chloritised clinopyroxene in a matrix of plagioclase, chlorite and opaques. Epidotisation and local hematisation are also common. The basalts are commonly amygdaloidal with quartz-filled amygdales that locally contain chalcopyrite. Specks of native copper can also be observed in the groundmass of the basalt in places. In places, amygdales are also filled with chlorite and zeolite.

East of the Prospect Creek road, a belt of felsic rocks occurs within the dominantly mafic succession. The most prominent belt has been mapped out as $\mathbf{CPvc_i}$ and is ~12km long and up to 1km wide, probably representing up to 500m of section. The rocks are dominantly volcaniclastic and probably include ignimbrite. They are mostly crystal-rich with fragments of plagioclase and subordinate K-feldspar. Quartz is rare. Dark wispy structures are probably fiamme. Lithic-rich varieties are also present and contain dark green mafic lithic fragments in addition to the feldspar crystals.

At about MGA 249600 7268700 to the south-west of Drumberle homestead, thick to very thick, massive beds of volcanic rudite in an interval ~200m thick form conspicuous trend-lines on the aerial photographs. The clasts are greenish grey to purple, angular and are probably dacite or rhyolite. The matrix is crystal poor and contains irregular, wispy clasts, which may be fiamme. The rocks may have formed as relatively proximal, pumiceous ash flows. The rocks have a fracture cleavage.

East of Drumberle homestead, as the Grevillea Thrust is approached, the Camboon Volcanics are commonly cleaved and more obviously altered to chlorite and epidote-bearing assemblages. Lithic clasts are flattened and aligned and a fracture cleavage is developed in more massive rocks.

Fossiliferous limestones were reported from the Camboon Volcanics in the Prospect Creek area by Dear & others, (1971) and Parfrey (1986), but these are probably part of the Buffel Formation. Other fossil localities reported by Dear & others (1971) and Parfrey (1986) are in a new unit, the Yaparaba Volcanics, to the east of the Grevillea Thrust.

Gogango Range

The rocks exposed in the Gogango Range in the south-western part of MOUNT MORGAN and south-eastern DUARINGA, extending into northern BANANA, lie in the easternmost part of the Gogango Overfolded Zone, and are the most intensely deformed and metamorphosed part of the unit. Rocks in this belt include the range of rocks seen elsewhere, mostly mafic lavas and volcaniclastics and minor felsic rocks, in addition to some fine-grained sedimentary rocks that may equate with the Woolein beds. All of the rocks are altered. Plagioclase phenocrysts are usually at least partly saussuritised or epidotised and the groundmass in thin section is commonly a turbid assemblage of saussurite and chlorite. Clinopyroxene is rarely preserved. In the clastic rocks, it is difficult to resolve clasts from matrix in thin section. In addition, as a result of deformation, the rocks are commonly strongly foliated and lineated, particularly the clastic rocks, in which the lithic clasts are flattened and stretched (Figure 150d,e). In some outcrops, the length of the clasts is up to ten times the cross section width. Many of the rocks can be described as chlorite schist and contain an assemblage of chlorite, epidote and albite. The deformation is most intense in a zone that extends ~5–10km west of the Rannes Thrust.

The main belt of Camboon Volcanics terminates ~15km north of Mount Wheal. However, a separate lenticular body of volcanic rocks ~5km long and 1km wide occurs ~5km farther to the north-west. It is overlain by, or possibly thrust against the undivided Back Creek Group to the west. It is crossed by the Capricorn Highway at about MGA 802500 7375100. The rocks in these cuttings include well-foliated thin to very thick-bedded volcanic arenite and rudite, and subordinate porphyritic andesite. Clasts in the rudite are flattened and aligned in the foliation, which cuts across bedding. They are mainly subangular greyish aphyric to porphyritic volcanic rocks (basalt or andesite?) supported by a matrix of greyish-purple to greyish-green, fine to very coarse-grained volcanic arenite. This area is the northernmost exposure of the Camboon Volcanics.

Discontinuous areas of felsic rocks occur in the Gogango Range within the Gogango Overfolded Zone from ~10km south-east of Rannes township to west of Mount Wheal and are mapped as **CPvc$_r$**. They are commonly strongly deformed with well-developed foliations and stretching lineations (Figures 10e and 150d,e). The rocks are mainly volcaniclastic, consisting of crystal fragments and felsic lithic clasts. Some examined in thin section are relatively well-sorted sandstone, but commonly the metamorphism has obscured the outlines of the lithic clasts making it difficult to distinguish them from matrix or groundmass, particularly in outcrop. Outcrops of conglomerate consisting of well-rounded volcanic clasts were also observed in places.

Other rocks clearly consist mainly of crystal fragments and very fine-grained groundmass and were possibly crystal-rich ignimbrite. Fine vitroclastic textures are usually not preserved, but in some specimens, grosser structures such as fiamme can be recognised in outline in hand specimen or thin section, because they have been replaced differentially by sericite or have slightly different textures. In some rocks, crystal fragments are entirely feldspar, but strained and fractured, embayed quartz fragments are commonly abundant.

The most intense deformation is between Mount Spencer and Rannes within ~5km of the Rannes Thrust, although relatively weakly deformed rocks were observed within 3km of the thrust at the southern end of the belt. The foliations are defined generally by anastomosing discontinuous seams or lenticles of very fine-grained muscovite or sericite and chlorite. Some of the best examples of the deformed felsic volcanic rocks crop out north of Rannes homestead along Stevenson Road around MGA 206400 7333050. The rocks there are matrix-supported volcanic rudite and contain strongly flattened and stretched aphyric volcanic clasts up to several centimetres long and sparse quartz, feldspar and biotite crystal fragments. Most of the clasts and matrix consist of very fine-grained muscovite and quartz in different proportions, but some clasts are dominantly quartz-feldspar mosaics and were probably rhyolite or microgranite. The muscovite is strongly aligned parallel to the flattened clasts.

Where deformation is most intense, a laminar fabric is present, consisting of alternating muscovite-rich and quartzo-feldspathic domains, wrapping around relict crystal fragments. Shear senses indicators such as quarter mats of muscovite and wings (Hanmer & Passchier, 1991) have developed on some of the feldspar crystal fragments. Minor biotite was observed in the Mount Spencer area, indicating that the metamorphic grade reached upper greenschist facies there.

Although the rocks here are mainly volcaniclastic, rare outcrops of flow-banded and autobrecciated rhyolite were observed. These could be dykes or small plugs rather than flows.

The felsic rocks are generally enclosed within the more mafic rocks, but contacts may be at least partly tectonic, so that they could be slices of Torsdale Volcanics, rather than units within the Camboon Volcanics. The SHRIMP dating of one sample (IWGG809) produced an age similar to that of the Torsdale Volcanics in the Banana Range (see Appendix and below).

Geophysical response

The mafic volcanic rocks and related clastic rocks of the Camboon Volcanics have low responses in all channels in the radiometric data and have dark brown to purple hues on composite images. The more felsic rocks are generally characterised by high potassium responses and low to moderate thorium and uranium and are represented by pinkish hues on composite images, rather than white like most of the Torsdale Volcanics, indicating some compositional differences.

In the magnetic data, the response of the Camboon Volcanics changes along strike from relatively low in BANANA and MOUNT MORGAN to moderate in THEODORE and CRACOW. This is also reflected in the measured magnetic susceptibility values. The values in the northern area have a mean of 115 x 10^{-5} SI units and a strongly skewed distribution with a mode at 20 and sporadic values up to about 4000. In the southern area, the mean is 860 x 10^{-5} SI units, with a bimodal distribution showing a strong mode at about 20 and another at about 1000 with sporadic values up to about 5000. The reason for the regional variation is not known.

Environment of deposition

The Camboon Volcanics are interpreted as being erupted in a non-marine, largely subaerial environment, with clastic rocks being deposited in local fluvial or lacustrine environments or by mass flow processes within the volcanic terrain.

The main possible exception may be the fossiliferous rocks that are exposed within the unit in the southern part of the Prospect Creek area (Dear & others, 1971; Parfrey, 1986). The structure in this area is not known in detail. However, it is likely that the rocks, particularly at localities L2261 and D8, are part of the Buffel Formation overlying the Camboon Volcanics to the west, and overthrust by them to the east, and this is the interpretation shown on the THEODORE map. Alternatively, as suggested by Dear & others (1971), it may reflect an eastward passage from continental to marine conditions. Marine rocks are also known from the Nogo and Narayen Volcanics, which are possible correlatives of the Camboon Volcanics. Dear & others (1971) and Parfrey (1986) show two other localities farther east. These have not been re-visited. One (D141) plots close to the mapped contact with undivided Back Creek Group, and may be in Buffel Formation. The other is entirely within the Camboon Volcanics as currently mapped.

The Mount Bulgi Conglomerate Member may represent alluvial fan systems developed adjacent to the older volcanic terrain of the Torsdale Volcanics prior to the renewed onset of volcanism. The systems may have coalesced eastwards with the compositionally similar Youlambie Conglomerate in the Yarrol Province.

The tectonic environment has been interpreted as back-arc extension during the inception of the Bowen Basin (Murray, 1990; Baker & others, 1993). Earlier interpretations regarded the rock as part of the Camboon Volcanic Arc developed on the site of an earlier Connors-Auburn Volcanic Arc. Holcombe & others (1997a,b) suggested that the two “arc” sequences are part of a single, relatively continuous late Carboniferous to early Permian magmatic episode related to a broad extensional event. They suggested that this event may not necessarily be related to active subduction but could be due to remelting of relatively young crust of calc-alkaline composition. They conceded, however, that the nature of the driving force is uncertain.

Geochemistry

Fifty-six samples from the Camboon Volcanics were analysed for a range of major and trace elements. Samples were mostly lavas, but some ignimbrites and other clastic rocks were also analysed, including three samples of the Gonyelinka Ignimbrite Member. Using the total alkalis-silica plot (Figure 11a), the data demonstrate that, according to the classification of volcanic rocks by Le Bas & others (1986), there is a relatively complete range from basalt through to rhyolite, although there is a predominance of basaltic andesite. Although some of the samples fall in the trachyandesite and basaltic trachyandesite fields according to Le Bas & others (1986), the rocks lie entirely in the subalkaline fields of Winchester & Floyd (1977) in Figure 12b. The three samples from the Gonyelinka Ignimbrite Member range from dacite to rhyolite, based on their silica content, although one sample (the least silica-rich) is close to andesite based on the immobile elements.

Although mafic compositions predominate, no compositional gap in the ‘andesite’ field is apparent in either Figure 11a or b as might be expected if the rocks were formed in an entirely extensional setting.

Although many of the lava samples could not be placed in a relative stratigraphic position, those in the Theodore area between Mount Irving and Barfield can be subdivided on the basis of their position relative to the Gonyelinka Ignimbrite Member. The lavas above the ignimbrite in unit **CPvc$_{a1}$** are basalt and appear to be less fractionated with higher *mg* values than those rocks in unit **CPvc$_{a2}$** that underlie the ignimbrite unit and are basaltic andesite. Apart from lower SiO_2, the basalts are higher in TiO_2, P_2O_5, Cr and Ni and depleted in Al_2O_3 with respect to volcanic rocks in unit **CPvc$_{a2}$** (Figures 11c–f).

Five samples of basalt to basaltic andesite were submitted for precise trace element analysis by laser ablation mass spectrometry, and the data have been used to construct the multi-element and REE plots in Figure 12a–h. Three separate groups are apparent from the data.

Two samples are more enriched in REE than the others and show a slight Eu anomaly, consistent with fractionation of plagioclase. They also show depletion in Ti and higher values of large-ion-lithophile elements (LILE) than the other samples. These samples are from the undivided part of the Camboon Volcanics north of Barfield.

Another two samples from the less fractionated unit **CPvc$_{a1}$** at the top of the Camboon Volcanics in the Theodore area show somewhat lower values for REE, particularly at the heavy end, and have no Eu anomaly. However, in the multi-element plot, the high field strength elements (HFSE) (except for Ti) are identical for both groups. Both groups show a distinct Ta-Nb trough consistent with a strong subduction component. However, the LILE are lower for the second group, and consequently, although Ta and Nb are identical, the second group has a lower Th/Nb ratio, suggesting that the subduction component may have been somewhat less important for the later basalts.

The plots were compared with those from modern basaltic suites using the database compiled from literature by Murray & Blake (2005, appendix 1). Ignoring the slightly different slopes in the REE plot, the two main

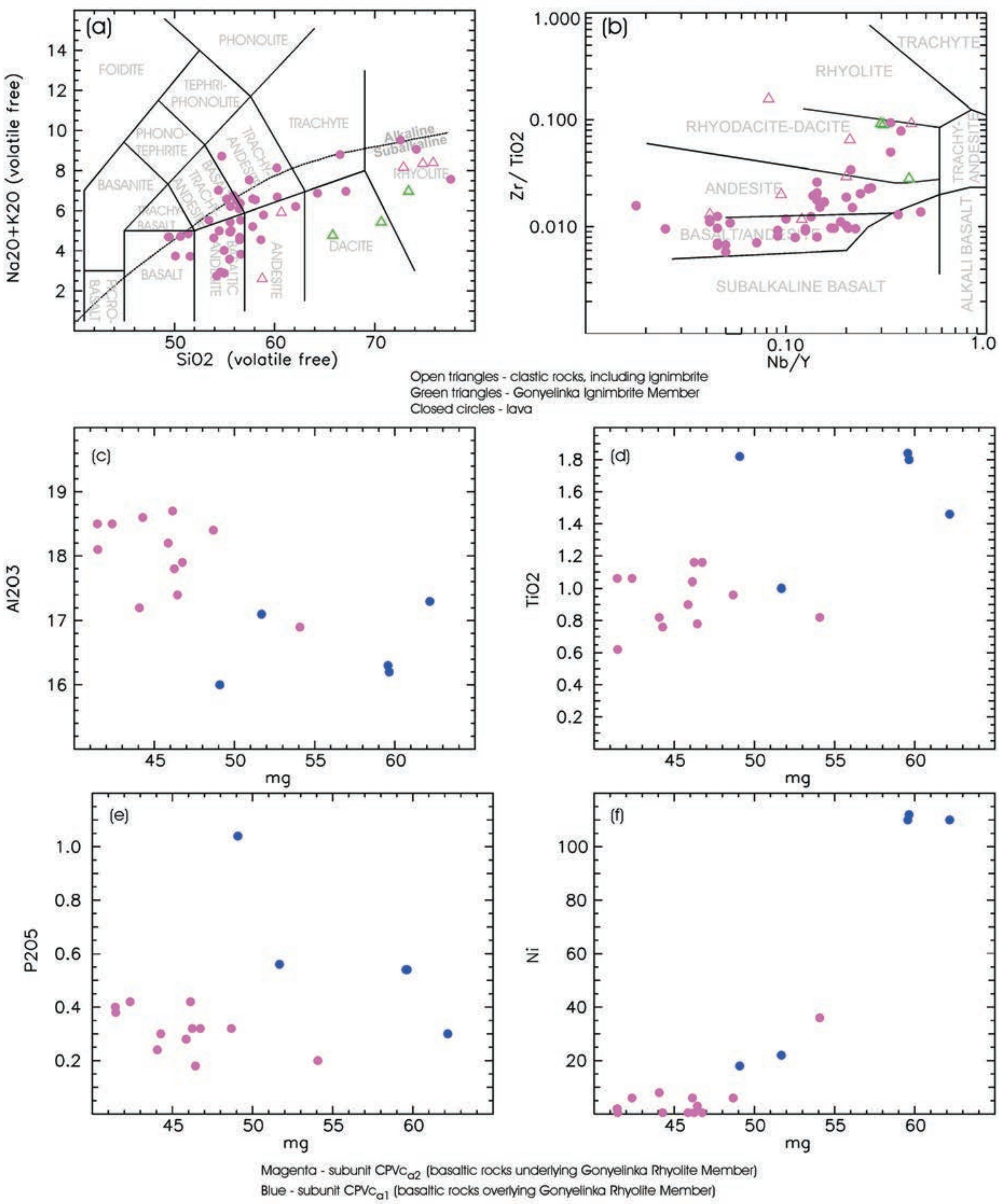

Figure 11. Geochemistry of the late Carboniferous to early Permian Camboon Volcanics: (a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986) and Irvine & Baragar (1971); (b) Nb/Y vs Zr/TiO_2 showing the fields of Winchester & Floyd (1977); (c–f). Plots of *mg* (molar ratio of MgO/(FeO+MgO) vs Al_2O_3, TiO_2, P_2O_5 in weight percent and Ni in ppm for samples from subunits $CPvc_{a1}$ (blue dots) and $CPvc_{a2}$ (magenta dots).

groups fit most closely with basalts from the Quetrupillan volcano in the Southern Volcanic Zone of the Andes (Hickey-Vargus & others, 1989), although the LILE of the latter lie somewhere between the two groups (Figure 12c,d). Crust underlying the Quetrupillan volcano is thought to be somewhat thinner (~35km) than under the Peteroa volcano (~45km), to which the Torsdale Volcanics have been compared. Crustal thickening increases the temperature of the crust and thereby increases the amount of crustally-derived melts incorporated into the magmas. This will raise the ratio of light REE to heavy REE. The steeper slopes of the Torsdale Volcanics REE and HFSE plots may be consistent with this, and could indicate that crustal thinning related to the development of the Bowen Basin was initiated during the eruption of the Camboon Volcanics.

The third group is represented by one sample (IWGG758) with significantly shallower slopes and lower values of REE and HFSE. A Ta-Nb trough although still evident is less pronounced. The shallower slope may

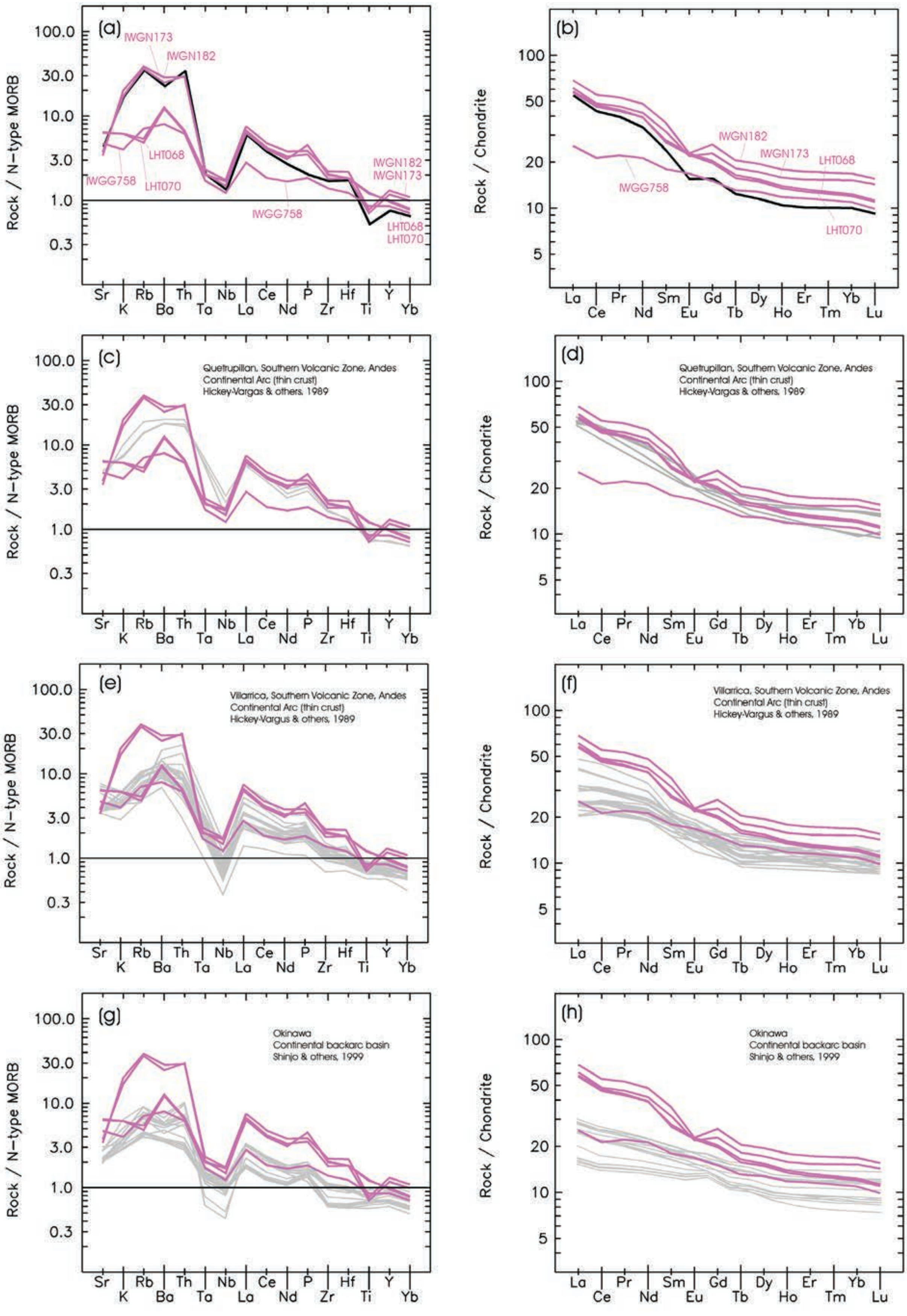

Figure 12. Multi-element plots for five basalt or basaltic andesite samples from the late Carboniferous to early Permian Camboon Volcanics — for comparison, patterns of modern basaltic suites as indicated are shown in grey: (a, c, e and g) N-MORB normalised multi-element plots (using values from Pearce, 1983); (b, d, f and h) chondrite-normalised REE plots (using values from Sun & McDonough, 1989). In (a) and (b), the Torsdale Volcanics sample (in black) is also shown for comparison.

suggest even thinner crust. However, in Figure 12e&f, a comparison has been made with the lavas from the Villarrica volcano in the Southern Volcanic Zone of the Andes (Hickey-Vargus & others, 1989), which occurs in the same east-west chain as the Quetrupillan volcano, and is therefore underlain by crust of similar thickness, although, being farther west, is closer to the subduction zone. Hickey-Vargus & others noted that significant geochemical variations can occur on a small scale in the Andes and must be evaluated to interpret the more regional trends. The variations could represent individual magma batches that reflect heterogeneities in the lithospheric source, or slab-derived fluids, which are not manifest in longer-lived volcanoes where extensive sub-crustal magma pooling and mixing occur. Therefore, this sample could simply represent such a local variation.

It is noted that the other two suites have a much more pronounced Nb trough than IWGG758. This is the most northern of the Camboon Volcanic samples and lies to the west of the belt of Rookwood Volcanics, although it is separated from them by the Rannes Thrust. A better match for the sample is given by basalt analyses presented by Shinjo & others (1999) from the Okinawa Trough, a backarc basin developed on continental crust. Thus, if the pattern really is due to much thinner crust, it may reflect more pronounced extension in this area, leading towards development of a continental backarc basin, although not as extreme as that represented by the Rookwood Volcanics. The REE and HFSE patterns are not as flat as those in the latter and the rock still retains some evidence of a subduction component. Some samples from the Mount Benmore Volcanics, Collaroy Volcanics and Carmila beds in the Connors Arch have similar profiles.

In summary, the Camboon Volcanics represent a continental volcanic arc with volcanic rocks ranging from basalt through andesite to rhyolite. They are similar to rocks in the modern Andes and are subduction-related, but flattening of the REE and HFSE patterns suggests that crustal thinning and extension possibly commenced towards the end of the eruption history.

Relationships and age

The Camboon Volcanics overlie the Torsdale Volcanics, the contact being marked in many places by conglomerate that locally includes clasts from granite bodies that intrude the Torsdale Volcanics. The relationship is therefore probably locally unconformable. However, overlapping SHRIMP ages suggests that these unconformities may be only local, and that volcanism was essentially continuous.

The basal Mount Bulgi Conglomerate Member may be equivalent to the Youlambie Conglomerate in the Yarrol Province farther east. SHRIMP dates of ~300Ma have been obtained from rhyolite clasts and an ignimbrite within the Youlambie Conglomerate (see Appendix). The Youlambie Conglomerate is characterised by a 'hot' radiometric signature due the abundance of felsic volcanic and granitic clasts. The Mount Bulgi Conglomerate Member also has a relatively 'hot' radiometric response like the underlying Torsdale Volcanics. Conglomerate appears to become more common on the eastern side of the Auburn Arch, especially in SCORIA, with a reduction in the amount of intermediate volcanics. This suggests that the unit is thickening eastwards towards the Yarrol Province where the Youlambie Conglomerate is well developed.

Basal units of the Back Creek Group overlie the unit. These include the early Permian, limestone-bearing Buffel Formation, which has a patchy distribution. Flood & others (1981) suggested that the Buffel Formation was deposited as valley-fill with younger parts onlapping the basement volcanics, while volcanism was still occurring. The limited occurrence of the Buffel Formation is probably due to its deposition in extensional sub-basins during the early extensional phase of the Bowen Basin evolution (Draper, 1988). In the Rannes area, rocks of the newly recognised lacustrine Woolein Formation overlie and possibly interfinger with the Camboon Volcanics in a sub-basin possibly formed during the same event. Elsewhere, the Camboon Volcanics are overlain with a hiatus by the late early Permian Oxtrack Formation or undivided Back Creek Group (where the characteristic limestones of the Oxtrack Formation are absent).

Some contacts between the Camboon Volcanics and undivided Back Creek Group in the northern part of the outcrop area, which falls within the Gogango Overfolded Zone, are interpreted as thrusts. These include the main contact with the mudstones of the undivided Back Creek Group south from near Thuriba to north-east of Banana. Measured dips in both units are mostly to the east indicating that the Camboon Volcanics structurally overlie the undivided Back Creek Group. The absence of Buffel and Oxtrack Formation equivalents along this contact is also consistent with a tectonic contact. South of Banana, these units are present, and the boundary is inferred to be stratigraphic.

The Camboon Volcanics have previously been assigned an early Permian age, based on the presence of *Glossopteris* and *Noeggerathiopsis* (Dear & others, 1971; Whitaker & others, 1974) and by the fact that they are overlain by early Permian rocks. As discussed elsewhere in this report, the lower part of the overlying Buffel Formation in the Cracow area is probably early Artinskian, based on brachiopods (Briggs, 1993). Marine fossils previously reported from the eastern part of the Camboon Volcanics in the Prospect Creek area are of similar age to the Buffel Formation (Parfrey, 1986; localities L2261 and D8). However, as noted above, the rocks at these localities may be small slices of Buffel Formation, overlying and partly in thrust contact with the Camboon Volcanics, rather than intervals within the volcanic succession. Palynomorphs in the coal from the base of the Buffel Formation in GSQ Mundubbera 11 indicate a mid-Sakmarian or younger age.

A palynoflora recorded by de Jersey (1963) from the Camboon Volcanics in UOD Undulla 1 has been assigned to unit APP12 that is latest Carboniferous to earliest Permian (Green & others, 1997).

Two samples of felsic volcanic rocks from the Camboon Volcanics have been dated by the SHRIMP method (see Appendix). Sample BB2535, an ignimbrite from Delusion Creek at MGA 2271240 7215820 in unit $\mathbf{CPvc_{i5}}$ near the base of the Camboon Volcanics gave a mean age of 308±5Ma late Carboniferous, although the zircon analyses show a wide spread and can be ‘unmixed’ to include a subordinate younger population at 295.2±6.2Ma. The significance of such a younger population is not known. It could be due to radiogenic Pb loss, or alternatively represent the magmatic age with the dominant older population due to inheritance of xenocrysts from the underlying Torsdale Volcanics. Sample IWGG809, a crystal-rich rhyolitic ignimbrite collected 11km north of Rannes at MGA 206790 7342880, gave an age of 297±2Ma (close to the Carboniferous–Permian boundary).

A SHRIMP age of 291.1±5.3Ma was obtained on zircons from a rhyolite dyke interpreted as being emplaced during the mineralising event at the Golden Plateau orebody at Cracow (unpublished report by C. Perkins, 1992; quoted by Dong & Zhou, 1996 and Worsley, 1995). This would also represent an event towards the end of the eruption of the Camboon Volcanics.

K–Ar dating of plagioclase from andesite from near the top of the Camboon Volcanics in the Cracow area gave an age of 282.8±5Ma (Jones & others, 1996). It is a minimum age, but is not inconsistent with the Artinskian (*ca* 285–275Ma) age of the overlying Buffel Formation there. Other previously published isotopic ages include two Ar^{39}–Ar^{40} ages of 281Ma (plagioclase) and 294Ma (total rock) from near the top of the unit (Runnegar & others, unpublished data, quoted by Runnegar, 1979, page 271).

The SHRIMP dating suggests that the time break with the Torsdale Volcanics (if there is one) could be quite short and in fact the units probably overlap. Apart from local unconformities volcanism was essentially continuous. The ignimbritic units in the lower half of the Camboon Volcanics in the Cracow area may record a transition from dominantly felsic volcanism in the Torsdale Volcanics to predominantly mafic in the upper part of the Camboon Volcanics.

The dates indicate a late Carboniferous to early Permian age, and are consistent with a correlation between the Camboon Volcanics and units in the Connors Arch. These include the Leura Volcanics (that give ages in the range 290–295Ma although they could be as old as 300Ma in the south) and Lizzie Creek Volcanic Group (285±4Ma). They also overlap with parts of the Carmila beds, which have given SHRIMP dates of 294Ma (Fielding & others, 1997a; Allen & others, 1998) and 295Ma (this study).

Other partial correlatives may be the Yaparaba Volcanics to the east of the Grevillea Thrust in the western part of the Yarrol Province and parts of the Nogo and Narayen Volcanics in the Mundubbera 1:250 000 Sheet area.

WOOLEIN FORMATION

Introduction

Withnall & others (1998a) first described the Woolein Formation as the “Woolein beds” and Dear & others (1971) previously assigned them to the Rannes beds. The name is derived from Woolein Creek in northern BANANA. The unit crops out over ~60km^2 forming a belt extending south-east for 20km from the north-eastern corner of BANANA (Figure 63). Another area of volcanilithic sedimentary rocks that lies between the Camboon Volcanics and Oxtrack Formation north of Thuriba homestead in DUARINGA is assigned to the Woolein Formation, although it probably represents a different, local depocentre. Within the Camboon Volcanics in the Gogango Overfolded Zone in the western part of MOUNT MORGAN, outcrops of fine-grained volcaniclastic sediments were also observed, but could not be fully mapped out. These could be equivalents of the Woolein Formation or intercalations of sediments within the Camboon Volcanics.

Type section

A section examined along Spring Creek between MGA 1991000 7398200 (the approximate position of the boundary with the underlying Camboon Volcanics) and MGA 200020 7339220 (the boundary with cleaved mudstone of the Back Creek Group) is herein designated as the type section. The mudstones of the Back

Creek Group are recognised by their more pelitic nature and consequent stronger cleavage, the presence of concretions, and grey colour where less weathered. The unit is ~500m thick in this section.

Lithology

The unit was examined along Stevensons Road (the main access road between the Leichhardt Highway and Villamosa homestead), the type section along Spring Creek, in tributaries of Woolein Creek on the northern part of Avonlea Station, between MGA 208500 7325960, and cuttings on the Leichhardt highway.

The Woolein Formation consists of khaki-weathering, cleaved siltstone and fine-grained sandstone, superficially similar to cleaved sedimentary rocks of the Back Creek Group that were originally included in the Rannes beds. However, the rocks have the same radiometric signature as the basalt and andesite of the Camboon Volcanics (relatively low in all channels giving purple hues on the composite RGB radiometric image). On aerial photographs in many places, the unit is characterised by clear, closely spaced bedding trend-lines that reflect the more resistant siltstone or sandstone beds.

The yellowish-grey siltstones that make up most of the unit are generally poorly stratified or unbedded, but locally the rocks are thin to very thick-bedded with local internal planar laminae (Figure 13b). A slaty cleavage is commonly the most obvious fabric. In Spring Creek, some siltstone beds contain dismembered slabs of more siliceous siltstone up to 1m long. Irregularly-shaped clasts up to 30cm long of siliceous tuff (that contain diffuse aphyric rhyolite (?) clasts up to 1cm long) were also observed locally. These may represent tuff beds dismembered by slumping or sliding. Exposures along Spring Creek contain sporadic beds of yellowish-grey, volcanilithic sandstone. The sandstone is generally fine to medium-grained, although locally very coarse-grained; pebbly beds are present. The beds are moderately to well sorted and locally graded. In thin section, the framework grains are plagioclase and andesitic lithic fragments, and minor silty matrix is present. The lithic clasts commonly consist of flow-aligned plagioclase laths. Pebbles are subangular to subrounded, and are mainly aphyric andesite or dacite. Although the rocks are usually not calcareous in outcrop, calcrete is commonly abundant in the soil, suggesting that the unweathered rocks may be slightly calcareous.

In the Avonlea area, the sequence contains a larger proportion of sandstone, but siltstone still is dominant. The sandstones are thick to very thick-bedded and mainly fine to medium-grained and moderately sorted. Locally granule to pebble conglomerate grading up into coarse sandstone is present. Pebbles are mainly subangular to subrounded, grey aphyric volcanics and subordinate cherty siltstone. Sedimentary structures, other than weak planar laminae in both siltstone and sandstone, are not common, but locally some trough cross-laminae and soft-sediment features such as slump folds and ball-and-pillow, small-scale growth faults, dish structures and sandstone dykes are present.

In the Avonlea section, two tongues of porphyritic andesitic lavas have been mapped. The sequence appears to dip consistently to the east, and where the Woolein Formation lenses out to the south, the tongues merge into the main mass of Camboon Volcanics, suggesting an interfingering relationship. However, it is also possible that the tongues represent thrust slices of Camboon Volcanics.

In Woolein Creek adjacent to the Rannes–Baralaba Road at MGA 205270 7328170, a thin concordant layer of white colloform-banded quartz (siliceous sinter?) up to 5cm thick occurs in a sequence of very fine-grained sandstone and siltstone (Figure 13c).

The rocks in the separate area north of Thuriba homestead were examined in a section from MGA 798800 7347460 to 798200 7347500, which consists of 150–200m of siltstone interbedded with lesser volcanilithic sandstone and conglomerate. The siltstone is thick to very thick-bedded, mainly massive and greenish to purplish-grey. Some of the more resistant beds may be tuffs. Rare indeterminate plant stems were observed. The sandstones are thick to very thick-bedded, massive, moderately to well sorted, consisting of plagioclase, yellowish to reddish-purple, aphyric andesite or felsite lithic clasts and minor saussuritised silty matrix. They contain no quartz. In the lower part of the sequence, conglomerate is present as minor thin beds or at the base of some sandstone beds. Conglomerate becomes more abundant and thicker towards the top of the succession, where it is thick to very thick-bedded, massive to crudely stratified and contains granules to pebbles of greenish to yellowish-grey, aphyric andesite and felsite. Some of these rocks are poorly sorted, with subangular clasts supported by a very fine to medium-grained sandstone matrix. Better-sorted beds have a coarser matrix and more rounded clasts.

Geophysical response

As noted above, the rocks have the same radiometric signature as the basalt and andesite of the Camboon Volcanics (relatively low in all channels giving purple hues on the composite image) distinguishing them from the cleaved mudstone of the Back Creek Group.

Figure 13. Woolein Formation
(a) Typical outcrop of thin to medium-bedded, khaki-weathering siltstone and fine-grained sandstone in Spring Creek. North-west part of Rannes Station at MGA 199449 7338683 (IWGG935)
(b) Detail of thinly bedded volcaniclastic siltstone with local cross-laminations. North-west corner of Avonlea Station at MGA 208311 7325587 (IWGN033)
(c) Laminated siliceous bed (siliceous sinter?) interbedded with mudstone. Woolein Creek along the Baralaba–Rannes Road at MGA 205266 7328166 (IWGG991)

Magnetic susceptibility values are almost all <10 x 10^{-5} SI units, consistent with the low flat response on magnetic images.

Environment of deposition

The dominance of fine-grained sediments, the absence of both marine body and trace fossils in the Woolein Formation and its restricted extent are consistent with deposition in a largely lacustrine environment in a rift setting during the early extensional phase of the Bowen Basin. The coarse-grained sediments in the Thuriba section may represent alluvial plains or fans and deltas. The radiometric response is similar to the underlying Camboon Volcanics, which may have been the main provenance of the sediments, although it is possible that there was some input from contemporaneous volcanism.

Relationships and age

The Woolein Formation is overlain by the Back Creek Group, and overlies the Camboon Volcanics, although there may be some interfingering with lavas in the south on Avonlea Station. The unit is therefore likely to be early Permian and probably correlates with the Carmila beds and Goodedulla beds.

STRATIGRAPHY OF THE NOGO SUBPROVINCE (YARROL PROVINCE)

A belt of volcanic rocks crops out east of the Auburn Arch and Rawbelle Batholith. It appears to mainly lie east of the Gogango Overfolded Zone and may be considered to be a part of the Yarrol Province. The northernmost unit in the study area, the Yaparaba Volcanics is relatively undeformed and is interpreted as being separated from the deformed Back Creek Group and Camboon Volcanics by a major fault, the Grevillea Thrust, which forms the eastern margin of the Gogango Overfolded Zone. The Grevillea Thrust can be traced in the magnetic images beneath the Biloela Basin and joins the Rannes Thrust along which the Rookwood Volcanics are interpreted to be thrust over the Back Creek Group. These structures are probably the equivalents of the Develin and Comanche Thrusts farther north. Farther south the thrust belt is engulfed by the Rawbelle Batholith and its location is uncertain. The Nogo beds lie along strike of the Yaparaba Volcanics and are inferred to be part of the same structural unit, herein termed the Nogo Subprovince and considered to be part of the Yarrol province. The Narayen beds are more problematic as they lie farther west and overlie deformed granitoids and could be part of the Auburn Arch. However, they are described here because of their similarities and proximity to the Nogo beds.

The rocks of the Nogo Subprovince may correlate with the Owl Gully Volcanics in the Yarrol Syncline south-east of Monto. They may also correlate with the Rookwood Volcanics (see below) and Berserker Volcanic Group (Crouch & Parfrey, 1999), but they are lithologically and geochemically distinct from either of these units.

YAPARABA VOLCANICS

Introduction

The Yaparaba Volcanics is a new volcanic unit in central SCORIA. Yaparaba is the name of a general locality and former state school 20km south-east of Thangool. The rocks were previously mapped as Camboon Volcanics, but have been renamed because they are separated from the Camboon Volcanics and a belt of Back Creek Group by a major structure, the Grevillea Thrust and their age is uncertain. The structure can be traced magnetically to the north-west beneath the Biloela Basin and probably marks the boundary between the Yarrol and Auburn Provinces. It is therefore possible that the separation was originally much greater. The units are also different magnetically, the Yaparaba Volcanics being more magnetic than the Camboon Volcanics that crop out in the Drumberle area to the west of the thrust. The Yaparaba Volcanics are probably related to other early Permian volcanic and volcaniclastic sedimentary rocks in the Yarrol Province, such as the Smoky beds to the north, the Owl Gully Volcanics to the east. Together with these units and also the Nogo Volcanics to the south in RAWBELLE and AUBURN, they have been assigned to the Nogo Subprovince, a new subdivision of the Yarrol Province.

Type area

Because the rocks are mainly relatively massive volcanic rocks and the structure is difficult to interpret, no type section can be defined. However, the rocks are well exposed along Grevillea Creek, south of the Lookerbie Igneous Complex (between about MGA 264350 7273150 and 266100 7271700) and this is designated as the type area. In this area, the rocks include aphyric to slightly porphyritic basalt, andesite and dacite and generally poorly sorted, volcaniclastic conglomerate and sandstone; subordinate crystal-rich, lithic-rich rhyolitic or dacitic volcaniclastic rocks, including probable ignimbrite crops out in places.

Lithology

The basaltic lavas in the Grevillea Creek area are dark greenish grey and aphyric. They are commonly altered and consist of randomly orientated plagioclase laths with interstitial chlorite, epidote and opaques. Small chlorite-epidote-filled amygdales are locally present. The andesitic to dacitic lavas are similar in hand specimen (apart from sparse plagioclase phenocrysts), and can only be distinguished in thin section or geochemically. In thin section, they consist mostly of at least partly flow-aligned feldspar laths and subordinate to minor interstitial chlorite, epidote and opaques. It is possible that some outcrops of mafic rocks in the Grevillea Creek area are later dykes, because mafic dykes cut the nearby Lookerbie Igneous Complex.

The volcaniclastic rocks are largely massive and poorly sorted, consisting of subangular to subrounded pebbles of mafic (and rarely felsic) volcanic rocks in a sandy to silty matrix (Figure 14a). Some outcrops of sandstone are better sorted, but still tend to be poorly bedded.

Figure 14. Yaparaba Volcanics
(a) Poorly sorted, pebbly volcaniclastic sandstone with subangular to subrounded clasts of porphyritic basalt or andesite. In Grevillea Creek 4.5km south-west of Dawes Hall at MGA 264963 7272445 (IWGN445)
(b) Polymictic conglomerate containing well-rounded clasts of felsic volcanic rocks and subordinate mafic rocks in a very coarse-grained lithic sandstone matrix. Quarry on Yaparaba School Road, about 4km south-south-west of Dawes Hall at MGA 266849 7271957 (IWGN450)

The felsic volcaniclastic rocks at MGA 263900 72722750 consist of feldspar (mainly plagioclase) crystal fragments and abundant volcanic lithic clasts in a very fine-grained, altered groundmass. Possible fiamme or flattened pumice fragments up to 1cm long can be observed on weathered surfaces. The lithic clasts are mostly aphyric to porphyritic felsite and reworked volcaniclastic rocks. Felsic rocks elsewhere in the unit are generally crystal-rich (again mostly feldspar, but locally rare quartz), but the proportion of lithic clasts is variable.

Well-bedded, volcanilithic sandstone and lesser conglomerate and siltstone crop out in scattered localities, and are well exposed in two gravel quarries along Yaparaba School road. At one of these at MGA 266850 7271960, the sandstone is thick to very thick-bedded, medium to very coarse-grained and locally pebbly (Figure 14b). The volcanic detritus appears to be largely felsic. The siltstone is thin to thick-bedded, dark grey and locally relatively carbonaceous. Thin sandstone beds associated with the siltstone show load features such as ball-and-pillow.

In the southern part of the outcrop area, north-east of Mount Shaw, pale greenish grey, slightly porphyritic dacite to andesite and fine grained quartzose and labile sandstone were observed. The andesite contains patches of actinolite crystals, probably due to contact metamorphism. It has andesine phenocrysts up to 1cm in a groundmass of feldspar, biotite, chlorite, amphibole (?) and epidote. The groundmass is granular and may be hornfelsed. Volcanic rudite, comprising granite clasts in an andesitic volcaniclastic matrix consisting of feldspar crystals and very fine groundmass crops out along Coominglah road west of the headwaters of the Rawbelle River.

In contrast to the Camboon Volcanics west of the Grevillea Thrust, the Yaparaba Volcanics are generally not cleaved, although a weak fracture cleavage was observed in a few localities.

Geophysical response

In the radiometric data, the unit has generally low values in all channels, consistent with the dominance of mafic rocks. However, patchy areas of moderate potassium response are probably related to the local felsic rocks.

The Yaparaba Volcanics have a noisy magnetic response with a generally low background and numerous moderately magnetic linear features. Some of these may be Permo–Triassic dykes, but the magnetic susceptibility data for both sedimentary and igneous rocks show a scattering of high values with an overall mean of 515 x 10^{-5} SI units. Although the distribution is strongly skewed with a mode at ~10 x 10^{-5} SI units, there are a significant number of values ranging up to 350, and sporadic values thereafter up to about 6000. Overall the unit is more magnetic than the northern part of the Camboon Volcanics or the Nogo and Narayen beds.

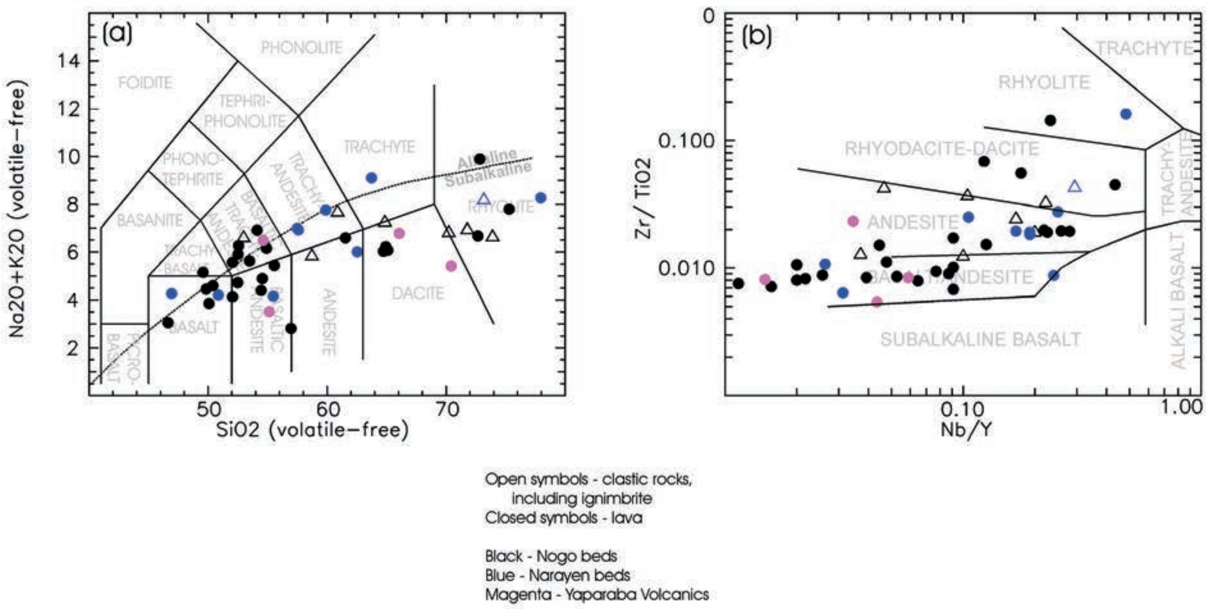

Figure 15. Geochemical classification of volcanic rocks from the Nogo beds, Narayen beds and Yaparaba Volcanics: (a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986) and Irvine & Baragar (1971); (b) Nb/Y vs Zr/TiO_2 showing the fields of Winchester & Floyd (1977)

Environment of deposition

No pillow lava or hyaloclastic breccias have been recorded, although in Grevillea Creek at MGA 264500 7272800, a peperitic contact between basalt and siltstone was observed, suggesting that the basalt was emplaced into wet sediments. Some of the felsic rocks have flattened fiamme and may be ignimbritic, but have not been studied petrographically in sufficient detail to confirm the presence of welding (and therefore a subaerial environment). The sedimentary rocks also have not been studied sufficiently to allow the environment to be determined. The massive, poorly sorted volcaniclastic rocks could be subaerial debris or mass flows, but the available data do not rule out subaqueous deposition. The better sorted sandstones may have been deposited in fluvial and lacustrine environments, although marine conditions obviously prevailed locally, because stenoperid bryozoans were recorded from D109 at MGA 253850 7279300 by Dear & others (1971) and Parfrey (1986).

Geochemistry

Four samples from the Yaparaba Volcanics were analysed for a range of major and trace elements. All were identified in the field as basalt or andesite, but the total alkali total alkalis-silica plot (Figure 15a) suggests that, although two are basaltic andesite or trachyandesite, the other two are dacite. However, it is possible that these two samples have been silicified. The plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) shows that three samples lie in the basalt-andesite field and one in the andesite field (Figure 15b). This plot provides a method of classifying the original composition of altered volcanic rocks, because of the immobility of these elements. In unaltered volcanic rocks Zr/TiO_2shows a strong correlation with SiO_2. Poor precision in determining Nb does not affect the classification for subalkaline rocks, because most field boundaries are relatively flat.

Only X-ray fluorescence (XRF) analyses are available for these rocks, so that it is not possible to present REE data. The XRF data for the three basalt-andesite samples are presented as a multi-element plot normalised to N-MORB in Figure 16d. The poor precision results in a very spiky pattern. However, the overall pattern is relatively flat and lacks the enrichment in high-field-strength elements (HFSE) and large-ion-lithophile elements (LILE) of most other Permian volcanic rocks in this study, although depletion of K and Rb may be due to alteration. A flat pattern could be similar to basalts formed in an oceanic spreading backarc basin like the Rookwood Volcanics farther north, although the data show a Nb trough, suggesting a subduction component. The Nogo beds to the south also appear to contain a suite of rocks with a similar pattern (Figure 16c).

The poor precision of the analyses makes it difficult to compare it with modern suites, but the data fit best with suites from oceanic settings rather than continental margin settings like the Andes. In Figure 16d, a comparison is made with basalts from the rifted backarc basin of the northern Mariana Trough (Gribble & others, 1998). These basalts show a Nb trough like the Yaparaba Volcanics and have relatively low levels of

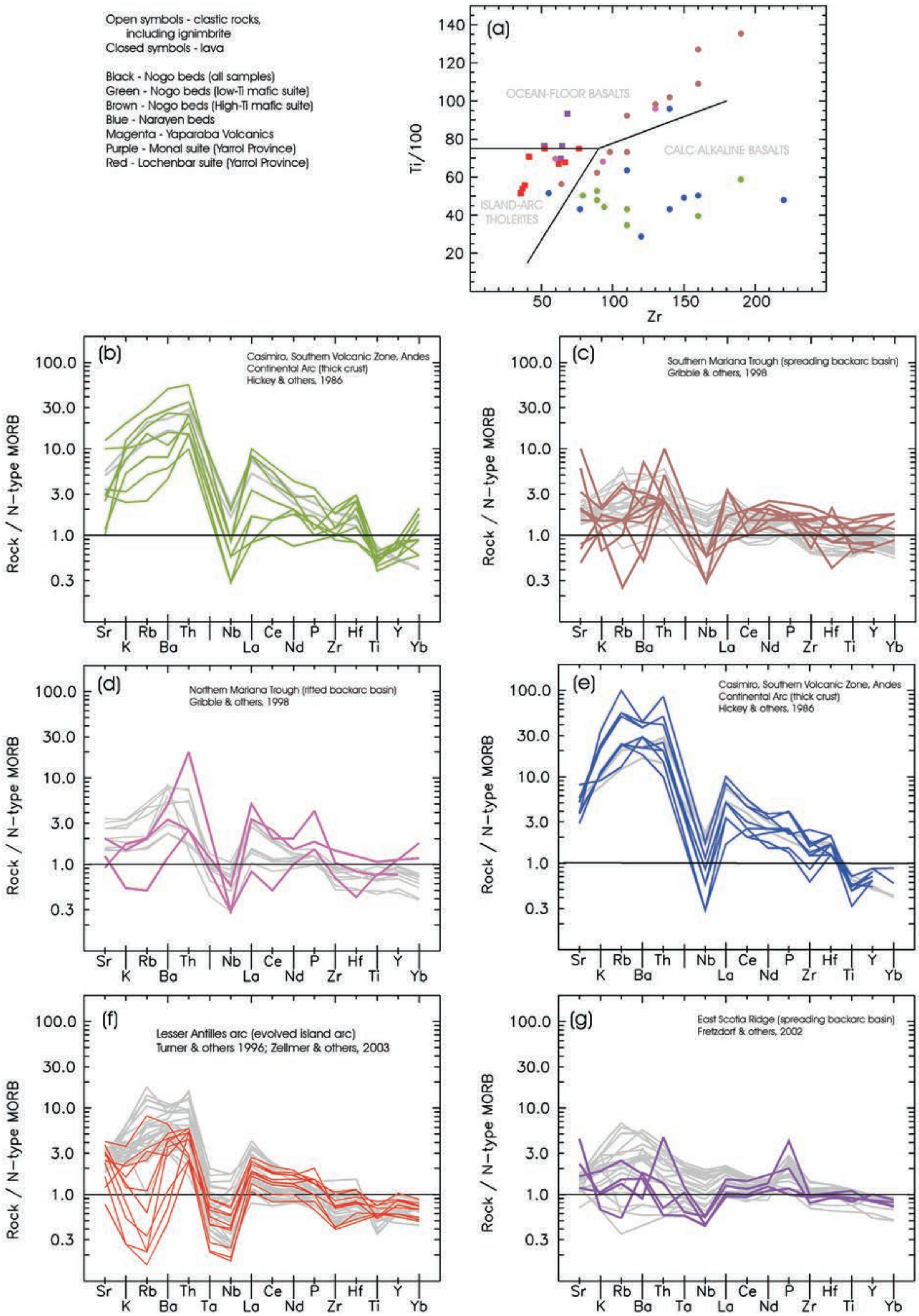

Figure 16. Geochemistry of volcanic rocks from the Nogo beds, Narayen beds, Yaparaba Volcanics and Lochenbar and Monal suites from the Yarrol Province: (a) Zr vs Ti/100 in ppm for mafic rocks (<60% SiO_2 weight percent) showing the fields of Garcia (1978); (b–f) N-MORB normalised multi-element plots (using values from Pearce, 1983) — for comparison, modern basaltic suites as indicated are shown in grey.

LILE. In Ti-Zr plot (Figure 16a), the three basalt-andesite samples fall in the fields of ocean-floor basalt, low-K tholeiite and just within the calc-alkaline basalt field.

As noted below, the age of the Yaparaba Volcanics is poorly constrained, and it is possible that at least part of them could be older. They may be equivalents of the Late Devonian Lochenbar Formation that crops out to the east (Yarrol Project Team, in preparation). Only a 5km-wide belt of Tertiary basalt and Lookerbie Igneous Complex separates the two units. Murray & Blake (2005) compared basaltic rocks from the Lochenbar Formation with various suites, and concluded that they show most similarities to rocks of evolved oceanic arcs, such as the Lesser Antilles, Marianas, Vanuatu and the Aleutians. In Figure 16f, a comparison of Lochenbar Formation basalts with basalts from the Lesser Antilles is shown.

Relationships and age

As described above, the Yaparaba Volcanics are faulted against the Back Creek Group along the Grevillea Thrust, a newly recognised structure that forms the western margin of the Yarrol Province in this area. The Permian to Early Triassic Wingfield Granite, Lookerbie Igneous Complex and Harrami Igneous Complex intruded and hornfelsed the volcanic rocks. The Lookerbie Igneous Complex appears to have a very complex contact with large areas of volcanic rocks partly enclosed by the intrusive rocks. Numerous mafic dykes intrude the Lookerbie Igneous Complex and are inferred to intrude the Yaparaba Volcanics as well. The magnetic pattern of the Yaparaba Volcanics could partly reflect swarms of these dykes.

The airborne magnetic data suggests that the volcanic rocks continue to the north-west beneath sediments of the Biloela Basin, and they could be continuous with the Smoky beds in north-western BILOELA. To the east, the Yaparaba Volcanics are overlain by Tertiary basalt.

On the SCORIA map, the Yaparaba Volcanics have been assigned an early Permian age like the Owl Gully Volcanics in MONTO and possibly the Nogo beds in EIDSVOLD and RAWBELLE. The only fossils known are stenoperid bryozoans from locality D109 (Dear & others, 1971; Parfrey, 1986) near Scoria Creek in the northern part of the outcrop area. However, geochemical evidence presented above suggests that all or part of the unit may be equivalent to the Late Devonian Lochenbar Formation that crops out to the east.

NOGO BEDS

Introduction

Whitaker & others (1974) proposed the name “Nogo beds” for largely hornfelsed strata of unknown thickness cropping out between the Rawbelle Batholith and the Jurassic Mulgildie Basin from near Eidsvold to west of Mundubbera. Total outcrop area is ~350km^2.The beds are named after the Nogo River, which traverses the area of outcrop north of Eidsvold. Mapping and geophysical interpretation has confirmed the extent of the Nogo beds with some slight boundary modifications in the north. The southern portion of the Nogo beds is interpreted to be more extensive, and includes areas previously mapped as Coonambula Granodiorite. Over much of the area, the rocks have been hornfelsed by the Eidsvold Complex and Rawbelle Batholith. Volcanic arenite and oligomictic rudite, mostly derived from andesite appear to be the most common rock types, but mafic lavas (andesite or basalt) and more felsic rocks such as flow-banded rhyolite and dacitic to rhyolitic ignimbrite have been identified. Fine-grained sediments, including cleaved siltstone, carbonaceous mudstone and minor sandstone crop out in places, but could be much more extensive than the sparse outcrops suggest.

The strongly hornfelsed components form fairly resistant ridges, but in general, the unit is recessive with deep soil cover and very poor outcrop apart from scattered boulders and low, rubbly outcrop or rock bars in streams. Bottle trees that grow on the dark brownish-red soil of the andesite and arenite, are a good indicator for Nogo beds where outcrop is poor. Andesite percussion drill chips at some water bores also served to indicate the presence of the unit. Calcrete profiles under Cainozoic alluvium along gullies were also distinctive.

The thickness of the Nogo beds is not known because of poor outcrop and poor bedding of the volcanic rocks. The APE Abercorn 1 well in the Mulgildie Basin intersected 667.5m of “Camboon Andesite”, but the actual thickness of the beds is presumed to be far greater (Hoyling & Stewart, 1964).

The Nogo beds have been intruded by small gabbro and diorite bodies some of which were described and mapped by Webb (1960). Due to their very similar responses on the composite radiometric and magnetic images, their poor outcrop and consequently unknown extent, these rocks were not subdivided from the Nogo beds. The gabbro and diorite are strongly uralitised, unlike the gabbro and diorite in the Eidsvold Complex.

Type locality

Whitaker & others (1974) designated a type locality in a road cutting along the Eidsvold–Cracow road, adjacent to the Burnett River crossing. The road cutting shows a good exposure of strongly hornfelsed well-banded volcanic lutite and arenite over some 50m. They are greenish-grey, very fine to fine-grained and well-banded. In places, monomict breccia that is possibly quench-fragmented lava crops out. A porphyritic (hornblende feldspar) andesite was also observed.

Lithology

The Nogo beds in general consist of intermediate to basic lavas and volcaniclastic rocks, lithic arenite, cleaved mudstone, chert and conglomerate. Dominant rock types and extent of hornfelsing can be described in terms of three main areas.

Wuruma Dam – Glen Leigh area

The northern outcrop area, east of Wuruma Dam and south of Glen Leigh is dominated by siltstone and mudstone but mafic lavas and volcanic arenite and rudite are also common. The rocks appear to be strongly hornfelsed and altered by the Wingfield Granite to the west.

Outcrop of the Nogo beds near Mount Eagle homestead is very poor and mostly confined to streambeds. Most of the rocks are very low-grade metasediments, namely well bedded siltstone, graphitic mudstone and minor sandstone. Most of the beds are thin to medium, although some are very thick (exceeding 2m). These rocks are not strongly hornfelsed or silicified and therefore are more susceptible to weathering. They are locally spotted with incipient aluminosilicates and most of the pelitic rocks are at least slightly cleaved.

Closer to Wuruma Dam, and north of the boat ramp, the Nogo beds consist of andesitic rudite and arenite which have been strongly altered to chlorite-epidote-carbonate, and possibly also silicified. Resistant hornfels was observed at several places in this area, probably due to proximity of the Wingfield Granite. Clasts within the rudite are usually moderately to well rounded, suggesting fluvial processes. The rudite beds are extremely thick (tens of metres) and are interbedded with massive arenite beds.

Some sheared volcanic rocks along the contact with the granite contain skarn-like mineral assemblages like the outcrop at MGA 297530 7213700 (diopside, epidote, grossularite, actinolite, plagioclase, quartz, titanite, iron oxides, calcite and secondary hornblende), indicating metamorphism to at least the hornblende hornfels facies. The plagioclase forms corroded, lath-shaped phenocrysts, in a fine-grained, granoblastic groundmass. Amygdales are filled with chlorite (Whitaker & others, 1974). Some of the rocks found along this contact zone have been referred to as “bowesite” by lapidarists (Kelly, 1986). They are light to dark green with off-white mottling or streaking and consist of diverse percentages of pale green diopside, yellowish green epidote, pink-brown grossularite, dark green to bluish green actinolite, nearly white andesine, colourless quartz, brownish titanite, white calcite, and magnetite.

Crystal-rich, lithic-poor ignimbrite, hornfelsed arenite, rudite and altered andesite or basalt, mudstone and siltstone have been observed east of Upson Downs homestead, but most of the less resistant rock types like siltstone and mudstone do not crop out.

The rocks in the Nogo River near Pointen homestead are dominantly poorly sorted rudite and arenite, for example at MGA 304600 7207250. Floaters in the river here and farther north comprise flow banded porphyritic rhyolite, some crystal-rich, moderately lithic-rich, welded rhyolitic ignimbrite and minor breccias, but it is likely that they were sourced from the Triassic Mount Eagle beds. A medium grey aphyric, possibly hornfelsed mafic lava was also observed at MGA 303500 7208950.

Ceratodus – Eidsvold Station – Woodlands homestead area

The central area west of Eidsvold and Ceratodus south to about Woodlands homestead is dominated by strongly hornfelsed volcaniclastic sedimentary rocks, along the western margin of the Eidsvold Range. The hornfelsing decreases to the west. Common belts of andesite lava have a northerly trend but could not be mapped out consistently.

Near the Nogo-Burnett River junction, the Nogo beds are predominantly hornfelsed arenite and poorly sorted rudite with some andesite or basalt. The mostly well-rounded pebbles to cobbles include red, brown, grey, cream and green, aphyric to quartz-feldspar-phyric, lithic- rich rhyolitic to dacitic volcanic rocks. Some very fine-grained, laminated volcaniclastic rocks containing sulphides (possibly chalcopyrite grains with oxidised rims) were observed along the Burnett River at MGA 306450 7202350.

The western rim of the Eidsvold Range is interpreted as a strongly silicified and hornfelsed mylonite of granitic and volcanic rocks up to 200m wide, dipping moderately east. Some of the rocks along this zone, which corresponds with a sharp contact on the magnetic data, resemble skarn rocks like those described above. Although the hornfelsed zone extends more than 700m to the west of the contact of the Eidsvold Complex, the Nogo beds are poorly exposed in this area. On Eidsvold Station, the rocks are dominantly strongly silicified and hornfelsed, felsic to intermediate volcanilithic arenite and rudite, but some fine-grained hornfelsed aphyric andesite is also present. Webb (1960) described chert, porphyritic andesite flows and “agglomerate”, and “calcareous conglomeratic greywacke” in the area directly west of Eidsvold.

Some crystal-rich, lithic-poor ignimbrite, probably rhyolite (because of the abundance of quartz crystal fragments up to 3mm), crops out east of Ormsary homestead on the western side of the Burnett River at Ross Crossing (MGA 309300 7186900) along with common, very fine-grained, pale green-grey altered and hornfelsed aphyric volcanic rocks (possibly andesite). Other rocks seen were aphyric, locally vesicular, andesite, common fine-grained arenite and minor rudite.

St John Creek – Ti-Ti Creek area

The most extensive area of Nogo beds is in the south around St John Creek, but again, outcrop is very poor. Hornfelsing is generally not pronounced, except in the west where there is a strongly hornfelsed aureole against the Widbury Granite. The Nogo beds within this area appear to be more extensive than previously mapped. Some areas of hornfels were mapped as Coonambula Granodiorite by Whitaker & others (1974), notably adjacent to the road in the McConkey Creek area, where the hornfels forms prominent tors.

The most common rock types are cleaved siltstone, slate, mudstone and volcanic arenite, although they are poorly exposed except where hornfelsed. Relict sedimentary structures observed in hornfelsed parts include flaser bedding. Pencil cleavage is developed in slaty portions, due to two approximately orthogonal slaty cleavages or bedding fissility. Probable cordierite porphyroblasts are developed in places. Rocks around Deep Bank homestead are mostly floaters and rubble of andesite, arenite and siltstone. In a quarry at MGA 304000 7172350, green, fine-grained, altered andesite was worked.

Around Perlinga homestead the Nogo beds are dominantly arenite, andesite and rudite, all strongly altered, but not particularly hornfelsed. One occurrence of crystal-rich, dacitic ignimbrite was found near Trap Trap Creek (MGA 304400 7163100). Relatively fresh outcrops at MGA 296600 7165700 in the Ti-Ti homestead area also consist of crystal-rich, lithic-poor, dacitic ignimbrite and some aphyric andesite. Any sedimentary rocks may be masked by thick soil cover in this area.

Geophysical response

The Nogo beds are recognised on composite radiometric images by dark brownish hues, due to the low response in all channels. The unnamed intrusive gabbros and diorites cannot be distinguished from the Nogo beds.

The Nogo beds have a very low magnetic response, contrasting sharply with the Eidsvold Complex to the east, which is highly magnetic. Magnetic susceptibilities measured in the field were generally very low, mostly 0–100 x 10^{-5} SI units with a mode at ~20 x 10^{-5} SI units and sporadic values up to 3000 x 10^{-5} SI units. The magnetic susceptibility of the small unnamed gabbros intruding the Nogo beds show a similar range to the volcanic rocks in strong contrast with the intrusive rocks of the Eidsvold Complex.

Environment of Deposition

Because of the poor outcrop, it is difficult to assess the depositional environment of the Nogo beds. However, poorly preserved marine fossils reported by Webb (1960) from west of Eidsvold suggest a partly marine environment. No plant fossils have been found. Due to the abundance of arenite and conglomerate, shallow-water deposition in a high-energy environment was inferred by Whitaker & others (1974). In the northern part of the Nogo beds, there appears to be an eastward transition from dominantly relatively coarse volcaniclastic rocks to siltstone, mudstone and sandstone. This could represent a transition from dominantly fluvial (alluvial plains or fans) to nearshore, marine or lacustrine environments. In the south, andesite is more abundant throughout the sequence, and such a transition was not observed.

Geochemistry

Thirty-one samples from the Nogo beds were analysed for a range of major and trace elements. They include lavas and volcaniclastic rocks. The total alkali-silica (TAS) plot shows that the rocks range from basalt to rhyolite (Figure 15a). The plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) generally confirms this spread of compositions, although it suggests that the clastic rocks are mostly andesitic (Figure 15b). This plot provides a method of classifying the original composition of altered volcanic rocks, because of the immobility of these elements. In unaltered volcanic rocks Zr/TiO_2shows a strong correlation with SiO_2. Poor precision in determining Nb does not affect the classification for subalkaline rocks, because most field boundaries are relatively flat. The clastic rocks therefore may have been silicified or quartz may have been concentrated by weathering and sedimentary processes.

The Ti-Zr plot (Figure 16a) suggests that the Nogo beds include two mafic suites. One suite, represented by ten samples, is enriched in Ti and plots in mostly in the field of ocean-floor basalts. The other suite of eight samples has lower Ti and plots as calc-alkaline basalts.

Only X-ray fluorescence (XRF) analyses are available for these rocks, so that it is not possible to present REE data. However, the XRF data for the two suites are presented as a multi-element plots normalised to N-MORB in Figure 16d and c. The two suites show significantly different patterns, although because of the poor precision they are somewhat spiky.

The low-Ti suite is generally similar to most other Permian volcanic rocks in this study, showing depletion in Ti and Y, a relatively steep slope for the high-field-strength elements (HFSE), a pronounced Nb trough and enriched large-ion-lithophile elements (LILE). The latter show values, generally higher than many of the other Permian units, except for the Narayen beds which may originally been continuous with the Nogo beds. The plot was compared with those from modern basaltic suites using the database compiled from literature by Murray & Blake (2005, appendix 1). The steep slope is consistent with thick crust and a comparison is made in Figure 16b with the Casimiro suite in the Southern Volcanic Zone of the Andes (Hickey & others, 1986).

The high-Ti suite shows a much flatter pattern, with no clear depletion in Ti and Y relative to MORB and relatively low enrichment in other HFSE and LILE. The data show a weak Nb-trough, although most of the samples are close to detection for XRF and the reliability of this trough is uncertain. The flat pattern indicates thin, possibly oceanic crust and, except for the weak Nb-trough, the pattern is suggestive of spreading backarc basins. Data from the spreading backarc basin of the southern Mariana Trough from Gribble & others (1998) is plotted for comparison in Figure 16c.

The presence of two completely different suites suggests that the Nogo beds are a composite unit, and that units of contrasting tectonic settings and possibly even different ages are juxtaposed. Outcrop is poor and mapping out two otherwise similar units would be very difficult. Examination of the distribution of the suites indicates that the low-Ti suite is mainly from the east adjacent to the Eidsvold Complex, although a few samples occur farther west amongst the high-Ti samples. The high-Ti suite may be related to the early Permian Rookwood Volcanics, which also show geochemical similarities to spreading backarc basins (see Figure 21). However, basalts of the Monal suite, which occurs in the Late Devonian Three Moon Conglomerate, has a flat pattern like the high-Ti Nogo beds on the multi-element plot (Figure 16g). Murray & Blake (2005) noted that the Monal suite can also be compared with those of modern backarc spreading centres like the East Scotia Ridge.

In the Kroombit area, the Three Moon Conglomerate is structurally interleaved with the Lochenbar Formation that contains basalts that Murray & Blake (2005) suggested to have formed in an evolved oceanic arc. Murray & Blake concluded that the Late Devonian rocks represent a transition from an intra-oceanic to continental-margin arc. The Yaparaba Volcanics, that have been correlated with the Nogo beds, have similar geochemistry to the Lochenbar Formation.

The Kroombit area is ~40km north-north-west of the nearest outcrops of Nogo beds. The volcanic rocks are separated by granitoids of the Rawbelle Batholith and Jurassic sedimentary rocks. However, it is possible that Late Devonian rocks originally extended into the Eidsvold area where they are represented by the high-Ti basalts. This may be a preferable scenario, to correlating the high-Ti suite with the early Permian Rookwood Volcanics. Juxtaposing oceanic and continental margin volcanic arcs, either stratigraphically or structurally, would be simpler if the rocks are of widely different ages rather than both early Permian.

Relationships and age

As noted above, the Nogo beds are intruded by unnamed gabbro bodies, but the exact age of these is unknown. Both the Nogo beds and the gabbros are intruded and locally strongly hornfelsed by the early Permian Widbury Granite and Eidsvold Complex and the late Permian to Early Triassic Wingfield Granite. They are overlain unconformably by the Jurassic Evergreen Formation of the Mulgildie Basin.

Webb (1960) reported poorly preserved specimens of the mollusc *Aviculopecten* and possibly the brachiopod *Notospirifer*. In APE Abercorn 1 in the Mulgildie Basin, spores, considered to be pre-Triassic, were described by de Jersey (1964) from various depths below the Mulgildie Basin in rocks possibly correlated with the Nogo beds. However, these are not particularly specific. Due to the position of the well east of the Anyarro

Fault the correlation of these rocks to the exposed Nogo beds can be questioned. No fossils were found during the recent mapping.

In spite of the non-definitive fossil evidence, the age of at least some of the rocks is likely to be early Permian, and the rocks probably correlate with the Narayen beds and Owl Gully Volcanics and at least partly with the Camboon Volcanics as suggested by Whitaker & others (1974). The dominance of sedimentary rocks that are at least partly of marine origin may indicate a similar setting and perhaps correlation with rift-related sequences like the lacustrine Woolein beds and the marine Buffel Formation.

However, as noted above, two distinct geochemical suites occur in the Nogo beds, and one of these, the high-Ti suite, could be equivalent to Late Devonian basalts in the Three Moon Conglomerate. The low-Ti suite is probably Permian.

NARAYEN BEDS

Introduction

This unit was introduced by Whitaker & others (1974) for andesitic volcanic rocks and volcaniclastic sediments that crop out from Yerilla homestead in the north to south of Hawkwood homestead in AUBURN. In general, the distribution of Narayen beds shown on the existing Mundubbera 1:250 000 Sheet was confirmed, although some additional areas have been recognised, the most prominent of these being about 3km east of Auburn homestead. The unit is poorly exposed over a total area of ~300km^2, but large areas are covered by Cainozoic sediments and the rocks presumably continue southwards under the Jurassic Evergreen Formation of the Surat Basin. The rocks from a flat soil-covered plain in the north, but crop out as north-west-trending strike ridges in the south.

Type area

Because of the poor outcrop, it has not been possible to identify a single continuous section. However, andesitic lavas and clastic rocks along the Mount Narayen Road from MGA 275050 7153300 to 276200 7148500 are considered typical of the unit, and this is given as the type area.

Two distinct andesite types are exposed in the Mount Narayen area. In one, the plagioclase phenocrysts are more abundant than hornblende/clinopyroxene phenocrysts, and the rock is usually relatively strongly but variably magnetic. In the other, hornblende/clinopyroxene phenocrysts are much more abundant than plagioclase, and the rock usually has low magnetic susceptibility. Indurated laminated siliceous siltstone occurs in the area also.

Andesite and rudite are common along the Mount Narayen Road around Mount Narayen itself. The rudites are mostly oligomict to monomict, appearing to coarsen and become more polymict towards Mount Narayen. The clasts are usually moderately to well rounded, suggesting fluvial processes. Alternatively the clasts may have been rounded by gas-streaming or other volcanic processes rather than sedimentary means. Angular clasts have also been reported from the area (Whitaker & others, 1974), consistent with a volcanic environment. Rudite horizons appear to be metres to tens of metres thick, intercalated with laminated volcanic arenite. Dip reversals are apparent from the orientation of laminated horizons.

The unconformity with foliated granite is well exposed at MGA 277465 7166200 in Cheltenham Creek near Giaka homestead and the section upstream to MGA 280160 7165600 is given as a reference locality for the base of the unit. The basal conglomerate is very thick-bedded and is poorly sorted with subangular to subrounded, pebbles to boulders of the granite as well as intermediate volcanic clasts in a medium to very coarse-grained lithic sandstone matrix. It is overlain by a sequence of lithic sandstone to polymictic conglomerate ~700m thick and then passes into cleaved mudstone. Farther east towards the contact with the Yerilla Metamorphics, the mudstone appears to be overlain by strongly cleaved andesitic volcaniclastic rocks, but these are not included in the reference section because the strong deformation renders them atypical of the unit.

Lithology

The Narayen beds comprise rhyolitic to dominantly andesitic rudite, arenite, and lava flows, lithic siltstone, sandstone, conglomerate and rare coquinite, limestone and chert.

The most prominently exposed rock-types are andesite and massive indurated andesitic rudite, which are common throughout the outcrop area of the Narayen beds. Unless hornfelsed, the sedimentary units are very poorly exposed. An exception is the basal part of the sequence near Giaka, as described above in the reference section. Coquinite and limestone crop out in the central west of the unit, at MGA 269000 7153250 near Thooruna homestead. The coquinite forms a thick bed with internal layering defined by alternating siliciclastic sandy layers alternating with calcareous layers comprising shelly material, mostly brachiopod, bivalve and bryozoan fragments up to several centimetres across.

In general, felsic rocks and chert are more common in the south and south-west of the unit. The newly recognised area of volcanic-sedimentary rocks east of Auburn homestead comprises folded, rhyolitic volcanogenic arenite and polymictic rudite, possibly in a series of upward-fining cycles. They are similar to, but coarser than the unnamed Triassic volcanics elsewhere in the area and could be related to them rather than the Narayen beds.

Near Giaka homestead, towards the contact with the Yerilla Metamorphics, the rocks are much more strongly deformed and have a strong cleavage and the rudites have flattened and elongated clasts similar to those in the Camboon Volcanics in the Gogango Overfolded Zone. The reason for the stronger deformation is unknown, but it may be related to thrusting, and it could have juxtaposed the unit against the Yerilla Metamorphics in a continuation of the Gogango Overfolded Zone that is largely obscured by the late Permian to Early Triassic granitoids of the Rawbelle Batholith.

Geophysical response

Magnetic susceptibility values for the andesitic rocks show a strongly skewed bimodal distribution with a major mode for values up to 100 x 10^{-5} SI units, and a weak mode at ~1200 x 10^{-5} SI units. Sporadic values up to 3500 were recorded. The sedimentary rocks have very low values (0–10 x 10^{-5} SI units). These values are consistent with the response in the airborne magnetic data. The intensity is very low over most of the area, with a few sporadic moderate to high zones.

The Narayen beds show a two-fold subdivision in the radiometric data with a central belt characterised by moderate potassium, thorium and uranium responses flanked by zones of low response in all channels. The central zone has pinkish grey hues on composite images similar to some of the Back Creek Group that overlies the Camboon Volcanics to the west. It is possible that the central belt of the Narayen beds may represent a change to a sediment-dominated sequence, although the field data indicates that some volcanic rocks still crop out there.

Environment of Deposition

Because of the lack of detailed studies, it is difficult to assess the depositional environment of the Nogo beds. However, the local marine fossils from near Thooruna indicate a partly marine environment. Whitaker & others (1974) considered that the conglomerate and arenite could have been deposited in either marine or continental environments, but areas where volcanic rocks were dominant may have been deposited under entirely subaerial conditions.

Geochemistry

Twelve samples from the Nogo beds were analysed for a range of major and trace elements. They are mostly lavas but include one volcaniclastic rock, interpreted as an ignimbrite. The total alkali-silica (TAS) plot shows that the rocks range from basalt to rhyolite (Figure 15a). The ignimbrite sample is rhyolitic. The plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) confirms this spread of compositions (Figure 15b).

Mafic rocks in the Ti-Zr plot (Figure 16a) show that the Narayen beds mostly fall in the calc-alkaline basalt field like the low-Ti suite of the Nogo beds.

Only X-ray fluorescence (XRF) analyses are available for these rocks, so that it is not possible to present REE data. However, the XRF data is presented as a multi-element plot normalised to N-MORB in Figure 16e. The pattern is generally similar to most other Permian volcanic rocks in this study, showing depletion in Ti and Y, a relatively steep slope for the high-field-strength elements (HFSE), a pronounced Nb trough and enriched large-ion-lithophile elements (LILE). The latter show values, generally higher than most of the other Permian units except for the low-Ti suite of the Narayen beds. The plot was compared with those from modern basaltic suites using the database compiled from literature by Murray & Blake (2005, appendix 1). The steep slope is consistent with thick crust and an example comparison is made in Figure 16e with the Casimiro suite in the Southern Volcanic Zone of the Andes (Hickey & others, 1986).

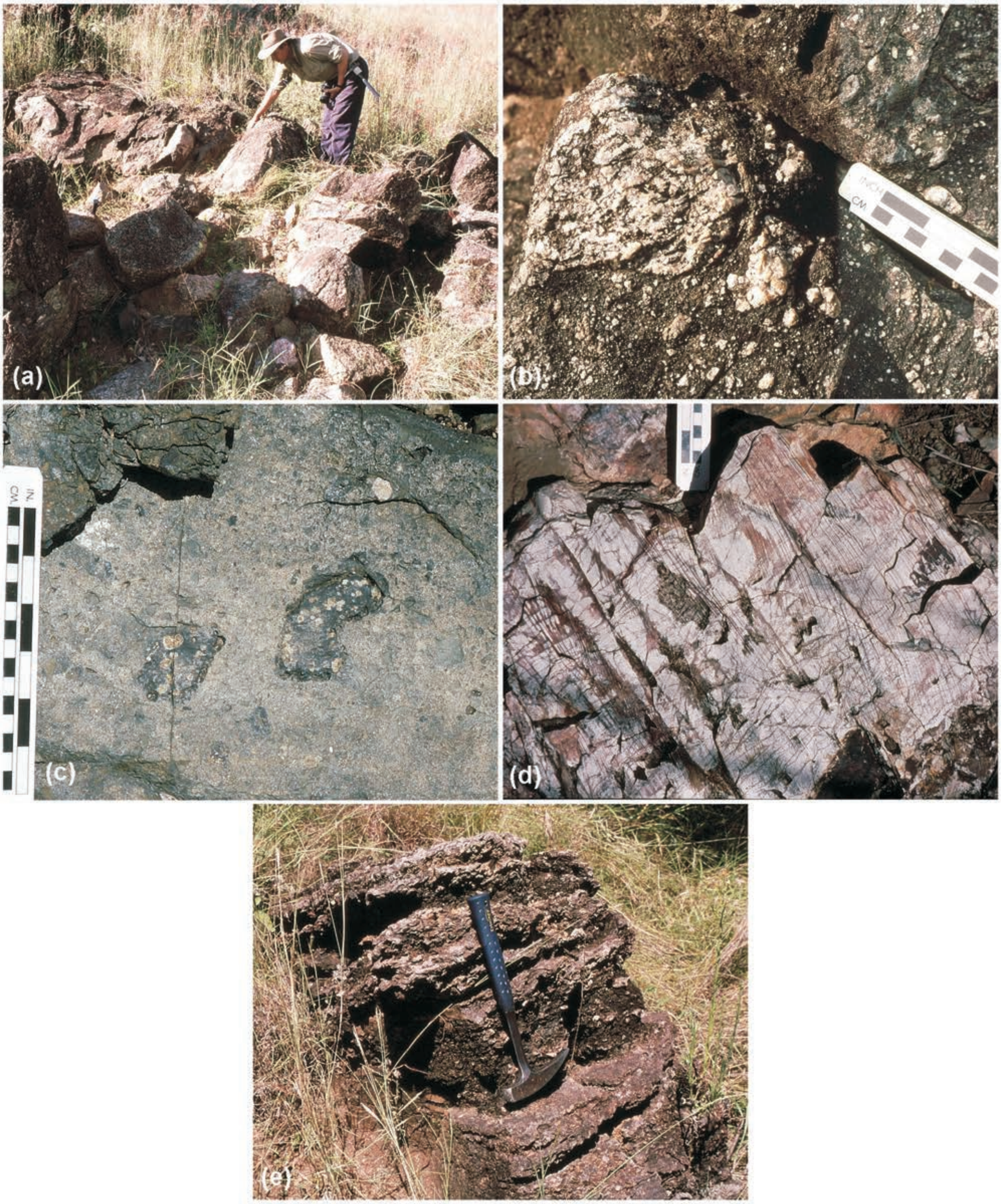

Figure 17. Narayen beds
(a) Ian Rienks pointing to the unconformity between foliated granite of the Horse Leucogneiss (to the right) and the steeply dipping, but unstrained basal conglomerate of the Narayen beds. Cheltenham Creek, west of Giarka homestead at MGA 277460 7166177 (IRAU633)
(b) Foliated granite clast in the basal conglomerate. Same locality as (a)
(c) Andesitic or basaltic volcanic rudite containing vesicular basalt bombs. Nerangy Creek at MGA 7159677 277805 (IRAU114)
(d) Cross-bedded siliceous siltstone or fine-grained sandstone. Near Koko Creek, 15km east of Auburn homestead at MGA 275655 7130377 (IRAU227)
(e) Coquinite with siliciclastic sandy layers alternating with calcareous layers comprising shelly material. Near access road to Thooruna homestead at MGA 269000 7153250 (IRAU369)

Relationships and age

In the west, the Narayen beds unconformably overlie foliated granites of the Horse Leucogneiss which is a component of the basement rocks within the Yerilla Metamorphics, but to the east, the contact with the Yerilla Metamorphics is a fault. Adjacent to the fault, the rocks have a strong cleavage and flattened and elongated clasts. They are also faulted against the Carboniferous Evandale Tonalite. The newly recognised volcanic and sedimentary rocks east of Auburn homestead unconformably overlie the Carboniferous Glissons Granodiorite. The main part of the Narayen beds are intruded by various late Permian to Early Triassic granitoids, including the Greencoat Quartz Monzonite, Mount Saul Quartz Monzonite, Delubra Gabbro and some small unnamed plutons. They are unconformably overlain by the Jurassic Evergreen Formation.

A Permian marine fauna was recovered from the Hooper Creek crossing area along the Mount Narayen Road, and the beds were considered to be most likely early Permian (Whitaker & others, 1974). Fossils recovered more recently from the coquinite in the far west of the unit near Thooruna homestead by Geopeko geologists confirmed the early Permian age, and suggest a correlation with the Buffel Formation (S. Parfrey, personal communication, 1998). The Thooruna site was recollected during the present survey but no further palaeontological studies have been made on it. Whitehouse (1936) described plant fossils from near Yerilla and considered them to be Late Devonian or Carboniferous.

STRATIGRAPHY OF THE GRANTLEIGH SUBPROVINCE (YARROL PROVINCE)

The name Grantleigh Trough was introduced by Kirkegaard & others (1970) and the concept was further developed by Day & others (1978, 1983) for a deep marine basin to the east of the Bowen basin proper and separated from it by volcanism along a basement ridge (the Camboon Volcanic Arc along the Connors–Auburn Arch). Rocks deposited in it included the “Rannes beds”, part of the Boomer Formation, which was interpreted as ‘flysch’, and the Rookwood Volcanics.

Fielding & others (1997a) stated that they could find no evidence to support the notion of an upstanding Permian volcanic arc along the Connors–Auburn Arch during sediment accumulation in the Bowen Basin, and no evidence that Permian rocks of the Gogango Overfolded Zone were separate from the basin except during early Permian extension when the area was divided into discrete sub-basins. Within correlative formations, facies assemblages are identical on either side of the Connors–Auburn Arch, and no evidence of basin-marginal facies is found adjacent to that basement feature. They also noted that palaeocurrent data indicate that sediment dispersal was consistently westward across the Connors–Auburn Arch and into the Bowen Basin from a source at least as far east as the present coastline. They therefore proposed that use of the term Grantleigh Trough be discontinued. Observations during this study support their conclusion.

The term Grantleigh Subprovince has however, been used here for the Rookwood Volcanics. These submarine volcanic rocks appear to be relatively unique in the area, showing similarities to oceanic basalts and suggesting more extreme extension than elsewhere in the region during the early Permian. However, the subprovince is here regarded as part of the Yarrol Province, rather than the Bowen Basin, because the Rookwood Volcanics mostly lie east of the main thrust that defines the eastern limit of the Gogango Overfolded Zone. The areas of Rookwood Volcanics that occur west of the thrust within the Gogango Overfolded Zone are probably folded klippen. They conformably overlie and apparently interfinger with the Youlambie Conglomerate that forms a key stratigraphic assemblage within the Yarrol Province. It is admitted, however, that the distinction between the Bowen Basin and Yarrol Province is somewhat arbitrary and that they were probably continuous in the early Permian, prior to the onset of foreland thrusting that ultimately formed the Gogango Overfolded Zone.

Two other units are described in this chapter because they form an apparently conformable succession with the Rookwood Volcanics, although they are not strictly part of the Grantleigh Subprovince. The underlying early Permian Youlambie Conglomerate is a widespread unit and is considered to be part of the Rockhampton Subprovince. The overlying Moah Creek beds are equivalent to the Back Creek Group in the Bowen Basin and were probably continuous with that unit, further demonstrating that the distinction between the two structural units in the Permian was relatively arbitrary.

YOULAMBIE CONGLOMERATE

Introduction

The Youlambie Conglomerate was named by Dear (1968) as a result of detailed mapping in the Cania area north of Monto and was later extended north-west over the Monto, Rockhampton and Duaringa 1:250 000 Sheet areas by regional mapping programs (Malone & others, 1969; Kirkegaard & others, 1970; Dear & others, 1971). The unit forms a discontinuous, north-west trending belt 250km long and up to 25km wide. The study area includes the structurally complex northern end of the belt straddling the Fitzroy River from Moah Creek in the south to near Develin homestead (Figure 18) and also the southern end of the belt near Cania in north-east SCORIA. The unit is resistant to erosion and forms hilly, lightly timbered country with deeply incised streams. The unit is described by the Yarrol Project Team (in preparation).

Type section

The type section comprises two overlapping parts on either side of Youlambie Creek 13km north of Monto, and was described in detail by Dear (1968). The unit was estimated by Dear (1968) to be 1320m thick in the type area, where both the bottom and top are exposed. Kirkegaard & others (1970) suggested thicknesses of 750–1800m in the Rockhampton 1:250 000 Sheet area.

Lithology

Conglomerate, though not dominant, is characteristic of the unit. Rock types include light brown, commonly polymictic, granite and rhyolite-bearing conglomerate; light brown to pinkish brown lithofeldspathic to lithic quartz-bearing sandstone; dark grey to bluish grey thinly bedded to laminated siltstone and mudstone, locally carbonaceous; and minor greyish purple, rhyolitic ignimbrite.

The conglomerates are rarely cross-bedded and locally imbricated. The medium to coarse lithofeldspathic to lithic sandstones have 5–20% quartz, and are locally pebbly to cobbly with up to 20% granitic clasts, and up to 50% dark grey to purple dacitic to rhyolitic volcanic clasts. The sandstones commonly exhibit cross stratification. They are commonly interbedded with thin mudstone beds that contain abundant plant stems and leaves. In the Cania area, a particular facies consists of thin, rhythmically laminated siltstone and mudstone comprising five or more graded laminae per centimetre with rare pebble dropstones (Dear & others, 1971; Jones & Fielding, 2004; see Figure 19a,b). As noted below, these are interpreted as varved deposits and locally are disrupted by slump folds. They are interbedded with very poorly sorted sandstone and matrix-supported conglomerate that contains subangular to subrounded pebbles to cobbles (and locally boulders to 1.5m) of granite to diorite and subordinate felsic volcanic rocks (Figure 19c). The sandy matrix to the conglomerate is commonly fine to medium-grained.

The local marine intervals consist of thinly interbedded fine to medium calcareous feldspatholithic to lithic sandstone and mudstone. The sandstones contain sparse marine fossils including gastropods, bivalves, and brachiopods.

Environment of deposition

The conglomerates and sandstones in the unit were dominantly sourced from granitic and rhyolitic rocks (Dear, 1968) reflecting extensive unroofing of granitic plutons and erosion of rhyolitic volcanics in the provenance area. Rhyolitic ignimbrites in the succession are similar in both colour and geochemical signature to rhyolitic clasts in conglomerates, indicating that volcanism in the source area was still active at the time of deposition. The felsic composition of the volcanic rocks and the clasts in the sedimentary rocks is reflected in the high radiometric response in all three channels (potassium, thorium, and uranium).

The Yarrol Project Team (in preparation) have identified nine facies and six facies associations in the Youlambie Conglomerate. The unit was deposited in a dominantly terrestrial environment and contains abundant plant fossils including both stems and leaves. Short-lived marine incursions are recorded by the presence of thin beds containing sparse but widely distributed marine fossils.

The terrestrial environment was dominated by fluvial processes and deposition in a braided stream environment, as evidenced by the presence of cross-bedding and imbrication in the conglomerate and sandstone facies, and the lateral extent of the coarse grained facies in the unit. In the Cania area, varved siltstones with dropstones were interpreted by Dear & others (1971) and Jones & Fielding (2004) to have been deposited in a proglacial lacustrine environment. Dear & others (1971) observed faceting of pebbles and cobbles in the conglomerates in the formation, suggesting that ice flows or glaciers were involved in the transport of this material. They also suggested that the matrix-supported conglomerates associated with the

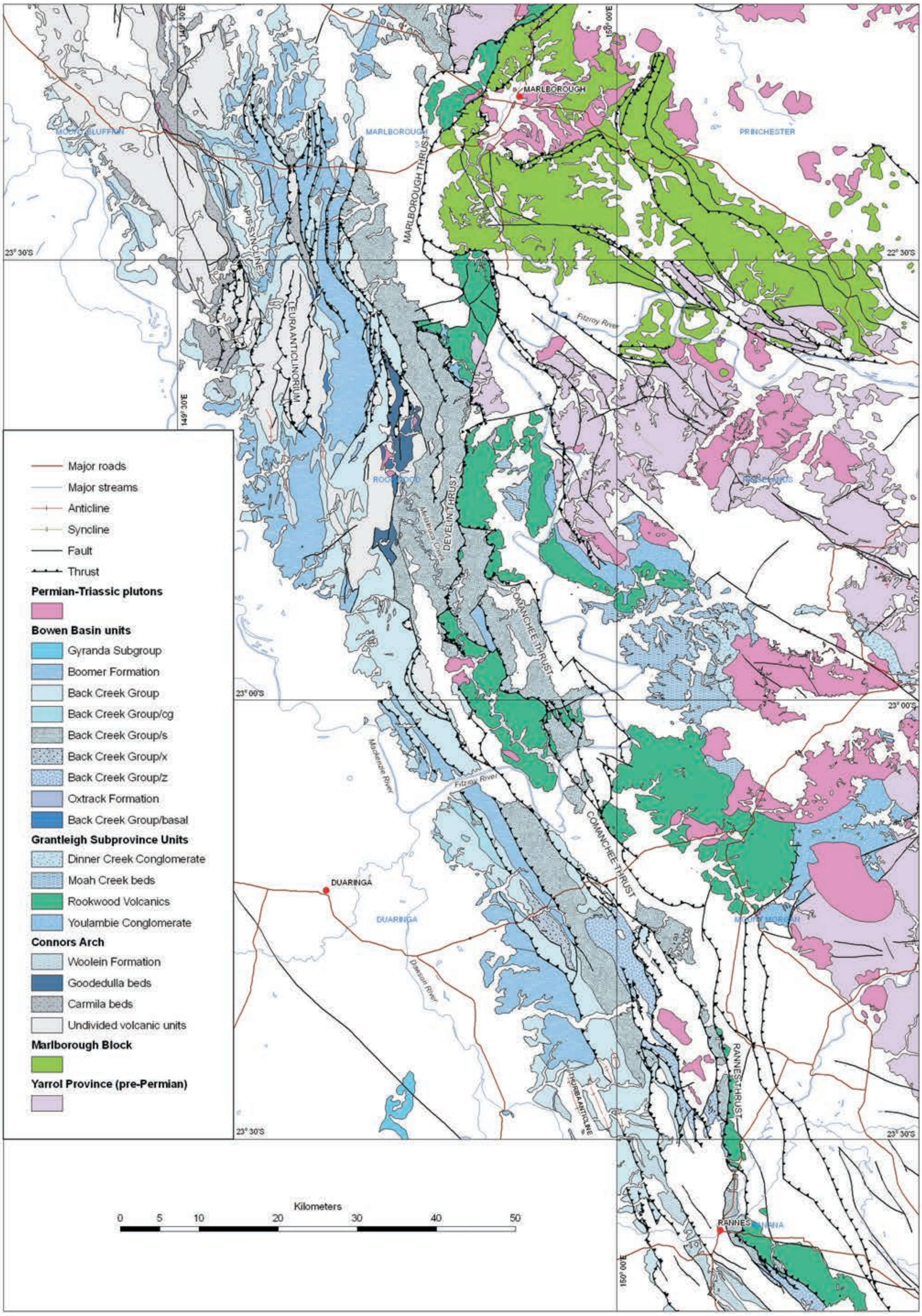

Figure 18. Geology of the Gogango Overfolded Zone and Grantleigh Subprovince

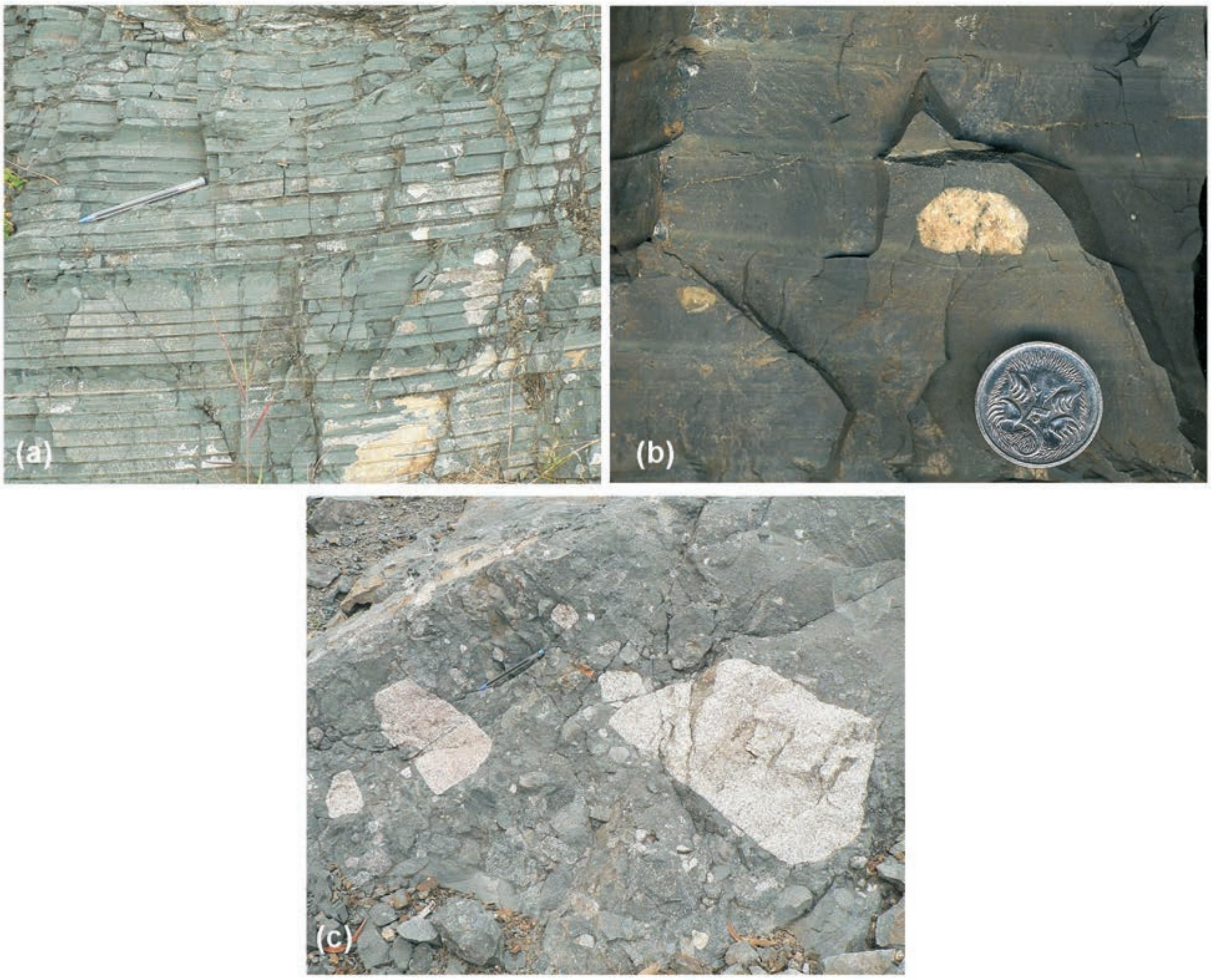

Figure 19. Youlambie Conglomerate
(a) Rhythmically laminated siltstone, interpreted as varved deposits. Spillway of Cania Dam at MGA 295250 7272010 (IWGN469)
(b) Granite dropstone in rhythmically laminated siltstone. Coin is 19mm in diameter. Same locality as (a)
(c) Matrix supported conglomerate containing subangular pebbles to small boulders of diorite to granite and felsic volcanics in a fine-grained sandy matrix. Same locality as (a)

varved siltstones represented fluvioglacial deposits. The presence of cobble sized rip-up clasts, the poor sorting, and mixed provenance of these conglomerates combined with their association with fine grained deposits of a much lower energy regime supports the interpretation that these deposits were transported by ice flows or glaciers. Jones & Fielding (2004) concluded that the glaciation was confined to local valley or mountain glaciers, a finding that is consistent with the absence of evidence for glaciation in rocks of the Youlambie Conglomerate north from Cania (Kirkegaard & others, 1970).

Fossils and age

The most abundant fossils in the Youlambie Conglomerate are plants, including *Cardiopteris polymorpha*, *Noeggeraththiopsis hislopi* Bunbury, *Gangamopteris* and *Glossopteris*. These indicate a Permian age, as the *Cardiopteris* overlies a marine fauna including *Eurydesma* (Dear, 1968).

Marine faunas occur at several localities midway through the unit in the type area of the Spring Creek Syncline. The faunas, described by Dear (1968), Webb (1977) and Briggs (1998), cover the *Strophalosia concentrica* to *Bandoproductus walkomi* zones of Briggs (1993, 1998), indicating a Sakmarian (early Permian) age, although the entire unit may extend down into the late Asselian and upwards into the early Artinskian. Another fauna in Stag Creek in BILOELA towards the top of the unit was described by Beeston (1975) and is assigned the same age as those from the Spring Creek Syncline.

Malone & others (1969, page 18) recorded a poorly preserved brachiopod fauna of probable early Permian age from the top of the Youlambie Conglomerate just east of the eastern boundary of the Duaringa 1:250 000 Sheet area. This appears to be in the same stratigraphic position as the marine fauna reported by Fielding &

others (1997a) from the Youlambie Conglomerate at Scrub Creek 30km south-west of Ridgelands. This fauna is significantly younger than those from the Spring Creek Syncline and Stag Creek, being referable to the *Echinalosia warwicki* or lower *Echinalosia preovalis* zones of Briggs (1993, 1998) and therefore of Artinskian age. In this area, the upper part of the sequence mapped as Youlambie Conglomerate by Fielding & others (1997a, figure 6) has been included in the Rookwood Volcanics on the RIDGELANDS map because of the presence of extensive interbedded pillow basalts that are unknown from the Youlambie Conglomerate. The fossil locality falls near the contact between the two units, and could come from either the top of the Youlambie Conglomerate or the base of the Rookwood Volcanics. The latter alternative is supported by the occurrence of Artinskian foraminifers in the Rookwood Volcanics to the west (O'Connell, 1995; Fielding & others, 1997a).

Although fossils in the Youlambie Conglomerate are confined to the early Permian, deposition may have begun in the latest Carboniferous. An ignimbrite interbedded with the conglomerate as well as three ignimbrite clasts in the conglomerate were collected from along the Dawson Highway north-east of Biloela and submitted for zircon dating by SHRIMP. All ages are in error of each other (see Appendix). The ignimbrite (MHRO970 from 262661 7319645) gave an age of 300.8±3.4Ma (MSWD 1.7. The clasts from site MHRO971 at 258242 7318366 gave ages from 300.0±3.8Ma to 303.6±3.7Ma. These lie on the Carboniferous–Permian boundary in the ISC timescale (Gradstein & others, 2004).

Relationships

In the main part of its outcrop area, the Youlambie Conglomerate unconformably overlies a number of Yarrol Province units that range in age from Middle Devonian to early Carboniferous, indicating a substantial interval of non-deposition or erosion (Yarrol Project Team, 1997). Some contacts show moderate to strong angular discordance, and at others the units appear to be concordant. The variation in relationships at this basal contact can be attributed to different degrees of tilting of basement blocks during latest Carboniferous to early Permian extension. This regional event changed the paleogeography and formed extensional basins that received coarse clastic sediments and rhyolitic volcanics (Holcombe & others, 1997a; Fielding & others, 1997a). The sediments include widely distributed granite clasts that suggest accelerated erosion and unroofing of plutons in the hinterland, probably located to the west in the Connors–Auburn Arc (Hutton & others, 1999a).

The Youlambie Conglomerate overlaps the Lorray Formation in age. East of Monto, the Lorray Formation is part of a continuous marine sequence from the early Carboniferous to the early Permian, but farther west, the Youlambie Conglomerate is mainly terrestrial, and directly overlies the early Carboniferous Rockhampton Group.

North from Mount Morgan to west of the Fitzroy River at Craigilee homestead, the Youlambie Conglomerate is mapped as a discontinuous belt overlying the Lorray Formation. No marine fossils are known from this belt apart from the fauna reported by Fielding & others (1997a) from the top of the Youlambie Conglomerate or bottom of the overlying early Permian Rookwood Volcanics at Scrub Creek. Fielding & others (1997a) suggested that outcrop patterns near Scrub Creek "demonstrate interfingering between the Youlambie Conglomerate and the Rookwood Volcanics". Their Figure 6 shows extensive belts of pillow basalts within the Youlambie Conglomerate. Pillow basalts are not known from the Youlambie Conglomerate, but are characteristic of the Rookwood Volcanics, and the Rookwood Volcanics in this area contain interbedded sediments (O'Connell, 1995). Therefore, the upper section of the unit mapped as Youlambie Conglomerate by Fielding & others (1997a, figure 6), with pillow basalts, is included in the Rookwood Volcanics on the RIDGELANDS map. In this same area, the Youlambie Conglomerate is unconformably overlain by the Cretaceous Alton Downs Basalt and Mount Salmon Volcanics.

The Youlambie Conglomerate probably correlates at least in part with the Mount Bulgi Conglomerate Member that overlies the Torsdale Volcanics at the base of the Camboon Volcanics. Rhyolitic ignimbrite and comagmatic granites in the Torsdale Volcanics probably contributed to the felsic detritus in the Youlambie Conglomerate. SHRIMP dating of ignimbrite from the top of Torsdale Volcanics near Biloela gave an age of 298.2±5.1Ma, which is in error of the ages of ~300Ma from clasts and ignimbrite from the Youlambie Conglomerate (see Appendix). North of the Marlborough Block, the Glenprairie beds may be a correlative of the Youlambie Conglomerate.

ROOKWOOD VOLCANICS

Introduction

The Rookwood Volcanics were defined by Malone & others (1969) as a unit of dominantly spilitic lavas in the eastern part of the Duaringa 1:250 000 Sheet area extending into the Rockhampton and Monto Sheet areas. The unit crops out in several disconnected areas (Figure 18). The main outcrop areas of the Rookwood Volcanics are in the Rookwood–Ohio area (where a type area was designated in Melaleuca Creek), Develin Creek area, Glenroy-Scrub Creek area (straddling the Fitzroy River) in ROOKWOOD, DUARINGA and RIDGELANDS; Westwood–Gogango in MOUNT MORGAN; and Lakeview and near Goovigen in BANANA. Previously unmapped mafic volcanics that crop out around the north-western margin of the Marlborough Block in MARLBOROUGH are also assigned to the Rookwood Volcanics. Most of the areas (except for the latter area and the Lakeview and Goovigen areas) were studied by R. Barker and J. Domagala as part of the Department’s Yarrol Project (see Yarrol Project Team, 1997 and in preparation). However, I. Withnall also made some observations in the Rookwood-Ohio area.

Type area

The type area of the Rookwood Volcanics is along Melaleuca Creek (Malone & others, 1969). It consists mainly of lavas, with minor volcanic breccia; chert, volcaniclastic sandstone and siltstone are also present.

Lithology

The Rookwood Volcanics have also been studied by Clare (1993), Messenger (1994), O’Connell (1995), Bendall (1996) and Holcombe & others (1997b). The Rookwood Volcanics in the areas studied by these other authors are mostly altered basaltic pillow lavas and high-level intrusives with minor sedimentary rocks. Pillows, autobreccia, and peperite are relatively common in the northern blocks (Figure 20a) whereas the southern exposures are dominantly massive.

The lavas are mostly aphyric, but porphyritic basalt crops out in places. Phenocrysts are mainly plagioclase up to 7mm and minor augite. Where least altered, the aphyric basalt usually consists of randomly orientated laths of plagioclase to 0.25mm, with interstitial augite and skeletal opaque grains. The augite is commonly titaniferous, and in some samples, it forms aggregates of needle-like crystals, possibly a quench texture. However, alteration is generally extensive, the plagioclase being partly saussuritised, the augite replaced by chlorite and actinolite, and the opaque grains replaced by titanite.

At Develin Creek, Bendall (1996) stated the Rookwood Volcanics are represented by pillowed and massive facies, and that the basalt has undergone lower greenschist metamorphism. Messenger (1994) described the massive basalts as aphyric to porphyritic, with amygdales (<5% to 20%) in the former, filled with calcite, chlorite, hematite, jasper, and epidote. Veins of jasper are crosscut by veins of epidote and chlorite. Secondary calcite is also present in veins, fractures and cavities. Quartz veins exist at the contact with massive sulphide mineralisation. The pillow basalts dominate the sequence, and are similar mineralogically to the massive basalts. Bendall (1996) described the pillows as 0.2–1m across, rarely 2m, with an altered plagioclase groundmass, and phenocrysts of plagioclase up to 2mm, commonly replaced by sericite, epidote, and chlorite. He observed a dark chloritised ‘rind’ with a perlitic texture that surrounds the pillows and appears to flake off and be incorporated into the yellow-green, crystalline matrix. Veins of epidote, quartz, jasper, chlorite or calcite fill the tensional fractures of the pillows. Breccias of massive and pillow basalts are commonly found near the mineralisation and are characteristically monomict, and have jigsaw fit fractures. Messenger (1994) also described peperitic contacts between the sedimentary units and the pillow basalt and hyaloclastite.

Messenger (1994) described the sedimentary rocks in the mineralisation host sequence at Develin Creek, although there they comprise <1% of the section. They consist of polymict breccia, basaltic sandstone-mudstone, chert, jasper and sulphide-oxide exhalite. Ore-grade intersections of Cu and Zn occur at the Scorpion prospect in sedimentary breccias that contain clasts of basalt and sulphide. The sandstone-mudstone intervals are usually <1m thick and occur between pillow basalt units. Bedded sulphides, commonly finely laminated and showing normal grading are interbedded with basaltic mudstones and magnetite exhalites. Grey chert containing sparse micro-fossils resembling sponge spicules are associated with some of the bedded and massive sulphides. Contacts with the basalts are usually peperitic.

Sedimentary intervals up to 300m thick are more common elsewhere in the northern areas, particularly in the Scrub Creek area and in the Develin Creek area east of the mineralised belt. The intervals include lithofeldspathic sandstone, and thin-bedded to laminated siltstone and mudstone, locally containing trace fossils including *Planolites*, *Rhizocorallium* and *Chondrites* which characterise the *Cruziana* ichnofacies. O’Connell (1995) described the sandstones as very fine to very coarse-grained, moderately well-sorted and

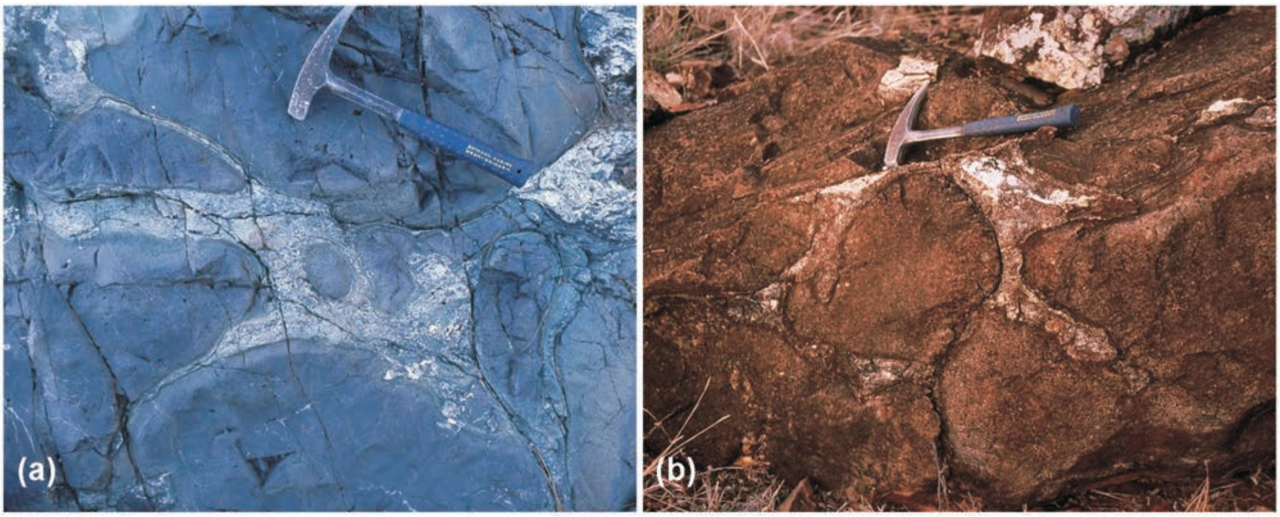

Figure 20. Rookwood Volcanics
(a) Portions of pillow basalt showing silicified hyaloclastic material. Melaleuca Creek at the Rookwood – Yarra Road crossing at MGA 792164 7396700 (IWGG459)
(b) Well-developed pillow basalt. Glenerin Station about 9km east-south-east of Rannes at MGA 215074 7327055 (IWGG957)

consisting of angular to sub-rounded quartz (<15%), feldspar (35–45%), lithics (15–25%) with up to 25% silt-sized matrix. Bedding is poorly defined and no cross-bedding was observed. The lithic clasts include mafic volcanics, containing acicular crystals of plagioclase and minor pyroxene, chloritised volcanic glass and siltstone and cherty sedimentary clasts. Some pebbly sandstone and pebble breccia are associated with the sandstone. Siltstones are dark grey and commonly relatively siliceous.

Slices of massive rhyolite occur with pillow basalt near Comanche homestead, and other belts of felsic rocks occur in the Scrub Creek area and to the north-west and south of Westwood. However, the contact relationships between the felsic and mafic rocks are unclear. Thin sections of 'rhyolite' samples collected by R. Barker in the Rookwood Volcanics from the Westwood and Scrub Creek areas consist predominantly of feldspar (plagioclase and probably K-feldspar) phenocrysts in a very fine (generally *ca* 0.01–0.02mm) groundmass of feldspar and chlorite and probably quartz. In some samples, the groundmass contains microspherulites. No quartz phenocrysts were observed, and in most cases the euhedral form of the feldspars indicates that the rocks were magmatic, either dykes, plugs or flows rather than volcaniclastic. One sample from the Scrub Creek area was a siltstone containing abundant feldspar and minor quartz crystal fragments.

O'Connell described a pumice breccia from within the main sedimentary interval in the Scrub Creek area. Clasts in the breccia are subrounded to rounded, up to 5cm in diameter, and include collapsed pumice and other felsic volcanics, siltstone and minor mafic volcanics. The matrix consists mainly of tubular pumice and plagioclase crystal fragments.

The Rookwood Volcanics recognised adjacent to the Marlborough Block were examined on 'Rock Wallaby' Station on the southern side of the Bruce Highway, the southern foot of Pine Mountain, and along the Glenprairie and Belah Valley roads north of Marlborough. The rocks consist mainly of aphyric to locally porphyritic basalt, and minor chert, carbonaceous mudstone and lithic sandstone. The rocks are intruded and hornfelsed by small bodies of gabbro and dolerite. In thin section, the basalts consist of randomly orientated plagioclase laths to 0.25mm and interstitial amphibole and opaque grains and/or titanite. Hornfelsed, cleaved mudstone in a cutting along the Bruce Highway at MGA 792250 7474600 contains andalusite porphyroblasts up to 1mm across. Coarse-grained sandstone in a nearby cutting at MGA 791650 7474950 has been strongly mylonitised with thin seams filled with iron-oxide and anastomosing around phenoclasts of feldspar and minor quartz in a very fine-grained hornfelsed matrix of quartz, feldspar and biotite.

The rocks examined by this project in the Lakeview and Goovigen areas are similar to the rocks farther north. They consist mainly of altered, dark greenish-grey aphyric basalt; some porphyritic basalt or andesite, containing greenish epidotised plagioclase phenocrysts up to 5mm, occurs locally. Alteration is common in most outcrops, and rocks are at least partly altered to epidote and chlorite. However, overall, the rocks appear to be less altered than in the Rookwood and Scrub Creek areas. In thin section, the fresher rocks that were sampled for geochemistry consist of intergrown plagioclase laths and augite (commonly titaniferous), but the plagioclase is commonly at least partly saussuritised and augite is replaced by chlorite. Most of the ilmenite is replaced by titanite. Epidotisation is commonly extensive in many outcrops, and is both pervasive and present as networks of veinlets. Local spectacular pillows and hyaloclastic breccias (Figure 20b) confirm subaqueous emplacement. The pillows are ovoid and range from 15cm–2m across. Interstices are generally filled with epidote and silica (chert), but in some cases, hyaloclastic material that has a silica-epidote matrix is present. The hyaloclastite consists of clasts of basalt up to 10cm with a weak jigsaw fit, in a matrix of finer fragments (less than 5mm) and cherty material. Radial fractures in some pillows are also filled with epidote and silica. Amygdales are not common. According to Clare (1993), the upper part of the section in the Goovigen area is dominated by sheet flows that have brecciated or chilled tops.

No sedimentary rocks were observed intercalated with the lavas in either the Lakeview or Goovigen areas. Dear & others (1971) stated that the rocks in the Goovigen area are intruded by dolerite. Some possible dolerite outcrops were observed in the Lakeview area, but except for a slightly coarser grainsize, they are difficult to distinguish from the basalt.

The Rookwood Volcanics are essentially massive, and except for the rare sedimentary intervals, dips are difficult to discern, although approximate dips and overall younging direction can be determined from the pillow lavas. Bedding trends are only poorly developed on aerial photographs. The thickness of the Rookwood Volcanics thus is uncertain, although Clare (1993) estimated thicknesses of 3km and 4.5km for the Westwood and Goovigen areas respectively. In the latter area, this assumed dips of 45° to 85° to the north-east, and no repetition by folding or faulting.

Geophysical response

The Rookwood Volcanics have a very low radiometric response in all channels resulting in dark purple to black hues in the composite images, except for the areas of mudstone and rhyolite, which have a moderate potassium response and low to moderate uranium and thorium, resulting in deep pink composite hues.

The Rookwood Volcanics generally have a low magnetic response, although locally strongly magnetic linear belts are present. This is consistent with the magnetic susceptibility values, which show a strongly skewed distribution with a mode at 30 x 10^{-5} SI units and a mean of 207. Values do extend to ~6000, although 70% of values are <250.

Environment of deposition

Holcombe & others (1997b), O’Connell (1995) and the Yarrol Project Team (1997) discussed the environment of deposition and concluded that a marine origin for the sequence was likely, with water depths no deeper than shelfal (<200m), but below storm wave base. This was based on locally abundant trace fossils of the *Cruziana* ichnofacies, macro-invertebrate fragments and the one foraminifera locality. The volcaniclastic deposits are interpreted as density current deposits. The thin to laminated carbonaceous siltstones are interpreted as hemipelagic or low-concentration turbidites. The depositional environment of the VHMS deposit at Develin Creek, however, remains enigmatic. The sulphide mineralogy suggests formation at water depths >700m (Messenger, 1994; O’Connell, 1995). This could be explained by an epigenetic replacement mechanism for the deposit, although O’Connell preferred a model involving differential subsidence.

The shelfal environment also disagrees with previous interpretations of deep marine environments by Malone & others (1969) and Clare (1993). Malone & others (1969) interpreted the petrographic characteristics of the Rookwood Volcanics as being due to spilitisation in a deep marine environment. However, Holcombe & others (1997b) pointed out that similar mineralogy and textures are present in subaerially-erupted lavas in the region, such as in the Lizzie Creek Volcanic Group and Camboon Volcanics, and that these are due to burial metamorphism during the Bowen Basin evolution.

The Rookwood Volcanics were interpreted by Holcombe & others (1997b), Fielding & others (1994, 1997a) as representing the extensional phase during the early stages of development of the Bowen Basin. Geochemical analyses by O’Connell (1995), Messenger (1994), Stephens & others (1996) and this study indicate MORB-like affinities, consistent with an extensional setting.

Geochemistry

Twenty-eight samples from the Rookwood Volcanics were analysed for a range of major and trace elements. In addition, four analyses from O’Connell (1995) were also included in the database. All samples are lavas. The total alkali-silica (TAS) plot shows that the rocks form a bimodal suite of mainly basalt and rhyolite (Figure 21a) and this is confirmed by the plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) in Figure 21b. Because it uses immobile elements, the latter plot provides a method of classifying the original composition of altered volcanic rocks. In particular it suggests that the high silica in the rhyolite samples are primary and not due to silicification. The bimodal distribution of compositions is consistent with generation in a rift setting. The Ti-Zr plot (Figure 21c) shows that most samples lie in the field of ocean-floor basalts.

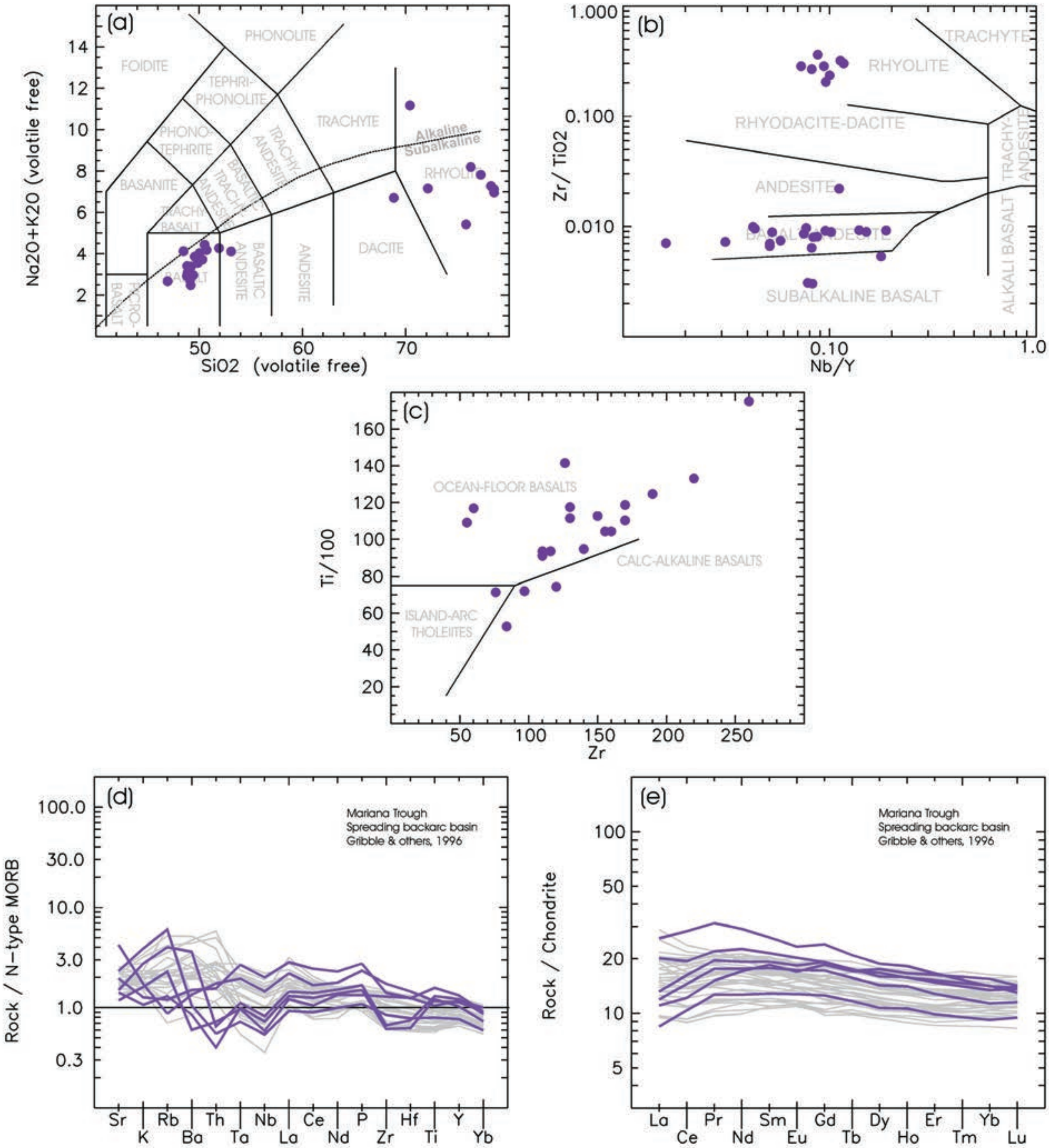

Figure 21. Geochemistry of the early Permian Rookwood Volcanics: (a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas (1986) and Irvine & Baragar (1971); (b) Nb/Y vs Zr/TiO_2 showing the fields of Winchester & Floyd (1977); (c) Zr vs Ti/100 in ppm for basalt samples showing the fields of Garcia (1978); (d) N-MORB normalised multi-element plot (using values from Pearce, 1983) for basalt samples; (e) chondrite-normalised REE plot (using values from Sun & McDonough, 1989) for basalt samples. For comparison, basalts from a modern spreading backarc basin, the Mariana Trough, are shown in grey.

Two samples of basalt were submitted for precise trace element analysis by laser ablation mass spectrometry, and the data along with that of O'Connell (1995) have been used to construct the multi-element and REE plots in Figure 21d-e. In both plots, the patterns are flat, indicative of very thin or oceanic crust, and there is only a slight enrichment relative to MORB with a very weak Nb-trough in the multi-element plot. Comparison with modern basaltic suites in the database compiled from literature by Murray & Blake (2005, appendix 1) shows close similarities with spreading backarc basins such as the Southern Mariana Trough (Gribble & others, 1996).

This contrasts with most other Permian volcanic units in the study area, with the exception of the high-Ti suite in the Nogo beds, although there is a possibility that those rocks are Late Devonian. The Rookwood

Volcanics are part of the Yarrol Province, east of the major system of thrusts that separate it from the Connors and Auburn Arches. The difference in chemistry suggests that the provinces may have been underlain by significantly different basement, and Murray (2007) noted that the geochemistry of the Rookwood Volcanics provides strong support for an oceanic rather than a continental basement to the Yarrol Forearc Basin, as originally suggested by Morand (1993b, page 258). Stephens & others (1996, page 418) concluded that ‘the sub-continental lithosphere (in Early Permian) time was very thin or absent, such that an evolved lithosphere did not contribute significantly to the sources of the magmas’.

The location of the Rookwood Volcanics east of the main Carboniferous to early Permian continental margin arc suggests that the subduction zone stepped to the east in the early Permian and a new arc and backarc developed farther east. The Owl Gully Volcanics, equivalent in stratigraphic age to the Rookwood Volcanics, are located further south and east in MONTO. Compositions range from andesite to basalt with a strong subduction component. On discriminant diagrams, analyses fall close to the boundary between tholeiitic and calc-alkaline compositions and well within oceanic arc fields (Murray, 2007).

Relationships and age

Exposed contacts are rarely observed, and consequently, relationships with adjacent units are difficult to establish in the field. However, the Rookwood Volcanics are inferred to be mostly in fault contact with adjacent units.

In particular, the western contact of the belts appears to be major thrusts of the Rookwood Volcanics over the Back Creek Group. These are variously named the Rannes, Comanche and Develin Thrusts. Unlike the rocks to the west in the Gogango Overfolded Zone, including the Camboon Volcanics, the Rookwood Volcanics are not pervasively foliated. The contrast is quite marked, consistent with the presence of a major thrust. The thrust thus marks the eastern extent of the Gogango Overfolded Zone. East of this structure, the rocks of the Yarrol Province are much less deformed, with relatively shallow dips and weak to absent cleavage.

In the Scrub Creek (or Aeroview) area, Holcombe & others (1997b) and O’Connell (1995) reported that the Rookwood Volcanics overlie and partly interfinger with the Youlambie Conglomerate, although farther west O’Connell (1995) interpreted a thrust contact dipping to the north-east. The geophysical data also indicate that along part of the contact, the Youlambie Conglomerate is thrust over the Rookwood Volcanics.

The relationship of the Rookwood Volcanics to the Back Creek Group rocks (formerly Rannes beds) that lie to the east of the belt near Rookwood and Ohio homesteads is probably mainly faulted, although stratigraphic contacts may occur in places.

Malone & others (1969) and Dear & others (1971) both stated that the Rookwood Volcanics overlie the Rannes beds. A ferruginous bed containing angular blocks of sedimentary rock and some quartz pebbles at the inferred base of the Rookwood Volcanics was cited by Malone & others as evidence of an unconformity. However, neither group of authors discussed the possibility that the contacts may be thrusts. Based on regional lithological correlation and biostratigraphic evidence (see below), the Back Creek Group should overlie the Rookwood Volcanics. The Moah Creek beds in the north-western part of MOUNT MORGAN overlie the Rookwood Volcanics and they are probably correlatives of the Back Creek Group and Boomer Formation (Kirkegaard & others, 1970; Fielding & others, 1997b).

Drilling by QMC Exploration Pty Ltd (1995) at their Sweet Caroline prospect in the Lakeview area provided evidence for an easterly-dipping thrust contact. Holes sited in Rookwood Volcanics near their western boundary, drilled through the thrust into carbonaceous sedimentary rocks.

Relationships in the area west of Goovigen are uncertain. The Rookwood Volcanics are in contact with an assemblage of strongly foliated, locally mylonitic, phyllitic mudstone, lithic sandstone and chert or siliceous siltstone, tentatively assigned to the Back Creek Group (units $\mathbf{Pb_s}$ and $\mathbf{Pb_z}$). As observed elsewhere, the Rookwood Volcanics here are not foliated, and the contact is probably a thrust. The Rookwood Volcanics also enclose an area of cleaved mudstone, lithic sandstone and siliceous siltstone or chert that has the typical ‘hot’ radiometric signature of the Back Creek Group. These rocks may be a “window” of Back Creek Group exposed as an antiformal core, beneath the thrust. However, exposure is poor, and bedding is poorly developed within the deformed sedimentary rocks, so this folding model could not be proved.

Early Permian (Artinskian) fossils have been found in the upper part of the underlying Youlambie Conglomerate or in the basal part of the Rookwood Volcanics (Holcombe & others, 1997b; O’Connell, 1995). They were mainly *Tomiopsis ovata,* which is referable to the *E. warwicki* and *E. preovalis* Biozones. Artinskian foraminiferids that belong to the *Pseudohyperammina radiostoma* Zone were found in the upper part of the Rookwood Volcanics in the Scrub Creek area (V. Palmieri, written communication, 1995; O’Connell, 1995, appendix 2).

MOAH CREEK BEDS

Introduction

The unit was first recognised and described by Kirkegaard & others (1970) for a succession of sedimentary rocks cropping out in the area drained by Moah, Emu, and Breakfast Creeks on the common boundaries of RIDGELANDS, MOUNT MORGAN, and ROOKWOOD (Figure 18). Further detailed work at the type section was reported by Fielding & others (1997b). The unit is also described by the Yarrol Project Team (in preparation) but is included here because of its relationship with the Rookwood Volcanics.

The massive mudstone intervals in the Moah Creek beds form low rounded hills, but strike ridges are developed where the sediments are well bedded. Much of the unit is concealed by thin Cainozoic deposits, but the unit is well exposed in creeks which have eroded through these deposits.

Type section

The section from the head of Emu Creek to its junction with the Fitzroy River, and thence west along the river was designated as the type section. It was partly studied by Fielding & others (1997b) in the Fitzroy River at MGA 196000 7402550 downstream of the crossing of the road to Glenroy homestead (Figure 22).

Thickness

Kirkegaard & others (1970) stated that the maximum thickness of the unit is ~2100m, but this could be an overestimate. The thickness is difficult to estimate because of the shallow dips and extensive cover. The section studied by Fielding & others (1997b) in the Fitzroy River is ~350m thick, but this does not represent a full section.

Lithology

Kirkegaard & others (1970) stated that the Moah Creek beds consisted dominantly of conglomeratic mudstone and mudstone, with minor conglomerate, coarse-grained lithic sandstone, and fine-grained to medium-grained sandstone.

Kirkegaard & others (1970) defined the characteristic rock type of the lower part of the unit as conglomeratic mudstone. This consists of pebbles, cobbles, and boulders of sandstone, mudstone, and limestone in a sandy mudstone matrix. The cobbles and boulders are generally angular and constitute up to 40% of the rock. They include fragments of oolitic limestone and fossiliferous mudstone, indicating that the Rockhampton Group and Lorray Formation were exposed when the sediments were deposited. One block of oolitic limestone in the Fitzroy River is ~45m across, but most are only 0.1–1m across. The mudstone also contains round, tough, fine-grained concretions, many of which contain abundant fine pyrite. Carbonised plant debris occurs in the matrix. The conglomeratic mudstone grades into sandy and in places pebbly mudstone which contains poorly defined sandy streaks and thin sandstone interbeds. Interbeds of coarse-grained sandstone and pebble to cobble conglomerate are also present. The pebbles and cobbles are rounded, up to 15cm in diameter, and consist mainly of fine-grained sandstone, with some cobbles of vitric volcanics. The pebbles and cobbles are set in a sandy matrix.

The upper part of the unit consists dominantly of mudstone, which is generally finer than that in the lower part. It is blue grey when fresh, greenish grey when weathered, generally massive, slightly indurated, and crumbles into small pieces. Some is sandy, and contains ill-defined sandy bands and sandstone interbeds.

In places in the middle and upper parts of the section, mudstone and fine-grained to medium-grained sandstone are regularly interbedded in beds 5–8cm thick. These sections are identical to the Boomer Formation.

Detailed work at the type section by Fielding & others (1997b) established two alternating facies associations, A and B, containing nine facies. Association A consists dominantly of fine-grained clastics (Figure 22a). Siltstones contain scattered dropstones (lonestones) and concretions, *Planolites* burrows and body fossils of crinoids, bivalves and brachiopods (mostly intact and articulated). Sandstone beds are sharp-based, typically graded and display flat laminations and ripple cross-laminations in their upper parts. Plant debris is also abundant, ranging from macerated detritus to large stalks and branches. Bioturbation can be ascribed to the *Cruziana* ichnofacies.

Association B comprises a variety of conglomerate and diamictite (Figure 22b), with one distinctive, closely associated sandstone facies. The coarse-grained facies have either sand or silt matrix and are transitional into

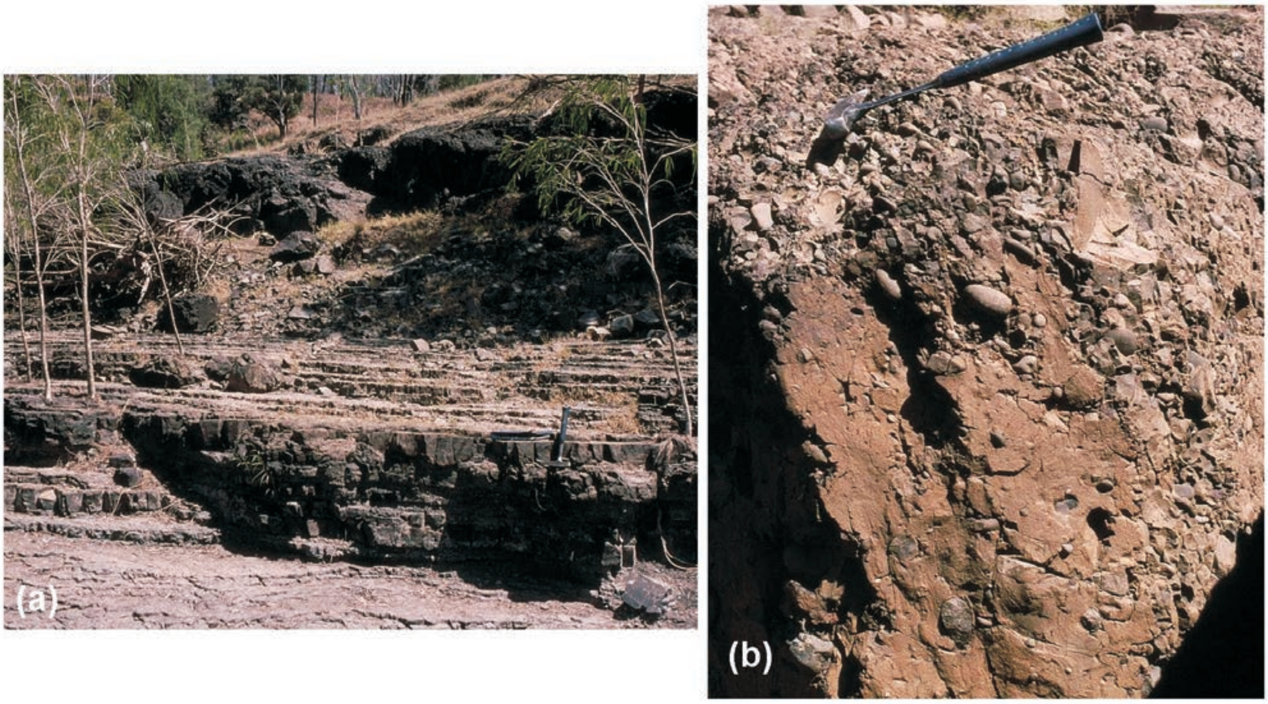

Figure 22. Moah Creek beds
(a) Thin-bedded mudstone and siltstone of Facies Association A. Fitzroy River downstream of the crossing of the road to Glenroy homestead at MGA 196000 7402557 (IWGN195)
(b) Diamictic conglomerate of Facies Association B consisting of well-rounded clasts of sandstone, chert, volcanic rocks and quartz in a muddy to silty matrix. Same locality as (a)

one another. They are clast to matrix-supported and in many beds these also grade laterally into one another. Two populations of clasts are evident: (1) well-rounded pebbles and cobbles of basement rock types (mainly sandstone, chert, volcanic rocks and quartz), and (2) angular to rounded pebbles, boulders and large rafts of internally coherent, intraformational sandstone and interbedded sandstone and siltstone. In some cases these allochthonous masses are folded into cylindrical forms and overturned slump folds. Plant debris is again abundant throughout the facies association in the finer-grained beds.

The conglomerate and diamictite correspond to the conglomerate described by Kirkegaard & others (1970) and are identical to those that crop out farther west in the undivided Back Creek Group (page 182). The range of clasts is similar to that in the Dinner Creek Conglomerate to the east.

Geophysical response

The Moah Creek beds generally give a moderate to high radiometric response from potassium, thorium, and uranium similar to that of the undivided Back Creek Group to the west. They also have a similar low magnetic response.

Environment of deposition

Fielding & others (1997b) interpreted the entire succession to have formed in a marine environment and stated that the sediments of Associations A and B of the Moah Creek beds exposed at the Fitzroy River crossing were deposited on a gently sloping submarine surface that became periodically unstable. They noted that Association A is typical of mid-Permian offshore marine shelf facies across the greater part of the Bowen Basin, with facies representing suspension fallout and current deposits. The preservation of articulated fossils and absence of any wave- or combined-flow-generated structures suggest a relatively quiet environment. Sharp-bounded sandstones were deposited by tractional currents that flowed westwards. Some of these currents may have been related to turbidity flows. Lonestones may have been introduced from floating ice. The accompanying Association B contains facies indicative of slide, slump or debris flow deposits, debris surge, or high-concentration turbidity flow, all interpreted to be products of an unstable, submarine slope. The relatively fine-grained succession of marine sediments is indicative of a period of passive, thermal subsidence, but the coarse-grained intervals reflect the onset of a foreland thrust loading event to the east, associated with the Hunter–Bowen Orogeny.

Relationships

The unit unconformably overlies the Rookwood Volcanics and is overlain by the Dinner Creek Conglomerate to the east. The Moah Creek beds appear to be equivalent to the undivided Back Creek Group and probably, at least in part, to the Boomer Formation. They are intruded by andesitic and trachytic dykes and sills.

Fossils and age

The upper part of the unit is sparsely fossiliferous in places. Several small *Atomodesma* (*Aphania*) sp. and rare poorly preserved "*Strophalosia"* were noted and collected by Kirkegaard & others (1970, appendix A). *Atomodesma* is restricted to Fauna IV of the Bowen Basin, and indicates an early late Permian age. Rare leaves of *Glossopteris* are also present.

STRATIGRAPHY OF THE NORTHERN PART OF THE YARROL PROVINCE (CAMPWYN AND STOODLEIGH SUBPROVINCES)

Malone & others (1969) mapped the rocks that crop out north of the Marlborough Block towards Charon Point as Carmila beds. However, the Carmila beds are now restricted to the belt of rocks that crops out relatively continuously mainly along the eastern flank of the Connors Arch. A 20km-wide belt of younger undivided Back Creek Group rocks separate the rocks north of Marlborough from the Carmila beds. It is likely that the boundary between the Back Creek Group and the units on Charons Peninsular is a thrust, although Cainozoic cover conceals it. Although the Carmila beds are lithologically diverse, there are some important lithological differences between them and the units north of Marlborough, and the latter are probably best regarded as part of the Yarrol Province.

The rocks in this area are assigned to four new units, the Late Devonian or early Carboniferous Tanderra Volcanics (including the Charon Point Rhyolite Member) and the late Carboniferous to early Permian Glenprairie beds and Wongrabry beds. The Tanderra Volcanics are equivalent in age to the Campwyn Volcanics that crop out intermittently along the coast and adjacent hinterland from about Sarina. They have been assigned to the Campwyn Subprovince of the Yarrol Province. The younger rocks are included in a new structural unit, the Stoodleigh Subprovince, but are probably equivalent to the Grantleigh Subprovince to the south of the Marlborough Block.

The rocks on the western side of Stanage Peninsular and nearby Long and Quail Islands were not examined during our survey, but were described by Leitch & others (1994). The rocks include a sequence of early Carboniferous volcaniclastic rocks interbedded with oolitic limestone, that Leitch & others assigned to the Campwyn Volcanics, but which we prefer to include in the Rockhampton Group. They are overlain by rocks assigned by Leitch & others (1994) and Malone & others (1969) to the Neerkol Formation. Following the revision of the Yarrol Province stratigraphy by the Yarrol Project Team (in preparation), this unit is now included in the Lorray Formation, and this name is adopted herein. Rocks on Quail Island, assigned by Leitch & others to the Youlambie Conglomerate, are herein assigned to the Wongrabry beds.

CAMPWYN VOLCANICS

Introduction

The Campwyn Volcanics form the northernmost part of the Yarrol Province to the east of the Connors Province and crop out in a narrow belt ~180km long, along the coast and for up to 10km inland, between the southern part of CARMILA (Figure 23) and Laguna Quays in CALEN to the north of the project area. The unit was originally recognised in the Mackay 1:250 000 Sheet area and named the Campwyn beds by Jensen & others (1966). Clarke & others (1971) described the unit farther north in the Proserpine Sheet area. The name was formalised to Campwyn Volcanics by Fergusson & others (1994), because the unit includes proximal volcanic rocks, including lavas and shallow intrusions, and the remainder was considered to be dominated by coarse-grained volcaniclastic rocks. This name was retained by later researchers (Bryan & others, 2003b, 2004a, b) and also by us, although we note that some sections are dominated by sedimentary rocks, albeit volcanic-derived, and the term 'formation' might be more appropriate.

The unit is well exposed on coastal headlands and some of the beaches along the coast, but inland it is mostly strongly weathered and poorly exposed. In the study area, the best exposures are between Yarrawonga Point

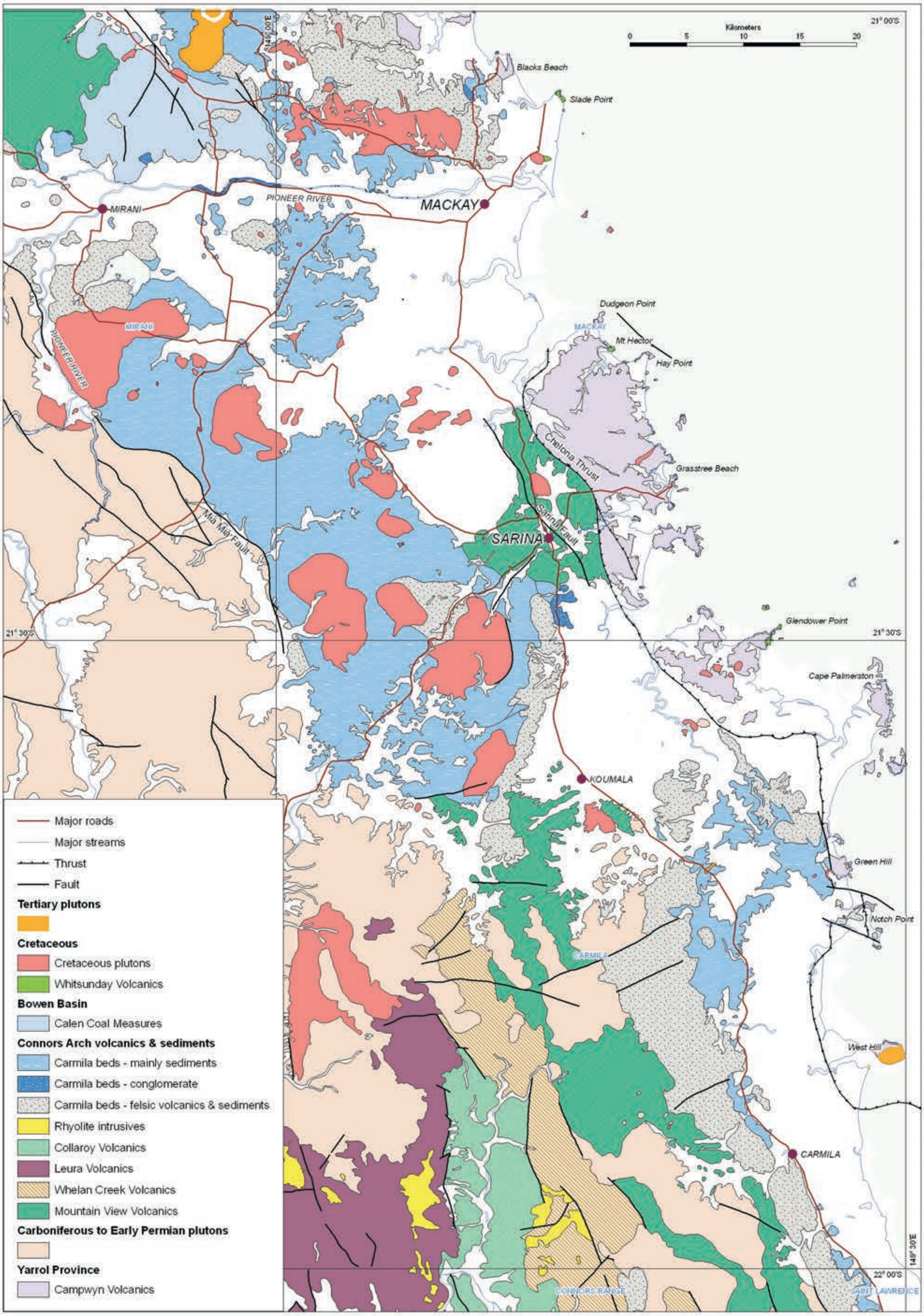

Figure 23. Geology of the Campwyn Subprovince and adjacent Connors Arch

and Dudgeon Point. The coastal section around Mackay mainly has outcrops of Cretaceous volcanic rocks and probably early Permian Carmila beds or Calen Coal Measures intruded by younger dykes, but Campwyn Volcanics again crop out farther north.

The two detailed studies of Fergusson & others (1994) and Bryan & others (2003b) have some points of agreement, but show significant differences in interpretation of the stratigraphy, facies architecture and even on the lithological makeup of the unit. They agreed that much of the Campwyn Volcanics has abundant coarse-grained volcaniclastic and volcanic rocks, along with siliceous sandstone, siltstone, mudstone, limestone and intrusive rocks. However, Fergusson & others (1994) recognised no sequential stratigraphic pattern to the assemblage, whereas Bryan & others (2003b) divided the rocks into a lower facies association of mafic volcanic affinity and an upper facies association of silicic affinity. One of the main issues appears to be that some of the outcrops of clastic rocks that Fergusson & others interpreted as mafic were regarded by Bryan & others as felsic and ignimbritic. These differences in rock assignment seem to be more marked in the northern part of the belt, beyond our project area. Other differences between the studies were the identification of coherent lavas *versus* syn-sedimentary intrusions, a strong variance between their palaeocurrent datasets, interpretation of the facies architecture and the significance of the biostratigraphic constraints. These differences were further debated by Henderson & Fergusson (2004) and Bryan & others (2004a).

Field work during our project was done partly by P.R. Blake, who examined outcrops south of Mackay prior to the work of Bryan & others. Without re-examining the entire belt and particularly outcrops where the observations and interpretations of the two groups of researchers are most at variance, it is difficult to present a critical appraisal of the geology as presented by the two groups. The discussion of the geology that follows concentrates on the southern part of the belt, from which Bryan & others presented detailed logs of five sections and where there appears to have been closer agreement between the protagonist in identification of rock-types, if not in facies interpretation. The lithological summary below is based on Bryan & others' descriptions of the rocks with additions from observations by GSQ geologists and those of Fergusson & others (1994) where appropriate.

Type area

Because they used the name informally, Jensen & others (1966) did not give a type section. Although Fergusson & others (1994) formalised the unit, they also did not nominate a type section because of the lack of a section containing the complete succession due to facies complexity, gentle dips, local structural complications and poor outcrop inland. However, they nominated a type area that contained a representation of the general character of the unit from Midge Point for ~9km northwards along the coast. This lies north of this project area

Lithology

Mafic facies association

Bryan & others (2003b) noted that the best sections through the mafic facies association are exposed in the southern part of the belt at Knobblers Point to Green Hill and Perpetua to Salisbury Point (around Sarina Inlet). The base of the section is not exposed, but they observed an upper contact with the silicic facies association. They suggested a minimum thickness of 1000m based on exposures from Knobblers Point to Green Hill.

At Knobblers Point at MGA 753380 7602610, rocks are representative of the mafic, volcanic-sourced, lithic sandstone/siltstone facies in the lower part of the mafic facies association, are exposed. About 100m of rhythmically-bedded, laminated siltstone and fine-grained sandstone to pebble conglomerate is exposed (Bryan & others, 2003b, figure 6) and forms part of a coarsening-upward trend through an interbedded sequence of siltstone, lithic sandstone and mafic volcanic-derived sedimentary breccias into a breccia-dominated sequence at Green Hill. The sandstone compositions are dominated by mafic volcanic rock fragments with only minor feldspar and no quartz.

At Green Hill, the mafic facies are dominated by coarse-grained volcaniclastic rocks. In a section illustrated by Bryan & others (2003b, figure 4) at MGA 753920 7600340, the lower 25m consists of dark brown to grey, massive, poorly sorted polymict mafic volcanic-derived, pebble to cobble sedimentary breccia, which Bryan & others (2003b) noted is the most widespread facies of their mafic association. Clasts are angular to subangular, mafic to intermediate volcanic rocks that range from being dense to scoriaceous, devitrified to formerly glassy and aphyric to plagioclase ± pyroxene-phyric. The beds range from matrix to clast-supported. At Green Hill, the sedimentary breccia is overlain by ~35m of clast-supported, mafic hyaloclastite breccia that consists of aphyric lava fragments mostly up to 6cm and less commonly to 50cm. Above this in the succession is a 10m-wide syn-sedimentary andesite sill that has peperitic margins and intrudes texturally mature lithic

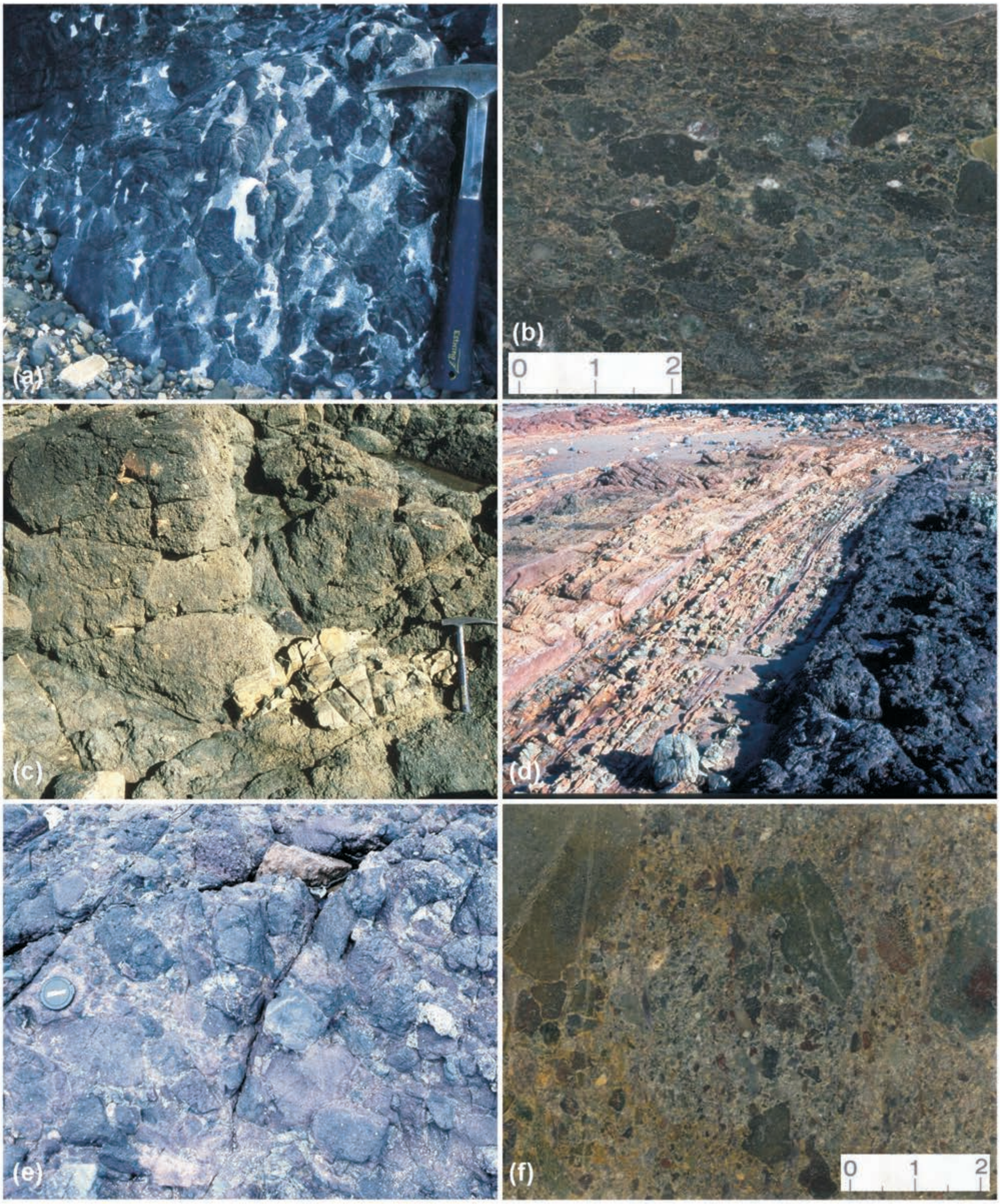

Figure 24. Campwyn Volcanics mafic facies association
(a) Basaltic hyaloclastite. At “Walter Reid” ~2km north of Notch Point at MGA 755786 7596910 (PBCO006)
(b) Scanned slab of poorly sorted monomict aphyric basaltic breccia or pebbly volcaniclastic sandstone of the mafic facies association. Clasts are angular and probably largely of pyroclastic origin with little reworking. 7.5km north-west of Grasstree Beach at MGA 733739 7641236 (QFG3627). Scale is 2cm.
(c) Poorly sorted conglomerate consisting largely of mafic volcanic rocks as well as a large rip-up clast of siltstone. Yarrawonga Point at MGA 756484 7593515 (PBCO001)
(d) Mafic volcanic conglomerate, sharply overlain by thin-bedded siltstone and chert. Pavement west of Cape Palmerston at MGA 756864 7616698 (BB3304)
(e) Detail of poorly sorted mafic volcanic conglomerate in (d), consisting of massive to amygdaloidal andesite or basalt.
(f) Scanned slab of pebbly volcaniclastic sandstone containing angular clasts of mafic volcanics and some felsic detritus. Interbedded with the felsic volcaniclastic sandstone shown in (Figure 25b) suggesting interfingering of the mafic and felsic facies associations. East side of Dudgeon Point at MGA 734202 7648868 (QFG3638). Scale is 2cm.

sandstone and pebble conglomerate. The uppermost part of the mafic association in this section is 10m of maroon, planar-stratified, monomict, pebbly sandstone comprising dense to vesicular basaltic clasts. Bryan & others interpreted it as a phreatomagmatic surge deposit. It is overlain by rocks of their silicic facies association.

At Salisbury Point in Sarina Inlet at about MGA 738600 7632000, the upper part of the mafic facies association contains a thick section (~100m) of amygdaloidal basalt lava and monomict breccia. At the lower contact, the basaltic lava and breccia cut down into mafic volcanic-derived sandstone and sedimentary breccia, which locally shows soft-sediment and loading structures at the contact. The coherent lavas form laterally continuous sheets up to 6m thick and discontinuous bodies up to 5m long in breccia zones. The sheets tend to have dense, less vesicular interiors. The contacts with the breccia are sharp, but irregular and commonly reddened. The breccias are clast-supported aggregates of angular, variably vesicular basalt fragments. The top of the interval is reddened and overlain by a thin conglomerate and welded rhyolitic ignimbrite. The absence of pillow structures and jigsaw-fit textures in the lavas and the breccias, together with the common reddening and nature of the overlying succession was interpreted by Bryan & others (2003b) as indicating subaerial emplacement, and they suggested that the breccia was analogous to aa-type lava flows.

At Perpetua Point in Sarina Inlet, Bryan & others (2003b, figure 8) described another section ~300m thick that illustrated an overall coarsening upward succession from mafic volcanic-derived sandstone and conglomerate into sedimentary breccia. Within the section were two 10–15m zones of peperite breccia that are entirely brecciated and consist of plagioclase-phyric basaltic clasts with some sedimentary material in interstices. At the top of the section are two intervals of breccia that contain abundant dark green, angular to attenuated, fluidal-shaped mafic clasts. They are interbedded with massive to bedded lithofeldspathic sandstone. Similar rocks occur at Green Hill and Campwyn Beach. Bryan & others (2003b) argued that the contorted to folded and highly attenuated nature of the clasts suggests that they were hot and plastic during deposition, but that they were likely to have been deposited subaqueously, perhaps related to phreatomagmatic eruptions. Fergusson & others (1994) described a thick interval of breccia, which they interpreted to have formed in a Strombolian-style eruption, from Dewars Beach. It may be of the same type as the fluidal breccia described by Bryan & others (2003b).

Similar rocks to some of those described above are illustrated in Figure 24 from sites visited during this project.

Silicic facies association

The silicic facies association includes a variety of clastic rocks, including ignimbrite and accretionary lapilli tuff and sandstone-dominated sedimentary facies, and possibly some rare syn-sedimentary intrusions. Bryan & others (2003b) regarded this facies association as forming the upper part of the Campwyn Volcanics and suggested a minimum thickness of 1km.

Epiclastic crystal-rich sandstone occurs throughout the silicic facies association and in the project area forms considerable thicknesses at Dudgeon Point and Green Hill. It contains abundant volcanic quartz and feldspar, contrasting with the mafic lithic-dominated sandstone in the mafic facies association. The coarser sandstones, which are commonly interbedded with ignimbrite, have tabular to trough cross-bedding, whereas planar to ripple cross-laminae occur in the finer sandstone.

Fergusson & others (1994) described restricted occurrences of ignimbrite, but Bryan & others (2003b) considered them to be much more widespread. They observed that ignimbrite occurs towards the base of their upper silicic facies association, in some places actually defining the contact between the two facies associations, such as in the Sarina Inlet area. According to Bryan & others, the ignimbrites range from crystal-poor to crystal-rich with fragments of K-feldspar, plagioclase and quartz. Mafic minerals are rare. Units are moderately to densely welded and eutaxitic textures defined by attenuated pumice are common, although shards and vitroclastic textures are poorly preserved because of pervasive low-grade alteration and cleavage development. Individual units range from 5 to ~30m thick and in places form stacked sequences up to 200m thick. Lithic clasts are concentrated towards the bases of flows and pumice towards the top. A possible ignimbrite from north-west of Grasstree Beach is illustrated in Figure 25a.

Accretionary lapilli tuffs occur at the base of some ignimbrite units, notably at Green Hill. They contain angular fine-grained fragments of quartz and feldspar and minor rock fragments but are notably ash-rich.

Rocks at Cape Palmerston were also assigned to the silicic facies association by Bryan & others (2003b). The bulk of the section there consists of rhythmically interbedded, siliceous very fine-grained sandstone and cherty siltstone (Figure 25d). The beds are thin to medium, laterally continuous, massive to weakly laminated and locally have convolute bedding, loading and de-watering structures. The sandy beds rarely have ripple

Figure 25. Campwyn Volcanics felsic facies association
(a) Scanned slab of feldspar-phyric crystal-rich, moderately lithic-rich rhyolitic ignimbrite(?) of the felsic facies association. 6.3km north-west of Grasstree Beach at MGA 734178 7639603 (QFG4632). Scale in (a) and (b) is 2cm.
(b) Scanned slab of well-sorted volcaniclastic sandstone consisting mainly of feldspar and felsic lithic clasts of the felsic facies association. East side of Dudgeon Point at MGA 734202 7648868 (QFG3638)
(c) Coarse-grained volcanolithic sandstone bed showing grading. Cape Palmerston at MGA 757207 7616815
(d) Rhythmically interbedded, siliceous, very fine-grained sandstone and cherty siltstone. Same locality as (c) (PBCO035)
(e) Poorly-sorted matrix-supported conglomerate containing clasts of silicic volcanic rocks and large bedding-parallel rip-up clasts of the underlying thin-bedded facies. Cape Palmerston at MGA 756805 7616822 (PBCO036)

cross-laminated tops. Quartz (some with embayed faces) and rare feldspar grains to 0.5mm occur in a microcrystalline siliceous matrix. Fergusson & others (1994) and Blake (personal communication, 2000) have reported radiolarians from these rocks.

Interbedded with the rhythmically bedded sandstone and siltstone at Cape Palmerston are intervals of conglomerate up to 40m thick. The rocks are matrix supported and contain clasts of silicic lava and ignimbrite and quartz-feldspar-phyric pumice, locally more than 1m across. The sandy matrix consists of volcanic quartz, feldspar and volcanic lithic clasts. The beds have erosional bases and contain large bedding-parallel rip-up clasts or rafts up to 2m long of the underlying thin-bedded facies (Figure 25e). Some of the thinner intervals show grading into crystal-rich sandstone tops. Bryan & others (2003b) also noted the occurrence of a black, dacitic, peperitic intrusive within the section.

Limestone is interbedded locally with the silicic facies association. North of the project area, oolitic and bioclastic limestones are common, but in the south limestone is rarer and not oolitic. However, Fergusson & others (1994) noted the presence of micritic limestone at Allom Point and a 70m thick interval of similar limestone with sandstone interbeds at Glendower Point. Bryan & others (2003b) referred to fossiliferous limestone directly overlying ignimbrite along the Notch Point Road at MGA 753880 7595870.

Although most of the sandstone in the unit is of volcanic origin, quartzose sandstone of cratonic derivation was noted by Fergusson & others (1994) at Lamberts Beach near Mackay. Quartzose sandstone was also observed during this project as screens between dolerite dykes at the northern end of Blacks Beach. Bryan & others (2003b, 2004a) also discussed the anomalous sandstone at Lamberts Beach and noted that such compositions are more characteristic of Permian sandstones from the Bowen Basin. Given that the ignimbrite at Slade Point, which lies between these two occurrences, is now known to be Cretaceous, it is possible that the quartzose sandstone outcrops are also younger and not part of the Campwyn Volcanics. They may be outliers of the Calen Coal Measures.

Geophysical response

The Campwyn Volcanics have a variable low to moderate magnetic response with locally prominent linear magnetic features alternating with areas of low response. Although some of these linear magnetic features may be younger Permian or Cretaceous dykes, some are arcuate in outline and may represent stratigraphic units within the Campwyn Volcanics such as mafic flows. The variability contrasts with the Carmila beds to the west, which are generally uniformly low, and also with the basaltic parts of the Mountain View Volcanics which are uniformly moderate to high in response. In Sarina and Carmila areas, the contact between the Campwyn Volcanics and these units is relatively sharply defined in the magnetic data, but farther north near Mackay, the overprinting of Cretaceous intrusions has obscured the boundary.

Magnetic susceptibility readings taken from the Campwyn Volcanics are overwhelmingly <100 x 10^{-5} SI units. However, sporadic higher readings at some localities that range up to 4000 x 10^{-5} SI units may account for some of the linear features in the unit.

In the radiometric data, most of the inland outcrop area in the Sarina-Grasstree area may be part of the silicic facies association, because the responses although relatively low are higher than might be expected from a dominantly basaltic composition and have abundant patches of pinkish to pale bluish grey hues on the composite images we used. No bipartite subdivision is obvious, suggesting that the mafic facies association may mostly lie offshore.

Environment of deposition

One of the key elements of the volcanic architecture put forward by Fergusson & others (1994) was that the entire Campwyn succession was dominated by proximal basaltic to andesitic volcanism on a shallow marine shelf on which emergent volcanic edifices with a variety of related facies association developed. Silicic volcanism, although minor, occurred throughout the history of the basin but the silicic volcanic-bearing sedimentary breccias and epiclastic sandstones as well as the few ignimbrites were sourced distally from a supra-subduction zone arc to the west in the Connors Arch.

While Bryan & others (2003b) agreed broadly with Fergusson & others (1994) that the rocks were deposited mainly in a shallow marine environment, they disagreed in detail with many of the interpretations of the facies associations. They also interpreted the silicic facies association as being much more abundant than was recognised by Fergusson & others (1994) and that it was entirely younger than the mafic facies association.

The presence of both mafic and felsic-derived sandstones at Dudgeon Point (Figure 24f and 25b) indicates that at least locally the two facies intercalated, although this may be a transition zone

Bryan & others (2003b) interpreted the mafic facies association as representing mostly submarine, mafic extrusive volcanism and shallow intrusions, and that there were no large volcanic edifices. Mafic volcanism was largely effusive, producing hyaloclastic breccias, but some mafic phreatomagmatic activity may have occurred locally. The lack of sedimentary structures and fossils provides few constraints on water depth and depositional environment, but shallow water conditions were interpreted to have prevailed for the most part. In places towards the closing stages of the association, some of the lavas and breccias may have been deposited subaerially.

The contact with the silicic facies association was inferred to record a change from predominantly subaqueous emplacement to widespread subaerial deposition with silicic volcanism producing welded ignimbrites accompanied by or alternating with sand-dominated deposition. The dominance of sand reflects the abundance of sand-grade material generated by the felsic volcanism. Phreatomagmatic eruptive phases recorded by the presence of accretionary tuffs were also common suggesting that vents interacted with surface water, either in caldera lakes or seawater. Bryan & others interpreted fluvial and hyperconcentrated flood-flow lithofacies for some of the sandstones interbedded with the ignimbrites, but others interbedded with crystal-rich volcanic breccias were thought to be deposited in shallow marine environments, the breccias representing pyroclastic flows that entered the sea. Hummocky cross-bedding that is locally present indicates deposition above storm wave base. Fossiliferous limestone associated with the silicic facies association also indicates shallow marine environments, especially north of the project area, where oolitic limestones are common and were deposited on tidally influenced ooid shoals.

However, some rocks of the silicic association may have been deposited in deeper marine conditions. The rhythmically bedded sequence at Cape Palmerston was interpreted by Fergusson & others (1994) to have been deposited in deep water facies, at least below storm wave base. The poorly preserved radiolarians in this facies were considered by them to indicate an offshore environment and could be related to blooms promoted by submarine volcanic activity. Bryan & others (2003b) considered that there was little evidence for this, but agreed that the rocks indicate low-energy, suspension-dominated sedimentation conditions with some current activity indicated by erosive bases, normal grading and rare ripple cross-laminated tops in some beds. Nevertheless, Bryan & others (2004a) argued that the presence of radiolarian and Bouma sequences are not necessarily evidence for deep water. Radiolarians are pelagic organisms and Bouma sequences have been recorded in all water depths (*e.g.* Nelson, 1982). Bryan & others (2003b) suggested that the breccia units interbedded with the rhythmically bedded sequence were syn-eruptive and emplaced by high-concentration gravity flows related to subaqueous silicic eruptions. Some of the cherty siltstones could be resedimented pyroclastic vitric ash.

Palaeocurrent measurements presented by Bryan & others (2003b) suggest that the dominant transport directions were to the north-west, particularly for the sandstone in the silicic facies association. They used this transport direction, apparently towards rather than away from the supposed arc represented by the Connors Arch, as further evidence to support their tectonic model of the Yarrol Province as having formed in a back-arc rather than a fore-arc setting in the Late Devonian to early Carboniferous. The current direction can probably be better described as being parallel to the postulated arc rather than towards it. The back-arc tectonic model was originally put forward by Bryan & others (2001) and vigorously debated by Murray & others (2003) and Bryan & others (2003a). Subsequently Murray & Blake (2005) provided definitive geochemical evidence against the model.

Geochemistry

Eight samples from the Campwyn Volcanics were analysed for a range of major and trace elements. In addition, ten analyses from Bryan & others (2003a, table 2) were also included in the database. The samples included mafic lavas (in peperite and hyaloclastite) as well as a range of volcaniclastic rocks including sandstone and ignimbrite. Peperite and hyaloclastite from the mafic facies association lavas plot as basaltic trachyandesite to trachyandesite and dacite in the total alkalis-silica (TAS) plot (Figure 26a). Peperite samples from the felsic facies association are more siliceous and plot as dacite and trachyte. The ignimbrite samples all plot as rhyolites, based on their SiO_2 content, whereas the other clastic rocks plot mainly in basaltic to andesitic fields.

However, all of the samples are altered, particularly the lavas, which average 4% loss-on-ignition (LOI), with the ‘dacite’ from the mafic facies association containing almost 11% LOI. Comparison of the TAS plot with the plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) in Figure 26b suggests that many of the rocks may be silicified. Because it uses immobile elements, this plot provides a method of classifying the original composition of altered volcanic rocks. It suggests that the dacite and trachyte peperites may be altered basalt or andesite, and even the ignimbrites plot in the andesite field, suggesting that the felsic facies association may not be as felsic as supposed by Bryan & others (2003a).

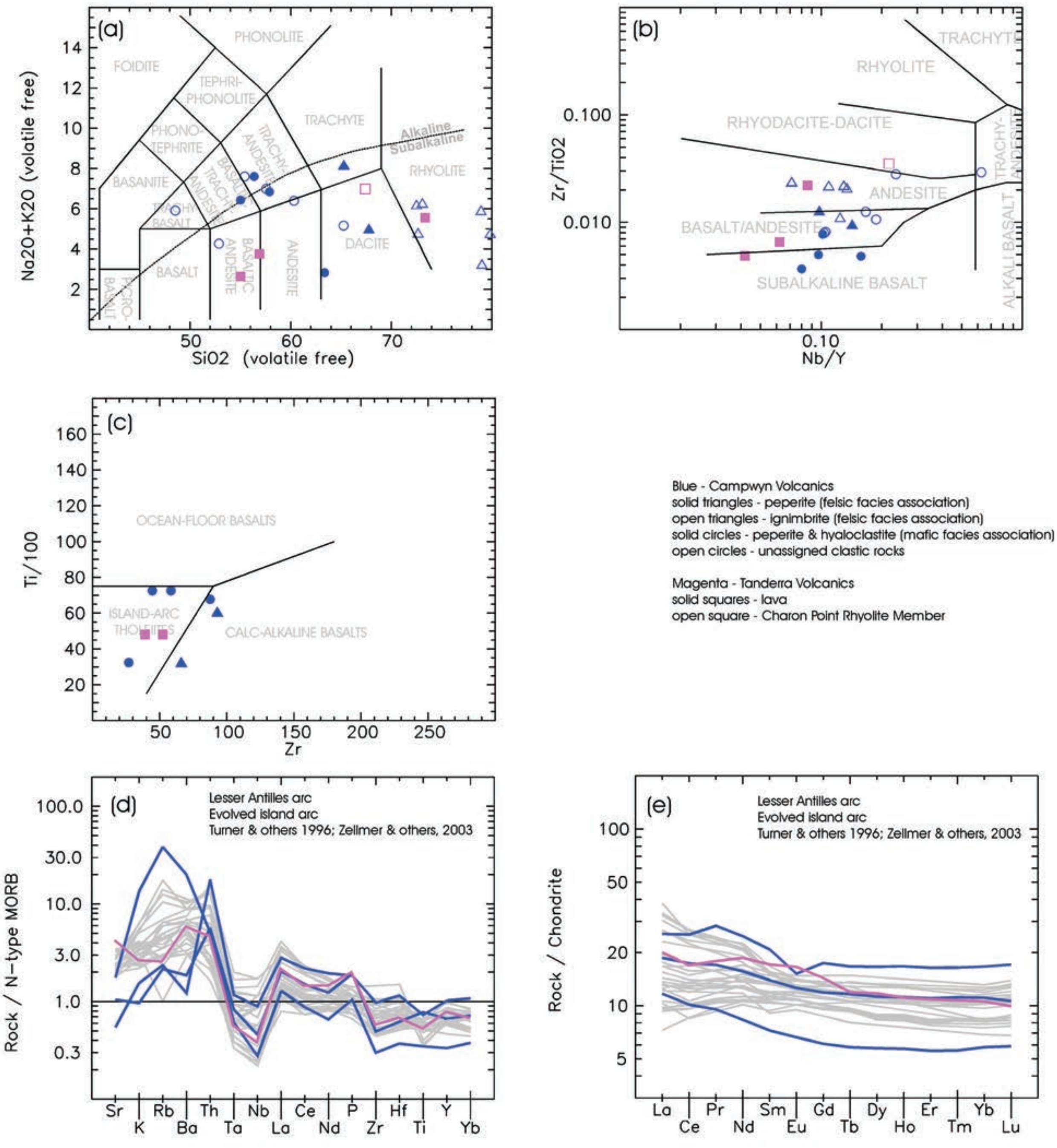

Figure 26. Geochemistry of the Devonian Campwyn Volcanics (blue) and Tanderra Volcanics (magenta):
(a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986) and Irvine & Baragar (1971);
(b) Nb/Y vs Zr/TiO_2 showing the fields of Winchester & Floyd (1977);
(c) Zr vs Ti/100 in ppm for basaltic andesite samples showing the fields of Garcia (1978);
(d) N-MORB normalised multi-element plot (using values from Pearce, 1983) for basaltic samples;
(e) chondrite-normalised REE plot (using values from Sun & McDonough, 1989) for basalt samples. For comparison, basalts from a modern evolved island arc, the Lesser Antilles Arc, are shown in grey.

Mafic lava samples are plotted in Figure 26c using the Ti-Zr discrimination diagram of Garcia (1978). Like the lavas from the Tanderra Volcanics, the lavas from the mafic facies association plot in the field of island-arc tholeiites and the two lavas from the supposed felsic facies association plot just within the field of calc-alkaline basalts.

The samples of Bryan & others (2003a) were analysed for trace and rare-earth elements (REE) by Inductively Coupled Plasma Mass Spectrometry. The data for the three basalt to andesite samples (based on their silica content) have been used to construct the multi-element and REE plots in Figure 26d–e, and Figure 27. In these plots the Campwyn Volcanics are compared with analyses from the Tanderra Volcanics and other

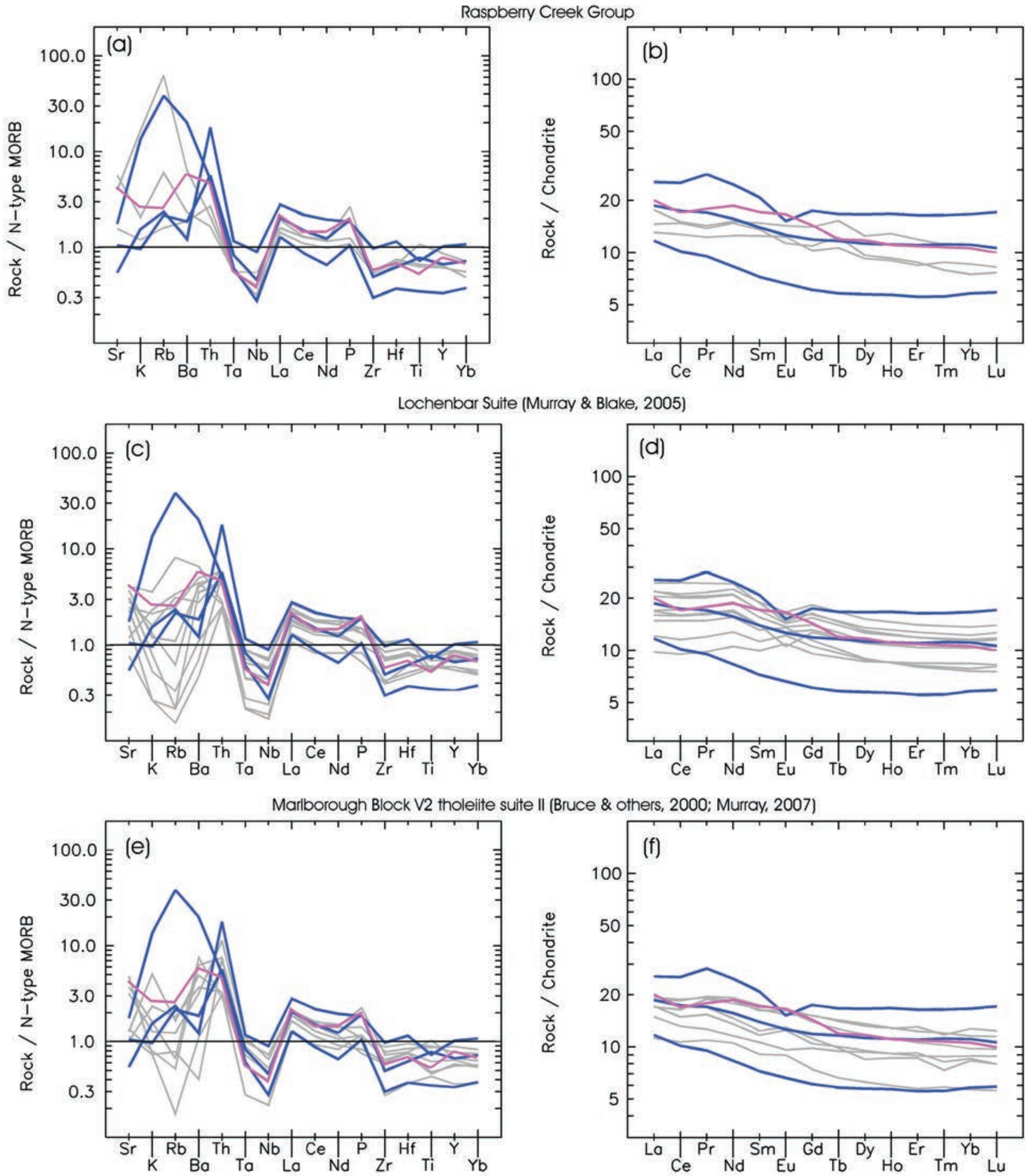

Figure 27. Multi-element plots of basalt or basaltic andesite samples from the Devonian Campwyn Volcanics (blue) and Tanderra Volcanics (magenta) - for comparison, patterns of Devonian basaltic suites from the farther south in the Yarrol Province and Marlborough Block as indicated are shown in grey: (a, c, e and g) N-MORB normalised multi-element plots (using values from Pearce, 1983); (b, d, f and h) chondrite-normalised REE plots (using values from Sun & McDonough, 1989).

Devonian suites in the Yarrol Province and Marlborough Block as well as modern basalts from the Lesser Antilles island arc.

The Campwyn Volcanics have a relatively shallow REE pattern and in the multi-elements plot show slight depletion or mild enrichment relative to MORB of high-field-strength elements producing an overall shallow slope. Both the REE and multi-element patterns are consistent with having formed under thin, probably oceanic crust. The pronounced Ta-Nb trough indicates a strong subduction component.

The Tanderra Volcanics sample falls within the range shown by the Campwyn Volcanics, which also show broad similarities to basalts from the Middle Devonian Raspberry Creek Formation and Lochenbar Suite of

Murray & Blake (2005) in the multi-element plot (Figure 27). These suites are all volcanic arc tholeiites or are transitional with calc-alkaline basalts. They are also similar to the Late Devonian tholeiitic basalt dykes from the Marlborough Block (Bruce & others, 2000; Murray, 2007).

In the REE diagram, the Campwyn Volcanics show a spread of values, although the patterns for the three of the samples are roughly parallel and have a similar overall slope to the Devonian suites. Like some of the Lochenbar suite samples, one sample from the Campwyn Volcanics has an Eu anomaly suggesting that plagioclase fractionation has occurred.

The similarity of the Campwyn Volcanics and Tanderra Volcanic to the other Devonian suites suggests that the rocks formed in a similar intra-oceanic tectonic setting. Murray & Blake (2005) compared basaltic rocks from the Lochenbar Formation with various suites, and concluded that they show most similarities to rocks of evolved oceanic arcs, such as the Lesser Antilles, Marianas, Vanuatu and the Aleutians. They further concluded that the Late Devonian rocks represent a transition from an intra-oceanic to continental-margin arc. Comparisons in Figure 26d–e show the similarities between the Campwyn Volcanics and basalts from the Lesser Antilles island arc. The felsic facies association, if they are indeed the upper part of the Campwyn Volcanics, may reflect this transition to a continental margin arc in the early Carboniferous.

Relationships

Bryan & others (2003b) maintained that there were stratigraphically separate lower mafic and upper silicic facies associations and that the silicic association was much more abundant than had been recognised by Fergusson & others (1994). Henderson & Fergusson (2004) appear to have accepted that the two associations could be placed in such a stratigraphic context in the Green Hill area, but elsewhere they maintained the view that the two units were mixed together as facies variants and that they had no stratigraphic significance. Bryan & others (2004a) countered by citing evidence from sandstone petrography, that no examples of a mixed mafic-silicic provenance had been observed. Sandstones in the mafic association are devoid of quartz, even when close to the facies transition contact. They also cited the long-recognised observation that thick sequences of Late Devonian mafic volcanic and volcaniclastic rocks overlain by more silicic ones of early Carboniferous age are a regional feature of the Yarrol and Tamworth Provinces. Consequently they stated that it should not be surprising that the same compositional change should be present in the coeval Campwyn Volcanics. While this view is supported, mapping the two units regionally would be extremely difficult, given the poor outcrop inland and the possibility of multiple thrust repetition.

Along their western margin, the Campwyn Volcanics are interpreted to be faulted against the inferred early Carboniferous Mountain View Volcanics and the early Permian Carmila beds. The contact is interpreted as a thrust, at least in the Sarina–Carmila area. Between Green Hill and Cape Palmerston, the Campwyn beds are steeply dipping to overturned and are juxtaposed against subhorizontal Carmila beds. Bryan & others (2003b) suggested that this observed geometry was most consistent with a major thrust ramp or a synclinal break-through fault associated with a major east-dipping blind thrust. On CARMILA, it is interpreted as a thrust, herein named the Chelona Thrust, and it continues farther north where the Campwyn Volcanics are mapped against the Mountain View Volcanics on the basis of magnetic interpretation. Bryan & others (2003b) suggested that the contact may correspond with the Sarina Fault as mapped by Jensen & others (1966), but the latter appears to lie entirely within the magnetically defined Mountain View Volcanics. Farther north Bryan & others (2003b) suggested that the thrust may step out to the east along the Pioneer Lineament which they postulated as a tear fault. Farther north, the Campwyn Formation would then lie on the footwall of the thrust and might be simply unconformably overlain by the Carmila beds. Currently available structural data cannot confirm this one way or the other.

The Campwyn Volcanics are intruded by swarms of mafic dykes ranging from dolerite to microdiorite as well as small stocks. These probably include both Permian and Cretaceous rocks. Bryan & others (2004b) dated two dykes, one at Half Tide Beach in this project area and the other at Midge Point. Both gave early Permian ages of ~275Ma.

Fossils and age

Fossil localities in the Campwyn Volcanics were documented by Jensen & others (1966) and Dear *in* Clarke & others (1971). Fergusson & others (1994, figure 1) referred to additional sites but did not document any details about them. Most of the localities are from the limestone-rich units and contain a variety of fossils, including crinoids, brachiopods, rugose corals and gastropods, as well as some *Lepidodendron* sp. from sandstones. The fossils largely confirm an early Carboniferous age for the limestone-bearing parts of the Campwyn Volcanics, although some Late Devonian marine fossils were reported by Dear *in* Clarke & others (1971). According to Jensen & others (1966) the youngest age is mid-Tournaisian but farther north where the shallow marine rocks are supposedly overlain by terrestrial deposits, the youngest marine deposits are late

Tournaisian (Dear *in* Clarke & others, 1971). The Edgecumbe beds, which may be a continuation of the succession in the Proserpine 1:250 000 Sheet area probably range into the Visean.

Middle Devonian fossils have been reported from the Campwyn Volcanics but their significance and even the age ascribed to them is controversial (Henderson & Fergusson, 2004; Bryan & others, 2004a). In the project area at Campwyn Beach, Middle Devonian fossils have been recognised as clasts within mafic volcanic-derived sandstone. The age appears to have been based on a single stromatoporoid recorded at the locality by Whitehouse & Reid (1939), whereas according to Bryan & others (2004a), coral bioclasts collected by them did not permit differentiation between a Middle or Late Devonian age. In any case, Bryan & others (2003b, 2004a) argued that the fossils may have been reworked and indicate only a maximum age for the unit, a point that Henderson & Fergusson (2004) could not accept. Bryan & others (2004a) pointed out that allocthonous late Early and early Middle Devonian limestone blocks are reported from the base of the Late Devonian units in the Yarrol Province farther south (Yarrol Project Team, 1997; Blake & others, 1998), although it should be noted that these are in blocks rather than as individual fossils. Therefore until further work is done, the Middle Devonian age should be regarded as somewhat uncertain.

Bryan & others (2004b) reported U-Pb ages for silicic volcanic rocks from the Campwyn Volcanics, based on analysis of zircons by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). They also analysed zircons from coeval units in the Yarrol Province farther south (Mount Alma Formation and Rockhampton Group). Samples of ignimbrite from the Campwyn Volcanics included two from the basal part of their silicic facies association at Green Hill and Salisbury Point. The work was not able to constrain the age of the boundary between the facies associations precisely because of subtle inheritance and/or Pb-loss that resulted in a considerable spread of ages that gave unacceptably high MSWD values and so may contain more than one population. The mean ages obtained were 364.3±7.2Ma and 373.6±2.9Ma respectively. Another sample analysed from Point Victor, north of Sarina Inlet was of a subaqueously emplaced pyroclastic breccia. It produced an age of 367±2.8Ma (MSWD 1.49) but also had a small population of analyses giving an age of 348±2.8Ma (MSWD 0.82) of uncertain significance. The authors concluded that the main groups of ages obtained from the three samples were likely to be maximum ages for the ignimbrite emplacement. These ages are Frasnian to Famennian on the ISC Timescale (Gradstein & others, 2004).

Zircons from a rhyolitic ignimbrite from Inner Redcliffe Island, north of this project area, defined a single population with an age of 354.7±3.3Ma (MSWD 1.61, based on 14 analyses). Another from Laguna Quays gave a similar age 354.3±4.1Ma, but with significantly more scatter (MSWD 2.83, based on 22 analyses). These are Tournaisian on the ISC timescale.

The ages obtained for ignimbrites from the Mount Alma Formation (361.1±5.2Ma) and Rockhampton Group (350.9±2.7Ma) correspond with the two populations from the Campwyn Volcanics and support a general correlation between the Campwyn Volcanics and these two units. The younger age also corresponds with the SHRIMP age obtained by us on the Charon Point Rhyolite Member (352±5Ma). The mafic facies association may correlate better with the Three Moon Conglomerate, which contains basalts, unlike the Mount Alma Formation.

In summary the evidence indicates that the Campwyn Volcanics are Late Devonian to early Carboniferous although parts of the mafic facies association may extend back to the Middle Devonian.

TANDERRA VOLCANICS

Introduction

The Tanderra Volcanics crop out in three main areas interpreted as anticlinal cores in the northern part of the peninsular between Tanderra homestead (from which the unit takes its name) and Charon Point (Figure 28). The airborne magnetic data indicate that the rocks extend northwards under Broad Sound. Some smaller areas of deformed mafic volcanic rocks near Glenprairie homestead and south-west of Bald Hills homestead are also assigned to the unit.

The Tanderra Volcanics form low hills and have reddish brown soil. On the composite radiometric images, they are characterised by dark grey to purple hues consistent with their mafic composition. They also have a strong magnetic response that contrasts with that of the surrounding units.

Type area

Because the base is not exposed, a complete section cannot be given for the unit. However, a type section for the uppermost part is designated along a fenceline from MGA 790200 7512960 to 791145 7512940 (the base

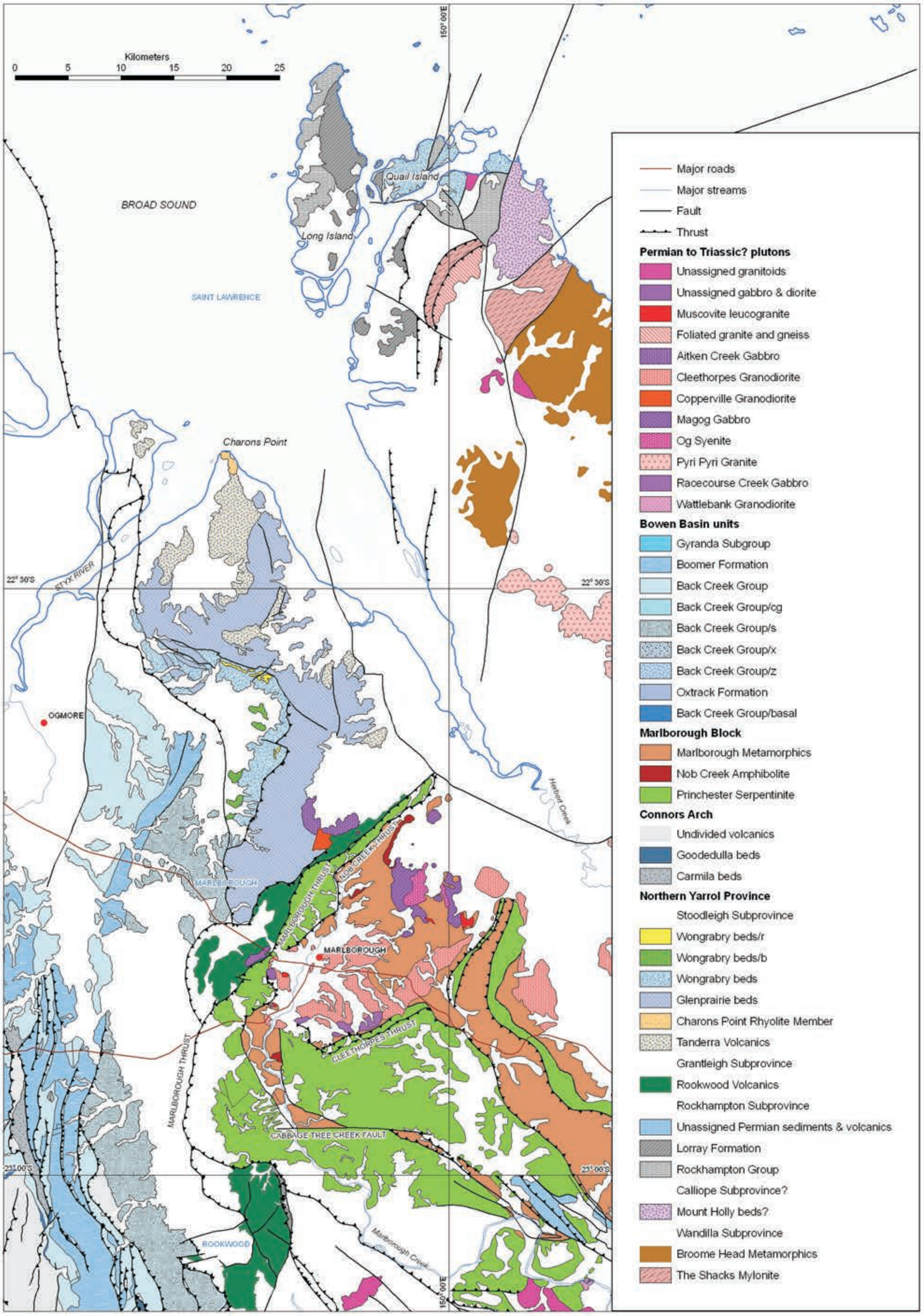

Figure 28. Geology of the Marlborough–Broad Sound area

of the type section for the Glenprairie beds). The section consists of porphyritic andesite or basalt and volcaniclastic sandstone and conglomerate.

Lithology

The Tanderra Volcanics consist mainly of andesitic or basaltic lavas and volcaniclastic sedimentary rocks and generally minor felsic rocks apart from a major development of rhyolitic ignimbrite at Charon Point. The latter is described separately as the Charon Point Rhyolite member.

The andesitic or basaltic lavas range from aphyric to porphyritic and are locally amygdaloidal. The phenocrysts are mostly plagioclase and in some rocks are partly replaced by saussurite or zeolite. In the groundmass the laths range from randomly orientated to strongly flow-aligned. Clinopyroxene is interstitial to plagioclase in the groundmass, but also forms euhedral phenocrysts and glomeroporphyritic aggregates in some rocks. Chlorite is generally present in the groundmass of most rocks and is probably derived from clinopyroxene. Other constituents include magnetite and titanite after ilmenite. Fine-grained zeolite, chlorite, epidote, calcite or quartz fills the generally sparse amygdales.

Mafic volcaniclastic rocks form a major proportion of outcrop within the Tanderra Volcanics. They are mostly poorly sorted and range from medium to very coarse-grained sandstone to matrix-supported to clast-supported pebble conglomerate or breccia, but some moderately to well sorted sandstone and granule conglomerate beds occur locally. The rocks are very thick-bedded and generally massive, although the better-sorted sandstones have some internal stratification, mainly horizontal planar laminae. The lithic clasts are exclusively angular to subangular, aphyric to porphyritic andesite or basalt. Plagioclase crystal fragments occur in the sandstone and in the matrix to the conglomerates and breccia. The poorly sorted sandstones have a silty matrix.

Thick-bedded siltstone and mudstone were observed locally, but are not common in outcrop. However, their apparent rarity could be a function of the relatively poor outcrop in many areas.

Apart from the Charon Point Rhyolite Member, felsic rocks are not common. However, a pale grey, relatively felsic lava at MGA 789700 7518090 contains plagioclase phenocrysts in a groundmass dominated by small spherulites ~0.25mm in diameter. A rhyolitic tuff or possible ignimbrite crops out at MGA 789750 7515600 and contains feldspar crystal fragments and elongate felsic lithic clasts in an aphanitic groundmass.

Deformed and slightly metamorphosed mafic rocks at Glenprairie homestead and to the north are tentatively assigned to the Tanderra Volcanics, and are interpreted as anticlinal cores. They mostly have a foliation defined by anastomosing fractures, but are otherwise unbedded or massive. Because of the metamorphic overprint, it is difficult to determine in outcrop or even in thin section whether the rocks are lavas or volcaniclastic sandstone. However, outlines of pebble or cobble-sized clasts can be observed in places indicating that some clastic rocks are present. In thin section, the rocks contain single laths and clusters of partly saussuritised plagioclase and rare relict clinopyroxene in a matrix of saussuritised plagioclase, chlorite, titanite and scattered epidote. Some areas do not have the typical high magnetic response of the main areas of Tanderra Volcanics, but this could be due to alteration and magnetite destruction associated with the deformation and metamorphism.

Geophysical response

The main area of Tanderra Volcanics has a low radiometric response in all three channels, and is almost black on composite images. Small patches of higher response in the three channels and pale pinkish composite hues are probably due to the small areas of felsic volcanic rocks described above. The mafic volcanic rocks in the anticlinal cores south of the main area are also slightly higher in the three channels and have pale purple composite hues.

The main area of Tanderra Volcanic has a strong magnetic response, but the areas in the smaller anticlinal cores are mostly low. Magnetic susceptibility readings were taken on only four outcrops and none of these were in the main area. The values are in the range 0–1015 x 10^{-5} SI units with a mean of 165. The higher values correspond with a moderate to high linear magnetic feature near Glenprairie homestead.

Environment of deposition

No pillows or other features indicative of a sub-aqueous environment have been observed in the Tanderra Volcanics and siltstone and mudstone are not common. Although more study is needed, the available evidence suggests that the unit was largely the product of subaerial volcanism with final deposition of clastic material by debris flows.

Geochemistry

Four samples from the Tanderra Volcanics, including one from the Charon Point Rhyolite Member, were analysed for a range of major and trace elements. The total alkalis-silica (TAS) plot in Figure 26a shows that two lava samples are basaltic andesite and one falls in the rhyolite field. However, the plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) in Figure 26b suggests that the latter may be a silicified andesite. Because it uses immobile elements, this plot provides a method of classifying the original composition of altered volcanic rocks. The plots also suggest that the Charon Point Rhyolite Member is dacite, although the abundant quartz crystal-fragments in the rocks are more consistent with it being rhyolite. In Figure 26c, the two basaltic andesite samples plot in the field of island arc tholeiites.

One of the basaltic andesite samples was submitted for precise trace element analysis by laser ablation mass spectrometry, and the data have been used to construct the multi-element and REE plots in Figures 26d–e and Figure 27, where it is compared with analyses from the Campwyn Volcanics as well as other Devonian suites in the Yarrol Province and Marlborough Block.

The Tanderra Volcanics sample falls within the range shown by the Campwyn Volcanics and is also similar to basalts in the Middle Devonian Raspberry Creek Formation and Lochenbar Suite of Murray & Blake (2005). These suites are all volcanic arc tholeiites or are transitional with calc-alkaline basalts. The Tanderra Volcanics are also similar to the Late Devonian tholeiitic basalt dykes from the Marlborough Block (Bruce & others, 2000; Murray, 2007).

These similarities support a Devonian age for the unit and also suggests that the rocks formed in a similar intra-oceanic tectonic setting. Murray & Blake (2005) compared basaltic rocks from the Lochenbar Formation with various suites, and concluded that they show most similarities to rocks of evolved oceanic arcs, such as the Lesser Antilles, Marianas, Vanuatu and the Aleutians. They further concluded that the Late Devonian rocks represent a transition from an intra-oceanic to continental-margin arc. Comparisons in Figure 26 show the similarities between the Tanderra Volcanics sample and basalts from the Lesser Antilles island arc.

Relationships and age

The Tanderra Volcanics are the oldest rocks in the area between the Marlborough Block and Charon Point and are overlain by the Glenprairie beds. The Charon Point Rhyolite Member that crops out to the north around Charon Point is regarded as a member within the Tanderra Volcanics (see below).

Hornblende diorite or gabbro apparently intrudes the Tanderra Volcanics in places. Floaters were observed at MGA 788680 7508100 to the north of Tanderra, but it was not observed in outcrop so that the size or nature of the bodies is not known.

The precise age range is uncertain, but given the early Carboniferous SHRIMP age of 352±5Ma obtained for ignimbrite in the Charon Point Rhyolite Member, it is likely that the Tanderra Volcanics are Late Devonian to early Carboniferous and may be correlatives of the Campwyn Volcanics to the north and the Mount Alma or Balaclava Formations in the south. If they extend into the Late Devonian, they may also be correlatives of other volcanic successions in the Yarrol Province such as the Mount Hoopbound Formation, Lochenbar Formation or Three Moon Conglomerate. They are chemically similar to the Lochenbar suite. The Hoopbound and Lochenbar Formations were deposited in shallow marine to subaerial environments, but currently evidence suggests that the Tanderra Volcanics are mostly subaerial.

CHARON POINT RHYOLITE MEMBER

Introduction

The Charon Point Rhyolite Member crops out at Charon Point and for ~2km south. It is well exposed at the point and along the ridge to the south. It should be noted that the name is misspelt on the SAINT LAWRENCE map as Charons Point Rhyolite Member, but is herein changed to conform to the official spelling of the feature from which the unit takes its name, Charon Point.

Type area

The type locality is at the boat ramp at Charon Point (MGA 788990 7522010; Figure 29), but the unit is well exposed along and adjacent to the access track south to MGA 790250 7520070 (the approximate boundary with the mafic part of the Tanderra Volcanics) and this is designated the type area.

Figure 29. Rhyolitic ignimbrite of the Charon Point Rhyolite Member with crudely developed columnar jointing. Charon Point at MGA 788992 7522000 (IWSC1280)

Lithology

The Charon Point Rhyolite Member consists of very crystal-rich, lithic-poor to moderately lithic-rich rhyolitic ignimbrite. Most of the rocks contain >50% fragments of feldspar and subordinate strongly embayed quartz crystals. One sample from MGA 789620 7520950 consists of ~80% crystal fragments with only very minor very fine-grained matrix. Relatively coarser-grained felsic mosaics between crystals may have been formed by vapour-phase crystallisation in the pore-spaces between the crystals. The lithic clasts in the ignimbrite are mainly aphyric felsite up to 2cm, and locally aligned elongate fiamme up to 3cm long are present. In the absence of fiamme, the rocks are massive. The outcrops at Charon Point show columnar jointing.

Geophysical response

The Charon Point Rhyolite Member shows low to moderate responses in the three radiometric channels and has mottled pink and greenish composite hues not distinguishable from the surrounding tidal flats. It crops out on the edge of an area of high magnetic response, probably due to mafic volcanics, but its response is probably low. No magnetic susceptibility measurements were made.

Relationships and age

The Charon Point Rhyolite Member is regarded as a member within the Tanderra Volcanics. It appears to be underlain on the eastern side of Charon Point by basalt or andesite and very poorly sorted mafic volcanic conglomerate similar to the rocks elsewhere in the Tanderra Volcanics. Its relationship to the Tanderra Volcanics to the south is uncertain. Abundant porphyritic andesite or basalt dykes that may be related to the overlying volcanic rocks can be observed intruding the ignimbrite in coastal exposures.

SHRIMP dating of the Charon Point Rhyolite Member indicates that it is latest Devonian or early Carboniferous (see Appendix). The age, based on analyses of 13 zircon grains, is 352±5Ma (MSWD = 1.5, ± external error).

ROCKHAMPTON GROUP

Introduction

These rocks were studied on the western side of Long Island by Leitch & others (1994) and were assigned to the Campwyn Volcanics. Previously they were mapped as unnamed D-Ca on the Saint Lawrence 1:250 000 geological map (Malone, 1970). On the advice of Paul Blake of the Yarrol Project team, the lithological association, particularly the oolitic limestones and the age range suggest a correlation with the Rockhampton Group, which is now applied to the early Carboniferous sedimentary succession throughout the Yarrol Province.

Lithology

The rocks on Long Island consist of a lower 1500m-thick succession of coarse-grained, red, green and grey volcaniclastic rocks ranging from breccia, conglomerate and pebbly sandstone. Red silicic ash-flow tuff is a minor component of the succession. The rocks are thick-bedded and massive, although some beds have planar laminae, stringers of coarser detritus and rare cross-beds. Shell debris is widespread and Leitch & others (1994) described two main fossil localities at MGA 797800 7544600 and MGA 797400 7547400 that contained brachiopod and coral faunas.

The upper 600m of the unit is finer-grained, clasts are well rounded, and most of the rocks are grey. Thick pyroclastic units are absent, but graded beds of volcaniclastic sandstone with sharp tops are interpreted as reworked air-fall tuff. Generally the clastic rocks are medium to thin-bedded and massive, although some medium-scale cross-beds are present. Clast-supported pebble to cobble conglomerate with a sandy matrix has also been reported.

Oolitic limestone is common in the upper part of the formation with individual beds up to 20m thick occurring in a zone 280m thick. Individual beds are internally stratified defined by terrigenous detritus, and locally have bi-directional cross-beds. Coral and crinoid fragments are locally abundant.

A fault sliver of rocks that include oolitic limestone, volcanilithic sandstone and conglomerate occurs on Quail Island. Similar rocks also occur in a fault-disrupted area west of Jessie Peak on the northern end of Stanage Peninsula. Leitch & others (1994) mapped both set of rocks as ‘undifferentiated Carboniferous’ but the presence of oolitic limestone suggests that they should be assigned to the Rockhampton Group.

Environment of deposition

Leitch & others (1994) suggested that the rocks were deposited in ‘shallow, frequently current-swept conditions on the flanks of a major volcanic complex that was erupting magmas of a wide range of compositions’. This is consistent with the fore-arc model generally invoked for the Rockhampton Group. As with the rest of the Yarrol Province, there is difficulty in locating the position of this supposed arc in the early Carboniferous. As described elsewhere in this report, there is a paucity of definite early Carboniferous volcanic rocks in both the Auburn and Connors Arches because most of the reliably dated volcanic rocks are late Carboniferous. However, the Clive Creek Volcanics and the Mountain View Volcanics could be representative of this source. It is also possible that more extensive early Carboniferous volcanic rocks are buried beneath the younger volcanic rocks in the Connors Arch, and also beneath the Back Creek Group to the east of the arch.

Relationships and age

The Rockhampton Group on Long Island is overlain conformably by rocks assigned to the Lorray Formation, with an apparently gradational contact.

J. Roberts examined the brachiopod faunas collected by Leitch & others (1994) and Pickett (1992) identified the corals. The fauna from the lower part of the unit is latest middle to late Tournaisian (*Schellwienella burlingtonensis* Zone).

LORRAY FORMATION

Introduction

Rocks assigned to the Lorray Formation are mapped on the eastern side of Long Island and also tentatively along the western edge of the mainland on Stanage Peninsular.

Lithology

As described by Leitch & others (1994), very thin to very thick-bedded volcaniclastic sandstone and dark siltstone with widespread ash-fall tuff and less common pebble conglomerate dominate the sequence on Long Island. The succession is ~2100m thick, but the top is not exposed. Slump-disrupted units in packets up to 10m thick occur towards the top of the unit. Features include cobbly siltstone and irregular folds. Many of the sandstone beds are massive, but some show diffuse parallel lamination and some are graded and there is rare cross-bedding. Load casts and ball-and-pillow are locally prominent. Tuffs are pale green, thin-bedded and range from crystal-lithic to fine-grained vitric varieties. Clasts in the conglomerate are mainly intermediate to silicic volcanics, but rare granite, diorite and limestone are present.

Grey sandstone and siltstone crops out along the east coast of the island near Middle Passage. It characteristically contains hummocky cross-bedding and irregular load casts. The interbedded carbonaceous siltstone includes siderite nodules and plant debris. Leitch & others (1994) suggested that these rocks may be part of the sequence on adjacent Quail Island.

Environment of deposition

Leitch & others (1994) considered that these rocks included turbidites and re-deposited conglomerates. They could see little evidence of traction current activity or definitive shallow water characteristics, and also noted the absence of body fossils. However, the hummocky cross-bedding towards the top of the unit could have been formed under shallow marine or paralic conditions indicating a shallowing of the depositional regime.

Leitch & others explained the more distal character of the succession as being due to the westward retreat of the locus of volcanic activity, consistent with the absence of primary pyroclastic rocks and the presence of only thin air-fall tuffs.

Relationships and age

The Lorray Formation conformably overlies the Rockhampton Group, but its top is not exposed in the Stanage area. The rocks tentatively assigned to the Lorray Formation on the mainland are in mapped contact with the Shoalwater Formation, and this contact may be a thrust.

A fauna of brachiopods, crinoids and bryozoans collected from sandstone near the boundary between the Lorray Formation and Rockhampton Group on Long Island was identified by Roberts (*in* Malone & others, 1969) as including *Levipustula levis* and indicating that the rocks are Namurian. This sandstone is probably from the Lorray Formation. Due to the absence of body fossils higher in the unit, its upper limits are uncertain. Isotopic dating of some of the tuff beds could resolve the age. The rocks could at least partly correlate with the Glenprairie beds (described below) south of Charon Point, which have been dated as earliest Permian, but could range back into the Carboniferous.

GLENPRAIRIE BEDS

Introduction

This is a new name given to a belt of locally strongly deformed sedimentary and felsic volcanic rocks on the peninsula north of the Marlborough Block (Figure 28). They crop out for ~30km from near Pine Mountain to a few kilometres south of Charon Point on the eastern side of the peninsula. In the northern half of the belt, less deformed rocks assigned to the unit crop out in a western extension through Tanderra Station towards the western side of the peninsular. The rocks were previously mapped as Carmila beds, along with the Wongrabry beds and Tanderra Volcanics.

Much of the terrain formed by the unit is relatively steep and hilly with relief of more than 300m, forming a prominent range that includes Mount Wellington and Mount Philp, the highest features in the area.

Type section

A composite type section is designated. The section north-west of the abandoned Bald Hills homestead from MGA 791145 7512940 (base) to MGA 792670 7512635 incorporates the lower part of the Glenprairie beds. It includes the pebble to cobble conglomerate and well-sorted lithic sandstone at the contact with the Tanderra Volcanics, and the ignimbrite sheet that has been dated by the SHRIMP (see Appendix and below). The upper part of the unit is not included, because the dip reverses to the east and the section is probably repeated. A section incorporating the upper part of the unit and the boundary with the Wongrabry beds occurs south-east of Tanderra homestead from MGA 790515 7502655 through felsic volcanilithic lithic sandstone, pebble conglomerate, mudstone and tuffaceous siltstone to andesitic volcanic sandstone of the Wongrabry beds at MGA 790480 7501760. The nature of the contact is uncertain and could be either faulted or stratigraphic.

Lithology

The Glenprairie beds are dominated by feldspatholithic sandstone and lesser conglomerate, siltstone, mudstone and felsic volcaniclastic rocks.

The sandstone is generally medium to very coarse-grained and locally pebbly, grading into conglomerate. It is generally moderately to well sorted and consists mainly of felsic volcanic clasts and up to 30% feldspar

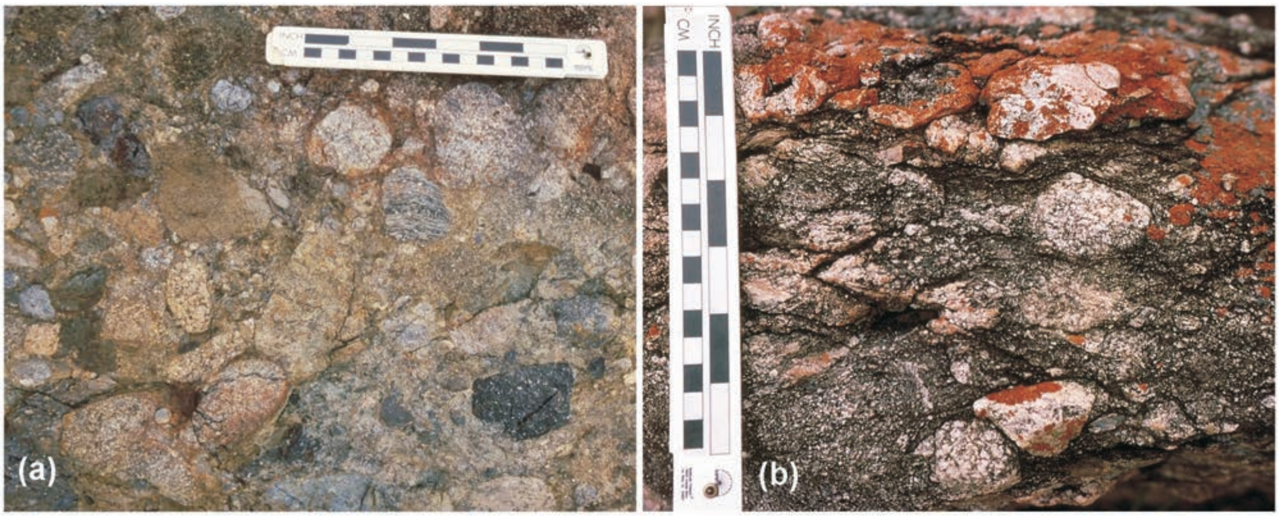

Figure 30. Glenprairie beds
(a) Clast-supported, polymict conglomerate containing pebbles and cobbles of felsic volcanic rocks and granitoid. Base of the Glenprairie beds, 9.4km south of Charons Point at MGA 791149 7512935 (IWSC1286)
(b) Deformed conglomerate with granite clasts in a crudely cleaved coarse-grained sandy matrix. Glenprairie–Bald Hill road, ~8km north-west of Glenprairie homestead at MGA 799237

(mainly plagioclase). Minor monocrystalline quartz grains are generally present, but rarely exceed 10%. Former pore spaces are infilled by fine-grained sparry quartz in some of the well-sorted sandstone. The rocks are mostly thick to very thick bedded and commonly massive. Internal stratification is generally horizontal planar laminae defined by stringers of granules and pebbles, but some trough cross-bedding and channelled bases containing granule or pebble lags were observed locally.

Finer-grained sandstone and more cleaved mudstone appear to become more common westwards towards the contact with the Wongrabry beds in the headwaters of Wellington Creek and south towards Pine Mountain, although coarse-grained sandstone and granule conglomerate and some poorly sorted volcaniclastic rocks are still evident. This finer-grained section has a different radiometric response (similar to mudstone-dominated parts of the Back Creek Group) and it has been tentatively mapped as a separate subunit (**CPp_x**). It contains leaves of *Noeggerathiopsis hislopi* and *Glossopteris indica* from locality M68 near Pine Mountain (White, in Malone & others, 1969, page 123). Fossil wood was also noted in this vicinity during this project, and *Glossopteris* and *Noeggerathiopsis* was observed in a rail cutting south of Pine Mountain at MGA 789300 7478140. The presence of plant fossils and lack of burrows and concretions distinguishes these rocks from the otherwise similar sandstone and mudstone of the Back Creek Group.

White (*in* Malone & others, 1969, page 123) described leaves of *Noeggerathiopsis hislopi* and *Glossopteris indica* from locality M72 in the southern part of the outcrop area. Equisetalean plant stems are locally preserved on bedding planes in fissile mudstone and siltstone in the less deformed rocks in the Tanderra area.

The conglomerates are generally also thick to very thick bedded and pebbly to cobbly with sub-rounded to well-rounded clasts mainly of felsic volcanic rocks, although locally microgranite and medium to coarse-grained biotite granite and leucogranite are present (Figure 30). They are bimodally sorted with the clasts mainly supported by a matrix of well-sorted sandstone as described above. Some beds fine upwards from a basal clast-supported conglomerate.

The felsic volcanic rocks include sheets of rhyolitic ignimbrite as well as thin beds of tuffaceous siltstone and poorly sorted crystal-rich and lithic-rich volcanic sandstone. The ignimbrite has been observed over a wide area from north-west of Glenprairie homestead near Mount Wellington to north-west of the abandoned Bald Hills homestead and in the area west of Tanderra homestead. It is likely that these widely dispersed outcrops represent the same interval in the stratigraphy, although in places there are probably multiple sheets. The thickness of the sheets is not known, because they mainly crop out in difficult topography covered in scrub and scree, but they are likely to be at least a few tens of metres in places, because they form prominent ridges along the spine of the peninsula.

The ignimbrites are grey and moderately crystal-rich, containing fragments of feldspar (mainly plagioclase) and only rare quartz. Fiamme are not common, but felsic lithic fragments are locally abundant. The groundmass has smaller crystal fragments and microcrystalline mosaics of quartz and feldspar and commonly also has well-preserved vitroclastic textures comprising abundant non-flattened cuspate shards with axiolitic devitrification textures. In some of the more metamorphosed rocks west of Glenprairie, the relict shards are outlined by sericite.

Medium to very thick beds of poorly sorted volcaniclastic rocks that are less clearly primary pyroclastic rocks are also interbedded locally with the better-sorted sandstone and mudstone throughout the area. They contain felsic volcanic clasts and crystal fragments (mostly feldspar) in a very fine-grained felsic matrix.

The Glenprairie beds are locally strongly deformed. This deformation is restricted mainly to the southern part of the area, south of Bald Hills homestead. It also appears to decrease in intensity to the west, although it is still relatively strong adjacent to the north-trending thrust (?) contact with the Wongrabry beds east and south-east of Oakleigh homestead. Where it is most intense, near Glenprairie, the deformation is manifest by strongly flattened and stretched pebbles and cobbles (Figures 30b and 156). Elsewhere, the mudstone has a strong slaty cleavage, and the sandstone and conglomerate also have a well-developed foliation defined by anastomosing fractures and spaced cleavage defined by seams rich in sericite and chlorite. Aligned flakes of sericite also occur through the groundmass of the felsic volcanic rocks. Along the Glenprairie road at MGA 800600 7494400 a deformed meta-tuff (?) has a strongly schistose fabric defined by muscovite, wrapping around quartz and feldspar crystal fragments. Biotite defines the foliation in sandstone south of Glenprairie, indicating that the metamorphic grade there was in the upper part of the greenschist facies.

Geophysical response

The Glenprairie beds have a moderate to high potassium response and moderate thorium and uranium responses, mainly producing pale pinkish to yellowish hues on composite images. This is consistent with the felsic composition of the detritus in the sandstone and conglomerate and the local felsic volcaniclastic rocks. In the south-western part of the unit, adjacent to the Wongrabry beds, the potassium response is lower and thorium and uranium are higher, producing a bluish white hue that has a relatively sharp boundary with the area of pinkish hues. This response corresponds with the finer-grained sandstone and mudstone subunit referred to above and is similar to that of the mudstone-dominated parts of the Back Creek Group.

The magnetic response is low and contrasts with the Tanderra Volcanics and the Wongrabry beds. Magnetic susceptibility readings from the sedimentary rocks were mostly <20 x 10^{-5} SI units. The ignimbrite, however, had values up to 1356 and appears to be associated with small, low to moderate linear anomalies in the airborne data.

Environment of deposition

In general terms, the characteristics of the Glenprairie beds, in particular the dominance of coarse-grained, well sorted, thick bedded, massive to locally cross-bedded sandstone and conglomerate is consistent with a fluviatile environment. The lack of marine body fossils or bioturbation and sporadic occurrence of plant remains is also consistent with a non-marine environment.

Relationships and age

The Glenprairie beds are distinguished from the Wongrabry beds by the presence of feldspatholithic sandstones derived from felsic volcanics. The Wongrabry beds are dominated by lithic sandstone and conglomerate (commonly poorly sorted), derived from a more mafic volcanic provenance. They also contain minor limestone and beds containing marine fossils.

Field evidence for the relationship between the Glenprairie beds and the Wongrabry beds is conflicting. Where the boundary trends north, the Wongrabry beds and Glenprairie beds both dip and young to the east. This suggests that the Glenprairie beds overlie the Wongrabry beds. However, where the contact swings westwards in the Tanderra area, the opposite relationship appears to exist along the contact, that is, the Glenprairie beds appear to underlie the Wongrabry beds. These conflicting relationships suggest that the contact is at least partly tectonic, probably a thrust.

SHRIMP dating of zircon from an ignimbrite in the Glenprairie beds from MGA 792500 7512530, north-west of Bald Hills homestead has given a best estimate for the age as 297±3.6Ma (see Appendix). Thus the rocks are probably latest Carboniferous or earliest Permian. As noted later, the Wongrabry beds have a well-preserved marine fauna that was briefly described by Dickins (*in* Malone & others, 1969, page 101) and is probably Artinskian (younger than 285Ma according to the ICS time-scale, Gradstein & others, 2004). They are therefore younger than the Glenprairie beds.

White (*in* Malone & others, 1969, page 123) suggested that the fossil plants from the southern part of the Glenprairie beds included leaves typical of late Carboniferous and early Permian strata, which is consistent with the dating.

The evidence therefore points to the north-trending contact between the units being a thrust, with the Glenprairie beds thrust from the east over the Wongrabry beds. The rocks along the contact in the headwaters of Landsborough Creek are locally strongly foliated and disrupted, resembling block-in-matrix melange (for example at MGA 792800 7492200) consistent with a faulted contact. The contact near Tanderra could be stratigraphic, but slices of Glenprairie beds within the Wongrabry beds in this area are likely to be partly bounded by thrusts. The structure in this area appears to be very complex, and understanding it was made more difficult by poor outcrop and access problems due to thick infestations of lantana.

The contact relationship of the Glenprairie beds to the Rookwood Volcanics that crop out along the margins of the Marlborough Block is not known. The SHRIMP age indicates that the Glenprairie beds are older, because evidence from ROOKWOOD indicates that the Rookwood Volcanics are also Artinskian (O'Connell, 1995). The contact may be tectonic, probably a thrust, because it appears to truncate the boundary between the different radiometric responses in the Glenprairie beds.

The SHRIMP data for the Glenprairie beds indicates that they could overlap partly in age with the Carmila beds, but they are probably older, and in fact are more likely equivalents of the Leura Volcanics. A thrust belt separates them from the Connors Province, and as already noted above, they are more likely part of the Yarrol Province. They therefore could be equivalent to the Youlambie Conglomerate, a largely fluvial latest Carboniferous to early Permian succession composed mainly of felsic volcanic and granitic detritus with local thin ignimbrite sheets. The provenance of the two units is therefore similar. SHRIMP dating of ignimbrites from the Youlambie Conglomerate (see Appendix) has given a mean age of 303±2.5Ma for part of the unit, although early Permian marine fossils have been recorded elsewhere. Therefore, the age ranges of the Glenprairie beds and Youlambie Conglomerate overlap.

The Glenprairie beds are intruded by the late Permian or Early Triassic Aitken Creek Gabbro and Copperville Granodiorite.

WONGRABRY BEDS

Introduction

This is a new name given to an area of volcaniclastic sedimentary rocks and some lavas north of the Marlborough Block on the central part of the peninsula (Figure 28). They crop out as an arcuate belt for ~20km long between Hill End homestead and the headwaters of Wellington Creek. The rocks were previously mapped as Carmila beds, along with the Glenprairie beds and Tanderra Volcanics.

The name is derived from Wongrabry Creek as spelt on the Marlborough 1:100 000 Topographic and Cadastral Series maps, but it should be noted that local usage refers to it as Wongabrai Creek.

The unit forms relatively low hills that contrast with the more rugged Glenprairie beds. The soils give rise to distinctly reddish to dark brown hues on coloured aerial photographs, consistent with the more mafic composition of the rocks.

Type area

A complete section for the unit cannot be designated, because the contacts with some, if not all, adjacent units may be tectonic. The boundary with the Glenprairie beds south of Tanderra may be stratigraphic and therefore a type section is proposed in the hills east of the Tanderra road between MGA 788700 7502600 (boundary with the Glenprairie beds) and MGA 788950 7502600 (where outcrop is concealed by alluvium of the Wellington Creek floodplain). The section contains a succession of volcanilithic sandstone, conglomerate and minor impure limestone and is locally fossiliferous.

Lithology

The Wongrabry beds are characterised by lithic sandstone and conglomerate derived from intermediate volcanic rocks . In the type section, these are generally thick to very thick-bedded, but some massive beds are 5–10m thick. Some internal stratification is locally defined by coarser stringers and, where the rocks are calcareous, by etched-out variations in carbonate content (Figure 31b). The stratification is mainly planar and cross-bedding appears to be rare. The sandstones are mostly moderately to well sorted and medium to very coarse-grained. They are commonly pebbly, grading into bimodal matrix-supported conglomerate. Clasts are mostly subangular. Shelly fossils are present in places in the sandstones, particularly between MGA 788955 7500820 and MGA 789030 7501240 (Figure 31a). They occur either as scattered shells or coquinitic layers up to 15cm thick and include brachiopods (productids and spiriferids), bivalves (pectens), bryozoans and crinoid

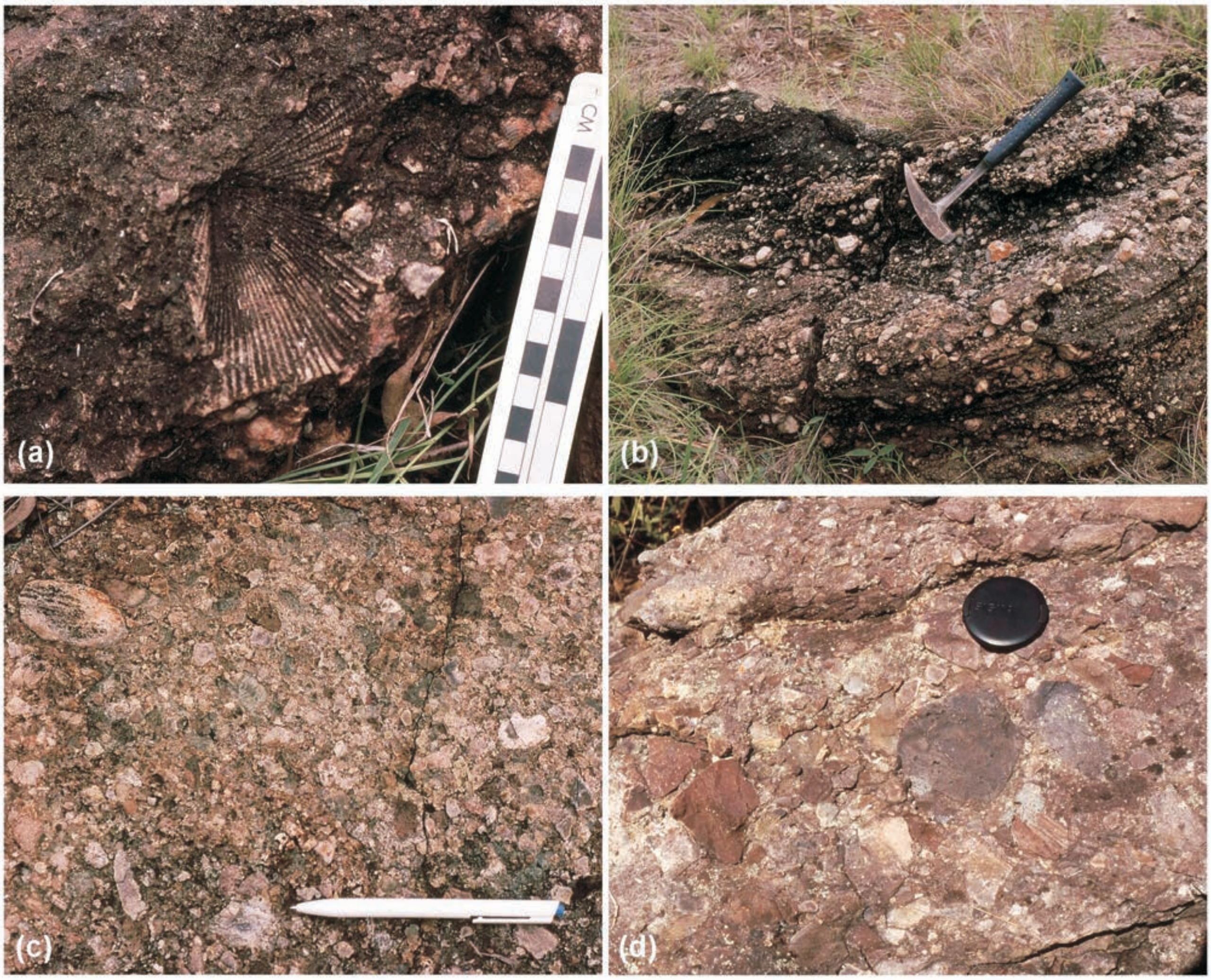

Figure 31. Wongrabry beds
(a) Portion of a pecten shell in medium to coarse-grained sandstone. Near Oakleigh Road ~2.8km south of Tanderra homestead at MGA 788968 7500811 (IWSC1019)
(b) Pebble conglomerate containing subangular felsic volcanic pebbles and a calcareous cement grading into impure limestone. Near Oakleigh Road ~2km south-south-east of Tanderra homestead at MGA 788968 7500811 (IWSC1021)
(c) Polymict pebble conglomerate containing subangular clasts of mafic to felsic volcanic rocks. Same locality as (b)
(d) Poorly sorted volcaniclastic conglomerate containing angular to subangular clasts of porphyritic andesite and dacite. ~2.5km east of Oakleigh homestead at MGA 793414 7496071 (IWSC1258)

stem segments. The scattered shells are disarticulated, but commonly intact, including some pectens up to 10cm across. The carbonate in the rocks is probably mainly shelly detritus, and in places the sandstone grades into thin beds of impure limestone.

In thin section, the lithic fragments are predominantly andesitic or basaltic and commonly consist of small plagioclase microlites in a very fine turbid groundmass, probably devitrified glass. Some of these are very scoriaceous or pumiceous and have abundant, very small chlorite-filled amygdales. Other clasts have a trachytic texture and consist mainly of flow-aligned feldspar laths, and there are sporadic felsic clasts of probable rhyolitic or dacitic composition.

Towards the top of the section, above the fossiliferous interval, the relatively well sorted rocks pass into very poorly sorted conglomerate and breccia (Figure 31c–d). These form very thick, massive beds that appear to be tens of metres thick in places. They consist of angular granules to pebbles, and locally cobbles and boulders of mafic volcanic rocks in a matrix of silt to very coarse sand-sized material. In thin section, the clasts are aphyric basalt or andesite that is strongly pumiceous or scoriaceous, containing chlorite-filled amygdales ~0.25mm in diameter. Similar thinner intervals occur in the underlying succession, but are not common. At MGA 788960 7502050, one bed consists dominantly of felsite clasts including some with flow-banding. It could be a debris flow or talus shed from the rhyolite flow or dome that lies ~200m to the north (see below).

Elsewhere the Wongrabry beds contain basically a similar range of poorly sorted to well-sorted sandstone and conglomerate to the succession described above. Clasts are dominantly andesitic or basaltic, but felsic volcanic rocks and rare medium-grained granitoids are locally present. Fossiliferous rocks, including moderately well sorted lithic sandstone conglomerate and minor impure limestone, crop out south-east of Oakleigh homestead at MGA 790795 7494175 and north-east at MGA 793700 7498600 (the so-called ‘Lost Limestone Bluff’ of Fielding & others, 1997a). Some mudstone and siltstone, locally containing burrows, are also interbedded with the sandstone and conglomerate in the southern part of the area.

South-east of Oakleigh homestead, towards the contact with the Glenprairie beds, the rocks become very strongly cleaved. The finer rocks have a slaty cleavage, but the sandstone and conglomerate have a spaced cleavage defined by seams of iron oxides that anastomose around the lithic grains and also occur within some of the larger lithic clasts themselves. The lithic clasts are also flattened, but are not stretched to the extent of those in parts of the Glenprairie beds.

Basaltic lava was observed east of Oakleigh homestead at MGA 792000 7495640 and underlying the fossiliferous rocks at MGA 790795 7494175, and it is inferred to underlie the black soil south of Oakleigh. The outcrops east of Oakleigh are aphyric and commonly have spherical epidote-filled amygdales up to 5mm in diameter. In thin section the rocks consist of randomly orientated, partly saussuritised plagioclase laths to 0.5mm and interstitial partly chloritised, colourless clinopyroxene and titanite.

Felsic rocks are a minor component within the Wongrabry beds. They form resistant ridges that have dip slopes concordant with bedding in the surrounding rocks, indicating that they are mainly tabular bodies (sills or flows). At MGA 793540 7494130, the rocks are pale grey, massive sparsely to moderately porphyritic with strongly fractured and broken plagioclase phenocrysts in a groundmass that has a well-developed trachytic texture of flow-aligned feldspar microlites. The actual composition is uncertain, but it could be dacite or trachyte. The rock has a crackle-brecciated appearance, the infill between the clasts being a very fine-grained felsic granular mosaic. The brecciation and fracturing of the phenocrysts may be associated with the nearby inferred thrust contact with the Glenprairie beds. Other ridges at MGA 792900 7500700 and towards the base of the type section at MGA 788500 7502320 consist of flow-banded and autobrecciated felsite.

The Wongrabry beds produce deep reddish to purplish hues on the composite radiometric images, suggesting that although potassium is probably relatively high in places, thorium and uranium are low. This is consistent with an andesitic or trachyandesitic to dacitic provenance for the rocks. It contrasts markedly with the pale pink to bluish white hues within the more felsic Glenprairie beds. The Wongrabry beds also have a distinctly higher magnetic response than the Glenprairie beds, but not as high as that of the Tanderra Volcanics.

Rocks on Quail Island on the eastern side of Broad Sound were described by Leitch & others (1994) and assigned to the Youlambie Conglomerate. Malone & others (1969) assigned them to an unnamed “Lower Permian” unit, based on the presence of marine fossils, although they also suggested that the Youlambie Conglomerate was a possible correlative. The area is a considerable distance from the nearest mapped occurrence of Youlambie Conglomerate (north-east ROOKWOOD) and it is preferable to equate the rocks with those south of Charon Point. They have been tentatively assigned to the Wongrabry beds rather than the Glenprairie beds on the basis of the presence of an early Permian marine fauna.

As described by Leitch & others (1994), the rocks on Quail Island include medium-bedded, polymictic conglomerate, lithic sandstone and mudstone. The conglomerate is poorly sorted, massive, and contains abundant sedimentary clasts including volcaniclastic oolitic sandstone, dark siltstone from the Rockhampton Group, quartzose sandstone, silicic to intermediate volcanics and rare granite. The lithic sandstone contains abundant quartz and is locally cross-bedded and burrowed. Calcareous sandstone crops out at several localities and contains abundant bivalves and productids and locally finer shell material that is sufficiently concentrated to form impure limestone. Cleaved mudstone is also present. Siderite concretions and small silicified logs have also been observed.

Geophysical response

The Wongrabry beds have a low to moderate potassium response and low thorium and uranium so that the unit is represented by distinctive dark red hues on composite images. The minor rhyolite flows have strong potassium responses.

Magnetic susceptibility data are available from only six outcrops and the values are relatively low (0–183 x 10^{-5} SI units). Nevertheless, the unit is characterised by a series of low to moderately magnetic linear features that parallel the strike of the unit and contrast with the low magnetic response of the Glenprairie beds.

Environment of deposition

The presence of the coarse grainsize and moderate to good sorting of many of the rocks in the Wongrabry beds and the marine fossils is consistent with high-energy conditions in a shallow marine environment, although in places, the energy was insufficient to break the large pecten shells. The sediment may have been reworked from material fed into the sea by debris flows from an adjacent volcanic source and represented by the very thick, very poorly sorted rudites. Some of the pumiceous material may be due to submarine or phreatomagmatic eruptions.

Geochemistry

One sample of basaltic lava from the Wongrabry beds east of Oakleigh homestead was analysed for a range of major and trace elements including rare-earth elements by laser ablation mass spectrometry. On the total alkalis-silica diagram (Figure 32a) the rock plots in the basaltic trachyandesite field. On the multi-element and REE plots (Figures 32b–c) the patterns have steeper slopes than most of the other Permian volcanic units in this study, although the Coppermine Andesite and one sample from the Carmila beds have comparable slopes. The data match analyses from the Casimiro suite at the northern end of the Southern Volcanic Zone of the Andes that developed on very thick continental crust (~50km) (Hickey & others, 1986).

The REE and multi-element patterns contrast with those of the Late Devonian or early Carboniferous Tanderra Volcanics that crop out to the east. It indicates either that the crust thickened considerably between the Late Devonian and early Permian, or that the thrust that marks the eastern margin of the Wongrabry beds is a major crustal boundary.

The steep REE pattern also contrasts with the relatively shallow slope of the Collaroy Volcanics, which are of similar age to the Wongrabry beds. The thinner crust suggested by the geochemistry of the Collaroy Volcanics may reflect it being closer to the axis of the Bowen Basin, where extension was greater, whereas the Wongrabry beds are closer to the eastern margin.

A more marked contrast is shown with the flat pattern of the Rookwood Volcanics. This unit is also of comparable age to the Wongrabry beds. The Rookwood Volcanics, which have affinities with basalts erupted in a spreading back-arc basin, crop out only ~20km to the south. They are bounded on their northern margin by a fault, which trends north-east and is probably a thrust or a strike-slip fault. The contrasting geochemistry of rocks of comparable age and in close proximity suggests that there may be considerable lateral movement along this fault, juxtaposing different crustal blocks. If it is a thrust, it may be an out-of-sequence thrust like that of the forming the contact of the over-riding Marlborough Block with the Gogango Overfolded Zone. Otherwise, it could be a splay of the Stanage Bay Fault that has been interpreted as a dextral tear fault forming the northern limit of the Gogango Overfolded Zone (Morand, 1993a; Henderson & others, 1993; Leitch & others, 1994; Holcombe & others, 1995, 1997a).

Relationships and age

The relationships to the Glenprairie beds have been discussed above. In summary, the evidence points to the Glenprairie beds being older than the Wongrabry beds. The north-trending contact between the units is interpreted as a thrust with the Glenprairie beds thrust from the east over the Wongrabry beds. Slices of Glenprairie beds within the Wongrabry beds in the Tanderra area, where the contact trends west-north-west, are likely to be partly bounded by thrusts, although some of the contacts are probably stratigraphic.

The relationship of the Wongrabry beds to the Back Creek Group to the west is mainly concealed by alluvium, but is probably also a thrust.

The Wongrabry beds have a well-preserved marine fauna that was briefly described by Dickins (*in* Malone & others, 1969, page 101). The sites are mainly in the northern part of the outcrop area, east of Wongabrai homestead and east of Oakleigh homestead. Dickins assigned the fossils to his Fauna I (now considered to be indistinguishable from his Fauna II). They are early Permian (probably Artinskian). Some of the sites were re-collected, but the fossils have not been examined and assessed by a palaeontologist. The rocks may correlate with and be a continuation of the Berserker Volcanic Group south of the Marlborough Block in the Rockhampton area, although the latter are mainly felsic.

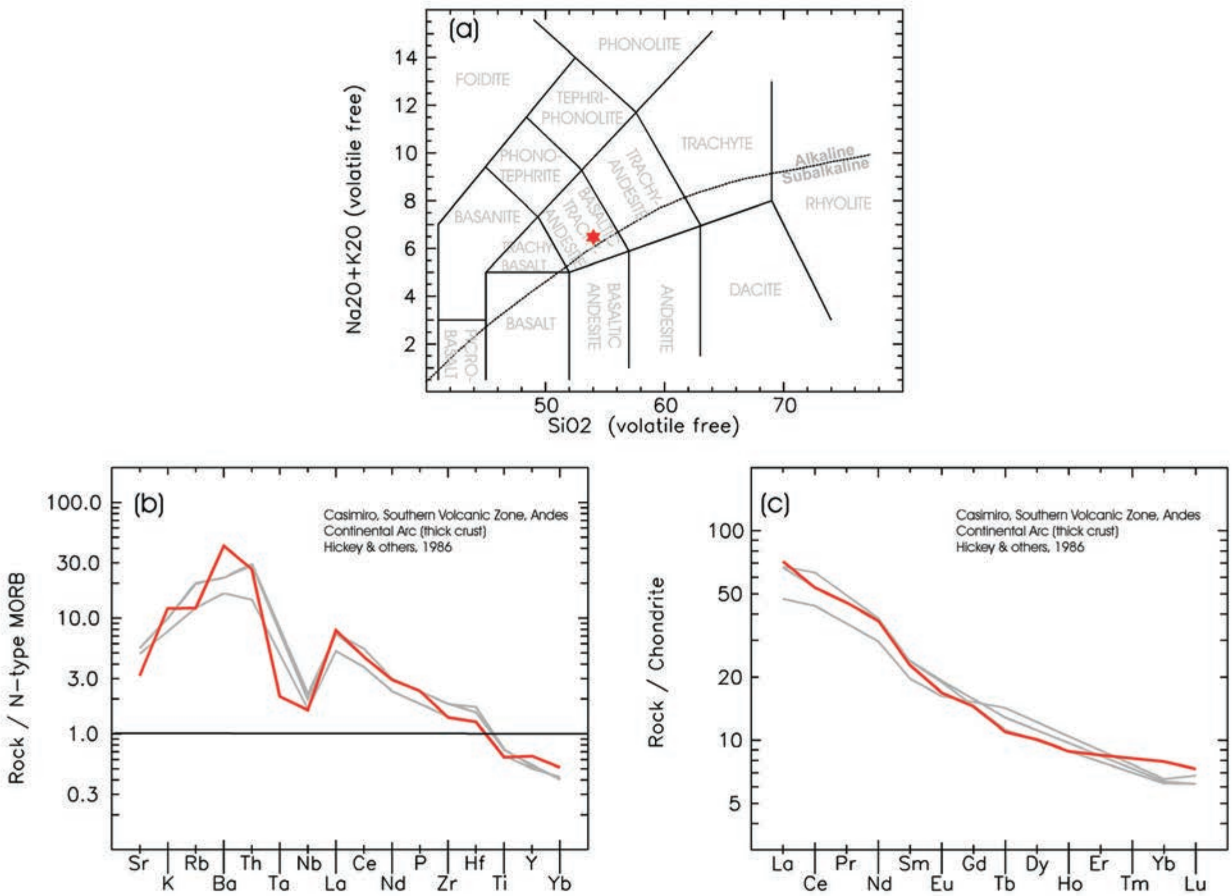

Figure 32. Geochemistry of volcanic rocks from the early Permian Wongrabry beds: (a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986) and Irvine & Baragar (1971); (b) N-MORB normalised multi-element plot (using values from Pearce, 1983) for the basaltic trachyandesite sample; (c) chondrite-normalised REE plot (using values from Sun & McDonough, 1989) for sample in (b). For comparison, the patterns of basalts from the modern Andean Casimiro suite are shown in grey.

STRATIGRAPHY OF THE CONNORS ARCH

The name Connors Volcanics was previously given to a sequence of dominantly felsic to intermediate ignimbrite, coherent lavas, and epiclastic rocks that extend from near Rookwood homestead west of Rockhampton to north-east of Urannah homestead south of Collinsville, a distance of ~350km. As originally mapped, they crop out in the Duaringa, Saint Lawrence (Malone & others, 1969), Mackay, Mount Coolon (Malone & others, 1964; Hutton & others, 1998) and the Bowen (Malone & others, 1966), 1:250 000 Sheet areas.

Malone (1964) introduced the term Connors Arch to include the Connors Volcanics as well as numerous intrusives including the Urannah Batholith. The term Connors Arch is used here as a structural feature with a core of Carboniferous to early Permian igneous and sedimentary rocks, flanked on both sides by rocks of the Permian Bowen Basin. To the south, some of the Carboniferous to early Permian igneous and sedimentary rocks are also exposed in smaller anticlinal cores, such as the Leura Anticlinorium and the Langdale Inlier. The latter lies to the east of the main Connors Arch between Tooloombah homestead and the old Bruce Highway and is partly fault-bounded. As discussed later (see page 144), the Langdale Inlier appears to have been a horst block that was a positive feature during the early Permian, whereas the Connors Arch itself and structures such as the Leura Anticlinorium formed during the late Permian Hunter–Bowen Orogeny.

The Connors Volcanics were originally included in the early Permian Lower Bowen Volcanics (Malone & others, 1964), but were defined as a separate unit after some granite plutons intruding them were dated as Carboniferous (Malone & others, 1969). A Late Devonian to early Carboniferous age was assigned. The remainder of the Lower Bowen Volcanics were assigned to the Lizzie Creek Volcanics by Malone & others (1969), although Hutton & others (1998) recognised that some of the volcanic rocks in the original definition belong to the older Connors Volcanics.

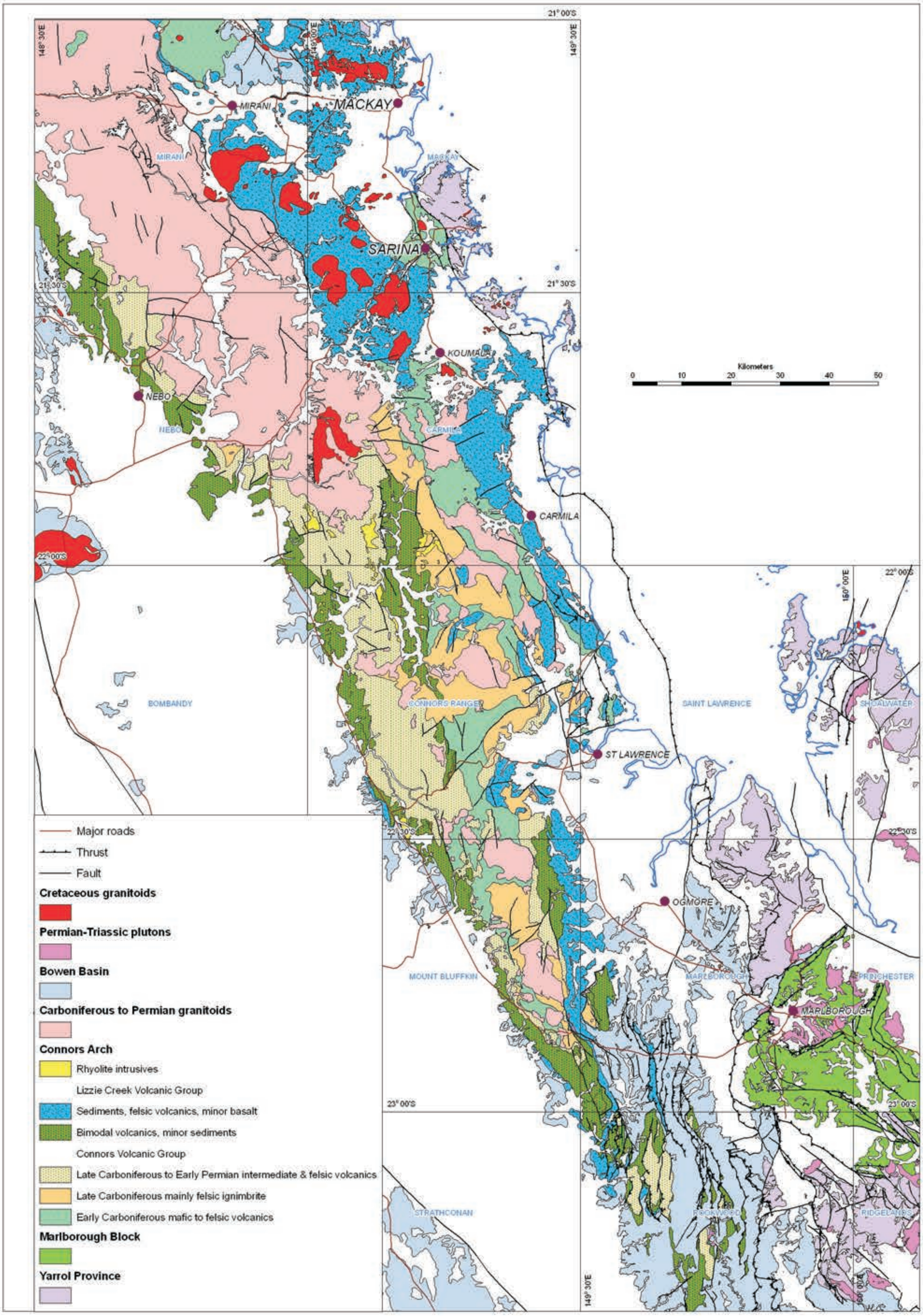

Figure 33. Generalised stratigraphy of the Connors Arch

Figure 34. Topography of the Connors Arch
(a) Deeply dissected and thickly vegetated topography and in the headwaters of Montrose Creek on the eastern side of the Broadsound Range at MGA 750300 7491500 (IWSC0791)
(b) Mount Gardiner at the southern end of the Connors Arch, viewed from east of Apis Creek homestead. The range here is formed from mafic volcanics of the Mount Benmore Volcanics capped by the Cerberus Rhyolite Member.
(c) Rhyolitic ignimbrite of the Whelan Creek Volcanics forming Fort Arthur, a prominent peak 17km south-west of Clairview
(d) Thickly vegetated topography in the Dalrymple Heights area west of Mackay at the northern end of the project area

Dear (1994a,b, 1995) mapped the Connors Volcanics during mineral exploration in the southern Connors Arch. He erected four cycles of volcanic/sedimentary rocks, three of which are in the Connors Arch. The fourth comprised the early stages of development of the Bowen Basin, and included the Carmila beds and basal Back Creek Group. Cycle 1 of Dear (1994a) was considered to be Early to Middle Devonian, Cycle 2 to be Late Devonian to early Carboniferous and Cycle 3 to be late Carboniferous.

The most recent work prior to our study resulted in a proposed new time frame for the Connors Arch. Holcombe & others (1997a,b) and Allen & others (1998) argued that the volcanism in the Connors Arch was restricted to the late Carboniferous to early Permian, including all of the rocks in the four cycles of Dear. However, the initial phase of the current project showed that the volcanism probably spanned most of the Carboniferous and extended into the early Permian. Samples collected from the Connors Volcanics (as then mapped) were dated by the U-Pb (SHRIMP) method (Withnall & others, 1997; Hutton & others, 1999b; see Appendix). A sample of rhyolite from Cycle 1 of Dear yielded an early Carboniferous age of 349±5Ma. A rhyolitic ignimbrite from Cycle 2 (from the type area of the Connors Volcanics as defined by Malone & others, 1969) yielded an earliest Permian age of 295±3Ma. Further dating has refined this time frame.

The cycles of Dear (1994a) provided an initial basis for subdivision of the Connors Volcanics. The original type area of the Connors Volcanics is restricted to a single unit, the Lotus Creek Rhyolite, which is probably Cycle 3. However, to retain the sense in which most workers have used the term "Connors Volcanics", it is suggested that the name Connors Volcanic Group could be used for all of the largely intermediate to felsic Carboniferous volcanic succession, from Cycle 1 through to Cycle 3A of Dear (1994a). This includes the Clive Creek Volcanics, Mountain View Volcanics, Broadsound Range Volcanics, Whelan Creek Volcanics, Lotus Creek Rhyolite, Leura Volcanics and Tartrus Rhyolite. The small area mapped as Macksford Volcanics may also be part of the group as it overlies the Leura Volcanics and may be older than the Tartrus Rhyolite. This grouping of the units is in spite of the presence of some apparent time-breaks. However, it is consistent with the practice adopted in north Queensland in recent years, when subdividing large volcanic successions that were previously mapped as single units. The original names have been retained as group names, even though dating has shown considerable time spans and probable breaks (for example, Featherbed Volcanic Group — Mackenzie, 1993)

The name has not been extended to the largely bimodal early Permian volcanic successions, even though some of these were originally mapped, at least partly, as the Connors Volcanics (specifically the Mount Benmore and Ametdale Volcanics). Farther north, the Mount Benmore Volcanics are equivalent to the rocks that were originally assigned to the Lizzie Creek Volcanics. These are dominated by basaltic lavas and have a different character to the Connors Volcanic Group with its extensive areas of rhyolitic ignimbrite that were probably related to cauldron subsidence. Some ignimbrite as well as other felsic volcaniclastics and rhyolitic lavas are present in these early Permian volcanic successions, but mainly as relatively thin discrete sheets.

The name Lizzie Creek Volcanic Group is now applied to all of the rocks that lie between the Connors Volcanic Group and the Back Creek Group, the lowermost part of the Bowen basin succession. This includes the Cobweb Mountain Rhyolite, Coppermine Andesite, Mount Benmore Volcanics, Ametdale Volcanics and Mount Buffalo Volcanics. The name has also been extended to include the Carmila beds, which although dominated by sedimentary rocks, contain widespread fine-grained volcaniclastic rocks in addition to significant areas of primary volcanic rocks including ignimbrites and basalt flows. The Collaroy Volcanics are also included in the Lizzie Creek Volcanic Group, although they probably overlap in age with the lowermost part of the Back Creek Group.

Some rocks not included in newly defined formations are mapped as undivided Lizzie Creek Volcanic Group. These include rocks mapped as $\mathbf{Pvz_{cg}}$, $\mathbf{Pvz_{r}}$, $\mathbf{Pvz_{s}}$ and $\mathbf{Pvz_{d}}$ on the various 1:100 000 scale geological maps. $\mathbf{Pvz_{s}}$ is a fine grained sedimentary facies near the top of the Lizzie Creek Volcanic Group, equivalent to the lacustrine facies described by Hutton & others (1998) at the top of the Lizzie Creek Volcanics in the Mount Coolon 1:250 000 Sheet area.

Generalised geology of the Connors Arch is shown in Figure 33 and more detailed maps in Figures 35, 37 and 53.

CLIVE CREEK VOLCANICS

Introduction

This name is herein given to the Cycle 1 volcanic rocks of the Connors Arch as described by Dear (1994a,b, 1995). The name is derived from Clive Creek (pronounced Cleeve), a tributary of the Mackenzie River and the name of a cattle station that incorporates part of the outcrop area of the unit. In earlier unpublished company reports, Dear (1977) referred to the rocks informally as the "Clive Creek Volcanic Member", but he later used the name "Clement Creek Volcanics" for the same unit (Dear, 1985, 1986a,b). However, in those reports, he also used both geographic names for complexes of intrusive rocks. In this report, the name Clive Creek Volcanics is applied in the sense used by Dear (1977).

As mapped by Dear, Cycle 1 rocks are restricted to the southern part of the area in the centre of the Broadsound Range between Mount Mackenzie and Clive Creek. Subsequent mapping in this project has not altered the mapped extent to any degree (Figure 35), although in places it was hard to see a distinction between these rocks and those of Cycle 2, the Broadsound Volcanics. However, the common occurrence of fine-grained lithic to quartzose sandstone and siltstone, as well as lithic-rich ignimbrite appears to distinguish the Clive Creek Volcanics.

The rocks tend to crop out poorly, although the topography is relatively steep, and rubble is locally plentiful. The area commonly has acacia scrub and a thick understorey of scrubby bushes making traversing difficult. Dense softwood scrub also occurs in a few places.

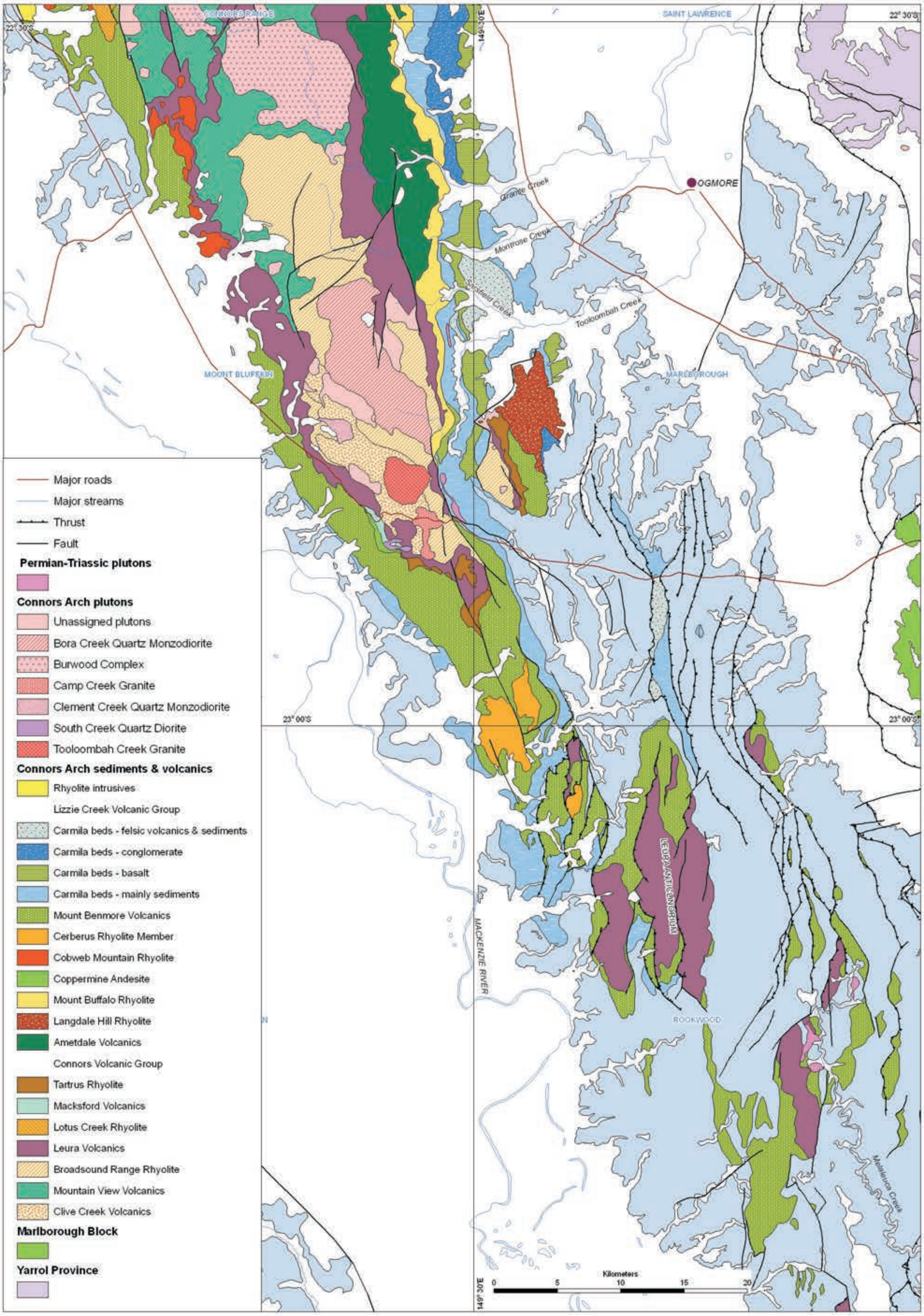

Figure 35. Geology of the southern part of the Connors Arch (Mount Bluffkin–Rookwood)

Type and reference area

It is difficult to define a full section for the Clive Creek Volcanics, because the base is not exposed, and the lack of structural data and poor outcrop makes it difficult to determine whether sections examined are continuous or contain repetitions or faulted-out gaps. Therefore a type area (rather than section) is designated in the upper reaches of Plumtree Creek and its tributaries from MGA 746300 7475200 on the powerline corridor (the approximate position of the contact with the overlying Broadsound Volcanics) to the watershed at MGA 748900 7476350. Fine-grained lithic sandstone, siltstone and lithic-rich ignimbrite crop out in this area.

A reference area is given along the Marlborough–Sarina road (old Bruce Highway) in the Broadsound Range from MGA 752100 7470600 (near the contact with the Camp Creek Granite) to MGA 749800 7470600 (an inferred faulted contact with the Macksford Volcanics). This section exposes a distinctive succession of well-bedded tuffaceous siltstone at around MGA 750400 7470850, and includes the SHRIMP-dated ignimbrite in a cutting at MGA 749900 7470900.

Lithology

Dear (1994a, 1995) suggested that the oldest part of Cycle 1 was represented by a monotonous succession of laminated siltstone and fine-grained quartz-rich sandstone, that crops out poorly at the northern end of the area between Clive Creek and Clement Creek. Several thin sections of very fine-grained to fine-grained sandstone and siltstone from the Clive Creek area were examined. The sandstones are well-sorted, and consist of approximately equal proportions of strained quartz and labile grains, but contact metamorphism has replaced the latter by aggregates of fine-grained muscovite and biotite and it is difficult to determine their nature. Detrital muscovite was also observed in some of the rocks. The more mature composition of the sandstones supports the notion that these rocks are the oldest in the area, forming before the onset of major volcanism. According to Dear (1994a), the fine-grained rocks grade upward through medium to coarse-grained quartzofeldspathic sandstone into the volcaniclastic sequence, but this transition was not observed during this study.

The volcaniclastic rocks are the most abundant, and are exposed in cuttings along the old Bruce Highway in the Broadsound Range as well as creek sections. They appear to be dominated by dark grey, moderately to poorly sorted, lithic-rich, felsic volcaniclastic rocks, including sandstone and locally siltstone. Thin to very thick beds (locally weakly laminated) of cherty siltstone crop out in Plumtree Creek and along the old Bruce Highway (west of the contact with the Camp Creek Granite). They are probably tuffaceous, and some contain scattered feldspar crystals and lithic fragments and grade into crystal-rich volcanolithic sandstone or tuff.

Well-bedded tuffaceous siltstone is exposed further west along the old Bruce Highway around MGA 740600 7470900 (Figure 36a). The rocks are mostly weathered to greyish yellow, but they are pale grey and somewhat cherty in unweathered cores. They are thin to thick-bedded and locally laminated, although mostly massive. They contain sparse feldspar crystals in places, usually <0.5mm, and are predominantly lithic poor, although rare beds contain abundant angular, strongly flattened, aphyric rhyolite up to 1cm. The beds show open folds and are locally steeply dipping.

Many of the volcaniclastic rocks are probably ignimbrite. They contain generally angular to subangular, felsic lithic clasts up to several centimetres in a very fine-grained to aphanitic matrix (Figure 36c). They include aphyric to porphyritic felsic to intermediate volcanic rocks, but also siltstone and fine-grained sandstone as described above, microdiorite and plutonic fragments (mainly monzonitic). Crystal fragments are usually present but commonly sparse, and are mainly feldspar; quartz, if present, is only minor. This contrasts the unit with adjacent areas of Broadsound Volcanics, in which quartz crystals are common. Elongate fiamme or collapsed pumice clasts (mostly up to 1cm, but locally 5cm) are also common. Vitroclastic textures are well-preserved in some of the rocks examined in thin section. The shards are mostly non-flattened and outlined by fine-grained sericite and chlorite or very fine-grained brown turbid alteration products.

The dated ignimbrite sample was collected along the old Bruce Highway at MGA 749900 7470900. The rock in the cutting has common white feldspar crystals to 2mm, elongate fiamme up to 1.5cm and some lithic clasts, similar to the range described above. The flattening of the fiamme is perpendicular to strong polygonal jointing, suggestive of columnar joints (Figure 36b). In thin section the groundmass preserves vague outlines of strongly flattened shards.

Geophysical response

The Clive Creek Volcanics have moderate potassium, a low to moderate thorium and moderate to high uranium responses resulting in mottled pink and bluish hues on composite images.

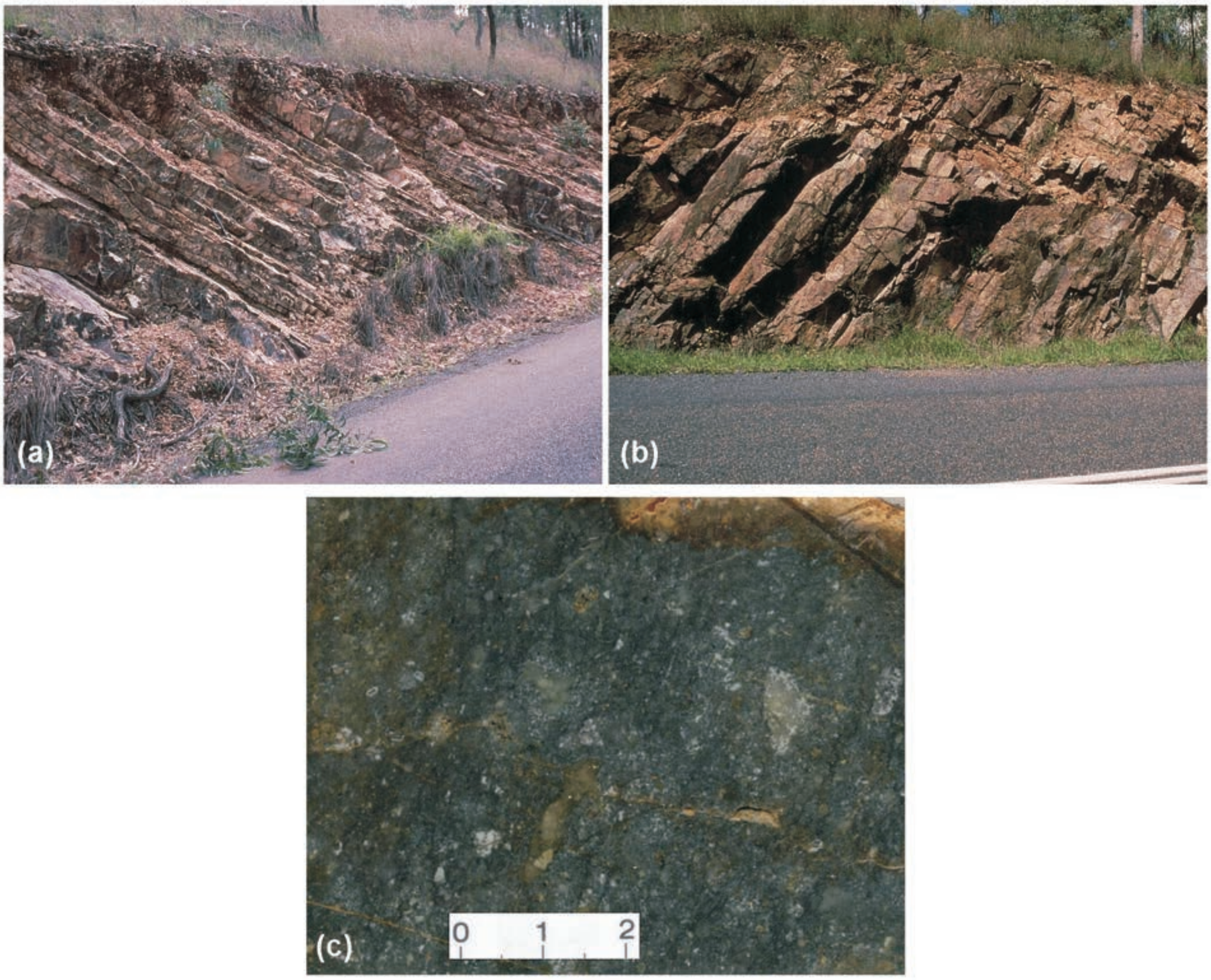

Figure 36. Clive Creek Volcanics
(a) Thin to thick beds of very fine to fine-grained volcanic sandstone and cherty siltstone (tuff?). Old Marlborough–Sarina road, ~1.5km north-east of Mount Mackenzie at MGA 749944 7470781 (IWSC0452)
(b) Columnar jointed rhyolitic ignimbrite. Old Marlborough–Sarina road, ~1.5km north of Mount Mackenzie at MGA 749944 7470781 (IWSC0456-RSC095)
(c) Scanned slab of crystal-poor, moderately lithic-rich rhyolitic ignimbrite. Track to microwave tower on Broadsound Range, 3km north-east of Mount Mackenzie at MGA 751904 7471645 (RSC095). Scale is 2cm.

The unit has a relatively low magnetic response consistent with the magnetic susceptibility values that are nearly all <100 x 10^{-5} SI units with a mean of 48 and a strong mode corresponding to values <10.

Environment of deposition

Dear (1994a,b, 1995) suggested that the rocks were deposited largely by mass flow processes in a submarine environment adjacent to an emergent volcanic arc. The occurrence of well-bedded, laminated siltstones may indicate a subaqueous environment, but not necessarily marine. At least some of the felsic volcaniclastics appear to be ignimbrites, suggesting a subaerial environment, and the abundance of coarse lithic fragments points to a proximal source. Aphyric to slightly porphyritic rhyolite, locally autobrecciated, crops out through the unit. Some of these may be related to the younger cycles, but some may be domes or flows emplaced with the Clive Creek Volcanics, perhaps related to vents.

Relationships and age

The Clive Creek Volcanics are overlain by the Broadsound Range Volcanics. The isotopic dating indicates a large hiatus and the variable dips in the Clive Creek Volcanics suggest that there may also be an angular discordance. East of Mount Mackenzie, the Broadsound Range Volcanics appear to be absent (probably due to erosion) and the Clive Creek Volcanics are directly overlain by the Leura Volcanics. The Clive Creek Volcanics are flanked to the east and west by younger rocks, indicating that they occupy the core of an anticline.

The Clive Creek Volcanics have been intruded and hornfelsed by the Carboniferous Camp Creek Granite, Tooloombah Granite, Bora Creek Granodiorite and Clement Creek Granodiorite as well several other small unnamed granite and microgranite plutons.

A sample from the unit (RSC093) gave an early Carboniferous SHRIMP date of 348.9±4Ma (MSWD of 1.3 from 11 zircons, see Appendix). It also contained inherited grains with ages of 370–380Ma.

MOUNTAIN VIEW VOLCANICS

Introduction

The name Mountain View Volcanics is given to a heterogeneous assemblage of volcanic rocks that crop in the Connors Arch as a partly discontinuous belt ~110km long and up to 25km wide from near Koumala in CARMILA through eastern CONNORS RANGE to near Clarkwoods homestead in MOUNT BLUFFKIN (Figure 37). Hutton & others (1999a) first used the name “Mountain View beds” for rocks in the northern half of this belt, but further studies have led to the unit being extended. As noted below, the unit may be one of the older parts of the Connors Arch. The name is derived from Mountain View Station in north-eastern CONNORS RANGE.

The unit generally forms closely dissected rugged topography. Exposure is plentiful, although relationships between different rock types are difficult to determine.

Type and reference areas

The base of the Mountain View Volcanics is nowhere exposed and the structure is poorly known, so that it is difficult to assign a type section. In addition they mostly crop out in rugged country where access is difficult. The rocks exposed along the Killarney–Burwood road demonstrate the heterogeneous nature of the unit and are here designated as a reference area.

Lithology

Koumala–Carmila area

The Mountain Creek Volcanics in this area consist mainly of very fine-grained to fine-grained, porphyritic basalt and andesite. The range of textures and mineral abundances indicate the presence of several lava flows that are invariably porphyritic. Calcic plagioclase is the dominant type of phenocryst, and is commonly accompanied by subordinate phenocrysts of clinopyroxene (generally unaltered) and minor opaque oxide. In some flows, clinopyroxene is confined to the groundmass as tiny granules (< 0.1mm) in interstices between plagioclase laths (~0.1–0.3mm long). Hornblende (pale green), as small groundmass grains and phenocrysts up to ~2mm long, is the main mafic mineral in a few of the flows examined in detail (*e.g.* east of the Three Sisters and at MGA 736200 7580060, north-west of Carmila).

Most of the basalts and andesites examined have well-preserved primary igneous textures and minerals. Epidote, sericite, and calcite are the most common secondary minerals. Some outcrops are characterised by the presence of sparse, small, irregular amygdales filled mainly with calcite ± epidote.

About 30m of massive andesite or basalt is exposed in the face of an abandoned quarry at MGA 721820 7605220 (west of Hatfield railway siding). The sequence is cut by several faults and is more extensively altered than the mafic rocks examined farther to the east and south-east.

Minor rock types recorded include volcanic breccia and sandstone, lithics-rich dacitic ignimbrite or volcanic breccia, and porphyritic rhyolite (lava).

Mountain View–Collaroy area

The rocks in the Koumala area extend southwards into the Mountain View area, although a separate mafic subunit has not been delineated. A sequence of mafic to intermediate volcanics, massive conglomerate with minor medium to coarse labile sandstone, and grey to cream siltstone to shale crop out along Kangaroo Creek north-east of Mountain View homestead. Clasts in the conglomerate beds comprise mainly felsic volcanics and are not derived from the adjacent mafic to intermediate volcanics.

In the eastern part of Collaroy Station, rock types include massive dark grey andesite to basalt, massive pebble to cobble conglomerate, fine-grained greyish purple sandstone, thin-bedded feldspathic sublabile

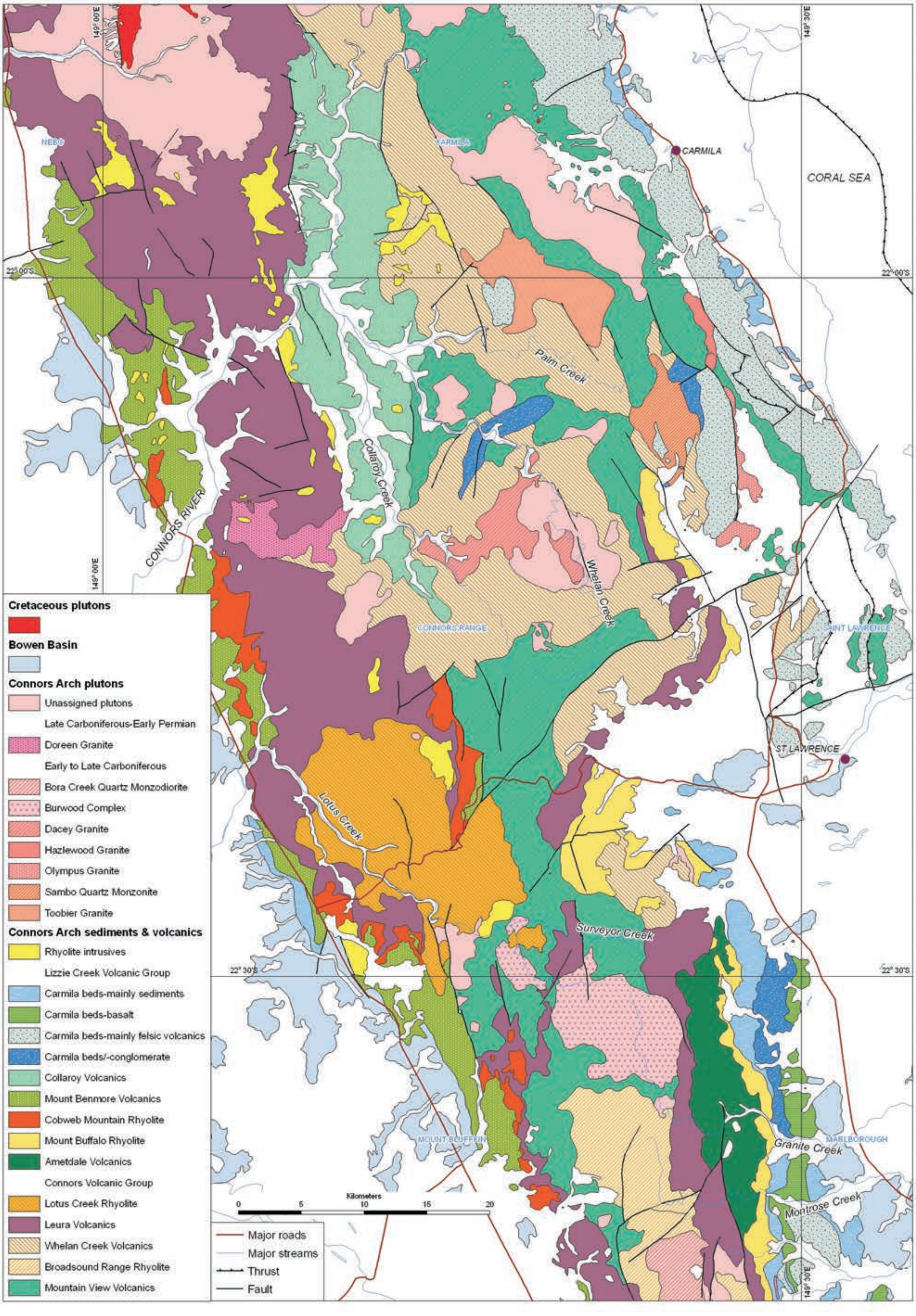

Figure 37. Geology of the central part of the Connors Arch (Connors Range)

pebbly sandstone, dacitic ignimbrite and andesitic breccia. Massive andesite to basalt and andesitic to dacitic breccia are the dominant rock types east of Marylands homestead.

Farther east, basalt or basaltic andesite crops out around Clairview homestead and in the valley of Clairview Creek.

Killarney–Burwood area

Another heterogeneous sequence of rocks crops out along and adjacent to the Killarney–Burwood road, north of the Burwood Complex. Hutton & others (1999a) did not assign them to their “Mountain View beds” but suggested that they could be related. These rocks are now assigned to the Mountain View Volcanics due to the similarity of radiometric response.

The sequence includes volcanic sandstone and conglomerate and crystal-rich ignimbrite (including varieties that contain only feldspar and others that include quartz crystal fragments), as well as mainly subordinate mafic flows and volcaniclastic rocks.

The sandstones are feldspatholithic, thick to very thick bedded, medium to very coarse-grained and are commonly moderately well-sorted. They contain up to 40% subangular to angular feldspar grains and generally minor angular volcanic quartz, (although locally it is abundant). The lithic fragments show a range of textures and compositions from aphyric and porphyritic felsite to andesite or basalt with felted (flow-aligned) fabrics. Matrix is commonly hard to resolve from the lithic fragments in thin section, but appears to be relatively minor in some samples. Some rocks however, do contain significant matrix (up to 50%), and some of these may include ignimbrite, although vitroclastic textures are rare in thin section. The sandstone beds are commonly massive and bedding is poorly defined. The better-sorted rocks locally have crude internal stratification, mainly planar laminae and rarely cross-bedding. A range of depositional mechanisms from fluvial to mass flow is suggested for the volcaniclastic rocks.

Also present are feldspar-phyric dacite or rhyolite flows and dark grey aphyric to porphyritic andesite or basalt. Thin sections of the latter contain flow-aligned plagioclase microlites and interstitial clinopyroxene and opaques.

Wahroonga–Clarkwoods area

In this area in the north-west of MOUNT BLUFFKIN, the rocks now assigned to the Mountain View Volcanics appear to dip to the east, contrasting with the westerly dipping Mount Benmore Volcanics overlie them to the west.

The lowermost rocks in the area are greyish purple, flow-banded feldspar-phyric rhyolite flows that have a deep pink hue on the composite radiometric image.

The rhyolite is overlain by dark grey to greyish purple, aphyric to slightly porphyritic andesite or basalt flows and minor volcanic sandstone and rudite. The rocks are commonly strongly hematised and epidotised. Where fresh, the lavas consist of flow-aligned plagioclase crystals to 0.2mm and interstitial hornblende, clinopyroxene and opaques.

Further east and up-sequence, the rocks also appear to be dominated by andesitic or basaltic volcaniclastic sandstone and rudite and flows. However, some rhyolite flows and crystal-rich (feldspar-phyric) ignimbrite that form prominent strike ridges were also observed. The ignimbrite sheets are probably mostly no more than a few tens of metres thick, contrasting with the more massive and thicker ignimbrites in the Broadsound Range Volcanics.

The mafic rocks are similar to some of those mapped as Leura Volcanics, and it is difficult to distinguish them where they are in contact. A tentative boundary in the Stockyard Creek and Clarkwoods areas is based on information from John Dear’s notebooks and observations made during this project. Rocks with clear westerly dips have been placed in the Leura Volcanics, whereas andesite and dacite intercalated with quartz-phyric ignimbrite are regarded as Mountain View Volcanics. In places, there also appears to be a thick-bedded conglomerate at the base of the westerly-dipping rocks. The problem is more difficult in the area to the east of Wahroonga and Spring Hills homesteads where the Leura Volcanics overlying a basal conglomerate define shallow synclines and partly down-faulted blocks within the Broadsound Range Volcanics well into the core of the Connors Arch. As an example of the difficulty in assigning the rocks, a sample of crystal-rich, lithic-poor rhyolitic crystal-rich ignimbrite (IWSC0897) from east of Wahroonga was dated by SHRIMP, to determine the age of the Mountain View Volcanics. However, the unexpected young age (early Permian — see Appendix) indicates that the ignimbrite is probably part of an in-faulted block of Leura Volcanics.

Geophysical response

The Mountain View Volcanics have variable but generally low radiometric responses in all three channels resulting in mottled dark greyish to pinkish hues in composite images that contrast with the more uniformly potassic Whelan Creek and Broadsound Range Volcanics and Lotus Creek Rhyolite. The lower radiometric response reflects the abundance of mafic volcanics in the sequence, but the variability reflects the scattered more felsic rocks. The response of the mafic rocks in southern CARMILA is uniformly lower and contrasts with the moderate responses of the felsic volcaniclastic rocks in the Carmila beds.

The Mountain View Volcanics have a moderate to high response in the airborne magnetic data, particularly in southern CARMILA. However, even in the southern part of the outcrop area between Burwood and Killarney, the response is moderate and contrasts with the low response of the Lotus Creek Rhyolite. This is consistent with the magnetic susceptibility data. Although about half of the measurements of both mafic and felsic rocks are <100 x 10^{-5} SI units, the mafic rocks range up to ~4500 with sporadic values up to 10000 and an overall mean of 1780. The more felsic volcanic and sedimentary rocks have a mean of 526 and are mostly <1000.

Environment of deposition

The Mountain View Volcanics are regarded as being of subaerial origin. Welded ignimbrites are locally present and pillow structures have not been observed in any of the mafic lavas. The volcaniclastic sedimentary rocks may have been formed by a variety of processes ranging from mass flows to fluvial traction currents. The rare fine-grained sedimentary rocks could represent locally developed lacustrine environments.

Geochemistry

Thirty-six samples from the Mountain View Volcanics were analysed for a range of major and trace elements. The samples are mostly of lavas, but some samples of clastic rocks including ignimbrite were also analysed. The rocks show a complete range from basalt to rhyolite using the total alkalis-silica plot (Figure 38a). In particular, andesitic compositions are well represented and there is no bimodality suggestive of an extensional tectonic setting. The plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) in Figure 38b supports this conclusion. Because it uses immobile elements, this plot provides a method of classifying the original composition of altered volcanic rocks. It suggests that the Mountain View Volcanics have not been altered significantly.

The Ti-Zr discriminant diagram in Figure 38c shows them to be predominantly calc-alkaline basalts rather than low-K tholeiites like the Campwyn Volcanics, which may partly overlap in age with the Mountain View Volcanics

Three of the basaltic samples were submitted for precise trace element analysis by laser ablation mass spectrometry, and the data have been used to construct the multi-element and rare-earth-element (REE) plots in Figure 38. The three samples are very similar to each other in both plots. The REE pattern is relatively steep with only a slight Eu anomaly, and in the multi-element plot, the rocks are depleted in Ti relative to MORB, but are otherwise enriched. They show a pronounced Ta–Nb trough indicating a strong subduction component.

The plots were compared with those from modern basaltic suites using the database compiled from literature by Murray & Blake (2005, appendix 1). The Mountain View Volcanics most closely match basalts from the Peteroa suite in the Southern Volcanic Zone of the Andes (Tormey & others, 1995), where the crust is 40–45km thick. This suggests that the Mountain View Volcanics were erupted in a continental margin volcanic arc on moderately thick crust.

The REE and multi-element patterns contrast with those of the Late Devonian to early Carboniferous Campwyn and Tanderra Volcanics and the Lochenbar suite of the Yarrol province which all have shallower slopes (Figures 26 and 27). The Lochenbar suite was probably erupted in an intra-oceanic volcanic arc setting (Murray & Blake, 2005). However, although most samples from the Late Devonian Mount Hoopbound Formation in the Yarrol Province are part of the Lochenbar suite (Murray & Blake, 2005), two samples of basaltic andesite from the unit are similar to the Mountain View Volcanics as illustrated in Figure 38d–e. Murray & Blake concluded that the Late Devonian rocks of the Yarrol Province represent a transition from an intra-oceanic to continental-margin arc. The two samples from the Mount Hoopbound Formation may reflect an advanced stage of this transition to a continental margin arc, which was fully established in the early Carboniferous when the Mountain View Volcanics were erupted.

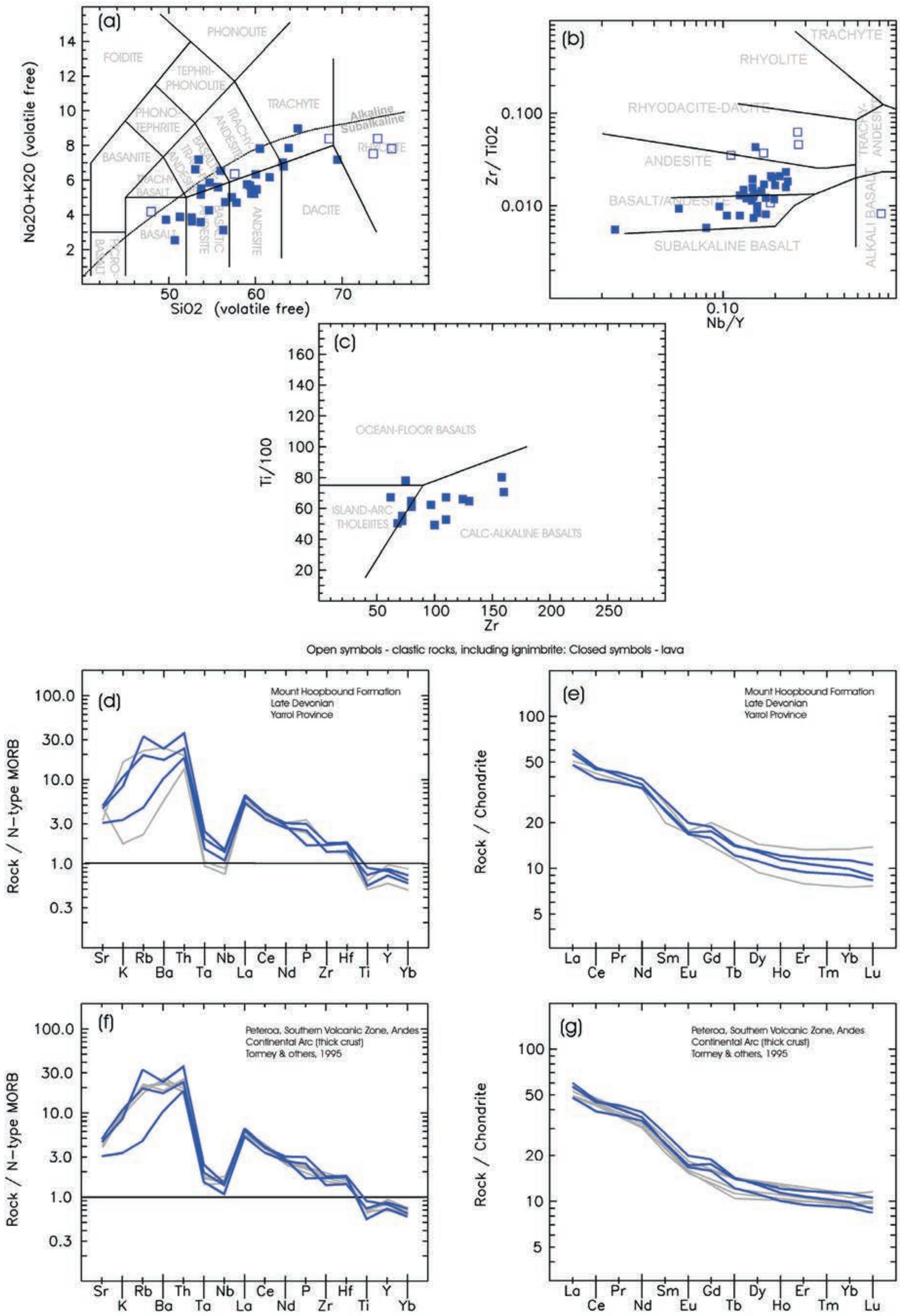

Figure 38. Geochemistry of the early Carboniferous Mountain View Volcanics: (a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986) and Irvine & Baragar (1971); (b) Nb/Y vs Zr/TiO_2 showing the fields of Winchester & Floyd (1977); (c) Zr vs Ti/100 in ppm for basalt and basaltic andesite samples showing the fields of Garcia (1978); (d, f) N-MORB normalised multi-element plot (using values from Pearce, 1983) for three basalt samples; (e, g) chondrite-normalised REE plot (using values from Sun & McDonough, 1989) for three basalt samples. For comparison, modern basaltic suites as indicated are shown in grey in (f) and (g).

Relationships and age

The Mountain View Volcanics have not yet been dated directly but are intruded by the Burwood Complex which has given a mid-Carboniferous age of 328±4Ma. Other plutons that intrude the Mountain View Volcanics are the Dacey Granite, Hazlewood Granite, Olympus Granite and Toobier Granite as well as smaller unnamed plutons of both Carboniferous and possible Cretaceous age.

The Killarney–Burwood sequence dips eastwards, suggesting that it overlies the Lotus Creek Rhyolite, which crops out to the west. This is inconsistent with the much younger SHRIMP age (295±5Ma) for the Lotus Creek Rhyolite. If the latter is a flat-lying sheet, it is possible that it unconformably overlies or is faulted against the easterly dipping rocks.

The Mountain View Volcanics are presumed to be overlain by the Broadsound Range Volcanics, but this is difficult to demonstrate in the field. However, the Broadsound Range Volcanics are known to be younger, based on SHRIMP dating. Farther north in CONNORS RANGE, the Mountain View Volcanics are overlain by the Whelan Creek Volcanics which have a similar age to the Broadsound range Volcanics.

The Mountain View Volcanics are overlain by the Leura Volcanics on the western side of the Connors Arch in the Clarke Creek area. The Leura Volcanics and locally the Carmila beds also overlie the Mountain View Volcanics west of Clairview.

The Mountain View Volcanics are thus interpreted as one of the oldest units in the Connors Arch, and may be early Carboniferous like the Clive Creek Volcanics at ~350Ma or perhaps of some intermediate age between the latter and the Burwood Complex at ~330Ma. However, given the abundance of mafic volcanics, particularly in the north in the Koumala and Clairview areas, it is possible that the Mountain View Volcanics are an onshore equivalent of the Late Devonian to early Carboniferous Campwyn Volcanics, which are dominantly submarine mafic volcanic and volcaniclastic sedimentary rocks. The Campwyn Volcanics crop out discontinuously along the coast north from about Notch Point to Midge Point in the Proserpine 1:250 000 Sheet area, and are considered to be a northern extension of the Yarrol Province.

BROADSOUND RANGE VOLCANICS

Introduction

This name is applied to volcanic rocks that make up the central core of the southern Connors Arch in the Broadsound Range, from east of Clarkwoods homestead to just south of the old Bruce Highway (Figures 35 and 37). They were assigned to Cycle 2 of the Connors Volcanics by Dear (1994a,b, 1995). The name was used informally for these rocks by Dear in some of his earlier reports (for example Dear, 1977, 1986a,b)

The unit generally forms closely dissected rugged topography. Exposure is plentiful, although relationships between different rock types are difficult to determine. The rocks are commonly massive and stratification not well defined.

Felsic volcanic rocks forming the oldest part of the Langdale Inlier have also been assigned to the Broadsound Range Volcanics.

Type area

No continuous section has been examined through the Broadsound Range Volcanics, so a type area is designated on the eastern side of the Broadsound Range from the old Bruce Highway north to the Tooloombah Granite. In this area they are underlain by the Clive Creek Volcanics and overlain by the Leura Volcanics. Good outcrop occurs in cuttings along the road and in Camp Creek to the north of the road and include rhyolitic lavas and crystal-rich ignimbrite.

Lithology

Rocks assigned to this unit are an assemblage of crystal-rich, mainly rhyolitic ignimbrite, rhyolite flows and probable domes, and subordinate more mafic flows and volcaniclastics and locally sandstone, conglomerate and siltstone.

Crystal content of the ignimbrites is commonly >50%, and generally includes abundant embayed quartz grains up to 4mm in diameter as well as feldspar fragments. Most thin sections examined also contain minor crystal fragments of biotite and/or hornblende or their alteration products. Lithic fragments are generally sparse

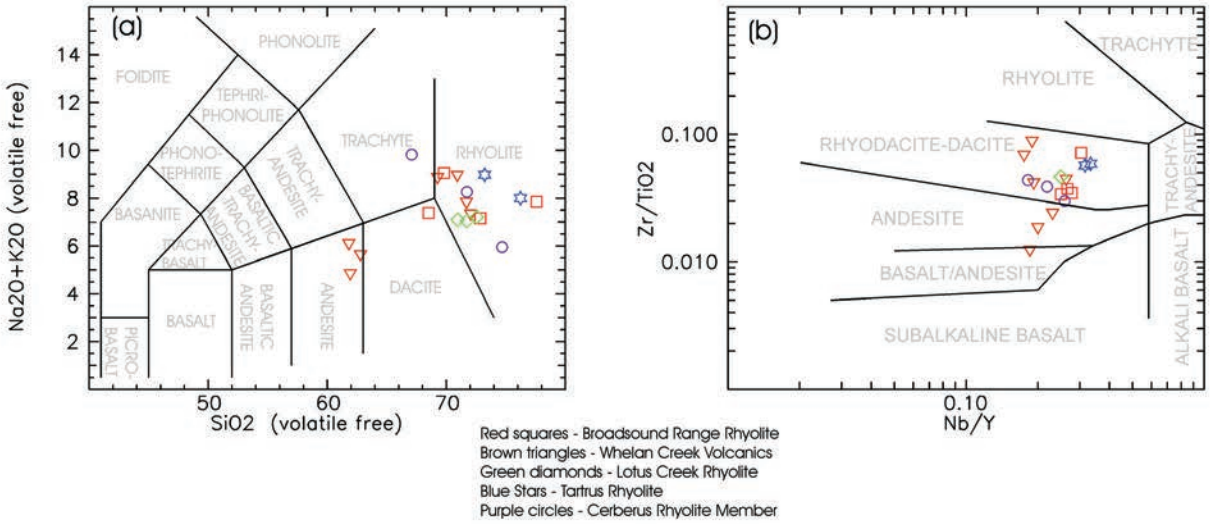

Figure 39. Geochemical classification of late Carboniferous to early Permian felsic volcanic suites from the Connors Arch: (a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986); (b) Nb/Y vs Zr/TiO_2 showing the fields of Winchester & Floyd (1977).

(<5%) and are mostly felsic, but also include microdiorite, granophyre and monzonite, and in some samples, siltstone and sandstone. Flattened and aligned fiamme consisting of aphyric to porphyritic rhyolite up to 1cm long are locally present. Relict flattened, platy shards are visible in most thin sections examined, except where the rocks have been recrystallised by proximity to the various plutons that intrude the unit.

Four samples of ignimbrite from the Broadsound Range Rhyolite were analysed for a range of major and trace elements. The plot of total alkalis vs SiO_2 indicates that rocks are predominantly rhyolite or rhyodacite-dacite if the classification based on immobile elements is used (Figure 39). A rhyolitic composition rather than dacite is consistent with the abundance of quartz crystal fragments.

Generally the paucity of continuous outcrop and lack of stratification does not allow the thickness of individual sheets to be determined, but the ignimbrite is uniform over several kilometres of traversing in some areas (for example east of Clarkwoods homestead), suggesting that some sheets could be hundreds of metres thick. This would suggest emplacement by cauldron subsidence, although mapping of the cauldrons has not been attempted.

The presence of quartz and paucity of lithic fragments distinguish the rocks from the Clive Creek Volcanics, although ignimbrites that are only sparsely quartz-phyric do occur in the unit. The quartz-bearing ignimbrites are similar to those in the Lotus Creek Rhyolite and some in the Leura Volcanics, but unlike those units are intruded and hornfelsed by various plutons such as the Bora Creek Granodiorite and Tooloombah and Camp Creek Granites. However, it is possible that some areas of quartz-bearing crystal-rich ignimbrites could be equivalents of the Lotus Creek Rhyolite or the ignimbrites in the Leura Volcanics.

Other rocks that crop out within this unit include flow-banded to massive, aphyric to slightly porphyritic rhyolite. This probably includes flows, domes and dykes as in the Clive Creek Volcanics. Basalt was also observed locally, and although it could include flows, it is likely that dykes related to the overlying Leura and Mount Benmore Volcanics are present.

Sedimentary rocks are rare, but beds of fissile siltstone were observed at MGA 755600 7469000.

O'Brien (1994) studied the southernmost part of the Langdale Inlier where the oldest rocks appear to be a sequence of grey, autobrecciated and locally flow-banded aphyric to feldspar-phyric rhyolite lavas. They are commonly strongly fractured and pyritic. Although similar rocks occur in both the Clive Creek and Broadsound Range Volcanics, the rhyolite is tentatively assigned to the latter. It is overlain to the north-east by pebble to cobble conglomerate and aphyric dacite or andesite, which probably correlates with the Leura Volcanics.

Geophysical response

As expected from a felsic volcanic unit, the Broadsound Range Volcanics show moderate to strong potassium response in the radiometric data, although the thorium and uranium responses are only moderate. The unit is thus characterised by mostly pale pink hues on composite images.

The unit has a variable magnetic response and is low in much of the area, although in the north between the Bora Creek Granodiorite and Burwood Complex it shows some moderate to strong magnetic features. This area was not accessed and the nature of these features is not known. The magnetic susceptibility values are mostly <100 x 10^{-5} SI units with a strong mode for values <10. However, the overall mean is 193 and sporadic values extend to about 4000.

Relationships and age

The Broadsound Range Volcanics overlie the Clive Creek Volcanics in the southern part of the Connors Arch, and are intruded by a variety of named and unnamed granite, granodiorite and monzonite plutons, including the Bora Creek Quartz Monzodiorite, the Camp Creek Granite and the Tooloombah Granite. The Leura Volcanics, which overlie the Bora Creek Quartz Monzodiorite and the Tooloombah Granite, also unconformably overlie the Broadsound Range Volcanics.

The relationship of the Broadsound Range Volcanics to the Mountain View Volcanics is difficult to demonstrate in the field, but the Broadsound Range Volcanics are known to be younger, based on SHRIMP dating. Although the Mountain View Volcanics have not been dated directly, they are intruded by plutons that have been dated at ~330Ma (early Carboniferous).

Two samples of the unit have been dated by SHRIMP (see Appendix). The two ages are within error of each other and indicate a late Carboniferous age. Dating of a sample of crystal-rich, lithic-poor rhyolitic ignimbrite (IWSC0699) from near its contact with the Bora Creek Monzodiorite gave a preferred weighted mean of 308.4±3.3Ma from 13 analyses with a MSWD of 1.16. Another sample from along the powerline south of the old highway (IWSC0323) gave an age of 313.8±3.4Ma (MSWD =2.2 from 15 analyses). Two grains gave inherited ages of ~340Ma and ~330Ma and may be derived from the Clive Creek Volcanics or granites like the Burwood Complex .

WHELAN CREEK VOLCANICS

Introduction

The Whelan Creek Volcanics crop out in northern CONNORS RANGE extending into CARMILA (Figure 37). The name is derived from Whelan Creek, a tributary of the Connors River in northern CONNORS RANGE. The rocks are relatively well exposed and form rugged, strongly dissected topography within the Connors Range. There are two main areas of outcrop separated by a narrow belt of Mountain View Volcanics along the valleys of Kangaroo and Back Creeks. Smaller outliers of felsic volcanic rocks (mainly ignimbrite) near Freshwater, Spring Valley, and Rosedale and along the edge of the Connors Range near Ripplebrook are also assigned to the unit. Total area is ~500km^2.

Type area

A type area is designated along 18 Mile Creek and the adjacent Maryland–Killarney road between MGA 732900 7541100 and MGA 735300 7535600. Outcrop consists dominantly of grey crystal-rich, locally lithic-rich rhyolitic ignimbrite and locally some minor intrusives and sedimentary rocks including peperite.

Lithology

The Whelan Creek Volcanics are dominated by massive, generally dark grey, crystal-lithic rhyolitic to dacitic ignimbrite sheets. The rocks are crystal-rich, mostly containing feldspar fragments, and are variably quartz-bearing (Figure 40c). Mafic crystals fragments, mainly hornblende are also present. Lithic clasts up to 15cm range from andesite to rhyolite (Figure 40d). Fiamme are locally present and define a foliation (Figure 40a).

Along the Maryland–Killarney road at MGA 735100 7537000, thick-bedded cobbly lithic sandstone overlies massive ignimbrite and is interbedded with mudstone and siltstone. Some of the siltstone is interbedded with thin crystal-rich ignimbrite layers. The siltstone appears to intrude into the ignimbrite and contains clasts of ignimbrite (Figure 40b). The rocks resemble peperite, which forms where volcanic rocks interact with wet

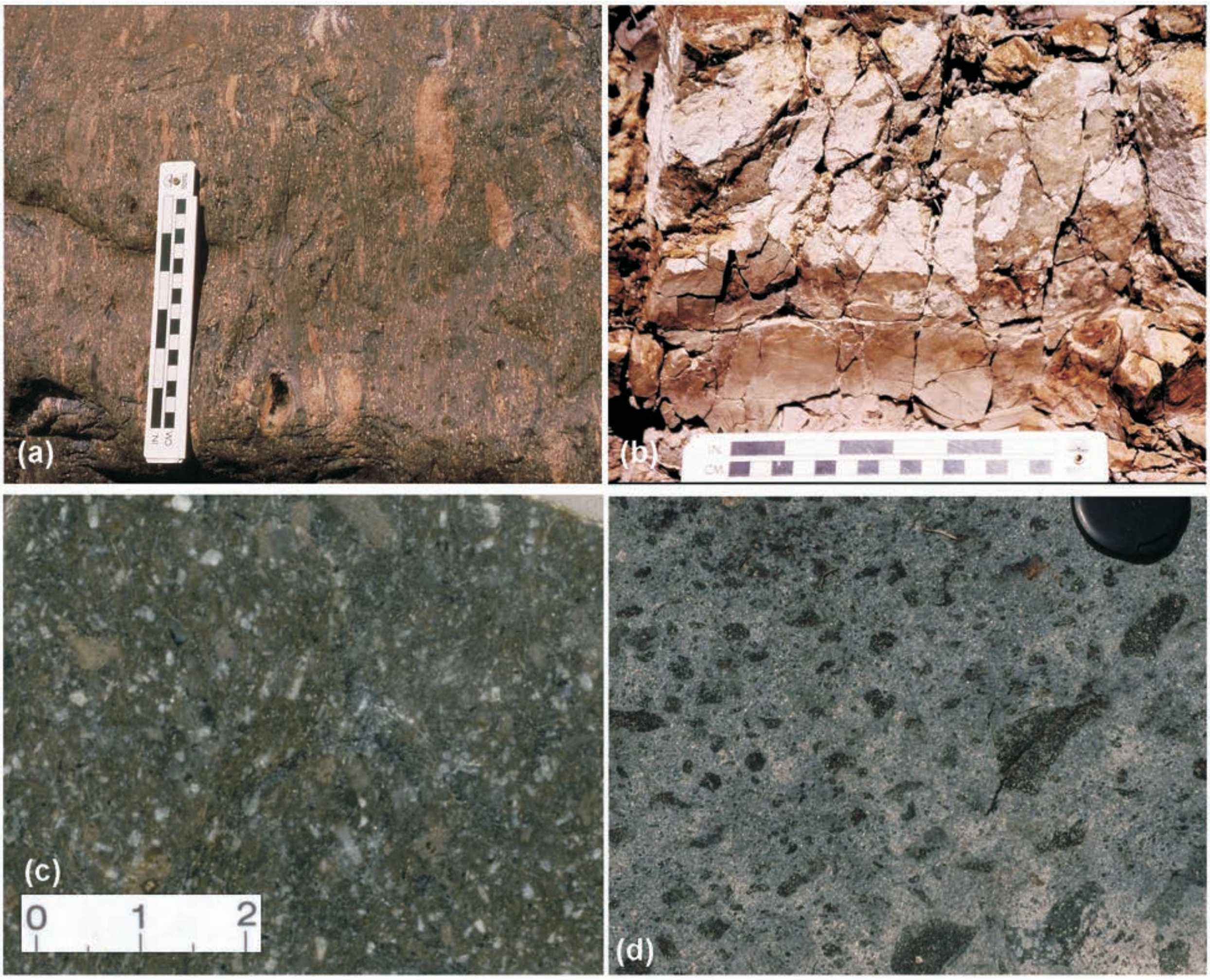

Figure 40. Whelan Creek Volcanics
(a) Feldspar-phyric, crystal-rich rhyolitic ignimbrite containing abundant flattened fiamme. Cattle Creek, 7.7km east of Collaroy homestead at MGA 733208 7560900 (LHC253)
(b) Peperitic contact between rhyolite ignimbrite(?) and an underlying siltstone bed. Jump-up on Maryland–Killarney road, 11km north of Killarney at MGA 735103 7536969 (RSC060)
(c) Scanned slab of moderately lithic-rich and feldspar-phyric crystal-rich rhyolitic ignimbrite. Same locality as (b). Scale is 2cm.
(d) Crystal and lithics-rich rhyolitic ignimbrite. Top of jump-up on Maryland–Killarney road, 11km north of Killarney at MGA 735157 7536753 (RSC061)

sediment. Lithic sandstone and thinly laminated very fine-grained volcaniclastic siltstone is interbedded with ignimbrite to the north of Dacey homestead.

The presence of fine-grained sedimentary rocks suggests local subaqueous deposition. The presence of very thick ignimbrite (which are most likely subaerial) indicates that a non-marine, probably lacustrine or fluvial environment is most likely for these sediments.

Fort Arthur, a prominent hill in eastern CONNORS RANGE south-west of Spring Valley homestead (Figure 34c), was previously mapped as a Cretaceous microsyenite plug. However, no evidence for such an intrusive was found during the current survey. The Fort Arthur area comprises grey, rhyolitic to dacitic ignimbrite with sparse lithic clasts, feldspar and mafic crystals, and abundant vitric groundmass. South-west of Fort Arthur, the dominant rock types are flow banded, aphyric rhyolite, rhyolitic to dacitic ignimbrite, and quartz-phyric rhyolitic ignimbrite.

Seven samples of ignimbrite from the Mount Whelan Volcanics were analysed for a range of major and trace elements. The plot of total alkalis vs SiO_2 indicates that, although four are rhyolite, three are andesite and this is supported by the classification using immobile elements (Figure 39).

Geophysical response

The Whelan Creek Volcanics have a moderate to high potassium response and low to moderate thorium and uranium, generally producing pale pinkish to bluish white hues on composite images. The response is similar to the granite plutons that intrude them, suggesting a similar composition and possible genetic relationship.

The southern outcrop area has a low to moderate, somewhat variable magnetic response. Almost half of the magnetic susceptibility values measured are <10 x 10^{-5} SI units, but values range up to 1200 and the overall mean is 260. A magnetically low area within a large circular feature, ~2km in diameter, noted on geophysical images south west of Mount Arthur, consists of argillically altered rhyolite surrounded mainly by quartz-phyric rhyolitic ignimbrite.

Relationships and age

The Mount Whelan Volcanics are interpreted to overlie the Mountain View Volcanics, at least disconformably. North-east of Dacey homestead they are overlain by a belt of conglomerate tentatively assigned to the Carmila beds. The unit is intruded by the Dacey Granite and Toobier Granite and various unnamed plutons.

SHRIMP dating of the Whelan Creek Volcanics indicates a late Carboniferous age (see Appendix). The data show scatter about a bimodal peak and include inherited grains as well as some with Pb loss. Rejecting these, produces ages of 314.1±5.0Ma (MSWD of 1.3, based on 8 analyses) and 317.7±5.6Ma (MSWD of 2.4 based on 11 analyses). The obviously inherited grains have ages of 976, 356 and 345Ma, but three at about 328 may also be inherited. They are similar in age to the Burwood Complex and an inherited zircon population in the Hazlewood Granite. The ages are within error of the age obtained for the Dacey Granite, suggesting a comagmatic relationship.

LOTUS CREEK RHYOLITE

Introduction

The Lotus Creek Rhyolite is a sequence of crystal-rich rhyolitic ignimbrite in the central part of the Connors Arch. The name is derived from Lotus Creek, a major tributary of the Connors River. As presently mapped, the unit crops out over a roughly rectangular area 10–14km wide, extending for ~15km from near the southern edge of CONNORS RANGE to north of Millers Mountain (Figure 37).

The unit crops out well, forming low boulder-strewn hills, closely dissected with a dendritic to trellised drainage pattern. The unit has a relatively strong radiometric response in all channels, and on the composite radiometric images, shows pale pink to whitish hues.

Type area

The section along the Killarney to Croydon road between the crossings of Big Coddling Creek and Lotus Creek was given as the type section of the Connors Volcanics (Malone & others, 1966, 1969). It is designated here as the type area for the Lotus Creek Rhyolite and it consists entirely of massive, grey, crystal-rich rhyolitic ignimbrite (Figure 41b). No location where the base is convincingly exposed is known. The unit may represent the infill of a large cauldron subsidence area, and many of the contacts with older units may be faulted. The contact with the overlying Leura Volcanics is mapped at MGA 724600 7516300 along the road west of Lotus Creek, but the exposure here is poor.

Lithology

As in the type area, the Lotus Creek Rhyolite mostly comprises massive, grey, crystal-rich, lithic-poor, rhyolitic ignimbrite. Crystal fragments are up to 60% of the rock and include quartz, plagioclase and K-feldspar up to 4mm. In some samples quartz is almost as abundant as feldspar and is generally strongly embayed. Chloritised biotite flakes up to 1mm are also common in all samples examined in thin section. Dark grey, aphyric to porphyritic, lithic fragments are up to 5cm, although they are generally sparse and subordinate to the crystals. They are mostly felsic (including reworked volcaniclastic rocks), but also include andesite with flow-aligned feldspar laths. Fiamme occur in places, but are generally not common. The groundmass is commonly completely recrystallised to a very fine-grained (0.01–0.02mm) felsic mosaic, but vague outlines of devitrified shards are present in some samples. No extensive areas of intrusive rocks are known to have affected the unit, so the recrystallisation suggests emplacement as very thick sheets or composite cooling units that cooled relatively slowly.

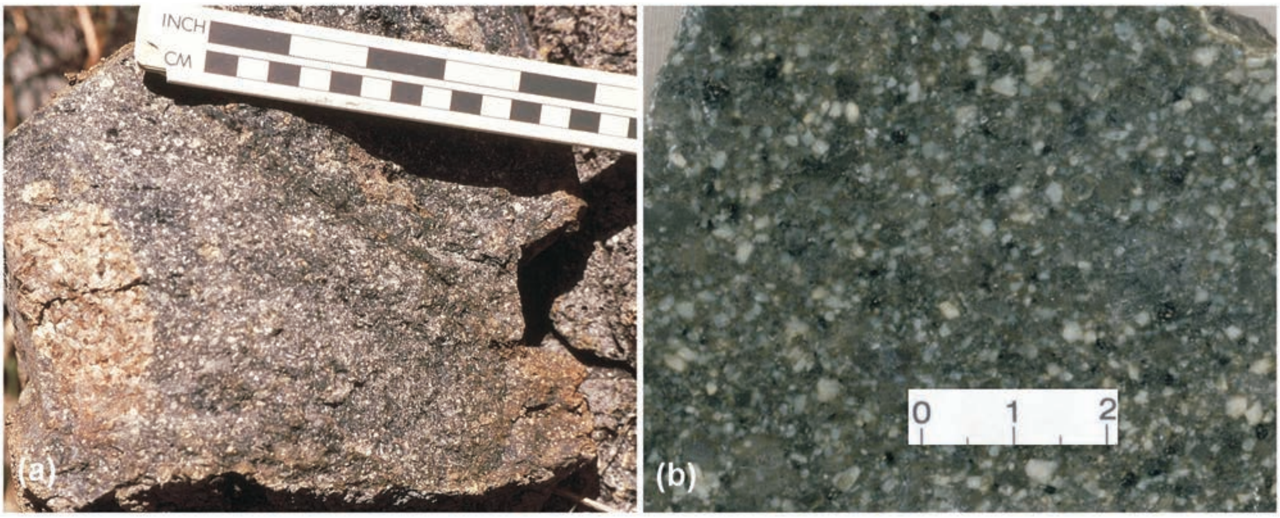

Figure 41. Lotus Creek Rhyolite
(a) Crystal-rich rhyolitic ignimbrite containing a granite clast. About 10.5km east of Croydon homestead at MGA 733551 7515396 (IWSC1109)
(b) Scanned slab of quartz-feldspar-phyric crystal-rich rhyolitic ignimbrite. Croydon–St Lawrence road ~8.5km north-east of Croydon homestead at MGA 729517 7519513 (RSC078). Scale is 2cm.

Throughout most of the outcrop area, the unit shows only minor variation. However, in the south, adjacent to Lotus Creek, abundant granitoid clasts up to 15cm and aligned, elongate fiamme up to 5cm are common (Figure 41a). These rocks have been delineated as a separate subunit of the Lotus Creek Rhyolite (Subunit $\mathbf{CPvo_f}$). The granitoid clasts are pink equigranular hornblende-biotite granite, similar to rocks in the Burwood Complex and unnamed plutons to the south of the Lotus Creek Rhyolite. Crystal fragments are also abundant, comprising feldspar, quartz and minor chloritised biotite. Although most are of volcanic origin, some fragments are derived from the granite. In thin section, outlines of devitrified, strongly flattened and aligned shards are preserved.

At MGA 732800 7515500, breccia consisting of subangular pink granite clasts and fine chips of quartz and feldspar in a fine-grained epidotised matrix was observed within subunit $\mathbf{CPvo_f}$. This probably forms a small pipe. Strong brecciation is also evident in some of the unnamed plutons adjacent to the southern edge of the subunit, such as at MGA 733650 7514750 and 732100 7513700. The breccias and clast-rich ignimbrite may indicate proximity to an eruptive centre.

Three samples of ignimbrite from the Lotus Creek Rhyolite were analysed for a range of major and trace elements. The plot of total alkalis vs SiO_2 in Figure 39 indicates that rocks are rhyolite.

Geophysical response

The Lotus Creek Rhyolite has a moderate potassium response and low to moderate thorium and uranium responses resulting in mottled greyish pink hues on composite images contrasting with the darker greyish hues of surrounding Leura and Mountain View Volcanics.

The unit has a low magnetic response consistent with the magnetic susceptibility values that are mainly $<100 \times 10^{-5}$ SI units with a strong mode representing values <10. The mean of 110 reflects sporadic higher values up to a maximum of ~1100.

Relationships and age

The Lotus Creek Rhyolite is latest Carboniferous or early Permian. A sample from Big Coddling Creek near the Killarney to Croydon road yielded a U–Pb (SHRIMP) age of 295±3.4Ma (11 grains with a MSWD of 0.85; see Appendix). This is younger than the preliminary age of ~303Ma referred to by Withnall & others (1997, 1998a) and Hutton & others (1999b), and is due to reprocessing of the original machine data using the SQUID program of Ludwig (2000).

The exact relationship of the Lotus Creek Rhyolite to some of the surrounding units is unclear. The unit may represent the infill of a large cauldron subsidence area, and many of the contacts with older units may be faulted. The curved outlines of the margins of the unit in the north-west and to some extent in the south-east suggest that they are ring faults. It is possible that the unit represents a single, flat-lying ignimbrite sheet.

This is consistent with the photo-pattern of the unit, which shows dendritic to trellised drainage reflecting joints and lacking any clear bedding trends. This pattern contrasts with that of the Mountain View Volcanics to the south, which show stronger bedding trends, and consistently dip to the east. It also postdates the Burwood Complex and other nearby plutons, because clasts of rocks similar to those of the complex occur in the ignimbrites of subunit $\mathbf{CPvo_f}$ along Lotus Creek, and in breccia pipes that cut the ignimbrite. This is consistent with the SHRIMP date of 328±4Ma obtained for the Burwood Complex (see Appendix).

Dear (1994a,b, 1995) considered that the rocks now assigned to the Lotus Creek Rhyolite (being the type area for the Connors Volcanics) were part of his Cycle 2. However, the isotopic dating and relationships suggest that it is part of his Cycle 3. Crystal-rich rhyolitic ignimbrite that crops out at the base of the Leura Volcanics east of Killarney and east and north of the Burwood Complex could be equivalent to the Lotus Creek Rhyolite, perhaps as outflow from the main cauldron. A thick development of crystal-rich rhyolitic ignimbrite in Montrose Creek, mapped as part of the Leura Volcanics, may represent a separate smaller cauldron, perhaps similar in age to the Lotus Creek Rhyolite.

West of Lotus Creek in the Cobweb Mountain area, the Lotus Creek Rhyolite is overlain by a sequence of greyish purple, pebble to boulder conglomerate and sandstone (derived from dacitic or andesitic volcanics), interbedded with lavas of similar composition. These rocks are assigned to the Leura Volcanics. Along Yellow Creek west of Killarney homestead, the Lotus Creek Rhyolite is overlain by a thin sequence of similar rocks, which are in turn overlain by felsic volcanogenic arenite, conglomerate and possible tuff assigned to the Cobweb Mountain Rhyolite.

Although probably post-dating the main intrusive units in the area, the Lotus Creek Rhyolite is locally intruded by small bodies of grey porphyritic microgranite. The extent of these bodies is unknown, but they are probably dykes or small plugs and are no more than a few hundred metres wide. They generally contain phenocrysts of embayed quartz, feldspar and minor altered biotite in a microgranular groundmass, and may be co-genetic with the Lotus Creek Rhyolite. Dolerite dykes also intrude the rhyolite.

LEURA VOLCANICS

Introduction

Withnall & others (1998a,b) gave this name to a sequence of mainly felsic to intermediate volcanic and related epiclastic sedimentary rocks that form the southern end of the Connors Arch, the core of the Leura Anticlinorium and partly fault-bounded slices in the Gogango Overfolded Zone in ROOKWOOD. There they form the oldest part of the sequence and are overlain in most places by the Mount Benmore Volcanics. They were previously mapped as Connors Volcanics. The name is derived from Leura homestead in western ROOKWOOD.

Hutton & others (1999a) extended the name into the main part of the Connors Arch to include a heterogeneous sequence of intermediate to felsic rocks that underlie the Mount Benmore Volcanics and overlie the dominantly rhyolitic volcanics of the Broadsound Range Volcanics. They also post-date the granite plutons of the southern part of the Arch, although in the north late Carboniferous or early Permian granitoids intrude them. As a result of further mapping and isotopic dating, the name is now applied to rocks extending along almost the entire length of the Connors Arch, underlying the Lizzie Creek Volcanic Group (Figures 35, 37 and 53). Some of these rocks were originally thought to be older (Unit Cvc_{2b} in Hutton & others, 1999a). The Leura Volcanics correspond in part to Cycle 3A of Dear (1994a,b, 1995).

Type and reference sections

A type section is designated between MGA 755500 7468400 and 756200 747000 along the track to the UHF repeater on the large hill south of the old Bruce Highway on the eastern edge of the Broadsound Range (see below). Two other well exposed sections designated as reference sections are: (a) in Tooloombah Creek downstream from MGA 753500 7474050, where the unconformable base is well exposed, to the faulted contact with the Carmila beds at MGA 753800 7474100; and (b) in Sarsfield Creek from MGA 751700 7487800, the unconformity with unnamed late Carboniferous microgranite to MGA 753200 7487400, the boundary with the Mount Buffalo Volcanics.

Lithology

Southern end of the Connors Arch

The hill that is topped by the UHF repeater station consists mainly of Leura Volcanics. On the northern flank of the hill at around MGA 755500 7468400, the rocks at the base of the sequence include crystal-rich, volcanilithic sandstone and pebble to boulder rudite with angular to subangular clasts of greyish purple to greyish green, aphyric to porphyritic andesite or dacite in a sandy matrix. The crystal fragments are white feldspar. The rocks are very poorly sorted and crudely stratified to massive. Probable dacitic ignimbrite with white feldspar crystal fragments in an aphanitic matrix also crops out. Similar rocks were also observed in the type section along the track to the repeater station, but ignimbrite (including both lithic-rich and crystal-rich varieties) appears to be dominant higher in the sequence. The crystal fragments are mostly feldspar, but large, embayed quartz grains and minor altered biotite are present in some ignimbrite. The lithic clasts include rare biotite granite.

In the valley to the west of the hill, very poorly sorted, matrix-supported greyish purple rudites contain subangular pebbles to boulders of greyish purple to green andesite or dacite and rare granitoid clasts in a silty matrix.

East of the Mount Mackenzie alteration system, the Leura Volcanics consist of a complex assemblage of poorly-bedded, matrix-supported conglomerate and breccia (Figure 42b). In the better-sorted conglomerates, the matrix is sandy, but commonly the rocks have a silty matrix and angular to subangular clasts. Many of these rocks may represent debris flows or lahars. Clasts are dominantly dark grey to greyish green and purple felsic to intermediate volcanics. In conglomerate outcrops at MGA 751950 7468150 and MGA 750850 7469350, near the base of the sequence, minor pink microgranite was noted and is similar to that in the Camp Creek Granite that crops out to the east (see also Figure 42f). Some lavas are interlayered with the clastic rocks, and are commonly porphyritic and greyish purple to bluish grey. The phenocrysts are almost exclusively plagioclase, but purple porphyritic rhyolite at MGA 751800 7467850 contains phenocrysts of feldspar and embayed quartz. Dear (1994a,b, 1995) referred to these rocks as trachyandesite and this appears to be borne out by the geochemistry, although some samples also plot in the rhyolite and basaltic trachyandesite fields. Flow banding is common, but is rarely strongly contorted. Some autobreccia was also observed. In thin section, the trachyandesite lavas have a distinctive trachytic texture, characterised by very fine-grained (<0.05mm) flow-aligned feldspar laths with some interstitial chlorite, epidote and opaques.

At the unconformity at the base of the Leura Volcanics in Tooloombah Creek at MGA 753400 7473850, very thick-bedded, purplish, pebble to cobble conglomerate and lithic sandstone overlie the Tooloombah Granite. Subangular to rounded clasts of the granite are conspicuous in the conglomerate, and smaller clasts are evident in thin sections of the sandstone. The clasts are mostly supported by a matrix of medium to very coarse-grained lithic sandstone. Mostly, the sandstones consist of clasts of greyish purple dacite or andesite, quartz-feldspar phyric rhyolitic ignimbrite and lava, vein quartz and discrete volcanic and plutonic quartz and feldspar grains. Both the conglomerate and sandstone have a relatively strong, spaced fracture cleavage (Figure 42a), indicating that the eastern flank of the Connors Arch shows effects of the deformation evident in the Gogango Overfolded Zone. The abundance of granite clasts decreases sharply to the south, where the Broadsound Range Volcanics underlie the unconformity. At MGA 753600 7473100, ~1km to the south of Tooloombah Creek, only felsic volcanic fragments are evident. Greyish purple, aphyric trachyandesite lava crops out nearby, and minor ignimbrite, containing pink feldspar crystals to 1.5mm and strongly flattened fiamme to 1cm, is interbedded with the sandstone and conglomerate at MGA 754100 7472550.

Langdale Inlier

A narrow north-west-trending belt ~8km long and up to 500m wide in the southern part of the Langdale Inlier is assigned to the Leura Volcanics. The sequence is probably ~200m thick and overlies rhyolite assigned to the Broadsound Range Volcanics and minor altered biotite granite to the north-west. It is overlain by crystal-rich ignimbrite that resembles and has been assigned to the Tartrus Rhyolite.

Grey to greyish purple, aphyric to porphyritic and locally amygdaloidal andesite lava and volcanilithic sandstone and conglomerate crop out. Andesite and basaltic trachyandesite described by O’Brien (1994) probably belongs to this unit. The conglomerate commonly consists of very thick-bedded, subrounded to rounded andesite clasts in a coarse sandy matrix and passes into rudites with more angular clasts. At the north-western end of the belt, conglomerate at the base of the unit contains clasts of the underlying biotite granite.

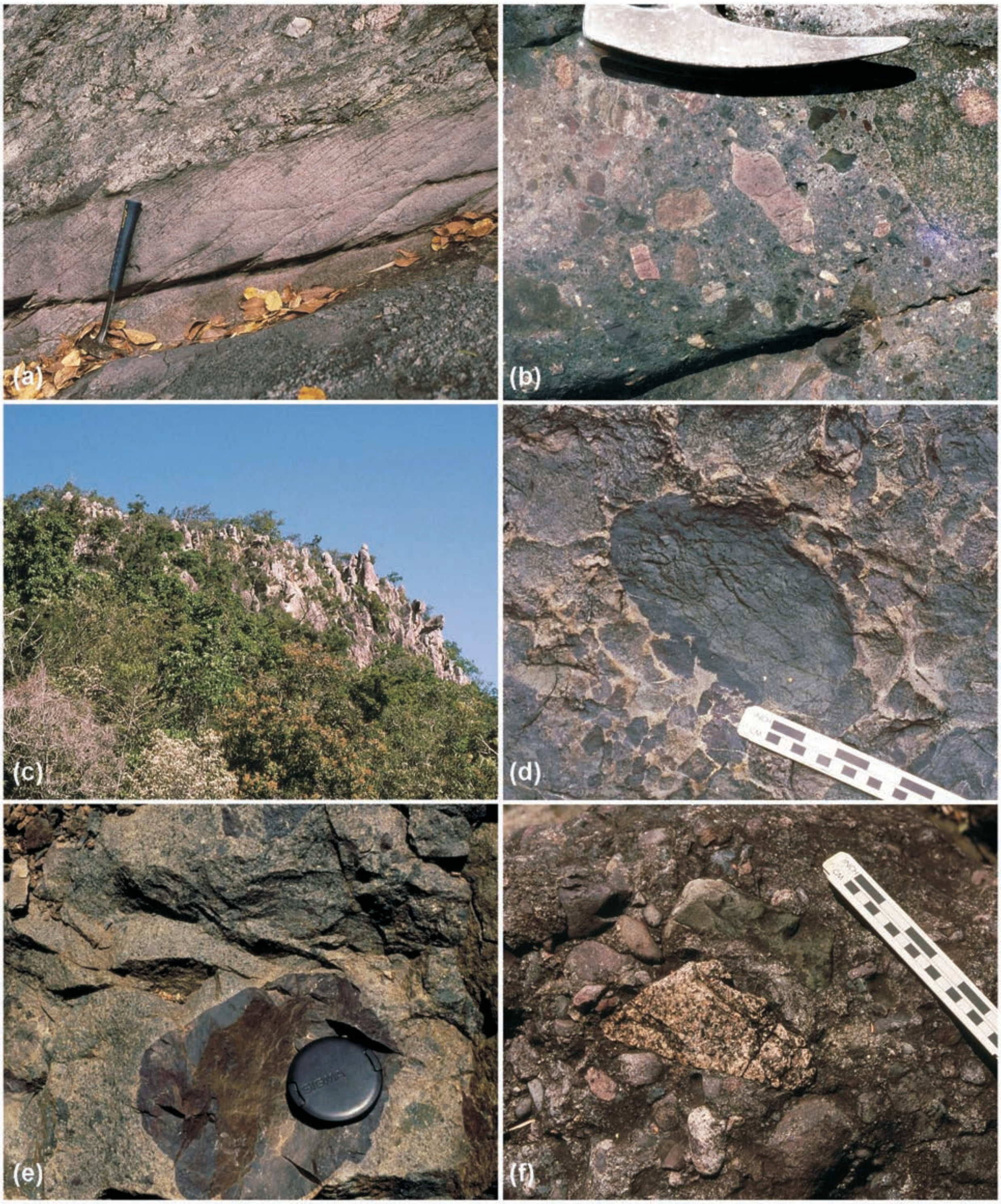

Figure 42. Leura Volcanics
(a) Pebbly sandstone containing granite clasts, interbedded with cleaved reddish mudstone. The rocks unconformably overlie the Tooloombah Creek Granite and Broadsound Range Volcanics ~100m upstream. South branch of Tooloombah Creek, ~12km south-west of Tooloombah homestead at MGA 753564 7474071 (IWSC0286)
(b) Poorly sorted volcaniclastic breccia of andesitic to dacitic clasts in a silty matrix. ~5km east-south-east of Mount Mackenzie at MGA 754079 7467061 (IWSC0329)
(c) Columnar jointed rhyolitic ignimbrite at the base of the Leura Volcanics and overlying Bora Creek Granodiorite. Mount Larry, a prominent dip slope or cuesta on the eastern side of the Broadsound Range at MGA 749700 7486300
(d) Probable peperitic breccia at the base of an andesite flow with a pillow of andesite with a crenulate margin in a silty matrix. Amity Creek, 4.2km north-east of Burwood homestead at MGA 747900 7508800 (IWSC1088)
(e) Aphyric andesite cobble and smaller subangular granules to pebbles of aphyric and porphyritic andesite in a poorly sorted sandy matrix. Croydon–Saint Lawrence road at the top of the jump-up, 6.3km east of Killarney homestead at MGA 741291 7525950 (RSC067)
(f) Float block of polymict conglomerate from the Leura Volcanics consisting mainly of andesite clasts with a granite clast derived from the nearby Camp Creek Granite. About 3km south-east of Mount Mackenzie at MGA 752070 7467437 (IWSC1491)

Eastern side of the Connors Arch

Similar rocks have been traced along the eastern side of the Connors Arch as far north as Sarsfield Creek, as a sequence of greenish grey to greyish purple, porphyritic trachyandesite to dacitic lava and some ignimbrite. Phenocrysts in the dacite are mainly feldspar, but some flows also contain mafic phenocrysts that have been altered to chlorite or epidote.

In the gorge along Sarsfield Creek, the base of the Leura Volcanics at MGA 751400 7487600 is a greyish purple rhyolitic ignimbrite that overlies strongly fractured rhyolite of the Broadsound Range Volcanics and contains quartz and feldspar crystal fragments and andesitic and granitic lithic clasts. It is overlain by sandstone and conglomerate that contains pebbles and cobbles of andesite, granitoid and clasts of the underlying ignimbrite. Above this basal interval which is probably <20m thick is a prominent cuesta-forming sheet of grey, crystal-rich and locally moderately lithic-rich ignimbrite. Crystal fragments are mainly feldspar and some sparse quartz, and lithic clasts appear to be mainly aphyric felsite. Fiamme are common towards the base and are mostly up to 3cm long, but some ~10cm were observed. The ignimbrite is probably of the order of 200m thick. The groundmass is microspherulitic, but has outlines of aligned platy shards. Lithophysae up to 5mm long are filled with a granular mosaic of quartz and have cores of clinozoisite.

Downstream from MGA 751950 7487650, the ignimbrite is overlain by greyish purple, porphyritic andesite (trachyandesite?). From MGA 752300 7487750, very crystal-rich ignimbrite containing feldspar and embayed quartz crystals and strongly flattened fiamme up to 5cm long crops out for ~200m along the creek. It is probably ~100m thick, but the top appears to be faulted off against basement volcanics or granitoids. The uppermost part of the Leura Volcanics, downstream from MGA 752500 7487600 to the contact with the Mount Buffalo Volcanics at MGA 753200 7487400, consists of andesite lava and subordinate volcaniclastic sandstone and conglomerate. The total thickness represented in Sarsfield Creek is probably ~700m, but faulting has removed an unknown part in the middle of the section.

The grey ignimbrite near the base of the unit in Sarsfield Creek crops out ~2km farther west at Mount Larry, a prominent east-dipping cuesta on the eastern margin of the Bora Creek Granodiorite (Figure 42c). It is forms a separate outcrop area, bound on the east by an east-block-up fault. The ignimbrite is probably ~20m thick and has conspicuous columnar jointing. At MGA 749750 7486800, it is moderately crystal rich, containing fragments of white feldspar. Sparse felsic lithic volcanic clasts and fiamme are present. In thin section, the groundmass consists of well-preserved strongly flattened and aligned shards. This ignimbrite sheet overlies reddish, very crystal-rich rhyolitic ignimbrite that contains quartz and feldspar fragments to 1.5mm and common elongate fiamme to 5cm. The latter ignimbrite is in contact with microgranite, close to the contact with the Mount Bora Granodiorite. Neither ignimbrite shows any sign of hornfelsing, consistent with an unconformable relationship with the microgranite and granodiorite.

Continuing north along the eastern edge of the Connors Arch, a thick pile of grey, very crystal-rich ignimbrite along Montrose Creek, underlying the Ametdale Volcanics is equivalent to that described in the middle part of the section along Sarsfield Creek. The ignimbrite contains up to 50% crystals, comprising embayed quartz to 3mm and feldspar fragments to 2mm, in a very fine-grained groundmass. Some fiamme can be recognised in outcrop, but fine vitroclastic textures have been recrystallised. Dear regarded these rocks as part of his Cycle 3. They could represent another volcanic cauldron similar to, although smaller than, the one in which the Lotus Creek Rhyolite was emplaced.

A heterogeneous sequence, equated by Dear (1994a,b, 1995) with his Cycle 3, crops out along the eastern margin of and unconformably overlying the Burwood Complex. Conglomerates at the base of the sequence in several places include clasts of granodiorite, for example at MGA 745750 7508850, north of Burwood homestead. Dear also recorded similar relationships in his notes, for example at MGA 747700 7502450 south-east of Burwood. The sequence north of Burwood was examined along the Burwood–Lavinia Park track and in Amity Creek. Immediately above the basal conglomerate is rhyolitic ignimbrite containing very abundant feldspar and quartz crystal fragments. It is overlain by a variety of poorly-sorted felsic, commonly lithic-rich, volcaniclastic rocks that are generally also crystal-rich. Crystal fragments are mainly feldspar, but quartz is common in some outcrops. The matrix is generally aphanitic. Some better sorted volcanilithic sandstone is locally present. All or part of this basal felsic sequence may equate to the Lotus Creek Rhyolite, and could be outflow facies from the main cauldron or depocentre. The felsic rocks are overlain to the east by grey, aphyric to porphyritic trachyandesite or dacite flows, similar to those elsewhere in the Leura Volcanics. At MGA 747900 7508800, the base of one flow is marked by peperitic breccia, with pillows of andesite with crenulated margins occurring within a silty matrix (Figure 42d)

At the top of the sequence, very crystal-rich (feldspar and quartz), moderately lithic-rich ignimbrite crops out, and is overlain by the Ametdale Volcanics. The groundmass has a well preserved vitroclastic texture with cuspate shards that are only slightly compressed. Similar quartz-phyric ignimbrite also crops out at the contact with the Ametdale Volcanics farther south along the northern branch of Granite Creek. The extent of these rocks in the rugged terrain between Granite Creek and Montrose Creek (Figure 34a) is uncertain. However, they may correlate with the ignimbrite in Montrose Creek. Dear made some observations there (unpublished field notes), but his descriptions of the rock types are difficult to distinguish from those of the Broadsound Range Volcanics.

Between Amity Creek and the Croydon–Saint Lawrence road, the Leura Volcanics were not examined, except at the base near MGA 745700 7512500, which is marked by crystal-poor to moderately crystal-rich ignimbrite containing feldspar and conspicuous biotite fragments in groundmass with a well-preserved vitroclastic texture of cuspate shards.

North of here, photo-interpretation suggests that the unit passes into a sequence dominated by large, subhorizontal rhyolite flows. Where examined, the flows consist of feldspar-phyric to aphyric, flow-banded and commonly autobrecciated rhyolite. They have not been examined in much detail, because they occur in thickly vegetated, rugged terrain on the edge of the scarp. Photo-interpretation suggests that to the north of Amity Creek, such flows (or perhaps sills) may be interbedded with the sequence described above, and that further north, they become dominant and represent a local complex of plugs, domes and flows. Their subhorizontal nature may indicate that they are younger, perhaps equating with the Mount Buffalo Volcanics to which they have been tentatively assigned on CONNORS RANGE. They appear to directly overlie the Broadsound Range Volcanics implying that the Leura Volcanics are absent in this area.

Rocks assigned to the Leura Volcanics along the Croydon–Saint Lawrence road include greenish grey to greyish purple dacitic or andesitic sandstone and conglomerate (Figure 42e). A prominent crystal-rich (quartz-feldspar) ignimbrite, which forms a low ridge at MGA 739100 7524550 is interpreted to be the base. It contains ~50% crystals, comprising feldspar and strongly embayed quartz to 1.5mm and common chloritised biotite to 1mm. The groundmass is strongly vitroclastic with abundant partly flattened platy to cuspate shards wrapping around the crystal fragments. Sparse fiamme to ~1cm are also present.

To the north of the road, along the eastern side of Schneider Creek gorge, well-bedded, moderately to well-sorted sandstone and conglomerate consist of felsic volcanic clasts, feldspar and abundant volcanic quartz.

North-west of Saint Lawrence, in the Spring Valley area, the Leura Volcanics have been tentatively recognised as a succession of crystal-rich ignimbrite and subordinate dacitic or andesitic lavas that underlie the Mount Buffalo Volcanics.

Western side of the Connors Arch

On the western side of the Connors Arch, the Leura Volcanics have now been recognised as far north as Nebo, although they appear to be absent just to the north of Mount Mackenzie, either from faulting or possibly erosion prior to the eruption of the Mount Benmore Volcanics. The Broadsound Range Volcanics also appear to be absent there.

North of Mount Mackenzie, conglomerate consisting of clasts of lithic ignimbrite from the underlying Clive Creek Volcanics and some clasts of microgranite were observed at the inferred base of the Leura Volcanics in gravel scrapes at MGA 747200 7474700 near the electricity substation. The Broadsound Range Volcanics still appear to be absent here.

The unit consists dominantly of porphyritic dacite or trachyandesite lava and related volcaniclastic rocks but minor quartz-feldspar-phyric ignimbrite occurs locally. Plagioclase is again the most common phenocryst phase in the lavas, but chloritised mafic minerals are present locally. The groundmass commonly has a trachytic texture. The rocks are difficult to distinguish from the overlying Mount Benmore Volcanics in some places. However, the latter are generally greenish grey and distinctly more mafic in appearance (andesite to basalt), whereas the rocks assigned to the Leura Volcanics are commonly greyish purple and somewhat more felsic (trachyandesite to dacite). As noted previously, they are also difficult to distinguish from some of the andesitic rocks in the Mountain View Volcanics.

A sequence of greyish purple lithic sandstone, conglomerate and minor andesitic lava was mapped east of Spring Hill and Wahroonga homesteads. Some of the lavas are quench fragmented. Dykes intruding the conglomerate have peperitic margins (Figure 43a) suggesting that they were intruded while the sediments were still unconsolidated. Minor feldspar-phyric ignimbrite is present. A sample collected for dating (IWSC0897 — see Appendix) contains well-preserved vitroclastic textures. The rocks are shallowly dipping and overlie the Mountain View Volcanics.

The Leura Volcanics tend to be discontinuous north of Spring Hills homestead, but south-east of Croydon homestead, a sequence of conglomerate, sandstone and dacitic or andesitic lava that overlies the Lotus Creek

Figure 43. Leura Volcanics (continued)
(a) Peperitic contact between an andesite dyke and conglomerate. Ross Creek ~15km west of Burwood homestead at MGA 735317 7503952 (IWSC1128)
(b) Crystal-rich dacitic or rhyolitic ignimbrite cut by irregular zones of hydraulic breccia. Yellow Creek, ~7.5km east of Markwell homestead at MGA 725008 7531432 (LHC907)
(c) Massive, unbedded, poorly sorted volcaniclastic conglomerate (mass-flow deposit?). Yellow Creek, ~8km east of Markwell homestead at MGA 725546 7530871 (LHC909)
(d) Poorly sorted volcaniclastic conglomerate consisting of subangular to subrounded clasts of intermediate to felsic volcanic rocks. Same locality as (k)
(e) Crystal-rich rhyolitic ignimbrite cut by a pebble-dyke of subangular to subrounded clasts of both hornblende monzonite or granite and ignimbrite in a very fine-grained rock-flour matrix. Falls at Saint Georges Waterhole on Lotus Creek, ~7.5km west-north-west of Burwood homestead at MGA 738881 7509605 (IWSC0875)
(f) Pebble to cobble conglomerate of well-rounded mostly felsic volcanics in a coarse to very coarse-grained sandstone matrix. About 7km south-east of Mount Benmore at MGA 768651 7446383 (IWGG084)

Rhyolite is probably equivalent to the Leura Volcanics. The conglomerate is very thick-bedded and contains subrounded to rounded pebbles to boulders of greyish purple, aphyric to porphyritic dacite and andesite supported by a matrix of medium to very coarse-grained lithic sandstone. Clasts of the underlying quartz-phyric ignimbrite of the Lotus Creek Rhyolite are rare, even just above the unconformity, although embayed quartz grains are present in the matrix. The sandstones are feldspatholithic and thick to very thick-bedded. The lavas, interbedded with the clastic rocks towards the top of the sequence, are greyish purple to greenish grey, generally feldspar-phyric, and locally amygdaloidal.

A sequence along Yellow Creek on Markwell Station is assigned to the Leura Volcanics and comprises dacitic to andesitic vitric tuff, massive dacitic crystal ignimbrite with sparse lithic clasts up to 5cm, siltstone, sandstone, and more dacitic to andesitic tuff and ignimbrite. Zones of hydraulic fracturing and pebble dykes were observed in places cutting across andesite or dacite lava (Figure 43b). Massive, poorly sorted, pebble to boulder conglomerate of subangular to subangular volcanic clasts is common through the succession. Some units appear to up to 100m thick with no obvious bedding breaks and are probably large mass-flows or lahar deposits (Figure 43c,d). Towards their tops they pass into better sorted, cross-bedded medium to thick bedded sandstone.

South-east of Sirram homestead on south-east NEBO, easterly-dipping felsic to intermediate tuffs and possible ignimbrites and intermediate lavas are interbedded with well-bedded sandstone, siltstone and felsic tuff. This sequence appears to be similar to the rocks that crop out to the south along Yellow Creek. If this correlation is correct, the western edge of the Connors Arch is defined by an easterly dipping sequence of Leura Volcanics, unconformably overlain to the west by the Mount Benmore Volcanics.

West of Waitara Station in central NEBO, small granite stocks locally intrude rhyolitic crystal-lithic tuff, rhyolitic tuff, conglomerate, and andesitic breccia assigned to the Leura Volcanics. This felsic to intermediate volcanic sequence is overlain by massive conglomerate and andesitic volcanics, sandstone and siltstone assigned to the Lizzie Creek Volcanic Group. The Leura Volcanics form the core of an anticline in this area.

Central Connors Arch in the Burwood area

Several east-dipping blocks of Leura Volcanics bounded on the east by east-block-up north-trending faults have been recognised within the middle of the Connors Arch around the western and northern side of the Burwood Complex. They include trachyandesite lavas and sheets of quartz-feldspar-phyric and feldspar-phyric ignimbrite.

Near the base of the unit at White Cliff near the southern edge of CONNORS RANGE, a prominent sheet of feldspar-phyric ignimbrite with a well-preserved non-welded vitroclastic texture is similar to the ignimbrite that was dated. Both resemble the cuesta-forming ignimbrite near the base of the Leura Volcanics in Sarsfield Creek and Mount Larry. The ignimbrite at White Cliff is underlain by a quartz-feldspar-phyric ignimbrite that is superficially similar (and may be equivalent) to the Lotus Creek Rhyolite, but appears to differ in containing altered hornblende crystal fragments rather than biotite. In the falls at Saint Georges Waterhole on Lotus Creek at MGA 738850 7509600, this ignimbrite is cut by subvertical pebble dykes up to 20cm wide (Figure 43e). These dykes contain partly milled, subangular to subrounded clasts of both hornblende monzonite or granite and ignimbrite. Similar crystal-rich ignimbrite along Lotus Creek at MGA 736200 7512600 is inferred to overlie one of the smaller plutons assigned to the Burwood Complex, and contains some areas of milled breccia consisting of ignimbrite clasts. The adjacent granite is also locally brecciated and altered.

Leura Anticlinorium

These rocks occur in a meridional belt ~7–8km wide, and ~14km long. Within this belt, the rocks are partly folded with and thrust against the Mount Benmore Volcanics and Back Creek Group in a complex anticlinal core, referred to here as the **Leura Anticlinorium**. The rocks were examined mainly along the track that runs east from Leura homestead along Leura Creek.

The unit is composed of a mixture of lavas and volcaniclastic rocks (arenite and rudite, and possible ignimbrite). The radiometric response gives rise to muddy grey to brown hues on the composite images. The lavas are generally medium to dark grey to greyish-purple and appear to be mostly trachyandesite to andesite, based on petrography and geochemistry. They are aphyric to porphyritic and consist of plagioclase phenocrysts in a trachytic groundmass of aligned feldspar laths and interstitial opaques and chlorite. Flow banding is locally present and is usually contorted. Autobreccia is also developed, and spherulites and amygdales are present in some outcrops, the latter being filled with chlorite or milky quartz.

The volcaniclastic rocks are purple to greyish-green, very poorly-sorted, very thick-bedded and massive. The rudites contain angular to sub-angular felsic to intermediate, porphyritic to aphyric volcanic clasts in a fine to very coarse-grained matrix of feldspar and locally embayed quartz crystal fragments, lithic clasts and recrystallised very fine-grained ash or glass. The rudites are interbedded with arenites similar in composition to the matrix. The presence of quartz indicates that rhyolitic compositions are mixed with the more intermediate rocks as in the main outcrop areas in the Connors Arch. Some of the arenites may be ignimbrite. They consist of crystal fragments in a fine-grained, vitric matrix and some outcrops show a weak parting which may be due to a eutaxitic foliation, although no fiamme were observed.

However, any igneous foliation is difficult to distinguish from the tectonic foliation. that becomes more common and stronger to the east. It is generally manifest in outcrop by anastomosing fractures from a few millimetres to a few centimetres apart and flattening and alignment of lithic clasts. In thin section, alignment of fine-grained secondary muscovite and chlorite is evident.

Alteration is common throughout the volcanics. It generally comprises alteration of feldspars to epidote, carbonate and sericite or muscovite, and pervasive to patchy chloritisation and hematisation of the matrix.

Upstream of MGA 768300 7446500 in a gorge immediately east of Mount Benmore homestead, a sequence of very thick-bedded sandstone and conglomerate is exposed. The conglomerate contains pebbles to cobbles of sub-rounded to well-rounded, mostly felsic, aphyric to porphyritic volcanics in a coarse to very coarse-grained sandstone matrix (Figure 43f). Rare biotite granite clasts are also present. The conglomerates are generally poorly stratified internally, but commonly have channelled bases and fine upwards into moderately well-sorted feldspatholithic sandstone. The sandstone contains abundant volcanic quartz, plagioclase and K-feldspar, a variety of mainly felsic to intermediate volcanic lithic clasts, and minor matrix that has been recrystallised to masses of phyllosilicates.

Minor volcanic rocks interlayered with the conglomerate, include a greenish-grey, aphyric andesite flow or sill ~10m thick at MGA 769000 7446300 and a sheet of grey, moderately crystal-rich, lithic-poor ignimbrite at least 6m thick at MGA 768300 7446500. The latter is possibly dacitic and contains crystals of feldspar and biotite to 2mm.

The sequence dips shallowly east and is apparently overlain by the andesitic to dacitic part of the Leura Volcanics described above. The contact with the Mount Benmore Volcanics downstream to the west is inferred to be an east-dipping thrust. It is possible that the contact with the volcanics to the east is also a thrust or there is more than one sandstone-conglomerate sequence, because farther east, these volcanics are apparently overlain by a sandstone-conglomerate sequence that again dips east.

Where observed in northern tributaries of Leura Creek, this eastern sequence is basically the same as described above, consisting of pebble to cobble conglomerate and pebbly sandstone with aphyric to porphyritic volcanic clasts. Clearly defined bedding trends are obvious on aerial photographs. An enigmatic outcrop in a gorge at MGA 771000 7443500 contains very thick beds (>10m) of conglomerate with well-rounded clasts and sporadic moderately sorted sandy breaks. However, the matrix to some of the sandstone is vitroclastic with abundant platy to cuspate shards and crystal fragments, suggesting it is a pyroclastic deposit.

Gogango Overfolded Zone

To the west of Melaleuca Creek within Goodedulla National Park, intermediate to felsic volcanics form another meridional belt ~10km long and up to 2km wide, tapering southwards. The rocks in this belt are more deformed than in the Leura Anticlinorium, and almost invariably show an anastomosing fracture cleavage or foliation that is commonly quite strong. Lithic clasts are commonly flattened and in places, a weak down-dip lineation defined by stretching of lithic clasts is also evident. As a result of the greenschist facies metamorphism associated with the deformation, the matrix of many of the clastic rocks contains abundant fine-grained chlorite and muscovite. In thin section, the foliation is defined by anastomosing domains of phyllosilicates that wrap around crystal fragments and lithic clasts.

Traverses were made east from the boundary of the park with Roselea Station in the southern part of the belt at about MGAN 7423700 and across the belt farther north at about MGAN 7427200. The rocks are mainly light greenish-grey to greyish-purple, aphyric lava and very thick-bedded, generally very poorly-sorted, pebbly volcanic arenite and rudite. The lavas are weakly flow-banded and locally autobrecciated andesite or dacite. Trachytic flow layering is accentuated by hematitic alteration. The rudites and arenites are gradational into each other. They consist of subangular to angular clasts of aphyric felsic to intermediate volcanic lithics to 1cm in a matrix of coarse to very coarse lithic fragments and some altered crystal fragments (mostly plagioclase, but locally including quartz), and generally finer-grained, originally more vitric material. They probably include crystal-lithic tuffs as well as epiclastic deposits. It is possible that some of the rocks may be primary volcaniclastics, including ignimbrite, but the strong foliation obscures any features that could confirm this. Some of the arenites are moderately-sorted and have crude stratification defined by concentrations of sub-rounded to rounded pebbles.

The relationship of this belt to the surrounding more mafic volcanic rocks (assigned to the Mount Benmore Volcanics) and Goodedulla beds is uncertain. It may be faulted in part, but although there is little measured structural data, the overall appearance is that the belt represents the core of a regional anticline.

An arcuate belt of strongly deformed rocks ~8km long and 2km wide is centred ~6km west-south-west of Rookwood homestead. The rocks were studied on a traverse along the track between Rookwood and Foleyvale homesteads. The rocks have a distinctive reddish-brown hue on the composite radiometric images. The belt is tentatively assigned to the Leura Volcanics. The belt is overlain to the east by alluvium along the valley of Paddys Creek. To the west, the contact with cleaved mudstone of the Back Creek Group is inferred to be a thrust. Although most of the rocks in the Gogango Overfolded Zone are chloritic, indicating greenschist facies conditions, biotite was observed in some of the rocks in this belt, indicating that the grade was probably somewhat higher and in the biotite zone.

The rocks are commonly greyish-purple and are strongly foliated to mylonitic with strongly flattened and stretched volcanic lithic clasts up to 1cm long in a schistose chlorite-muscovite-feldspar matrix. Some outcrops also have abundant white to pink altered feldspar crystals to 2mm. Shear sense indicators include winged inclusions and quarter structures around crystal fragments. Most of the rocks are probably deformed volcanic rudite and arenite, but less strained pods of porphyritic dacite or andesite with trachytic textures occur in places, for example at MGA 784340 7400300. Altered aphyric basalt or andesite with amygdales up to 2cm long was observed in the eastern part of the belt near MGA 784800 7400400.

Apparently more mafic, pale green, strongly cleaved or foliated volcaniclastic rocks crop out in places. Plagioclase crystal fragments are preserved, but it is difficult to resolve lithic fragments from the chloritic matrix. The rocks are very thick-bedded and have weak laminations slightly oblique to the foliation. A distinctive feature is the sporadic presence of ‘devils dice’ after pyrite up to 5mm. Thin to medium beds of weakly laminated cherty siltstone were also observed.

Near the creek crossing at MGA 783740 7400520, fine-grained cataclastic schist crops out. Local zones up to 2m wide of intense laminar differentiated (mylonitic?) foliation are overprinted by a differentiated crenulation cleavage. The schist consists of small grains of feldspar (mainly plagioclase fragments) up to 0.05mm in a matrix of chlorite and finer-grained feldspar. Chloritic domains ~0.5mm wide and ~1mm apart define the foliation.

Geophysical response

Because of the diversity of rock types in the Leura Volcanics, the radiometric response is quite variable. However in general, the response is low to moderate in all channels resulting in greyish hues in composite images. Where felsic rocks are more abundant dark pink hues may reflect higher potassium responses.

The magnetic response is also variable, but in general it is relatively low, with sporadic moderate to high spot anomalies. This is consistent with the measured magnetic susceptibility values. Of about 2300 values across a range of rock types, about half are $<30 \times 10^{-5}$ SI units and the data shows a long tail of values to about 2000 with sporadic values to 5000, irrespective of whether the rocks are felsic or mafic.

Environment of deposition

The Leura Volcanics formed in a subaerial environment, because they are dominated by lavas, some ignimbrites, and coarse-grained, mostly poorly-sorted volcaniclastics. Fine-grained sediments are lacking. The volcaniclastic rocks may have been formed by a variety of processes involving mass flows and fluvial traction currents. The conglomerate and sandstone sequence east of Mount Benmore is probably fluvial in origin.

Geochemistry

Twenty-nine samples from the Leura Volcanics were analysed for a range of major and trace elements. The rocks included both lava and clastic rocks including ignimbrite. The plot of total alkalis vs SiO_2 (TAS) in Figure 44 indicates that lavas are predominantly andesite to trachyandesite, although there are four rhyolites. Unlike many of the other Permian units, there are no basalts and only two basaltic andesites. The clastic samples are mainly dacite to rhyolite in the TAS diagram, although the plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) in Figure 44b suggests that four of them are andesitic. Because it uses immobile elements, this plot provides a method of classifying the original composition of altered volcanic rocks, and suggests that some of the clastic rocks may have been silicified.

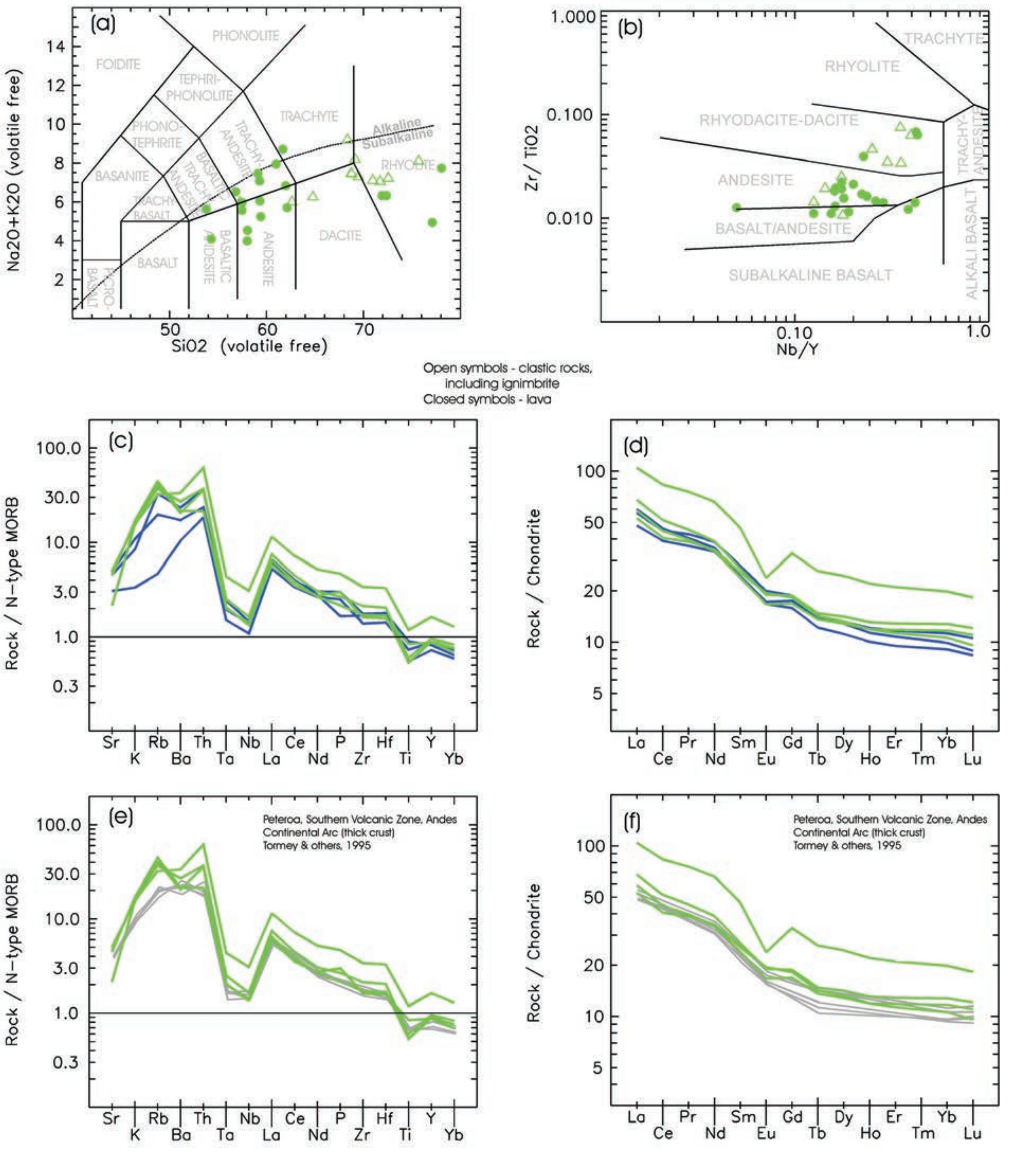

Figure 44. Geochemistry of the late Carboniferous to early Permian Leura Volcanics:
(a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986) and Irvine & Baragar (1971);
(b) Nb/Y vs Zr/TiO_2 showing the fields of Winchester & Floyd (1977);
(c, e) N-MORB normalised multi-element plot (using values from Pearce, 1983) for four basaltic andesite to andesite samples;
(d, f) chondrite-normalised REE plot (using values from Sun & McDonough, 1989) for four basaltic andesite to andesite. For comparison, the patterns of basalts from the Mountain View Volcanics are shown in blue and the modern Andean Peteroa suite in grey.

One sample of basaltic andesite and three of the least silica-rich andesite samples were submitted for precise trace element analysis by laser ablation mass spectrometry, and the data have been used to construct the multi-element and rare-earth element (REE) plots in Figure 44c–f. Three of the samples produce a tightly constrained group in Figure 44c–d that is similar to the Mountain View Volcanics in both REE and high-field-strength elements (HFSE), and therefore, like them, closely matches the pattern of basalts from the Peteroa suite in the Southern Volcanic Zone of the Andes. This suggests that they were also erupted in a continental margin volcanic arc on moderately thick crust.

One sample is much more enriched in REE and all of the HFSE. Although its profile is broadly parallel to that of the others in the REE plot, it shows a pronounced Eu anomaly indicating strong plagioclase fractionation. Although its SiO_2 content is similar to that of the others, it is much more fractionated in terms of its *mg* with a value of 25 compared with the others having 37–41.

Relationships and age

As described at various places above, the Leura Volcanics overlie Dear's Cycle 1 and 2 of the Connors Volcanic Group, in particular, the Clive Creek, Mountain View, Broadsound Range and Whelan Creek Volcanics and Lotus Creek Rhyolite. In some places, they also rest unconformably on late Carboniferous granitoid plutons of the southern Connors Arch.

In the south and west of the Connors Arch, the Leura Volcanics are overlain by the early Permian Tartrus Rhyolite, Mount Benmore Volcanics and Cobweb Mountain Rhyolite. On the east, they are overlain in various areas by the mafic Ametdale Volcanics and felsic Mount Buffalo Volcanics, which are probably early Permian. Within the Leura Anticlinorium, the Leura Volcanics are partly folded with and thrust against the Mount Benmore Volcanics and Back Creek Group in a complex anticlinal core. In places there, they are directly overlain by the Back Creek Group.

Several plutons intrude the Leura Volcanics, in particular, the South Creek Diorite near Mount Mackenzie and the Doreen Granite.

The total thickness of the Leura Volcanics is difficult to estimate in many areas, because of the shallow dips and irregular topography. However in the Tooloombah Creek area and UHF repeater station hill, the thickness is probably in the range of 300–500m, and at least 700m is exposed in Sarsfield Creek.

Three samples of Leura Volcanics have been dated, all from the northern half of the outcrop area. They give consistent early Permian ages(see Appendix).

SHRIMP dating of a sample of crystal-rich, lithic-poor rhyolitic ignimbrite (IWSC0897) from the Leura Volcanics east of Wahroonga homestead produced somewhat inconclusive results, due to excess scatter (see Appendix). On the basis of a cumulative probability plot, the data can be divided into two arbitrary groups of 291±3.5Ma (MSWD=0.5, 12 analyses) and 307±3Ma (MSWD=1.05, 9 analyses. The younger age is consistent with field relationships in the Croydon and Killarney areas, where the Leura Volcanics overlie the Lotus Creek Rhyolite for which a date of 295±3.4Ma was obtained.

Zircons were dated from sample LHC878 a hornfelsed rhyolite from near the contact of the Doreen Granite, south-east of Doreen homestead. The analyses show some dispersion about a general mean of 292±4Ma (MSWD = 1.3 for 12 analyses). This age is younger than that determined for the Doreen Granite which is interpreted to intrude the rhyolite (301±3.4Ma), although the two ages are only just outside error of each other and the granite could contain inherited zircon.

A sample of crystal-rich dacitic ignimbrite (BB3399) from ~10km north of Nebo gave a SHRIMP age of 293.5±4.0Ma (MSWD of 0.85, based on 17 of 23 analyses.

However, in the Mount Mackenzie area, the Leura Volcanics underlie the Tartrus Rhyolite for which an age of 300.8±4Ma was obtained (see Appendix). In this area, the Leura Volcanics are also intruded by the South Creek Diorite and overlain by the Coppermine Andesite (dated at 304±2Ma and 297±2.5Ma respectively — Burch, 1999). This suggests that the unit may be diachronous, with the Leura Volcanics being older in the south or that at least some of the rocks mapped as Leura Volcanics north from Wahroonga, and which are dominated more by felsic volcaniclastics than andesite, should be assigned to a separate unit.

Based on these data and the stratigraphic relationships, the Leura Volcanics as they are presently mapped are probably latest Carboniferous in the south, extending into the early Permian in the north.

MACKSFORD VOLCANICS

Introduction

This name is given to mafic volcanic rocks that underlie the Coppermine Andesite and appear to overlie the Leura Volcanics and Clive Creek Volcanics in the Mount Mackenzie area. They are affected by the advanced argillic alteration of the Mount Mackenzie alteration system. As mapped they are restricted to a narrow belt ~0.5km wide and extending for ~3.5km north-north-west from Mount Mackenzie on the western side of the

Broadsound Range (Figure 35). The name, which is derived from the nearby Macksford Station, was used informally in some early unpublished company reports (for example, Dear, 1977, 1986a,b) for all of the mafic volcanics overlying the "Connors Volcanics" in the Mount Mackenzie area. It was used in the more restricted sense adopted here by Terra Search Pty Ltd geologists (S. Beams, personal communication, 1998) and by Burch (1999).

Type section

A type section is specified from about MGA 750150 7470250, where the unit is inferred to overlie the Clive Creek Volcanics, to MGA 749550 7469800, the base of the overlying Coppermine Andesite. The Leura Volcanics appear to be absent in this area.

Lithology

The rocks exposed in the type section and elsewhere are basalt or andesite flows and volcaniclastic rocks. Thin sections were only examined from MGA 749970 7470070 in the type section, and they consist of partly epidotised and sericitised plagioclase laths up to 3mm in a groundmass of flow-aligned plagioclase laths to 0.2mm and interstitial chlorite, leucoxene and opaque oxides. Patches of epidote are common through the groundmass. Quartz and chlorite fill small irregular amygdales up to 1mm across. One of the samples from this locality was analysed chemically, and plots as a basaltic andesite. The volcaniclastic rocks are poorly bedded and contain up to pebble-sized clasts of porphyritic mafic volcanics in a poorly sorted sandy matrix rich in plagioclase crystals. Epidote alteration of plagioclase crystals and lithic clasts is common.

Geophysical response

The Macksford Volcanics have a radiometric response in all channels consistent with their mafic nature. The magnetic response is also low and magnetic susceptibility on the few outcrops measured ranges from 18–290 x 10^{-5} SI units.

Geochemistry

Two samples from the Macksford Volcanics were analysed for a range of major and trace elements. The plot of total alkalis vs SiO_2 (TAS) in Figure 49 indicates that rocks are dominantly basaltic andesite to andesite and this is supported by the plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977).

Only X-ray fluorescence (XRF) analyses are available for these rocks, so that it is not possible to present rare-earth element (REE) data. However, the XRF data for the two samples are presented as a multi-element plot normalised to N-MORB in Figure 46a. The two samples are very similar to each other and match reasonably well the profile of the less fractionated samples of the underlying Leura Volcanics. The profiles of the high-field-strength elements in the multi-element plot are less definitive than those of REE data, but the similarity of the Macksford Volcanic to the Leura Volcanics suggests that they are also associated with thick crust.

Relationships and age

As noted above, the Macksford Volcanics underlie the Coppermine Andesite and overlie the Leura Volcanics and the Clive Creek Volcanics. The argillically altered host rocks of the Mount Mackenzie gold mineralisation partly include the Macksford Volcanics. The Macksford Volcanics represent the upper part of Cycle 3A of Dear (1994a,b, 1995).

Burch (1999) determined a mid-Carboniferous age of 315±4Ma for the Macksford Volcanics, but because this was based on only three zircon grains that were separated from a basalt or andesite, inheritance is a distinct possibility. The unit is intruded by the South Creek Diorite, which also intrudes the Leura Volcanics and was dated by Burch (1999) at 304±2Ma using the SHRIMP. However, this date may be subject to revision using more recent processing techniques and the diorite could be younger (see Appendix).

The Macksford Volcanics are restricted to a small area north from Mount Mackenzie, where the distinctive Coppermine Andesite separates them from the lithologically identical Mount Benmore Volcanics. Where the Coppermine Andesite is absent, it is possible that equivalents of the Macksford Andesite could occur in rocks currently mapped as Mount Benmore Volcanics. However, south of Mount Mackenzie, the erosion that exposed the Mount Mackenzie alteration system and South Creek Diorite, may have removed such equivalents if they existed. Other areas that may be equivalent in age could include the Ametdale Volcanics on the eastern side of the Connors Arch. A thin interval of mafic rocks represented by an outcrop of chloritic basaltic to andesitic crystal-lithic tuff(?) overlies the Leura Volcanics and underlies the Tartrus Rhyolite at MGA 756220 7466940 on the track to the UHF repeater on Hill 579. This may be equivalent to the Macksford Volcanics.

TARTRUS RHYOLITE

Introduction

This name, derived from Tartrus Station, is given to a distinctive unit of crystal-rich ignimbrite that lies stratigraphically between the Mount Benmore and Leura Volcanics east of Mount Mackenzie in the southern part of the Broadsound Range (Figure 35). Hutton & others (1999a) included the rocks as an unassigned member forming the top of the Leura Volcanics, but it is defined here as a separate unit. The unit can be traced westwards from a prominent hill south of the old Bruce Highway (informally known as Hill 579) towards Mount Mackenzie as a narrow belt ~500m wide. The most westerly outcrops were observed at MGA 751350 7467600, a~2km south-east of Mount Mackenzie.

Similar rocks also crop out in the southern part of the Langdale Inlier, and are assigned tentatively to the Tartrus Rhyolite. Like those in the Broadsound Range, they lie between andesite and sedimentary rocks assigned to the Leura Volcanics and basaltic rocks assigned to the Mount Benmore Volcanics. In places, they form a conspicuous ridge.

Type locality

A type locality is given along the track to the Hill 579 UHF repeater from MGA 756100 7467100 to the repeater at MGA 755400 7465700. The hill is capped by a distinctive bluish grey, crystal-rich ignimbrite that forms a flat-lying sheet, probably several tens of metres thick.

Lithology

Between Hill 579 and the western extremity of the unit, the rocks are generally light grey to bluish grey and contain ~25–30% white feldspar crystal fragments to 4mm in an aphanitic groundmass. Up to 5% quartz fragments to 1mm are present, although locally they are absent. Altered biotite flakes to 1mm are also present. The sparse lithic fragments include subangular aphyric to porphyritic felsite and microdiorite to 1cm. In thin section, the groundmass commonly contains a well-preserved eutaxitic foliation with abundant flattened shards, but in some rocks, recrystallisation has obliterated most of the vitroclastic texture, except for ‘ghost’ outlines. Fiamme up to 2cm long can be seen on the weathered surface of some outcrops.

The rocks observed in the Langdale Inlier, between MGA 759940 7471890 and MGA 759510 7473340, are relatively uniform in appearance and identical to those rocks described above. However, at the northern end of the unit as mapped the rocks are more heterogeneous, showing greater variation in the crystal and lithic content, and also containing common embayed quartz crystal fragments up to 3mm. The intervening area was not examined and the reason for this variation is not known. Lithic fragments include granite from the underlying basement.

Two samples of ignimbrite from the Tartrus Rhyolite were analysed for a range of major and trace elements. Although quartz crystal fragments are minor to absent, the plot of total alkalis vs SiO_2 in Figure 39 confirms that rocks are rhyolite.

Geophysical response

The Tartrus Rhyolite has moderate potassium and thorium responses and a high uranium response resulting in bluish to pinkish white hues on composite images.

Magnetic susceptibility measurements were made on only three outcrops and they range from 0–320 x 10^{-5} SI units. In the airborne magnetic data, the unit has a low response that cannot be distinguished from the surrounding units.

Relationships and age

For most of its outcrop extent in both the Broadsound Range and the Langdale Inlier, the Tartrus Rhyolite overlies the Leura Volcanics and is overlain by the Mount Benmore Volcanics.

A sample of ignimbrite from Hill 579 (IWSC0353) has been dated by SHRIMP (see Appendix). The data show a broad scatter that gives a weighted mean of 300.8±2.2Ma with a MSWD of 1.8. Arbitrarily dividing the data into two populations gives ages of 296.9±3.5Ma and 303.8±2.8Ma. Although the exact age is somewhat uncertain, the data indicates a latest Carboniferous to earliest Permian age.

Hutton & others (1999a) suggested that highly altered, crystal-rich rocks in core from some of the Marlborough Gold Mines' drill holes around the Mount Mackenzie prospect ("Bald Hill Tuff" in some of Dear's earlier unpublished reports) may be Tartrus Rhyolite. If so, the Tartrus Rhyolite would be older than the Coppermine Andesite which underlies the Mount Benmore Volcanics. The Coppermine Andesite has an erosional unconformity at its base and is unaffected by the Mount Mackenzie alteration system. The SHRIMP age determined by Burch (1999) at 297±2.5Ma for the Coppermine Andesite is similar to that obtained by us for the Tartrus Rhyolite, but as noted below the reliability of Burch's age is uncertain and may be slightly younger. This would be consistent with the Tartrus Rhyolite being older. The relationship of the Tartrus Rhyolite and Coppermine Andesite was investigated in the field, but the former appears to lens out westwards, just short of where the latter lenses out eastwards.

In the Langdale Inlier, the rocks assigned to the Tartrus Rhyolite mostly overlie andesite, sandstone and conglomerate equated with the Leura Volcanics. However, at the extreme north-western end, the ignimbrites directly overlie altered biotite granite. Granite clasts occur in some of the ignimbrite and vitroclastic textures are well-preserved within a few metres of the contact, which is therefore clearly erosional, not intrusive. The unit is partly overlain by basaltic andesite equated with the Mount Benmore Volcanics, and to the north-west by rhyolite lava (Langdale Rhyolite), possibly equivalent to the Mount Buffalo Rhyolite.

COPPERMINE ANDESITE

Introduction

At Mount Mackenzie, the Macksford Andesite, South Creek Diorite and the mineralised alteration system are overlain by a distinctive andesitic unit, referred to informally as the "Coppermine Tuff" or "Coppermine Andesite" by Dear (1994a,b, 1995). It is defined formally here as the Coppermine Andesite. The name 'Tuff' is not used, because the rocks are not all unambiguously primary pyroclastic, but probably include lavas and epiclastic sedimentary rocks. The name is derived from Coppermine Creek, a small stream that crosses the old Bruce Highway, just to the north-west of Mount Mackenzie. The unit is ~150m thick at Mount Mackenzie and can be traced for ~4km along strike (Figure 35). The pronounced dip-slope on the western side of Mount Mackenzie corresponds to the base of the Coppermine Andesite (Figure 45a).

Type section

A type section is nominated along a tributary of Coppermine Creek from MGA 749550 7469800, the contact with the underlying Macksford Volcanics, downstream to 749300 7469550, the boundary with the Mount Benmore Volcanics. Crystal-rich, lithic-poor andesitic volcaniclastics are exposed.

Lithology

The Coppermine Andesite is generally grey to greyish purple with up to 20% distinctive crystal fragments or phenocrysts of greenish yellow, partly altered plagioclase to 7mm and less abundant but conspicuous altered hornblende crystals to 5mm. Sparse clasts of porphyritic andesite are commonly present, suggesting that the unit is mainly volcaniclastic. Around Mount Mackenzie, the andesite is massive and apparently unbedded. In thin section, the plagioclase crystals are generally extensively altered to epidote, carbonate and sericite and the hornblende is mostly replaced completely by epidote and chlorite. It is difficult to resolve the lithic fragments from the groundmass in thin section, because of the chlorite-epidote-carbonate-sericite alteration. Rare embayed quartz grains are present in some of the rocks, and because of this the unit was referred to as a quartz andesite by Dear (1994a). Geochemical analyses indicate that the rocks range from andesite to possibly dacite.

Although sparse clasts are visible in most outcrops, some lava may be present. In thin section, the groundmass in sample IWSC0385 from MGA 749990 7468500 shows a partly flow-aligned felted texture of plagioclase laths, suggesting that it is probably a lava.

The northernmost extent of the unit is in cuttings on the old Bruce Highway at MGA 749000 741100. It is represented by a very thick bed of volcanic sandstone containing abundant plagioclase crystals to 5mm and subordinate hornblende in a fine-grained matrix. It passes upwards into moderately sorted lithic sandstone with possible ripple marks.

Geophysical response

The Coppermine Andesite has a similar radiometric response to the Mount Benmore Volcanics (low in all three channels) and cannot be distinguished from them. It also appears to have a similar low magnetic

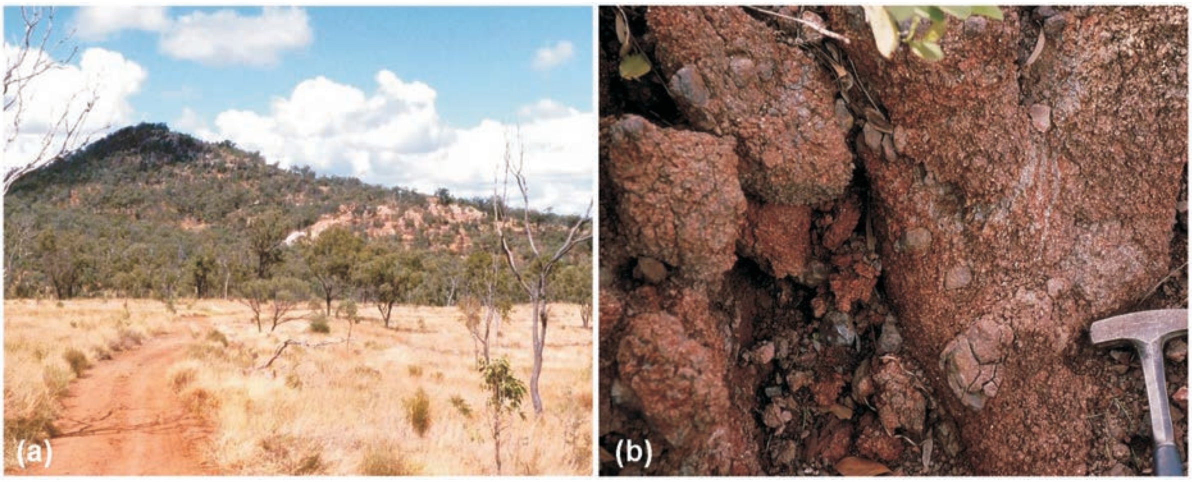

Figure 45. Coppermine Andesite
(a) Mount Mackenzie viewed from the north The dip-slope marks the base of the westerly dipping Coppermine Andesite overlying the alteration system.
(b) Weathered, poorly sorted hematitic conglomerate or breccia at the base of the Coppermine Andesite. In an exploration trench on the north-western flank of Mount Mackenzie at MGA 749735 7469510 (IWSC0465)

response. Magnetic susceptibility measurements were made at only three outcrops and they range from 2–740 x 10^{-5} SI units.

Geochemistry

Three samples from the Coppermine Andesite interpreted as lava were analysed for a range of major and trace elements. The plot of total alkalis vs SiO_2 (TAS) in Figure 49a indicates that lavas are dominantly andesite to possibly dacite. The plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) in Figure 49b confirms that two of the samples lie in the basalt-andesite field (because Nb was not determined on the dacite sample, it is not plotted).

The most silica-poor sample was submitted for precise trace element analysis by laser ablation mass spectrometry, and the data have been used in the multi-element and rare-earth element (REE) plots in Figure 46b–c. The profiles were compared with those from modern basaltic suites using the database compiled from literature by Murray & Blake (2005, appendix 1). Although no exact match was found, the slope of the REE profile is similar to those of basalts from the Casimiro suite in the Southern Volcanic Zone of the Andes (Hickey & others, 1986), where the crust is ~50km thick. The profile of the high-field-strength elements also matches those of this suite, although the multi-element profiles are less definitive and the Coppermine Andesite profile would match some other Andean suites developed on moderately thick crust such as the Peteroa suite to which the Leura Volcanics have been compared. The large-ion-lithophile elements are more enriched than most other suites from this study, with the exception of those in the Narayen beds and low-Ti suite of the Nogo beds. The REE profile is steeper than those of either the underlying Leura Volcanics or the overlying Mount Benmore Volcanics, and if representative, may suggest that the crust reached its thickest at this time, before the commencement of thinning related to the formation of the Bowen Basin.

Relationships and age

The significance of the Coppermine Andesite is that it overlies and is unaffected by the intense argillic alteration zone at Mount Mackenzie (Figure 45a). It also overlies the South Creek Diorite, a pluton just to the south of Mount Mackenzie. Exploration trenches on the northern flank of Mount Mackenzie at MGA 749735 7469510 expose a weathered, poorly sorted hematitic conglomerate or breccia at the base of the unit, immediately above the alteration zone (Figure 45b). It can also be recognised in drill sections (S. Beams, Terra Search Pty Ltd, personal communication, 1998). These relationships indicate an erosional break above the Macksford Andesite. However, because of the limited extent of the Coppermine Andesite, this break cannot be mapped out regionally, and it is possible that the Mount Benmore Volcanics may include some equivalents of the Macksford Andesite. The unconformity was first recognised by Dear (1994a,b, 1995) as separating his Cycles 3A and 3B.

SHRIMP dating of zircons from the Coppermine Andesite by Burch (1999) indicated an earliest Permian age of 296.6±2.5Ma (based on 14 analyses). However, her SHRIMP data have not had the rigorous statistical processing using the SQUID program (Ludwig, 2000) as samples from this study (see Appendix) and it is not certain whether they can be compared exactly. Reprocessing of some original data using SQUID resulted in ages being up to 8ma younger than in preliminary reports.

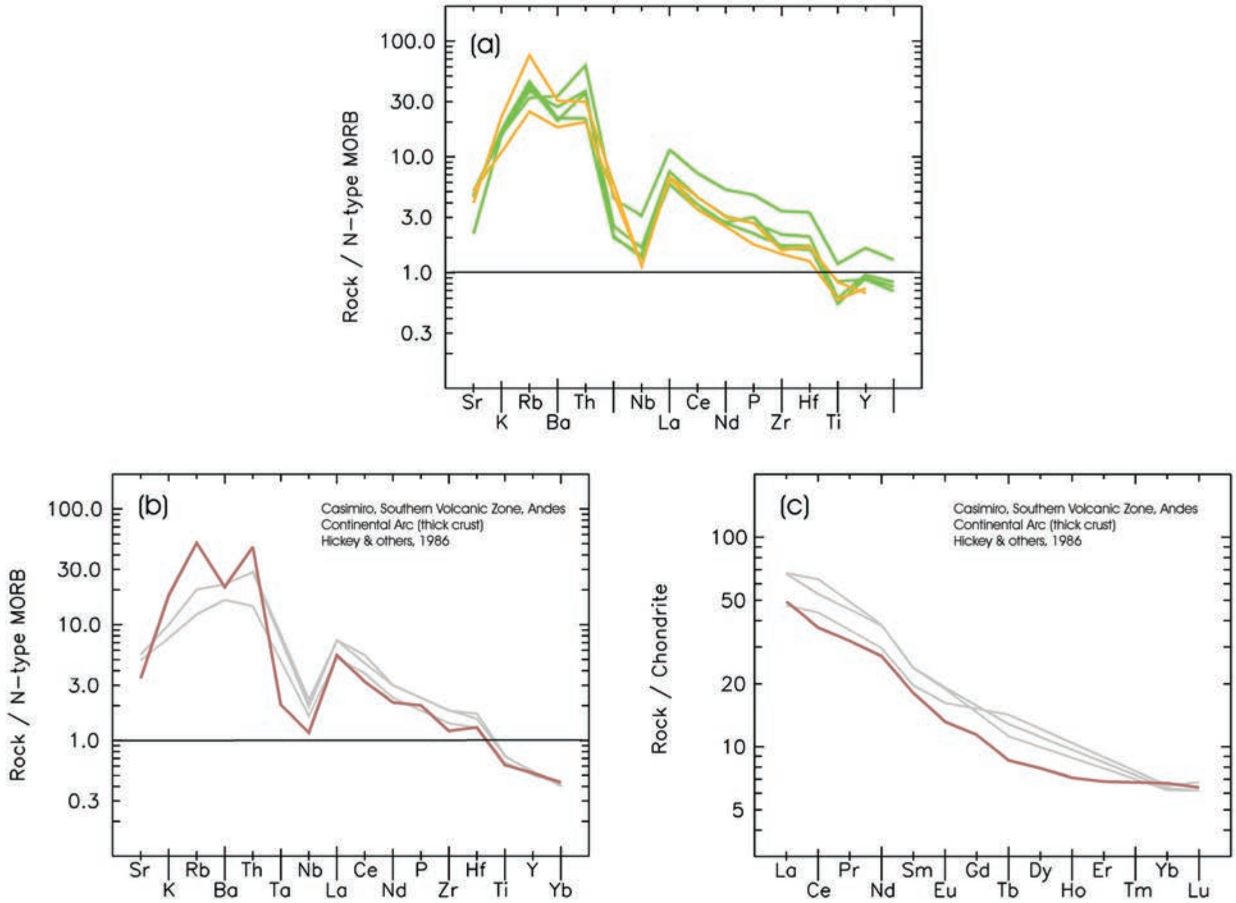

Figure 46. Multi-element plots of an andesite sample from the late Carboniferous Macksford Andesite (yellow) and Leura Volcanics (green) and early Permian Coppermine Andesite (brown) — for comparison, the pattern of modern Andean Casimiro basaltic suite is shown in grey:
(a, b) N-MORB normalised multi-element plots (using values from Pearce, 1983);
(c) chondrite-normalised REE plots (using values from Sun & McDonough, 1989).

COBWEB MOUNTAIN RHYOLITE

Introduction

This name is given to a sequence of mainly felsic volcaniclastic rocks underlying the Mount Benmore Volcanics and cropping out discontinuously in two separate areas on the western flank and central part of the Connors Arch (Figures 35 and 37).

One area is between the Cobweb Mountain area, south-east of Croydon homestead, and Bora Creek. To the east, a separate area of felsic volcaniclastic rocks, which crop out west of Killarney homestead in Yellow Creek and along the Croydon to Saint Lawrence road near Big Codling Creek, is also assigned to the unit. The rocks form a narrow north-trending belt ~12km long and up to 1.5km wide. Apart from areas adjacent to the road and along part of Yellow Creek, access is difficult because of thick acacia scrub. Felsic volcanics underlying the Mount Benmore Volcanics around Mount Raddle north of Markwell homestead are assigned to the unit because of their stratigraphic position.

The bedded nature of the unit is evident on aerial photographs and is expressed by conspicuous trend-lines. On composite radiometric images, the rocks are represented by pinkish hues, consistent with their rhyolitic composition.

Type section

The type section is designated at Cobweb Mountain between MGA 727750 7513900 (the basal conglomerate overlying the Leura Volcanics) and MGA 727900 7512950 (where it is overlain by basalt of the Mount Benmore Volcanics). The section is ~200m thick and is mainly volcanic sandstone, rudite and siltstone.

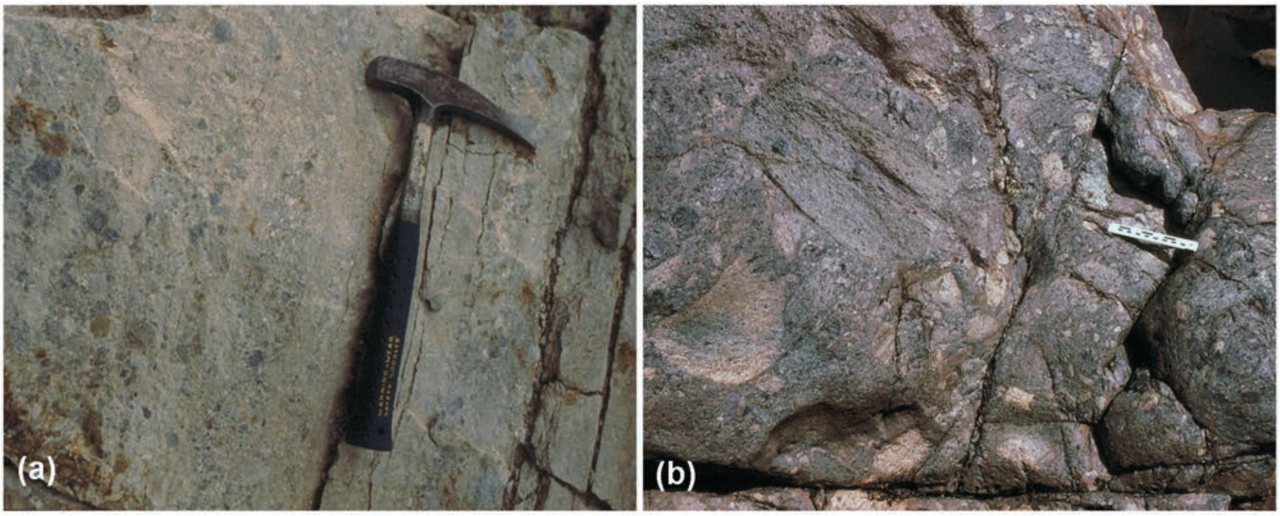

Figure 47. Cobweb Mountain Rhyolite
(a) Thinly bedded, poorly sorted, felsic volcaniclastic sandstone and conglomerate. Croydon–St Lawrence road ~12km north-east of Croydon homestead at MGA 732177 7521381 (RSC072)
(b) Poorly sorted, rhyolitic breccia. Gorge in Yellow Creek, ~2km west of Killarney homestead at MGA 732986 7525703 (IWSC1030)

Lithology

At Cobweb Mountain, the base of the unit is marked by very thick beds of pebble to boulder conglomerate that contains well-rounded clasts from the underlying Leura Volcanics as well as some rhyolite supported by a matrix of medium to very coarse-grained lithic sandstone. The basal section is probably ~5m thick. The remainder of the section consists of yellowish grey, volcanic sandstone and rudite. The rudite commonly consists of subangular to subrounded, aphyric to slightly porphyritic felsite granules and pebbles in a very fine-grained to aphanitic matrix. The sandstones contain felsic lithic fragments, pink feldspar and rare quartz crystal fragments. They are generally medium to very coarse-grained, moderately well sorted, and locally pebbly with subrounded to rounded felsite clasts. Some more poorly sorted rocks that have significant very fine-grained to aphanitic matrix and pass into siltstone are possibly waterlain or air-fall crystal and lithic tuff.

Farther south on Spring Hills Station near the large loop in Clarke Creek, the unit includes crystal-poor to crystal-rich and generally lithic-rich, poorly sorted, felsic volcanic breccia, sandstone and siltstone (tuff?). Lithic clasts are subangular to angular granules to pebbles and crystal clasts are mainly feldspar. Strongly flow-banded, feldspar-phyric rhyolite crops out at MGA 734500 7502150 and appears to be part of a sheet-like mass from its photo-pattern, and is probably a flow.

In the eastern area, the rocks are well exposed in cuttings along the Croydon to Saint Lawrence road from around MGA 732170 7521400 to MGA 731950 7520800 and along Big Codling Creek adjacent to the road. The rocks are dominantly thin to very thick-bedded, moderately sorted, pebbly volcanic sandstone consisting of angular to subangular lithic fragments, feldspar and quartz (Figure 47a). Internal stratification includes planar laminae and rare cross-laminae. The lithic clasts are mainly flow-banded, spherulitic, aphyric to porphyritic rhyolitic and vitroclastic tuff. The rocks are grey when fresh, weathering to greyish yellow. Some thin to very thick beds of pebble to boulder conglomerate and siltstone are interbedded with the sandstone. The siltstone beds commonly contain scattered feldspar and beta-quartz crystals and are probably waterlain tuffs.

Yellow Creek cuts a gorge through the unit between MGA 733450 7525400 (top) and MGA 732250 7525550 (base). The section, which is probably ~350m thick, was only observed at either end of the gorge. At the western (downstream) end of the gorge, the base of the unit consists of ~50m of medium to thick-bedded, planar laminated and very fine to very coarse-grained felsic volcanolithic sandstone and very thick-bedded conglomerate composed mostly of subrounded, aphyric, felsite pebbles to boulders supported by a sandy matrix. The sandstone is pale green, possibly due to alteration of glassy material to epidote. A 15m-thick bed of massive tuff overlies the sandstone and conglomerate. It contains ~25% feldspar and embayed quartz crystals and at least 50% angular felsite clasts to 2cm. In thin section the matrix is difficult to distinguish from the lithic clasts, both consisting of granular quartz-feldspar mosaics (<0.05mm).

At the upstream end of Yellow Creek gorge, the unit is dominated by rhyolitic breccia (Figure 47b). One breccia unit that forms a waterfall is ~50m thick and consists of subangular to subrounded (milled?) feldspar-phyric felsite clasts up to 1.5m across in very fine-grained matrix. It is mainly massive, but some crude stratification is suggested by variation in clast sizes. Some of the clasts have altered selvages, and in thin section these are shown to be saussuritised. Unaltered cores of some clasts appear to have a trachytic texture. In thin section, the matrix consists of a very fine granular mosaic (*ca* 0.01–0.02mm) and contains scattered feldspar crystals to 0.5mm and angular aphyric andesite (?) clasts up to 3mm across. The origin of this breccia is unclear. It may have been a pyroclastic flow.

Geochemistry

Four samples from the Cobweb Mountain Rhyolite were analysed for a range of major and trace elements. The samples comprised two samples of lava and two volcaniclastic rocks. The plot of total alkalis vs SiO_2 (TAS) in Figure 49 indicates that all samples are rhyolitic and this is supported by the plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977).

Geophysical response

The Cobweb Mountain Rhyolite has only a moderate potassium response and low responses in thorium and uranium resulting in mottled dark pink and bluish hues on composite images. The exception is the area around Mount Raddle which has a very strong potassium response. Although occupying the same stratigraphic position, this rhyolite is probably from a different eruptive centre to that further south.

The unit mostly has a low magnetic response consistent with measured magnetic susceptibilities mostly <50 x 10^{-5} SI units, although rhyolite and dacite near Mount Raddle had values in the range 850–4700 corresponding with an area of slightly elevated magnetic response in the airborne data.

Relationships and age

The Cobweb Mountain Rhyolite overlies the Leura Volcanics and is overlain by the Mount Benmore Volcanics, both with apparent conformity. Based on this relationship, the age is early Permian. Large rhyolite domes that occur in and adjacent to the unit in the Croydon area and near Yellow Creek may be related to the unit and could mark eruptive centres.

MOUNT BENMORE VOLCANICS

Introduction

Withnall & others (1998a,b) gave the name Mount Benmore Volcanics to a sequence of dominantly andesitic to basaltic volcanic rocks, previously mapped as Connors Volcanics at the southern end of the Connors Arch, and also in partly fault-bounded slices and anticlinal cores in the Gogango Overfolded Zone. The name is derived from Mount Benmore Station in north-western ROOKWOOD.

Mapping in 1998–1999 extended the unit farther north to rocks along the western margin of the Connors Arch, and they are now considered to be continuous, under a zone of cover, with the Lizzie Creek Volcanics that were previously recognised further north. The name is now applied to the dominantly mafic volcanic part of the Lizzie Creek Volcanics (which are raised to group status) and as such they extend along the entire length of the Connors Arch in Figures 35, 37 and 53. The Mount Benmore Volcanics corresponds to part of Cycle 3A and all of Cycle 3B of Dear (1994a,b, 1995). An unconformity or erosional break separates Cycles 3A and 3B at Mount Mackenzie.

The rocks are well exposed in the Broadsound Range between Apis Creek and Tartrus homesteads, but outcrop is poorer in the soil-covered downs west of the old Bruce Highway on the western side of the range.

Type section

The type section is designated along the access road to Manly homestead ~5km north-west of Mount Mackenzie. The base of the unit is at MGA 745785 7473930 where it overlies feldspar-phyric dacite (?) of the Leura Volcanics and the top is at MGA 744750 7471735 where it is overlain by pebbly sandstone and siltstone that contain plant stems and are assigned to the Carmila beds. The unit consists of basalt flows and volcanic sandstone and poorly sorted volcanic rudite. The flows are dominated by aphyric to slightly porphyritic (feldspar-phyric and pyroxene-phyric) basalt, which is locally amygdaloidal. Some outcrops appear to consist of autoclastic breccia.

Lithology

The unit consists of lavas and a variety of volcaniclastic rocks, probably mostly basaltic andesite or basalt in composition, although they may include some dacite and andesite. Except where specified below, the basaltic rocks are petrographically similar in most areas. The rocks are dark greenish-grey and generally contain sparse phenocrysts of ophitic clinopyroxene and plagioclase up to 2mm long. Some of the rocks are conspicuously amygdaloidal, the amygdales being variously filled with quartz, calcite, epidote/clinozoisite, chlorite or zeolite. In thin section, some rocks also contain small, irregular cavities less than 1mm across, infilled by chlorite and in some cases zeolite or quartz. In the less altered rocks, the groundmass consists of an interlocking network of plagioclase with interstitial clinopyroxene and opaques. Some rocks show partial flow alignment of the plagioclase laths. The groundmass pyroxene is commonly at least partly replaced by chlorite, the opaque grains (ilmenite) by titanite or leucoxene, and the plagioclase is partly saussuritised. Some grains pseudomorphed by chlorite retain the habit of olivine. Patchy zeolite alteration was observed in some thin sections.

Apis Creek – Mount Benmore area

In this area the rocks overlie the Cerberus Rhyolite Member and are overlain by and partly thrust over the Carmila beds. South-west of Apis Creek homestead, aphyric to porphyritic basalt lavas lie between the Cerberus Rhyolite Member and Carmila beds.

A distinctive porphyritic flow was observed between MGA 760500 7451000 and MGA 759700 7449500. It contains white plagioclase and augite phenocrysts up to 5mm long in a greyish-green groundmass of interlocking plagioclase laths. Chlorite or serpentine pseudomorphs after olivine up to 5mm long were observed in some samples. Embayed, milky quartz grains up to 1cm are locally conspicuous; they are possibly xenocrysts or infill of large amygdales. Other small irregular amygdales have infill of chlorite and locally calcite.

West-south-west of Mount Benmore homestead, on the southern side of Seven Mile Creek, lava is also dominant. The rocks are medium to dark greenish-grey, and are aphyric to slightly porphyritic with phenocrysts of altered clinopyroxene and plagioclase to 2mm. Amygdales up to 5mm in diameter and filled with quartz and calcite or chlorite are locally present. Columnar jointing was also observed.

In the hills to the north-west of Mount Benmore homestead, aphyric basaltic lavas predominate, but rudites and breccias are developed locally. In places, the lavas are strongly altered to epidote and chlorite, and have spherical to irregular amygdales up to 1.5cm across, filled with quartz or calcite. Around MGA 765400 7448140, massive, monomict breccia consists of angular clasts from pebble to boulder size of aphyric, commonly amygdaloidal basalt (Figure 48b). The clasts locally show jigsaw fits and the breccia is mostly clast supported with a matrix of granule to pebble-sized clasts in calcareous cement. A limestone bed ~20cm thick within the breccia contains ~20% angular basalt pebbles. The monomict character of the breccia and jigsaw fit texture suggest that the breccia may have formed by quench fragmentation, possibly in a lacustrine environment (in the absence of any evidence for marine deposition in the area). Where jigsaw fits are less apparent, partial resedimentation of the breccia may have occurred. The limestone bed is an obvious case for resedimentation. Blocky monomict breccia was observed around MGA 764200 7452600, and could be the top of an aa flow (Figure 48a).

Poorly sorted, polymict volcanic rudite and volcanic arenite crop out ~0.5km to the north-west near MGA 764500 7448500. The rudite is unbedded, but contains some crude internal stratification defined by variations in the proportion of clasts to matrix. The clasts are subangular to angular and range from granules to boulders, consisting of green, slightly porphyritic basalt or andesite and flow-banded, porphyritic, more felsic rocks. The fabric ranges from clast-supported to matrix-supported, grading into pebbly arenite, which is somewhat better sorted. The matrix of the arenites contains abundant carbonate, possibly due to alteration of the volcanic detritus. The andesitic clasts are probably also partly altered to carbonate, but the felsic clasts are probably less altered and stand out in relief on outcrop surfaces. A single bed of laminated, cherty (vitric) tuff was observed in one part of the exposure.

Very fine to fine-grained, cleaved, very thick-bedded volcanic arenite and siltstone appear to dominate in the lower country ~1km west of the homestead.

Felsic rocks are rare in the unit. A thin crystal-rich dacitic ignimbrite bed ~30cm thick, interbedded with siltstone and pebbly, andesitic volcanic arenite and rudite was observed at MGA 763585 7446880. At MGA 763770 7450580, a prominent knoll is formed by a plug ~50m in diameter consisting of medium grey, very fine-grained (originally vitric), flow-banded rhyolite (?) containing sparse white feldspar phenocrysts to 2mm. It intrudes slightly porphyritic basalt, which commonly shows the development of crackle breccias with silicified seams outlining the clasts. Xenoliths of andesite occur in the rhyolite.

Figure 48. Mount Benmore Volcanics
(a) Blocky monomict breccia of vesicular basalt (top of an aa flow?). Apis Creek–Mount Benmore boundary fence about 2km south of Apis Creek homestead at MGA 764174 7452611 (IWGG040)
(b) Breccia of irregular, angular basalt clasts in a calcareous matrix (possibly partially resedimented quench-fragmented lava). About 4km south-south-east of Mount Benmore at MGA 765415 7448145 (IWGG049)
(c) Amygdaloidal basalt containing irregular zones of jig-saw fit breccia (autoclastic?). About 9.5km north-east of Balcomba homestead near Four Mile Creek at775805 7413884 (IWGG308)
(d) Basalt pillows in a hyaloclastic breccia matrix. Main Range Creek near the Old Marlborough–Sarina Road ~13km north-west of Cardowan homestead at MGA 704116 7561854 (LHC030)

Langdale Inlier

Mafic volcanic rocks in the southern part of the Langdale Inlier are tentatively assigned to the Mount Benmore Volcanics because of their stratigraphic position. They form a 7km long, north-west-trending belt that is 1km wide at the south-eastern end and lenses out to the north-west. They overlie rocks equated with the Tartrus Rhyolite and are overlain by the Langdale Volcanics, which may be equivalent in age to the Mount Buffalo Volcanics or Carmila beds.

The mafic volcanics include lavas and volcaniclastic rocks. Poorly bedded volcanolithic breccia is the most abundant rock type, consisting of subangular to subrounded clasts of greyish green plagioclase-phyric andesite (?) supported by a matrix of plagioclase crystal fragments and fine-grained ash. Altered porphyritic andesite or basalt lavas also occur within the sequence. Although altered, chemical analyses indicate the presence of both andesite and basalt. Monomict breccias associated with the lavas probably formed by autoclastic processes or possibly quench-fragmentation. Plagioclase is the main phenocryst phase preserved, but chlorite pseudomorphs were probably originally clinopyroxene. Chlorite-filled amygdales are common. Alteration is widespread, and most of the rocks contain extensive chlorite and saussurite in the groundmass. These rocks were also described by O’Brien (1994).

Leura Anticlinorium

The Mount Benmore Volcanics overlie and flank the Leura Volcanics in a faulted anticlinorium that forms a meridional belt ~25km long and up to 7km across. The rocks are overlain by the Back Creek Group and in various places are overthrust by or overlie the Leura Volcanics. In places, the Back Creek Group directly overlies the Leura Volcanics, suggesting that the Mount Benmore Volcanics lensed out or were removed by erosion.

The rocks were examined in two main traverses — along the creek east of Mount Benmore homestead, and the track east from Leura homestead. In both areas, the rocks are dominantly coherent lavas, but locally include monomict breccias and more polymict volcanic rudite and arenite or sandstone. The breccias are probably autoclastic, but whether individual outcrops formed by autobrecciation or quench fragmentation is uncertain. Jigsaw-fit textures are common. Patchy alteration of the lavas and breccias includes epidotisation, chloritisation and hematisation.

Locally along the creek east of Mount Benmore homestead, beds of thick to very thick-bedded, coarse to very coarse-grained, moderately-sorted, pebbly volcanic sandstone crop out. The clasts are white feldspar and greyish-green andesitic, dacitic or basaltic volcanic lithics. Well-sorted sandstone at MGA 767020 7435920 also contains common embayed quartz clasts, suggesting derivation from contemporaneous felsic volcanics or reworking from the Leura Volcanics. Sedimentary structures observed include weak laminations, cross laminae and mega-ripples, suggesting a fluvial environment.

In a section examined south of Leura Creek from MGA 770785 7436050 to MGA 770850 7435550, an interval of volcanic sandstone, siltstone and dirty limestone in the order of 100m thick occurs within a sequence of lavas and autoclastic breccias. The volcanic sandstone is very thick-bedded, massive, moderately to poorly-sorted, medium to very coarse-grained and consists dominantly of basaltic lithic clasts. The siltstones weather to reddish-brown and are probably dominantly of andesitic derivation. The limestone occurs within an interval ~20m thick of flaggy, fine to medium-grained, calcareous sandstone. The limestone itself is ~2m thick, and contains abundant medium-grained, siliciclastic material (probably mainly volcanic lithic grains). The sandstone interval is overlain by monomict, autoclastic, aphyric andesite breccia that has a calcareous matrix and locally jigsaw-fit textures.

East of Balcomba and Roselea

In this area, the unit crops out as a series of lenses up to several kilometres long that may be the cores of small anticlines. The rocks also crop out in a much more extensive area at the southern end of the large meridional belt that lies on the western side of Melaleuca Creek. In all of these areas, the unit is dominated by aphyric to slightly porphyritic basaltic lavas. Phenocrysts, where present, include both plagioclase and pyroxene. The rocks are usually at least partly altered to epidote-chlorite assemblages, and locally are completely replaced by epidote. The lavas are commonly amygdaloidal and contain zones of monomict and autoclastic breccia (Figure 48c). The brecciated lavas are particularly well-developed and well exposed along Four Mile Creek around MGA 775800 7413900. In thin section, the basalt clasts consist of plagioclase laths to 0.5mm in a very fine-grained groundmass that may originally have been glassy; the matrix is sparry calcite. The breccias are generally irregularly distributed throughout the flows, passing laterally into coherent lava. In places, sheet-like breccia zones mark the top of flows.

Pseudopillows are locally developed. On weathered surfaces, these resemble real pillows, but in stream pavements they can be seen to be simply curved joints, the andesite being continuous in grainsize and texture across them. No chilling or interstitial hyaloclastite is apparent.

Minor areas of volcaniclastic sedimentary rocks were also observed. They range from siltstone to rudite and are generally massive and very thickly bedded or apparently unbedded. Most are poorly-sorted, the clasts being mainly angular to subrounded, greyish-purple to dark greyish-green, aphyric volcanic lithics and plagioclase crystals. A cleavage is commonly well developed in the volcaniclastic rocks.

Melaleuca Creek area

Rocks observed along the eastern side of the large meridional belt are similar to those described in the section above. Lavas, locally amygdaloidal, and autoclastic breccias are again dominant, with subordinate volcaniclastic arenite and rudite. In places, a cleavage defined in thin section by alignment of chlorite flakes and anastomosing seams of leucoxene or titanite is present. The groundmass of the rocks is commonly altered to assemblages of albite (?), chlorite and epidote, although relict phenocrysts of plagioclase and clinopyroxene survive.

Along the middle part of belt, several elongate bodies of altered diorite or gabbro intrude the Mount Benmore Volcanics. On geophysical images and aerial photographs, the diorite cannot be distinguished from the volcanic rocks, and the finer-grained variants are also difficult to distinguish in outcrop.

To the east of Melaleuca Creek, several lenticular bodies of Mount Benmore Volcanics have been interpreted from geophysical images. They have the same low response on the composite radiometric image as the rest of the Mount Benmore Volcanics, and are inferred to have similar rock types. However, it is possible that some of the bodies could be largely sedimentary rocks like the Goodedulla beds. Aphyric basalt or andesite lava and floaters of volcanic rudite were observed at MGA 785815 7424485 at the southern end of one of the bodies, whereas strongly cleaved, very coarse-grained volcanic arenite was observed in another lens at MGA 785580 7430460. The lenses are probably partly faulted. The regional structural pattern is one of westward directed thrusting. Using this model, the western contacts with the Back Creek Group are probably thrusts, whereas the eastern contacts may be at least partly stratigraphic, or the lenses may be entirely bounded by thrusts.

Morbank area

Partly thrust-bound lenses also occur to the north of Melaleuca Creek on Morbank and Clifton stations. Again they are dominated by aphyric to slightly porphyritic lavas that are commonly amygdaloidal and locally autoclastic with jigsaw-fit textures. Volcanic sandstone and rudite were observed locally.

Mount Gardiner to Stockyard Creek area

The lower part of the Mount Benmore Volcanics in this area was examined along and adjacent to Pluto Creek and on the northern flank of Mount Gardiner (Figure 34), which is capped by the Cerberus Rhyolite Member. The rocks consist of plagioclase-phyric and locally pyroxene-phyric basalt flows and some volcaniclastic rocks. Some of the flows have quartz- and chlorite-filled amygdales. The volcaniclastic rocks contain angular to subangular mafic volcanic clasts supported by a poorly-sorted matrix ranging from silt-sized material to sand-sized plagioclase and pyroxene crystal fragments and lithic clasts. At MGA 759580 7459650, volcanic rudite consisting of elongate scoriaceous mafic volcanic clasts was observed. Although most rocks are at least slightly altered to epidote and chlorite by burial metamorphism, more intense alteration is common along the valley of Pluto Creek. Strongly silicified zones up to 5m wide, including siliceous breccia, crop out between MGA 757700 7458100 and MGA 756800 7457500. The silicification is commonly associated with intense epidote and hematite alteration.

The upper part of the Mount Benmore Volcanics, overlying the Cerberus Rhyolite Member, was examined in the creek upstream of MGA 761500 7456850 on the eastern flank of Mount Gardiner and along the access track to Cerberus homestead. The sequence consists of feldspar-phyric basalt flows, locally intercalated with very thick-bedded to unbedded, pebble to boulder conglomerate, consisting of subangular to rounded andesite to basalt clasts supported by a matrix of volcanolithic sandstone. Some medium to thick beds of moderately sorted volcanolithic sandstone are also present. At MGA 761225 7456100, accretionary lapilli are present in the sandstone.

Above the Coppermine Andesite along the Tartrus access road and farther north, the Mount Benmore Volcanics are similar to the rocks in the Apis Creek – Mount Benmore area. They consist of basalt flows and volcanic sandstone and poorly sorted volcanic rudite. This includes the type section along the road to Manly homestead, where the flows are dominated by aphyric to slightly porphyritic (feldspar-phyric and pyroxene-phyric) basalt, which is locally amygdaloidal. The amygdales have a patchy distribution, and some outcrops appear to consist of autoclastic breccia.

Croydon to Mount Britton

In the belt between Croydon and Mount Britton, mafic to intermediate volcanic rocks assigned to the Mount Benmore Volcanics overlie the Leura Volcanics and are overlain by marine sedimentary rocks of the Back Creek Group in the Bowen Basin.

Along the road into Waitara Station south of Nebo, basaltic andesite is locally magnetite-rich and is interpreted as being hornfelsed. The hornfels is adjacent to the Waitara Granite indicating that this intrusion is post-early Permian. This granite is associated with advanced argillic alteration and possible porphyry Cu-Au mineralisation. Away from the hornfels zone in this area, the basaltic andesite is highly altered comprising mostly chlorite and sericite.

In Main Range Creek, east of the Sarina–Marlborough road (old Bruce Highway), spectacularly developed pillow lavas are developed (Figure 48d). Globular-shaped bodies of andesite to basaltic andesite are surrounded by hyaloclastite breccia. The andesite is highly altered and contains subhedral, extensively sericitised plagioclase phenocrysts and poorly preserved pyroxene phenocrysts in an altered plagioclase and clay groundmass.

In the Mount Britton area, basaltic andesite occurs in two different settings; as either massive amygdaloidal flows near the base of the unit, or as interbedded basaltic andesite, siltstone or shale nearer the top. Along the track into the Mount Briton workings, massive basaltic andesite is interbedded with khaki to green siltstone and grey to black fissile shale. Locally, the basaltic andesite layers incise the siltstone beds. At one locality, blocks of basaltic andesite enveloped by siltstone are interpreted as peperite. Further north along the track into Mount Britton, massive basaltic andesite is locally amygdale-rich but the distribution of amygdales is patchy. Here basaltic andesite comprises variably altered plagioclase laths, pyroxene and minor chlorite and opaques. Some plagioclase laths are enclosed in pyroxene grains giving a sub-ophitic texture.

South-east of Mount Britton along the road into Mount Adder Station, former volcanic glass-rich rocks contain spindly feldspar microlites with “swallow-tail” terminations typical of undercooled magmas. Phenocrysts in the rock are subhedral plagioclase.

Rhyolitic rocks are interlayered with mafic to intermediate volcanics in places in the northern part of the Mount Benmore Volcanics. Such rocks are well developed between Waitara and Nebo. Where they occur in large masses, they are mapped as Pvb_r but smaller outcrops too small to map out were also observed. Most are interpreted as rhyolitic to rhyodacitic lava and high-level intrusive rocks, but volcaniclastic rocks including ignimbrite have also been observed. They are similar to rhyolitic rocks near Lotus Creek in the central part of CONNORS RANGE, but these occur at the base of the Lizzie Creek Volcanic Group and have been assigned to a separate named formation, the Cobweb Mountain Rhyolite.

At the crossing of Dennison Creek on the Oxford Downs to Sarina road, grey, crystal-poor, moderately lithic-rich densely-welded rhyolitic ignimbrite has a well developed eutaxitic layering made up of flattened fiamme. Although no mafic to intermediate volcanics are recorded at this locality, they occur along strike to the south and north. South of The Valley homestead, rhyolitic tuff/ignimbrite is interbedded with andesitic breccia and andesitic lava. Woorumbah Knob, east of The Valley homestead, is a flow-banded, autobrecciated rhyodacite which is interpreted as a flow-dome complex within the Mount Benmore Volcanics.

Small bodies identified as dacite each ~1km^2, have also been mapped north-west of Burrenbring homestead in NEBO. They have been assigned to an unnamed subunit (**Pvz_d**). These bodies may be intrusive flow-dome complexes or flows interbedded in the sequence.

Geophysical response

The radiometric response reflects the dominance of mafic rocks and is low in all channels producing dark purple to black hues on composite images. The exceptions are the felsic volcanic members such as the Cerberus Rhyolite Member that has moderate to high potassium and uranium and generally low to moderate thorium resulting in dark pinkish hues on composite images.

The magnetic response is indistinguishable from that of the Leura Volcanics and in general it is relatively low, although slightly higher than that of the overlying sedimentary rocks. This is consistent with the measured magnetic susceptibility values. Of about 2300 values across a range of rock types, ~90% are <100 x 10^{-5} SI units although the mean is about 120 with sporadic values up to 5000. There is no consistent distinction between mafic and felsic rocks in the unit, and many of the felsic volcanic rocks actually have higher susceptibilities than the mafic ones. The relatively low magnetic susceptibility may be due to the common alteration associated with burial metamorphism. In addition, the abundance of leucoxene or titanite, observed in thin section as an alteration product, suggests that the opaque oxides were probably mainly ilmenite rather than magnetite.

Environment of deposition

The Mount Benmore Volcanics are dominated by lavas with subordinate, generally coarse-grained, poorly to moderately sorted volcaniclastic rocks. There is no evidence for submarine emplacement, and the unit was probably largely subaerial. Some of the autoclastic breccias may be due to quench fragmentation, but definite pillow lavas are rare. Quench fragmentation, if it does occur, and the rare pillow lavas could be due to emplacement into lakes. Much of the breccia could be simply due to autobrecciation of the outer surfaces of subaerial lava flows. The irregular patches of breccia in coherent flows are probably due to the foundering of the brecciated surface. The volcaniclastic rocks may have been formed by a variety of subaerial processes involving mass flows and fluvial traction currents. Local fine-grained sedimentary rocks may be lacustrine or fluvial overbank deposits.

Geochemistry

Fifty samples from the Mount Benmore Volcanics were analysed for a range of major and trace elements. The rocks were mostly lava but six clastic rocks were also analysed. The plot of total alkalis vs SiO_2 (TAS) in Figure 49 indicates that lavas are dominantly basalt or basaltic andesite with a few samples of andesite and dacite. This contrasts with the underlying Leura Volcanics, which are predominantly andesite. The clastic rocks mostly plot in the andesite or dacite fields, although the plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) in Figure 49b suggests that they are probably mainly andesite.

Six samples of basalt or basaltic andesite were submitted for precise trace element analysis by laser ablation mass spectrometry, and the data have been used in the multi-element and rare-earth element (REE) plots in Figures 49 and 50. Four of the samples produce an array of parallel profiles on the REE plot that have a moderately steep slope (Figures 49c–f). The two least enriched of these samples plot with the sample of Ametdale Volcanics.

The array was compared with those from modern basaltic suites using the database compiled from literature by Murray & Blake (2005, appendix 1). As a whole, the group fits most closely with basalts from the Tatara suite in the Southern Volcanic Zone of the Andes, although one of the samples is similar to the Peteroa suite, to which the Leura Volcanics and Mountain View Volcanics have been compared. Both of these volcanoes are developed on crust ~40–45km thick (Ferguson & others, 1992; Tormey & others, 1995). Thus the three main volcanic units in the Connors Arch from the early Carboniferous to early Permian are basically similar and represent a continental margin volcanic arc developed on thick crust.

Two samples from the Mount Benmore Volcanics are significantly different from the rest of the array and have much shallower REE profiles (Figure 50). Both come from the southern end of the Connors Arch. One of the samples (IWGG022) matches the REE profile of basalts from the Villarrica suite in the Southern Volcanic Zone of the Andes although the large-ion-lithophile elements in the multi-element diagram are depleted and the Ta-Nb trough is not quite as pronounced. The Collaroy Volcanics and a sample from the Carmila beds (as well as a sample from the Camboon Volcanics) have similar REE profiles. The profiles are also similar to those of the Okinawa Trough, a continental backarc basin in a marine environment, particularly for the multi-element plot, although the REE profiles from this study are slightly steeper.

The other sample from the Mount Benmore Volcanics (IWGG086A) produces an even flatter profile that is not unlike those of the Rookwood Volcanics except for a more pronounced Ta-Nb trough. Some samples from the Mariana Trough, with which the Rookwood Volcanics have been compared, do have a Ta-Nb trough and one of these samples is shown for comparison. IWGG086A was collected from near the southern limit of outcrop of the Mount Benmore Volcanics.

The reason for these different profiles is uncertain, and more analyses are needed to confirm whether this is a regional pattern. A continental backarc basin setting would suggest that the subduction zone and arc had stepped out to the east with the old arc becoming the site of extension. This might explain the increasing bimodality of the early Permian volcanic rocks and paucity of andesite relative to the Leura Volcanics and older rocks. Whether these volcanic rocks did form in a continental backarc or continental margin arc on thinner crust, they suggest that crustal thinning related to the formation of the Bowen Basin may have commenced during the eruption of the Mount Benmore Volcanics.

It may be significant that the samples from the southern end of the Connors Arch and the anomalous sample of Camboon Volcanics at the northern end of the Auburn Arch all lie to the west of and inboard of the Rookwood Volcanics. This could indicate that the crustal extension that gave rise to the Rookwood Volcanics in the Yarrol Province also affected the crust to the west. The Stanage Bay Fault, which has been interpreted as a dextral tear fault forming the northern limit of the Gogango Overfolded Zone (Morand, 1993a; Henderson & others, 1993; Leitch & others, 1994; Holcombe & others, 1995, 1997a), may be a reactivation of an earlier transfer fault that marked the northern limit of this extension.

Relationships and age

The Mount Benmore Volcanics are the major component of the Lizzie Creek Volcanic Group. In most areas, the Mount Benmore Volcanics overlie the Leura Volcanics and are overlain by the Carmila beds or, in their absence, by the Back Creek Group. Near Mount Mackenzie, the Mount Benmore Volcanics are separated from the Leura Volcanics by the Coppermine Andesite and Macksford Andesite. In the absence of the distinctive Coppermine Andesite, the Macksford Andesite and Mount Benmore Volcanics cannot be distinguished. Therefore equivalents of the Macksford Andesite could occur in the Mount Benmore Volcanics in some areas.

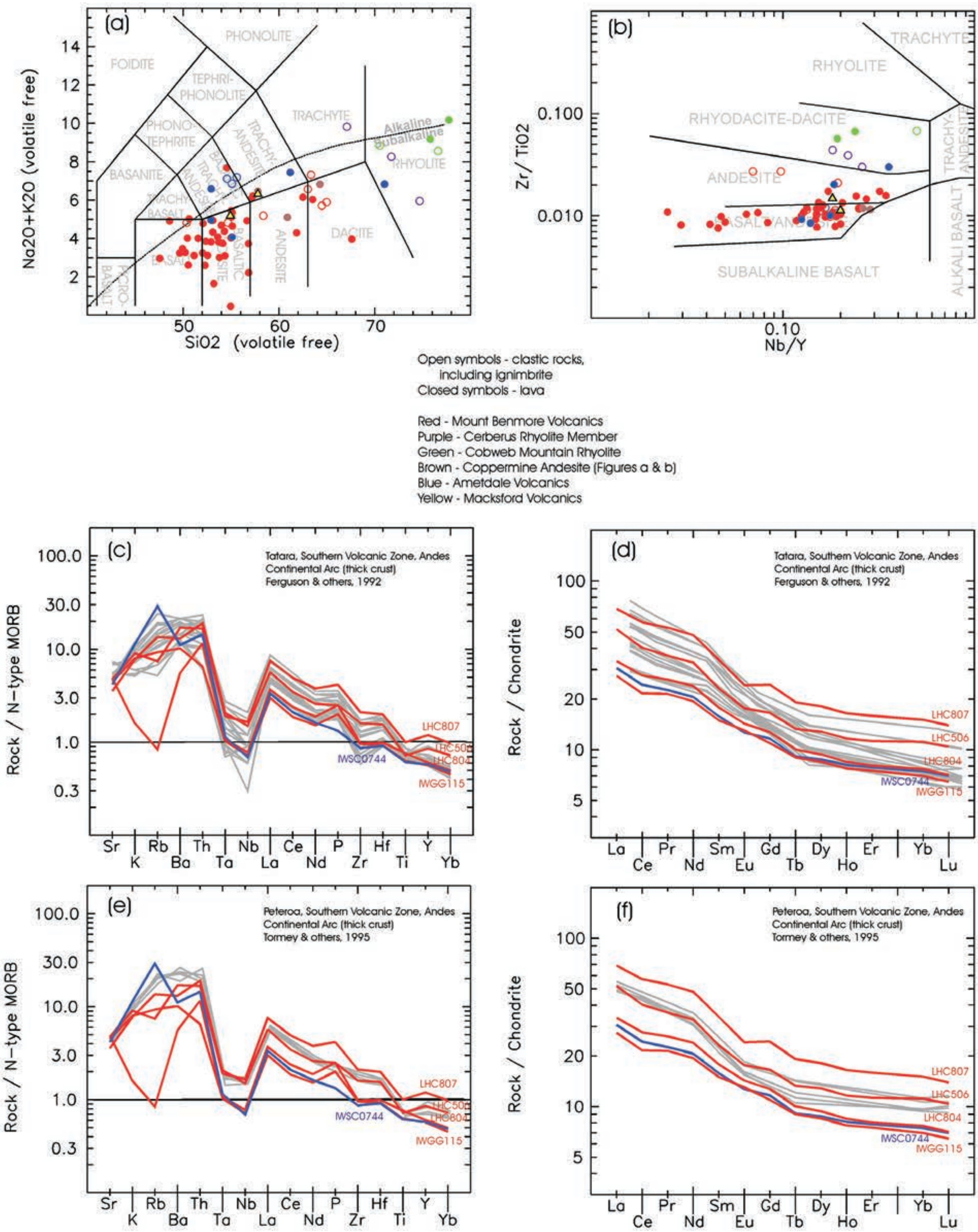

Figure 49. Geochemistry of early Permian Mount Benmore Volcanics (including Cerberus Rhyolite member), Cobweb Mountain Rhyolite, Coppermine Andesite, Ametdale Volcanics and Macksford Volcanics:
(a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986);
(b) Nb/Y vs Zr/TiO_2 showing the fields of Winchester & Floyd (1977);
(c, and e) N-MORB normalised multi-element plots of basalt or basaltic andesite samples (using values from Pearce, 1983);
(d, and f) chondrite-normalised REE plots (using values from Sun & McDonough, 1989). The main group from the Mount Benmore Volcanics (red) and Ametdale Volcanics (blue) are shown. For comparison, patterns of modern basaltic suites as indicated are shown in grey.

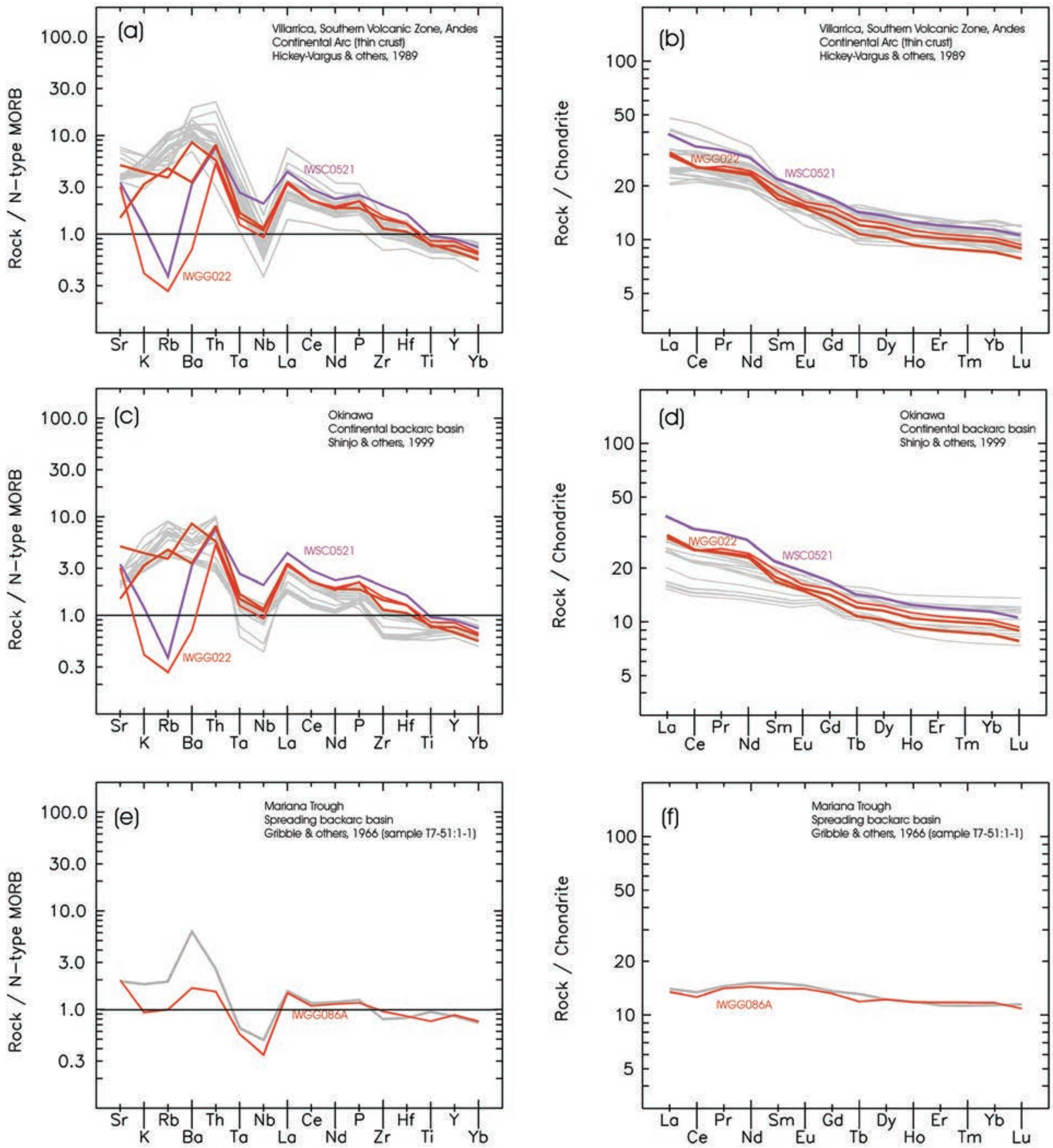

Figure 50. Multi-element plots of basalt or basaltic andesite samples from the early Permian Mount Benmore Volcanics in the southern part of the Connors Arch (red) and a sample from the Carmila beds (purple) — for comparison, patterns of modern basaltic suites as indicated are shown in grey:
(a, c and e) N-MORB normalised multi-element plots (using values from Pearce, 1983);
(b, d and f) chondrite-normalised REE plots (using values from Sun & McDonough, 1989).

To the east of Mount Mackenzie, and in the Langdale Inlier, the Mount Benmore Volcanics are underlain conformably by the ignimbritic Tartrus Rhyolite. However, it apparently lenses out before reaching Mount Mackenzie, and its place in the stratigraphy is taken by the Coppermine Andesite.

The total thickness of the Mount Benmore Volcanics in the Broadsound Range south of the old Bruce Highway probably ranges between 1000–1500m.

In the Gogango Overfolded Zone, the Mount Benmore Volcanics form the lowermost units in some of the thrust slices. In the Melaleuca Creek area, the Goodedulla beds are inferred to overlie the Mount Benmore Volcanics, although most of the contacts may be faults or thrusts.

The Mount Benmore Volcanics are the upper part of Dear's (1994) Cycle 3B, which he correlated with the Camboon Volcanics. Isotopic dating indicates that they are early Permian. They overlie the Coppermine Andesite that has tentatively been dated at ~296Ma (Burch, 1999). A sample (RSC011) of rhyolitic ignimbrite interbedded with mafic volcanic rocks north of Eungella Dam at MGA 636595 7667990 in HILLALONG was dated by SHRIMP (see Appendix). It gave a U-Pb zircon age of 284.7±4.4Ma (MSWD = 1.16, based on for 12 of 14 analyses. Using the ISC timescale (Gradstein & others , 2004), this suggests that the unit ranges up to the Sakmarian or Artinskian and is consistent with the Artinskian age preferred for the overlying Tiverton Formation by Draper & others (1990) and Briggs (1993).

CERBERUS RHYOLITE MEMBER

Introduction

This unit crops out in north-west ROOKWOOD and south-west MARLBOROUGH, mainly to the west and north-west of Apis Creek homestead and south of Cerberus homestead from which the unit takes its name. It is topographically prominent forming rocky hills with relief of over 200m, one of which is Mount Gardiner (Figure 34b). It can be distinguished from the more mafic volcanic rocks that generally occur in the Mount Benmore Volcanics by its radiometric response. The unit was originally described by Withnall & others (1998a,b) as the Cerberus Rhyolite, a separate unit underlying the Mount Benmore Volcanics, but work in 1998 showed that it is also underlain by mafic volcanic rocks. It is therefore now included as a member within the Mount Benmore Volcanics.

Type area

The top of the plateau that forms Mount Gardiner is specified as the type area. The base of the unit crops out at MGA 759250 7457740 where it overlies mafic volcanics in the lower part of the Mount Benmore Volcanics. The top of the unit is at MGA 760900 7456020 where it is overlain by the upper part of the Mount Benmore Volcanics. The thickness is difficult to determine because of the relatively shallow dips and the irregular topography, but is probably at least 150m.

Lithology

On top of the Mount Gardiner plateau, the Cerberus Rhyolite Member consists of bluish grey, crystal-rich volcaniclastic rocks, inferred to be mainly ignimbrite, containing abundant white plagioclase crystal fragments to 1.5mm, sparse aphyric to porphyritic, felsic lithic clasts to 1cm. In thin section, the groundmass is mostly recrystallised and no vitroclastic textures are preserved. However, rare fiamme were observed in outcrop. Elsewhere, irregular, partly epidotised patches up to 2cm across may have been pumice. Some of the rocks may be lavas, for example at MGA 760770 7456010, where the rock consists of abundant plagioclase phenocrysts in a locally autoclastic groundmass of very fine-grained (*ca* 0.02mm), felted, partly flow aligned feldspar laths.

The unit thins northwards, and at MGA 760000 7459850, is ~30m thick and represented by a low ridge of volcanic rudite containing angular to subangular pebbles to boulders of flow-banded dacite clasts. Some of the clasts are pumiceous in thin section, but most are of lava, commonly consisting of felted masses of flow-aligned feldspar laths. The matrix contains some crystal fragments and was probably originally vitric, but is now recrystallised to a very fine-grained (<0.01mm) mosaic. About 2km north, at MGA 759475 7461750, thick to very thick, locally laminated and channelled beds of moderately to well sorted, pebbly volcaniclastic sandstone, consisting of angular plagioclase crystals and felsic lithic clasts, may be a distal epiclastic facies of the member.

South-west of Apis Creek homestead, the unit consists of grey, moderately crystal-rich to crystal-rich, lithic-rich felsic volcaniclastic rocks. The crystal fragments are white feldspar (predominantly plagioclase) to 2mm. The lithic clasts are dark grey to olive green and are aphyric to feldspar-phyric. They are mostly less than 10cm long, but some outcrops were observed with blocks up to 1m long. These outcrops may be lag deposits and appear to pass upwards into rocks with much smaller clasts. The clasts are felsic and in thin section they show felted textures formed by alignment of plagioclase laths; some clasts are slightly more mafic and contain disseminated chlorite. The rocks are mostly massive, although crude parting planes observed in stream exposures may reflect primary layering. No fiamme or eutaxitic foliations were observed in outcrop.

A smaller area of felsic volcanics, ~4km to the south-east in the head of Hawks Nest Creek, north-west of Mount Benmore homestead, is tentatively assigned to the Cerberus Dacite Member. The rocks are mainly medium grey to greenish-grey, crystal-rich, lithic-rich to lithic-poor ignimbrite. The crystal fragments are white plagioclase to 2mm and locally biotite to 1mm. The lithic clasts are dark olive green to greyish-green, aphyric to porphyritic volcanics, usually less than 5mm, but up to 1cm. Clusters up to 5mm across of intergrown laths of plagioclase may be clasts of diorite. The groundmass is very fine-grained (<0.01mm) and contains spherulites. No shard textures were identified in thin section and no fiamme were observed in outcrop. However, on weathered surfaces the rocks have a streaky foliation (possibly eutaxitic) and prominent parting surfaces are evident in stream exposures.

The dominance of plagioclase and lack of quartz crystal fragments suggests that the unit may be dacite rather than rhyolite and that the unit should be renamed. However, three samples of ignimbrite from the Cerberus Rhyolite Member were analysed for a range of major and trace elements. In the plot of total alkalis vs SiO_2 in Figure 39 two samples plot in the rhyolite field and one in the trachyte field, although in the plot using immobile elements, the three samples plot in the lower part of the dacite-rhyodacite field.

Geophysical response

The Cerberus Rhyolite Member has moderate to high potassium and uranium and generally low to moderate thorium resulting in dark pinkish hues on composite radiometric images. The magnetic response is low. The measured magnetic susceptibility values range from 0–185 x 10^{-5} SI units and have a mean of 14.

Relationships and age

The Cerberus Rhyolite Member occurs within the Mount Benmore Volcanics, and is therefore of early Permian age.

AMETDALE VOLCANICS

Introduction

The name Ametdale Volcanics is given to a belt of mafic volcanics that crop out for ~20km along the eastern slopes of the Broadsound Range between Sarsfield Creek and Lavinia Park Station (Figure 37). The name is derived from Ametdale homestead in north-western MARLBOROUGH. The topography is more recessive than the felsic volcanics in the range to the west or the ridge of Mount Buffalo Rhyolite to the east, but is still relatively rugged and the rocks are well exposed

Type area

A type section is designated along the northern branch of Granite Creek from MGA 749200 7502700 (where crystal-rich rhyolitic ignimbrite of the Leura Volcanics crops out) to MGA 753950 7498700 (the contact with the overlying Mount Buffalo Rhyolite. Assuming an average dip of 15° and no repetition by folding or thrusting, the unit is ~1000m thick in this area.

Lithology

The unit consists dominantly of andesitic to basaltic volcaniclastic sandstone and conglomerate and some lava.

The lavas are generally porphyritic with phenocrysts of plagioclase up to 3mm and subordinate clinopyroxene as single crystals or glomeroporphyritic aggregates to 1.5mm. The clinopyroxene is colourless in thin section, and the plagioclase phenocrysts in some rocks show normal oscillatory zoning. Some rocks also contain chloritised grains that may originally have been olivine. The groundmass generally consists of laths of plagioclase to 0.1mm with interstitial clinopyroxene, chlorite, epidote and opaque oxides. Some thin sections show flow alignment of the plagioclase microlites. In most rocks, at least mild alteration is evident, and the plagioclase phenocrysts are partly replaced by sericite, saussurite, brownish epidote and minor carbonate and the clinopyroxene by chlorite. Amygdales are mostly small (<1mm) and only evident in thin section. They mostly have infill of chlorite but some have zeolite, calcite or quartz. Chemical analyses indicate that the rocks range from basalt to trachyandesite.

The sandstones are greyish green to greyish purple, fine to very coarse-grained and generally appear to be poorly sorted, consisting of plagioclase crystal fragments and lithic clasts in a fine matrix. However, alteration and degradation of the lithic clasts is common, and in hand specimen (and even thin section) it is commonly difficult to resolve the difference between clasts and matrix. Consequently, some of the rocks may be better sorted than they appear. Most outcrops are massive, although some irregular parting surfaces probably reflect poorly defined internal stratification. The conglomerates are also very poorly sorted, matrix-supported and consist of subangular to subrounded, pebbles to boulders of porphyritic andesite or

Figure 51. Poorly-sorted basaltic or andesitic breccia in the Ametdale Volcanics. About 6.5km south-east of Burwood homestead in Branch Creek, a tributary of Granite Creek at MGA 750474 7501396 (IWSC0776)

basalt (Figure 51). The matrix itself is poorly sorted, and in thin section consists of plagioclase crystal fragments to 1mm and silt-sized and finer feldspar, chlorite, epidote and opaque oxides. In some outcrops, blocks up to several metres across have been observed. The poor sorting and lack of clearly defined bedding suggest that the rocks probably originated as debris flows.

Geophysical response

Although the radiometric data is degraded in much of the outcrop area because of the proximity to the coastal scarp, in general the Ametdale Volcanics have low radiometric responses in all channels consistent with the mafic composition of the rocks.

The unit has a low to moderate magnetic response. Magnetic susceptibility values are mostly in the range 10–1200 x 10^{-5} SI units with a mode at about 70 and a mean of 700. Sporadic values range up to about 7000.

Geochemistry

Eight samples from the Ametdale Volcanics were analysed for a range of major and trace elements. The rocks included five samples of lava and three clastic rocks. They are included with other Permian volcanic units in the plot of total alkalis vs SiO_2 (TAS) in Figure 49a, which indicates that the lavas are basaltic andesite to trachyandesite, although one sample identified in the field as dacite, plots just within the rhyolite field. The clastic samples are all basaltic trachyandesite. The plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) in Figure 49b supports these conclusions. Because it uses immobile elements, this plot provides a method of classifying the original composition of altered volcanic rocks, and suggests that the rocks have not been altered significantly in terms of alkalis and silica.

One sample of basaltic andesite was submitted for precise trace element analysis by laser ablation mass spectrometry, and the data have been used in the multi-element and rare-earth element (REE) plots in Figure 49c–f along with samples from the Mount Benmore Volcanics. The sample matches well with the main group identified within the Mount Benmore Volcanics, consistent with the units being related. Compared with modern basaltic suites, using the database compiled from literature by Murray & Blake (2005, appendix 1), the sample most closely matches basalts from the Tatara suite in the Southern Volcanic Zone of the Andes, suggesting the volcanics were generated under thick continental crust.

Relationships and age

The Ametdale Volcanics overlie the Leura Volcanics, and are overlain by the Mount Buffalo Rhyolite. They have not been dated isotopically, but are probably early Permian, and may correlate with the Mount Benmore Volcanics, at least in part. Alternatively, if the Mount Buffalo Rhyolite is a correlative of the Cobweb Mountain Rhyolite, the Ametdale Volcanics could be older than the Mount Benmore Volcanics and could be equivalent to the Macksford Volcanics in the Mount Mackenzie area. Dear (1995) regarded them as part of his Cycle 3A, along with the Macksford Volcanics as now defined.

LANGDALE HILL RHYOLITE

Introduction

This is a new name given to a thick pile of rhyolitic volcanic rocks forming the northern and uppermost rocks in the Langdale Inlier (Figure 35). The name is derived from Langdale Hill, the site of a Telstra microwave repeater, ~1km south-east of Tooloombah homestead. The unit forms rugged, hilly topography and is well exposed. The northern half of the unit has either been cleared and has relatively open timber, but softwood and acacia scrubs are developed on the southern part.

Type area

The type section is designated from MGA 758300 7479200, the base of the lower rhyolite flow unit to MGA 759100 7479400, the base of the crystal-rich ignimbrite sequence (in hills just on the eastern side of the Tooloombah–Anglewood boundary fence), and thence to MGA 762100 7480300 (on Anglewood road). Cleared fencelines and station tracks mostly pass close to this line of section.

Lithology

The lowermost part of the Langdale Hill Rhyolite is a sequence of rhyolite flows that transgress across the Mount Benmore Volcanics and Tartrus Rhyolite. Where observed at their southern and northern extremities, they consist of brownish grey, autobrecciated rhyolite containing sparse feldspar phenocrysts. The thickness is difficult to determine, but could be up to 200m assuming a dip of 10°. They appear to thicken to the north-west.

Most of the Langdale Hill Rhyolite consists of yellowish to bluish grey crystal-rich rhyolitic ignimbrite. In the north and type area, the dominant rock type contains abundant crystals (mostly >50%) of feldspar to 2mm, subsidiary embayed quartz to 3mm and common biotite to 2mm in an aphanitic felsic groundmass that is mostly <0.01mm. In thin section, shards are mostly poorly preserved, but some rocks contain outlines of sparse platy shards with axiolitic devitrification. Lithic clasts (aphyric, greyish green felsite) are locally present, and many outcrops contain flattened fiamme up to 1cm. Some outcrops have crude parting, probably due to alignment of fiamme and elongate clasts.

Another variety of ignimbrite is greenish grey and contains up to 60% abundant feldspar crystal fragments and minor epidote pseudomorphs after hornblende crystal fragments. Elongate fragments of aphyric to porphyritic felsic rocks are also common and outcrops have a crude parting. The groundmass ranges from extremely fine (<0.01mm) to a somewhat coarser granular mosaic (0.01–0.05mm) that could be due to recrystallisation in a thick sheet. This rock type seems to be more common in the southern part of the unit, but was also observed in the north towards the top of the unit near Anglewood road.

The overall thickness of the ignimbrites is not known. Dips of 15–20° were observed, based on crude parting and alignment of fiamme in the ignimbrites. This suggests a thickness of 1000m along the type section, but it is likely that east-block-up faulting has resulted in repetition of the sequence and the thickness may be considerably less.

Argillic alteration is common within the ignimbrite. In the north around Langdale Hill, this was drilled by Marlborough Gold Mines Ltd in the early 1990s (A. Smith, Tooloombah homestead, personal communication), but does not appear to have been reported. During this study, other areas of alteration, brecciation and quartz veins were observed in several places. The most extensive area of argillic alteration appears not to have been investigated previously, because prior to 1996, it had a thick cover of softwood scrub. It occurs on a prominent ridge at MGA 762300 7477500, and was traced south for at least 500m. Its extent to the north was not investigated. Quartz veins and vughs are locally present, and the altered rock is locally brecciated with open cavities.

Geochemistry

One sample of ignimbrite from the Langdale Hill Rhyolite was analysed for a range of major and trace elements. The plot of total alkalis vs SiO_2 (TAS) in Figure 56 suggests that it is rhyolitic. However, it falls towards the bottom of the rhyodacite-dacite field in the plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) suggesting that it may actually be dacite.

Geophysical response

The Langdale Hill Rhyolite has a high potassium response, a moderate to high uranium response and a moderate thorium response resulting in light pink hues on composite images. The areas of argillic alteration do not stand out on the images.

The unit has a low magnetic response consistent with the small data set of magnetic susceptibility readings which range from 2–32 x 10^{-5} SI units on two outcrops.

Relationships and age

The Langdale Hill Rhyolite transgressively overlies the Mount Benmore Volcanics and Tartrus Rhyolite, suggesting an unconformity. Conglomerate and lithic sandstone and altered basalt of the Carmila beds unconformably overlie it to the east. In the south, the Carmila beds directly overlie the basal rhyolite, whereas to the north they overlie the full thickness of ignimbrite. This suggests uplift and subsequent erosion of the Langdale Inlier prior to the deposition of the Carmila beds. Overall, these relationships indicate that the unit is early Permian.

It is difficult to relate the Langdale Hill Rhyolite to other early Permian rocks in the area. It may be an accumulation within a local cauldron and possibly a time correlative of the Mount Buffalo Volcanics, although it should be noted that the abundant quartz in the ignimbrite conflicts with the lack of quartz in the felsic volcaniclastic rocks in the Mount Buffalo Volcanics. Alternatively, another area of felsic volcaniclastic rocks mapped as Carmila beds (Subunit $\mathbf{Pc_v}$) between Tooloombah and Montrose Creeks could be equivalent. However, these appear to lie above the basalt within the Carmila beds, whereas the Langdale Hill Rhyolite appears to be overlain unconformably by the Carmila beds.

MOUNT BUFFALO VOLCANICS

Introduction

The name Mount Buffalo Volcanics is given to a unit of felsic, mainly volcaniclastic rocks that underlie the Carmila beds along the eastern flank of the Connors Arch for ~80km north from Tooloombah Creek to Spring Valley (Figures 35 and 37). The name is derived from Mount Buffalo, a prominent ridge on the eastern flank of the Broadsound Range in eastern MOUNT BLUFFKIN at MGA 754000 7501000 (Figure 52a).

The unit crops out strongly along the edge of the Broadsound Range. It commonly is represented by pronounced bedding trends, and in places is ridge-forming (for example between the generally more recessive Carmila beds and Ametdale Volcanics). It was named informally and described briefly by Dear (1994b, 1995) as the basal unit of his Cycle 4.

Type and reference sections

The type section is designated as along Montrose Creek between MGA 754000 7492750 (where it overlies the Ametdale Volcanics) and MGA 754350 7492250 (below an outcrop of pyroxene-phyric andesite or basalt that marks the base of the overlying Carmila beds). It consists of ~300m of felsic volcaniclastic rocks, including some rhyolitic ignimbrite. A section consisting entirely of rhyolite flows along Granite Creek between MGA 754000 7498700 and MGA 754900 7498900 near Mount Buffalo is given as a reference section.

Lithology

In the Montrose Creek area, the unit consists of felsic volcaniclastic rocks overlying the Ametdale Volcanics. The lower part of the sequence in the type section is dark grey crystal-poor to crystal-rich, lithic-rich dacitic (?) tuff that is probably ~15m thick. The crystals are mostly aligned plagioclase laths to 2mm and subordinate K-feldspar. The lithic clasts are subangular aphyric to porphyritic felsite some of which have flow-aligned felted textures. Some clasts of andesite are also present. The groundmass is very fine-grained (<0.01mm) felsite and contains finely disseminated opaque grains. Flattened aligned clasts are up to 1.5cm long, and in thin section have a similar composition and texture to the matrix and could be fiamme. Only vague outlines of strongly flattened shards are preserved.

The basal tuff is overlain by a thick sequence (~300m) of poorly sorted, felsic volcanic rudite that consists of granules to pebbles of dark green to pale pink aphyric volcanolithic clasts and feldspar crystals in an aphanitic or silt-sized matrix. No quartz is present. In thin section, the lithic clasts show a range of textures and compositions; these include brown turbid andesite (?) with random plagioclase microlites, more felsic

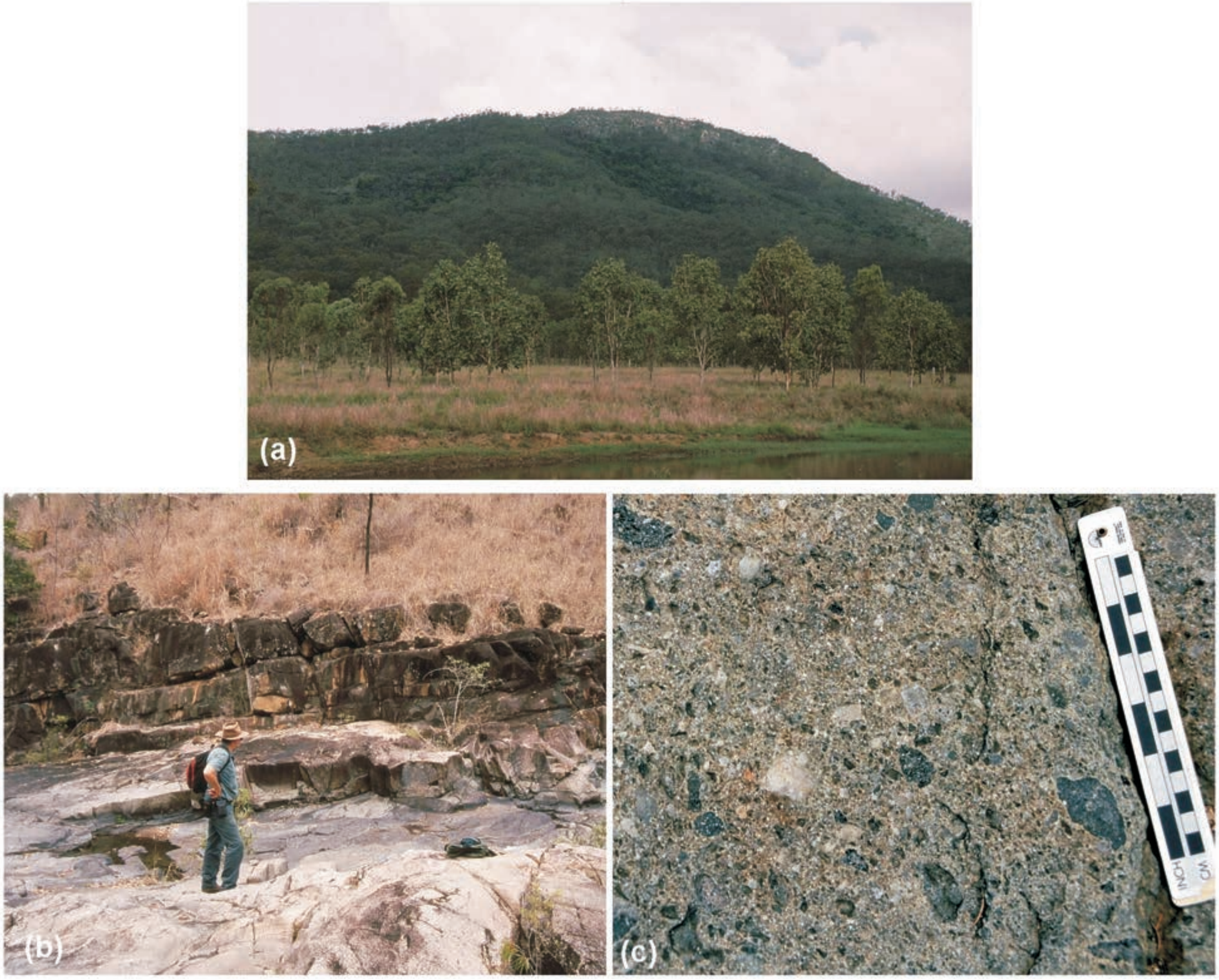

Figure 52. Mount Buffalo Volcanics
(a) Mount Buffalo from the western side along Branch Creek. The upper rocky crags are formed by the rhyolite flow that overlies the Ametdale Volcanics
(b) Crudely bedded felsic volcaniclastic sandstone and conglomerate. Sarsfield Creek at MGA 753493 7487343 (IWSC1454)
(c) Detail of the poorly sorted felsic volcaniclastic conglomerate. Sarsfield Creek at MGA 753269 7487410 (IWSC1455)

rocks with felted, trachytic textures (trachyandesite or dacite) and very fine-grained felsic granular mosaics (rhyolite). The matrix is locally up to 50% of the rock and consists of silt-sized felsic material as well as chlorite, leucoxene and epidote. The rocks probably originated as mass flows of various types, possibly including pyroclastic flows. The upper part of this sequence tends to be better sorted with much less fine matrix and passes into feldspatholithic sandstone containing stringers of subangular pebbles. An overlying pyroxene-phyric andesite or basalt marks the base of the Carmila beds.

Further sections were studied on the eastern scarp of the Broadsound Range farther south (for example, along Sarsfield Creek between MGA 753250 7487450 and MGA 755100 7487750, and near Tooloombah Creek around MGA 753900 7486000). In these sections, the underlying rocks are porphyritic trachyandesite and ignimbrite that are part of the Leura Volcanics, the Ametdale Volcanics having lensed out. The rocks consist of moderately to very poorly sorted, felsic volcanic sandstone and conglomerate, similar to that described above (Figure 52b,c). Some contain up to 40% very fine-grained felsic groundmass and may be crystal-lithic tuff or ignimbrite. A 10m-thick sheet of crystal-poor, lithic-rich ignimbrite crops out in Sarsfield Creek at MGA 753850 7487350. It contains common, flattened fiamme up to 5cm long. Quartz is again noticeably absent from the thin sections examined of the sandstone and tuff. Pyroxene-phyric andesite or basalt similar to that in the type section overlies the volcaniclastic rocks in the section near Tooloombah Creek and north of Sarsfield Creek around MGA 754600 7489450.

At its southern extent, the unit appears to consist of better-sorted, well-bedded, volcaniclastic conglomerate, pebbly to cobbly feldspatholithic sandstone and some siltstone. The conglomerate and sandstone are generally thick to very thick-bedded, and contain subrounded to rounded, pebbles and cobbles of felsic to intermediate volcanic rocks. Some of the finer sandstone and siltstone have feldspar and hornblende crystal fragments up to 2mm and may be tuffaceous. At MGA 753790 7475940, possible ignimbrite contains abundant feldspar crystal fragments and green, angular porphyritic felsic volcanic clasts.

North of Mount Buffalo, along the road between Lavinia Park and Burwood homesteads, the unit thins to ~100m, and includes beds of yellowish grey tuff that ranges from crystal-free to crystal-rich and locally lithic-rich. Well-sorted lithofeldspathic sandstone in this sequence is unusual in that it contains angular volcanic quartz grains as well chloritised biotite. The lithic clasts are angular to subangular porphyritic rhyolite and flattened pumice. The unit is again overlain by a thin greenish grey porphyritic andesite or basalt flow that contains partly chloritised pyroxene and saussuritised plagioclase phenocrysts.

Poorly sorted, quartz-free feldspatholithic sandstone and volcanic siltstone crop out northwards to the boundary between Lavinia Park and Rosedale stations, where the rocks appear to thin out entirely, and the Carmila beds appear to rest directly on Broadsound Range Volcanics. Erosion may have removed the Mount Buffalo and Leura Volcanics prior to deposition of the Carmila beds in this area.

However, farther north along the foot of the range adjacent to the Saint Lawrence–Croydon road on Beaconsfield Station, a partly fault-bounded sequence of felsic volcaniclastic rocks again crops out. The sequence shows pronounced bedding trends on aerial photograph, and the rocks are similar to those in the Montrose and Sarsfield Creek sections. They include thick to very thickly bedded, poorly sorted, pebble to boulder conglomerate and breccia, moderately sorted, pebbly, feldspatholithic sandstone and locally crystal-rich (feldspar and subordinate quartz), lithic-rich ignimbrite.

Similar rocks that also commonly showing bedding trends on aerial photographs continue northwards along the foot of the range from near Fort Arthur to Spring Valley, and are the northernmost rocks assigned to the unit. They overlie greyish purple lavas and ignimbrite that are assigned to the Leura Volcanics and are overlain by the Carmila beds. Felsic volcanic rocks farther north between Saint Lawrence and Koumala have been mapped as the lower part of the Carmila beds but they may be correlatives of the Mount Buffalo Volcanics.

Although the unit consists predominantly of volcaniclastic rocks, rhyolite flows are present in the central part of the belt around Mount Buffalo (Figure 52a). On Mount Buffalo itself and along Granite Creek, the unit is dominated by columnar-jointed, flow-banded, locally autobrecciated rhyolite and may be close to an eruptive centre and could include plugs or domes as well as flows. The rhyolite contains sparse phenocrysts of plagioclase and K-feldspar in an aphanitic to partly spherulitic groundmass. Two rhyolite plugs intruding the Ametdale Volcanics 3km and 5km south-south-west of Mount Buffalo respectively may also mark the sites of vents. The rhyolite flows are gently dipping and probably 50–100m thick. They extend for ~5km along strike.

Large, subhorizontal rhyolite flows crop out along the edge of the range west of Rosedale homestead. Where examined, the flows consist of feldspar-phyric to aphyric, flow-banded and commonly autobrecciated rhyolite. They have not been examined in much detail, because they occur in thickly vegetated, rugged terrain on the edge of the scarp. Their subhorizontal nature may indicate that they are unconformable on the Broadsound Range Volcanics that they appear to directly overlie. Therefore, they have been tentatively assigned to Mount Buffalo Volcanics.

Although the flows near Mount Buffalo are chemically rhyolite, the dominant composition of the source of the clastic rocks in the Mount Buffalo Volcanics may be dacitic rather than rhyolitic. This is based on the paucity of quartz and abundance of plagioclase grains. Many of the felsic lithic clasts have trachytic textures, more suggestive of dacite or trachyandesite, although clasts consisting of very fine-grained granular mosaics like rhyolite are also common.

Geochemistry

Seven samples from the Mount Buffalo Volcanics were analysed for a range of major and trace elements. The samples are clastic rocks except for one sample of rhyolite lava from Mount Buffalo itself. The plot of total alkalis vs SiO_2 (TAS) in Figure 56 confirms that the lava is rhyolite, but that the clastic rocks have compositions falling in the trachyte, dacite as well as rhyolite fields. The plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977) generally confirms this, although two of the clastic rocks fall in the andesite field.

Geophysical response

The radiometric response is variable and the quality of the data is commonly poor because the unit forms a narrow belt at the foot of the coastal scarp. Potassium response is generally moderate and the other channels are low to moderate, the unit being represented by mottled pinkish hues on composite images. The flows near Mount Buffalo however, are characterised by high responses in all three channels and are represented by composite whitish hues.

The magnetic response is low and consistent with the magnetic susceptibility values which are mostly <50 x 10^{-5} SI units although sporadic values up to 3400 were recorded.

Relationships and age

The Mount Buffalo Volcanics overlie the Ametdale Volcanics with apparent conformity, and in its absence, overlie the Leura Volcanics, presumably disconformably. They are overlain by the Carmila beds. The age is thus early Permian.

The volcanic rudite is similar to some from the Carmila beds in the Lavinia Park area. Thus, the Mount Buffalo Volcanics could possibly be incorporated into the Carmila beds as a basal member, although at present they are regarded as a separate unit. As noted above, the felsic volcanics forming the lower part of the Carmila beds between Saint Lawrence and Koumala may be correlatives.

The unit is similar to the Cobweb Mountain Rhyolite, which underlies the Mount Benmore Volcanics on the western flank of the Connors Arch. Unlike the Cobweb Mountain Rhyolite, it is underlain by mafic volcanics (the Ametdale Volcanics). Apart from the thin porphyritic andesite that commonly overlies it, there is no thick development of mafic volcanics directly above it. If these two units do correlate, it suggests that the Ametdale Volcanics are not a direct correlative of the Mount Benmore Volcanics.

CARMILA BEDS

Introduction

Jensen & others (1966) named and first described the Carmila beds in the Carmila area in the Mackay 1:250 000 Sheet area. Malone & others (1969) extended the unit to the south to include rocks on both sides of and around the southern end of the Connors Arch in the Saint Lawrence and Duaringa Sheet areas. They also included rocks to the north of Marlborough on the eastern side of the so-called Strathmuir Synclinorium. The unit as defined by these authors contains a diverse range of rock types. Malone & others (1969) described a lower sequence of felsic to intermediate volcanics and rudites, passing up through volcanic rudites and other volcanolithic sediments with felsic volcanics, into an upper sequence of volcanolithic sandstone and mudstone with minor interbedded volcanics and rudites. This generalised succession is probably not applicable regionally. The unit as previously mapped included rocks now assigned to older units such as the Leura Volcanics, Cobweb Mountain Rhyolite, Mount Benmore Volcanics and Broadsound Range Volcanics. The rocks to the north of Marlborough are now assigned to a new set of units, the Glenprairie beds, Tanderra Volcanics and Wongrabry beds. The distribution of the unit as now mapped is shown in Figures 23, 35, 37 and 53.

Malone & others (1969) identified marine sediments, including limestone, from near the top of the Carmila beds. However, these are regarded as the basal part of the Back Creek Group, possibly equivalent to the Tiverton Formation.

Type and reference sections

Jensen & others (1966) did not specify a type section or type area. Because of the diverse assemblage of rock types in different areas, it is difficult to specify one section typical of the unit. Faulting, shallow folding and poor outcrop in the northern part of the area where the unit was first defined make it difficult to select an appropriate section. Therefore selecting a type area should wait until more detailed studies on the unit are done. However, several reference sections can be specified that will serve to direct such future studies. These are as follows:

1. Dumbleton Rocks in the Pioneer River at MGA 715700 7660800 as measured and presented by Fielding & others (1997a) (Figure 54a). It is only 170m thick and does not include either the bottom or top of the unit, but does incorporate several typical lithofacies, including sandstone, conglomerate, rhyolitic ignimbrite and thinly interbedded sandstone and mudstone.

2. Along and adjacent to the Lavinia Park to Burwood road from MGA 751250 7506850 (the basal pyroxene-phyric andesite) through well-bedded feldspatholithic sandstone and mudstone into a very thick-bedded volcanolithic conglomerate succession to MGA 755300 7504300 (limit of exposure under alluvium of Amity Creek). The section is probably ~500m thick.

3. The basalt flows are exposed on Tooloombah Station from MGA 755900 7482750 to MGA 757750 7482150. This section includes both massive and fragmented flows, as well as some interbedded sedimentary rocks and more felsic volcaniclastic rocks, and is probably ~400m thick.

4. The old Marlborough–Sarina road from MGA 756600 7469150 (faulted contact with the Mount Benmore Volcanics) to MGA 758300 7468700 (contact with the overlying Back Creek Group). The section is mainly dark grey siltstone, mudstone and fine-grained lithic sandstone. The thickness is uncertain, because of repetition by faulting, but it is possibly up to 1000m.

5. A relatively complete, continuous section, ~300m thick, between MGA 760760 7450820 (contact with Mount Benmore Volcanics) and MGA 761310 7449930 (boundary with Back Creek Group), south-west of Apis Creek homestead, consisting mainly of siltstone, mudstone and minor basalt.

Details on the rock types in these sections are presented below.

Lithology

Because the Carmila beds crop out over such a large area and contain a diverse range of rock types, their description is broken up into seven areas. These are Mackay to Carmila, Carmila to Saint Lawrence, Saint Lawrence to Tooloombah Creek, Tooloombah Creek to the old Marlborough–Sarina road, south of the old Marlborough–Sarina road, Gogango Overfolded Zone and west of the Connors Arch.

Mackay to Koumala
(Figures 23 and 53)

The Carmila beds crop out east of the north-westerly trending belt of the Urannah Batholith. Scattered good exposures occur in creeks, road cuttings, quarries and gravel scrapes. Felsic volcanic units within the formation form prominent high strike ridges and cuestas, particularly in the Carmila area, as well as rough hilly country. In general, the sequence consists of felsic volcanic rocks at the base assigned to subunit $\mathbf{Pc_v}$. These are overlain by conglomerate, conglomeratic sandstone, sandstone, siltstone, tuffaceous (feldspathic) sandstone, and siltstone, mudstone, and shale assigned to subunit $\mathbf{Pc_s}$. Minor medium to thick-bedded dacitic to rhyolitic tuff, and rare volcanic breccia also form part of the upper sequence in places.

The felsic volcanic rocks consist mainly of densely welded, crystal-rich to crystal-poor, lithics-poor to lithics-rich, dacitic and rhyolitic ignimbrite up to >30m thick, with minor aphyric to slightly porphyritic lava. A commonly well-developed eutaxitic foliation, locally accompanied by poorly developed columnar jointing, is present in some ignimbrite outcrops. Fine flow-banding and autobrecciated zones are present in some of the lava flows. The volcanic rocks are generally moderately to extensively altered.

The finer-grained sedimentary rocks (mudstone, shale) are commonly laminated and highly carbonaceous. They are thin to very thick-bedded. Cross-beds (mainly low-angle) are common in the interbedded sandstone and siltstone layers. In the quarry at MGA 710700 7646500, the rocks consist mainly of interbedded, laminated to thinly-bedded, fine-grained pale brownish-grey sandstone, medium to dark grey siltstone and dark grey, carbonaceous mudstone. Some thin to medium mudstone beds contain coaly layers and plant stems.

Numerous plant fossil localities were recorded on the Mackay 1:250 000 geological map and determinations were given by M.E. White *in* Jensen & others (1966) that include species of *Glossopteris, Noeggerathiopsis hislopi*, *Samaropsis dawsoni* and equisetalean stems and leaf sheaths. Polystrate fossil plant trunks and roots, up to ~2m long, are also exposed locally (Figure 54e).

Successions dominated by conglomerate occur locally and some have been delineated by subunit $\mathbf{Pc_g}$. Clasts in the conglomerates range from granule size to ~40cm across. They are unsorted, almost invariably well rounded, and generally closely packed. The fragments consist predominantly of a range of volcanic rocks ranging from andesitic to rhyolitic. Minor, scattered clasts of basalt (?) and granitoid were also found in most outcrops examined. Some deposits also contain rounded boulders of reworked polymictic conglomerate. The matrix consists of dark red-brown, medium to coarse-grained, feldspathic or feldspatholithic sandstone.

The conglomerates generally form massive outcrops, up to 30m thick or more (base and top not exposed), with very few, if any, sedimentary structures apparent. Some outcrops contain sparse medium to thick beds and lenses of feldspathic sandstone and siltstone, and a few show normal grading. Such conglomerate is well exposed in the Sarina Council Quarry at MGA 730400 7622600 (Figure 54d).

The unit is cut by subvertical andesite or dolerite dykes up to 5m wide (Figure 54c), as well as by less common, more silicic (dacite?) dykes.

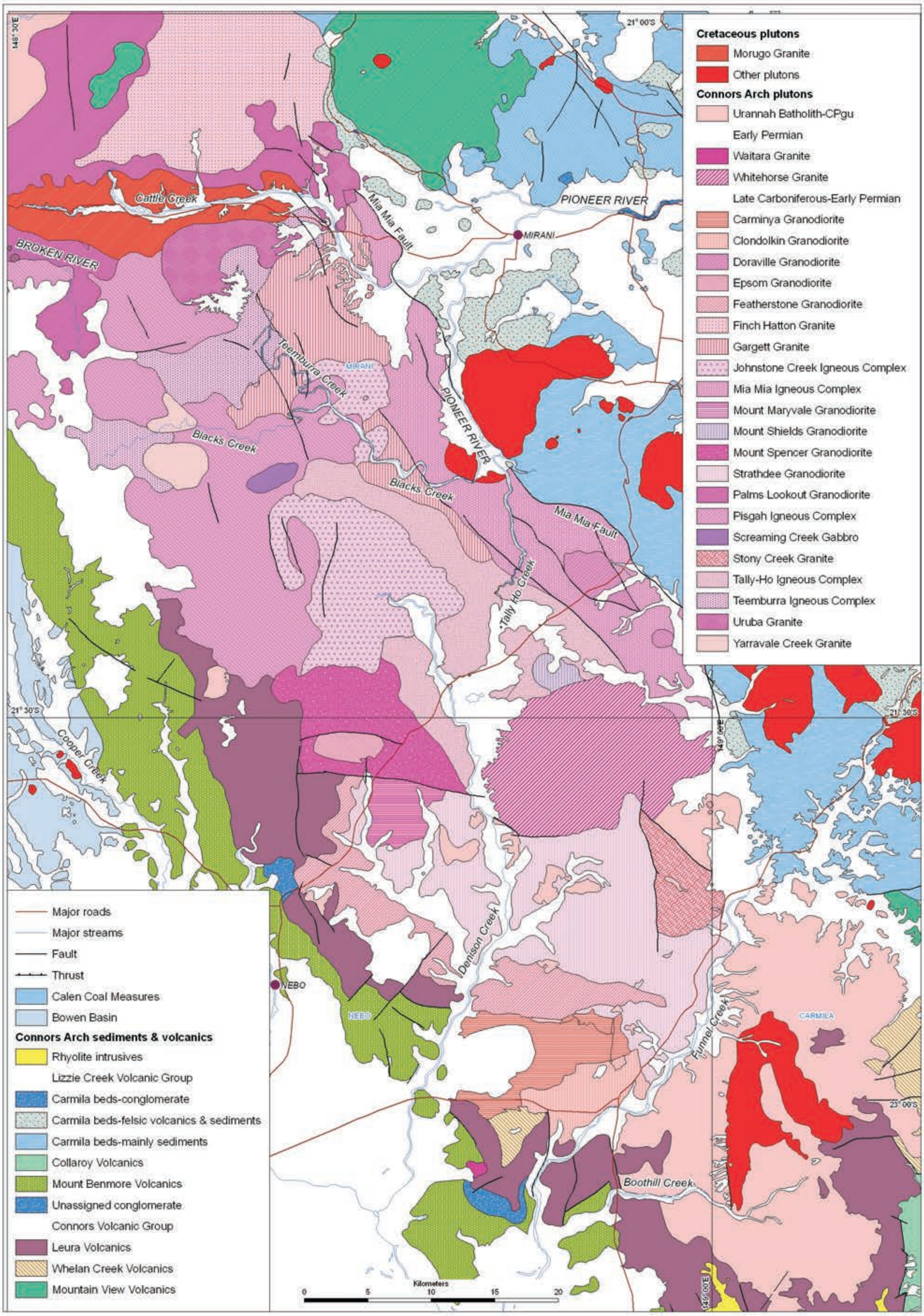

Figure 53. Geology of the northern part of the Connors Arch (Nebo–Mirani)

The succession was deposited in fluviatile and lacustrine environments. Based on a detailed measured section at Dumbleton Rocks in the Pioneer River at MGA 715700 7660800, Fielding & others (1997a) interpreted a variety of environments. These include alluvial channel, high-energy alluvial (represented by a thick conglomerate interval similar to that described above) and fluvio-lacustrine (represented by intervals of thinly interbedded fine-grained sandstone and mudstone). These were punctuated by the eruption of two ignimbrite sheets, one of which was dated at 294±4Ma (Allen & others, 1998). Elsewhere, the scattered nature of the outcrops, the diverse rock types, and the abrupt facies changes make correlation between outcrops and a detailed reconstruction of the depositional environment very difficult.

In the vicinity of the Ben Mohr Igneous Complex the Carmila beds are hornfelsed and locally appear to be overturned.

Koumala – Saint Lawrence
(Figure 37)

The Carmila beds occur east of the Connors Range in CARMILA, SAINT LAWRENCE and eastern CONNORS RANGE. The basal part of the sequence consists of rhyolitic to dacitic ignimbrite sheets assigned to subunit $\mathbf{Pc_v}$. These form a series of high strike ridges and cuestas with prominent easterly dip-slopes that extend north to the Funnel Range south of Koumala. Truncations and repetitions of the strike ridges suggest that repetition by faulting may have occurred, possibly by thrusting along east-dipping faults. Aphyric rhyolite and rhyodacite lava occur in the sequence north of Clairview. At Clairview, grey labile tuffaceous or sedimentary rocks contain concentrically banded clasts up to 1cm across that may be accretionary lapilli.

The felsic volcanic unit extends south towards Saint Lawrence where it splits into parallel strike ridges of rhyolitic to rhyodacitic ignimbrite which are interpreted to be repeated by faulting.

Along Oaky Creek in north-eastern CONNORS RANGE, mafic volcanics assigned to the Mountain View Volcanics and granite stocks are overlain by grey, dacitic, crystal-rich rhyolitic ignimbrite with sparse lithic clasts up to 2cm. Some of these clasts are granite, similar to that intruding the Mountain View Volcanics. More lithic-rich ignimbrites are locally present. The ignimbrites contain feldspar crystals but little or no quartz.

North of Olympus homestead, the ridge-forming crystal-rich rhyolitic ignimbrite is underlain by massive pebble to cobble conglomerate, which in turn overlies the Mountain View Volcanics and granite stocks.

The position of the basal volcanic rocks suggests that they may correlate with the Mount Buffalo Rhyolite that underlies dominantly sedimentary facies of the Carmila beds farther south.

Along the Bruce Highway north of Clairview, sandstone, siltstone and conglomerate overlie the felsic volcanic units. Conglomerate beds are massive with minor sandstone interbeds. Clasts are well rounded and comprise mainly felsic volcanics and also some granite. Most conglomerate beds are matrix supported with a medium to coarse-grained sandy matrix.

In Saint Lawrence Creek, a sequence of medium-grained labile sandstone, feldspar-phyric dacitic ignimbrite, very poorly sorted matrix-rich conglomerate, coarse-grained sandstone and mafic volcanics is exposed. The conglomerate has clasts ranging from small pebbles to boulders and may have been a lahar or debris flow deposit (Figure 55a). Further north along the Bruce Highway near Freshwater Creek, aphyric rhyolite and rhyolitic ignimbrite crops out. In Clairview Creek, massive dark green, very poorly sorted volcanolithic conglomerate with dominantly felsic and mafic volcanic pebbles to boulders may also have been deposited as a lahar.

Saint Lawrence to Tooloombah Creek
(Figure 35)

Between the Saint Lawrence–Croydon road and Lavinia Park, the Carmila beds consist predominantly of thick to very thick-bedded, medium to very coarse-grained, moderately well sorted, pebbly feldspatholithic sandstone and conglomerate containing subrounded to well-rounded clasts of felsic volcanic rocks. The beds commonly have planar laminae and locally medium-scale trough cross-bedding. Impressions of plant stems are common, and in Waverley Creek at MGA 751400 7516850 near Rosedale homestead, medium to thick-bedded very fine to medium-grained lithic sandstone and dark grey siltstone contain common carbonised equisetalean stems up to 1m long and 15cm wide. White (*in* Malone & others, 1969, page 123) identified species of *Noeggerathiopsis, Glossopteris* and *Gangamopteris* from several localities in this area.

Dickins (*in* Malone & others, 1969) identified early Permian marine fossils, supposedly in the Carmila beds, from a creek just west of Prospect Hill homestead at MGA 756600 7512450. This outcrop was re-examined

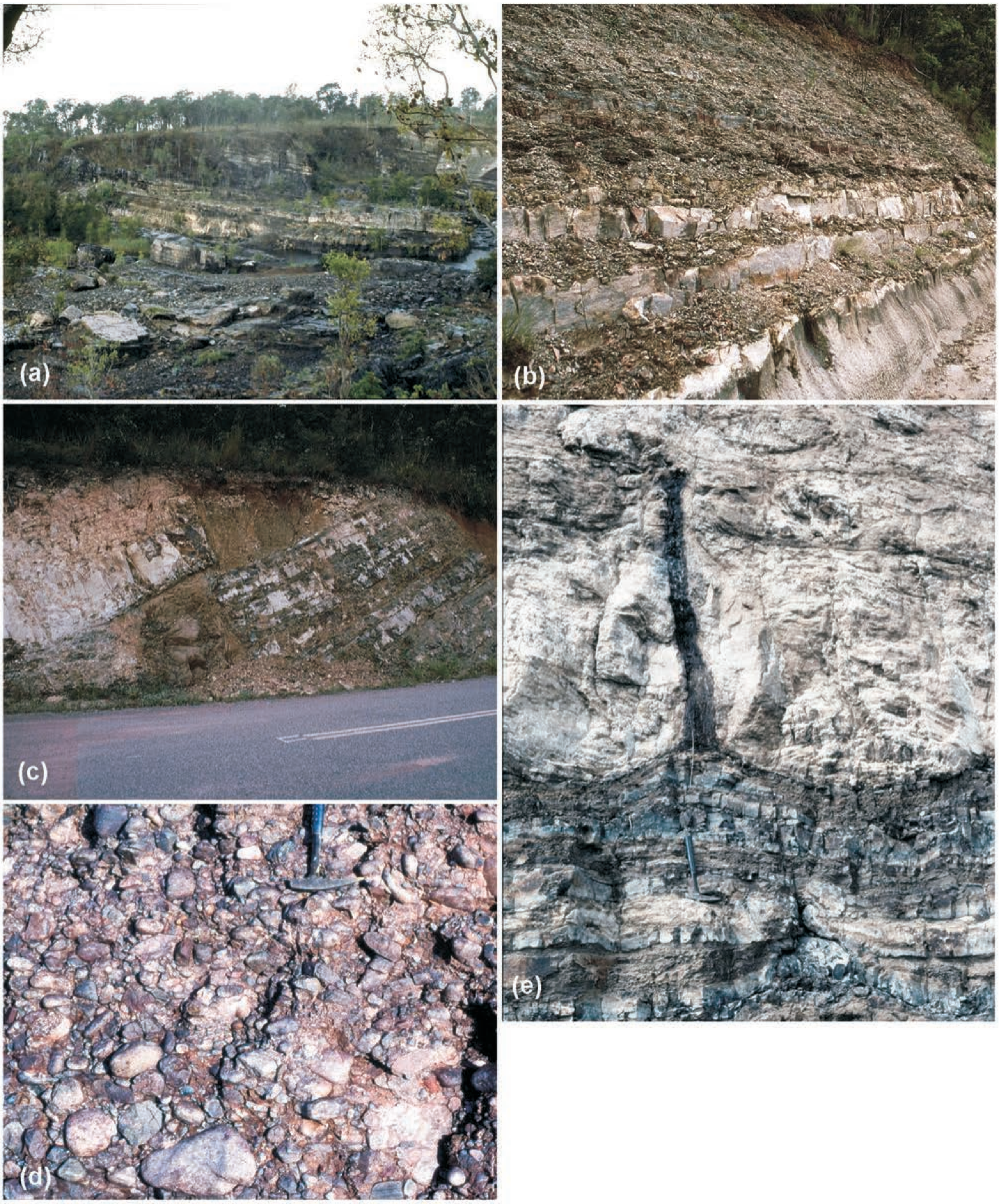

Figure 54. Carmila beds
(a) Interbedded rhyolitic ignimbrite (pale coloured intervals) and fine to medium-grained lithic sandstone and some conglomerate (darker intervals). Dumbleton Rocks Weir on the Pioneer River at MGA 715710 7660772 (RSC027)
(b) Light-coloured beds of lithic siltstone and fine-grained sandstone beds passing up into darker coloured more muddy beds. Spencer Gap on the Peak Downs Highway 8km south-west of Eton at MGA 701102 7639618 (QFG4068)
(c) Volcanilithic siltstone cut by a dilational dolerite dyke. Courtney's Gap Road 4.7km south-west of Sarina at MGA 728282 7625342 (QFG3657)
(d) Polymictic, clast-supported conglomerate containing well-rounded cobbles of felsic volcanic rocks. Sarina Shire Council Quarry at MGA 730370 7622584 (BB3020)
(e) Polystrate fossil plant trunk in tuffaceous siltstone or fine sandstone. Railway cutting on the northern side of Gillinbin Creek at MGA 744047 7588273 (BB3080)

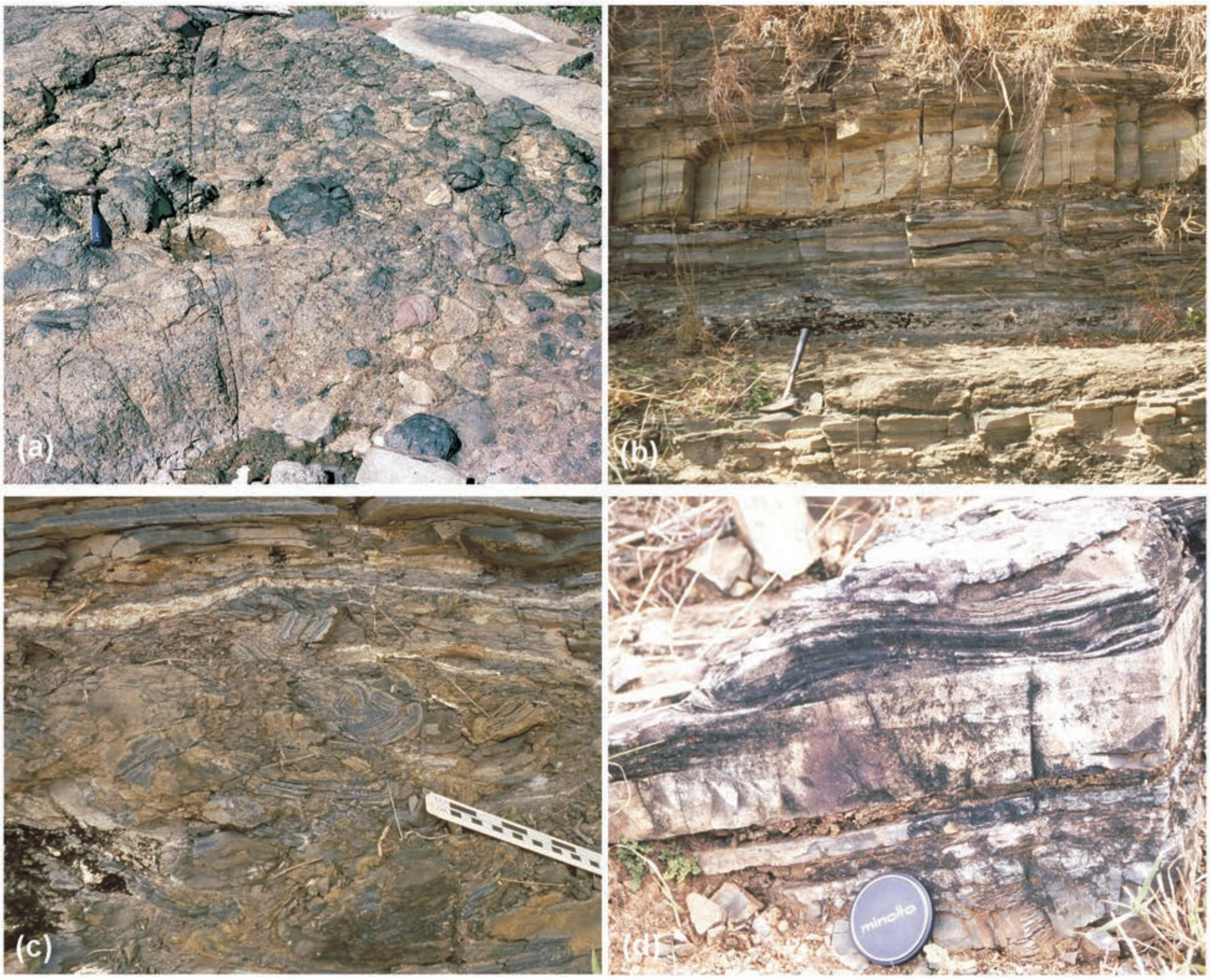

Figure 55. Carmila beds (continued)
(a) Massive, poorly sorted polymictic conglomerate with mostly rounded clasts of mafic to felsic volcanic rocks. In Saint Lawrence Creek near the Bruce Highway at MGA 755314 7530281 (LHC055)
(b) Well-bedded, laminated, fine-grained lithic sandstone and grey siltstone, typical of the sedimentary part of the Carmila beds. Tooloombah area, ~8km south-west of Tooloombah homestead at MGA 757309 7476428 (IWSC1424)
(c) Soft-sediment deformation in fine-grained sandstone and laminated siltstone (*c.f.* the deformation style in the probably correlative upper part of the Lizzie Creek Volcanic Group in Figure 60). Same locality as (b)
(d) Thinly bedded siltstone and very fine-grained laminated sandstone with wavy bedding or possibly hummocky cross-stratification. About 5km south-west of Mount Benmore homestead at MGA 762102 7442540 (IWGG076)

and its fauna of productids, spiriferids, pelecypods and gastropods was recollected. It is an isolated exposure of fissile, fine-grained lithic sandstone overlying granule to pebble conglomerate and very coarse-grained lithic sandstone, separated from the rest of the Carmila beds by alluvium. Its easterly location is consistent with the fossiliferous rocks being the basal section of the Back Creek Group, although the conglomerate might be the top of the Carmila beds.

Along the access road to Lavinia Park and Burwood, the lower part of the Carmila beds that overlies the Mount Buffalo Volcanics, consists of well-bedded, well-sorted, medium to very coarse-grained, feldspatholithic sandstone and mudstone. Equisetalean plant stems occur on some bedding planes. The lithic clasts are felsic to intermediate volcanic rocks and the feldspar is mainly plagioclase. Only minor quartz is present (<5%). Similar rocks were also observed at the foot of the Broadsound Range on the northern side of Tooloombah Creek in the south, where they are interbedded with crystal-rich (feldspar) rhyolitic or dacitic ignimbrite and volcanic rudite.

Here as throughout much of this area, the contact with the Mount Buffalo Volcanics is marked by a distinctive thin flow of pyroxene-phyric andesite or basalt. It was observed in all the sections examined from the Lavinia Park – Burwood road to Tooloombah Creek. It is best developed north of Sarsfield Creek around MGA 754600 7489450. Because of its continuity and presence of basalt higher in the succession, it is considered to be part of the Carmila beds rather than the Mount Buffalo Volcanics, which are all of felsic composition.

Overlying the well-bedded sequence is a succession of very thick-bedded to massive volcanic conglomerate with some interbeds of tuffaceous (?) siltstone and sandstone. The conglomerate is composed of subangular to subrounded granules and pebbles of felsic rocks (including ignimbrite) and more intermediate rocks (consisting in thin section of masses of flow-aligned feldspar microlites) in a matrix of sand-sized volcanic grains. Some of the beds are cobbly at the base. In some beds, the matrix appears to be silty. These poorly sorted conglomerates may be subaerial mass flow deposits (including talus, mudflows and debris avalanches), but those outcrops with a sandy matrix are probably thick fluvial deposits. The tuffaceous beds consist of very fine-grained plagioclase crystal fragments and lithic clasts up to 0.5mm in a fine-ash matrix. They may be air-fall or waterlain tuff. The conglomeratic interval has been mapped as far south as Montrose Creek.

The volcaniclastic conglomerate is similar in some respects to parts of the Mount Buffalo Volcanics. However, the rocks appear to be better sorted, and in the north are separated from the Mount Buffalo Volcanics by the well-bedded sandstone-mudstone succession. The latter appears to be missing between Granite and Sarsfield Creeks and the conglomeratic succession directly overlies the Mount Buffalo Volcanics. It is distinguished on the aerial photographs by being more recessive, although still moderately hilly.

The volcaniclastic succession is overlain through most of the area by aphyric to porphyritic, locally brecciated, basalt lavas that are a continuation of the belt to the south-west of Tooloombah homestead and delineated as subunit $\mathbf{Pc_b}$. The lavas have been traced in outcrop northwards to the southern side of Prospect Hill. They have not been observed farther north, and if they do continue, they are obscured by alluvium.

Between Montrose and Tooloombah Creeks, an area ~5.5km north-to-south and 3km west-to-east, consists dominantly of felsic volcanic rocks that overlie the basalt and are assigned to subunit $\mathbf{Pc_v}$. They appear to consist of an assemblage of mainly plagioclase-phyric dacitic (?) lava and volcaniclastic rocks.

Near Tooloombah Creek at MGA 756450 7485350 at the southern end of this pile of felsic volcanic rocks, a variety of generally pale greenish grey crystal-rich (feldspar) and lithic-poor to lithic-rich dacitic volcaniclastic rocks crop out as very thick (>5mm), poorly defined massive beds. Variation in clast size and abundance defines the crude stratification. The crystal fragments are mostly exclusively plagioclase to 2mm, although some amphibole crystals pseudomorphed by chlorite are locally present. Lithic fragments are aphyric to porphyritic dacite (?). The groundmass is very fine-grained felsic material, and no vitroclastic textures or fiamme are apparent.

Between Montrose and Sarsfield Creeks, where the volcanic rocks are thickest, the pile probably includes both lavas as well as volcaniclastic rocks similar to those described above. The lack of vitroclastic textures in the groundmass makes it difficult to determine whether some rocks are flows or volcaniclastics, except where the plagioclase crystals are dominantly fragmented or variation in clast abundance defines bedding. Some flow-banded and autobrecciated outcrops were observed, and at MGA 758600 7490100, dacite containing abundant xenoliths of micromonzonite has a groundmass of flow-aligned plagioclase microlites.

The felsic volcanic rocks described above do not appear to extend in any volume south of Tooloombah Creek or north of Montrose Creek, and could represent a local eruptive centre, possibly in a cauldron subsidence structure that confined the original and preserved extent of the rocks. They are overlain by several hundred metres of lithic sandstone and conglomerate, locally containing fossil wood, and these are overlain by nodule-bearing mudstone of the Back Creek Group.

Tooloombah Creek to the old Marlborough–Sarina road
(Figure 35)

This area lies between the Connors Arch and the Langdale Inlier, a partly fault-bounded block of volcanic rocks. Lithic sandstone increases in abundance, northwards from the old Marlborough–Sarina road. The sandstone is thin to thick-bedded, fine-to coarse-grained, and interbedded with mudstone. The rocks locally contain plant fossils and White (*in* Malone & others, 1969, page 123) identified species of *Noeggerathiopsis, Glossopteris* and *Gangamopteris* from M95, ~10km south-west of Tooloombah homestead.

Several belts of mafic volcanics are present in this area and are delineated as subunit $\mathbf{Pc_b}$. One near the base of the Carmila beds is up to 400m thick and ~5km long. It consists of aphyric to porphyritic basalt or basaltic andesite. At MGA 754500 7475600, the rocks are strongly quench-fragmented. The breccia consists of aphyric lava fragments, locally showing jigsaw-fit relationships, although generally less coherent. The matrix to the clasts is silicified volcanic sandstone, probably a hyaloclastite. An interval ~10m thick of grey, flaggy siltstone containing fossil wood impressions is interbedded with the basalt breccia at this site.

A larger belt further north, on the eastern side of Tooloombah Creek, is up to 2km wide (suggesting a thickness of up to 700m assuming an average dip of 20°) and is at least 9km long. It probably continues northwards under the floodplain of Tooloombah Creek as part of a belt of mafic volcanics that extends at least

25km to the north (see above). It consists mainly of massive, partly altered, aphyric basalt, but some porphyritic varieties with small clinopyroxene and plagioclase phenocrysts occur locally. The basalt commonly has elliptical to spherical chlorite or quartz-filled amygdales, 1–5mm and locally 2cm across. At MGA 757600 7482200, the basalt is extensively brecciated, probably by quench fragmentation. It contains angular clasts to 10cm, showing jigsaw fit, and locally surrounding bulbous blocks of basalt that may represent pillows.

In thin section, the basalt usually consists of randomly orientated plagioclase laths to 0.5mm with interstitial clinopyroxene (mostly ~0.05mm) and opaque oxides. Less commonly, the plagioclase laths are flow aligned and the clinopyroxene forms ophitic grains. The clinopyroxene is commonly partly replaced by chlorite, and the opaques are rimmed by titanite or anatase. Cores of plagioclase laths are commonly partly altered to sericite or saussurite.

Sedimentary rocks between the flows are mainly medium to thick-bedded, very fine-grained to very coarse-grained, feldspatholithic sandstone and siltstone. They contain fossilised wood as log segments up to 25cm in diameter. Minor felsic volcanic rocks also crop out. At MGA 756300 7482400, light greenish grey dacitic lava or tuff consists of white feldspar crystals to 1.5mm in a felsic, microspherulitic groundmass.

Thinner basalt flows appear to be present in the overlying succession, although in weathered outcrop they commonly resemble lithic sandstone. Their identity was only apparent in thin section.

The overlying rocks, such as those that crop out along the road between Charlyn and Tooloombah homesteads, include grey, laminated siltstone and sporadic, very thick beds of volcanic rudite containing grey, angular to subangular, aphyric felsite pebbles in a felsic, aphanitic, microspherulitic groundmass.

Basalt also crops out east of the Anglewood road ~1km east of Tooloombah homestead, on the eastern side of the Langdale Inlier. The basalt is locally amygdaloidal and is brecciated, possibly by quench fragmentation. Lithic sandstone and siltstone crop out between the basalt and the Langdale Hill Rhyolite.

In the southern part of the area, the upper part consists of an assemblage of medium to very coarse-grained, locally pebbly feldspatholithic sandstone, volcanic conglomerate, crystal-rich fine-ash tuff, siltstone and mudstone. The conglomerate is very thick-bedded and poorly sorted with subangular to subrounded clasts of basalt or andesite. At MGA 757300 7476450, thin to medium-bedded grey siltstone, mudstone and fine to medium-grained sandstone show soft-sediment deformation features such as wavy bedding, ball-and-pillow structures and in more extreme cases, recumbent folds (Figure 55b–c).

A sill-like body of altered gabbro ~4km long and up to 500m wide crops out from just north of the old highway near the westernmost crossing of Apis Creek. Its age is uncertain, but it could be related to the mafic volcanics within the Carmila beds.

South of the old Marlborough–Sarina road
(Figures 35 and 65)

Rocks in this area are dominated by greenish grey to dark bluish grey siltstone. The siltstone ranges from very thick massive beds to finely laminated beds. Thick to very thick-bedded, medium to coarse-grained, volcanolithic sandstone and granule conglomerate consisting mainly of basalt or andesite clasts also occurs locally. On the composite radiometric images, the rocks are represented by a dark reddish brown hue with bluish patches. This low radiometric response reflects a relatively mafic volcanic source for the sediments.

Strongly altered (carbonate and chlorite), amygdaloidal aphyric mafic lavas crop out in places. East of Mount Gardiner, a persistent layer of mafic rocks ~200m wide also appears to include at least some dolerite containing plagioclase laths, clinopyroxene and chlorite after olivine. An unusual breccia along the old highway at MGA 757000 7469050 could be quench fragmented lava. It contains angular embayed basalt or andesite clasts to 1cm in a poorly sorted sandy matrix of similar material.

The rocks dip eastwards, overlying and partly faulted against the Mount Benmore Volcanics north of Apis Creek. Assuming an average dip of 40°, the thickness ranges from 150m (between the highway and the access road to Cerberus homestead) to ~700m (south of Cerberus).

A relatively complete, continuous section was examined between MGA 760760 7450820 and MGA 761310 7449930, south-west of Apis Creek homestead. The base of the unit is marked by siltstone, directly overlying porphyritic andesite of the Mount Benmore Volcanics. A strongly altered amygdaloidal, aphyric lava flow, occurs ~10m above the base. The section is ~300m thick, and consists mostly of greenish-grey siltstone. The siltstone ranges from very thick massive beds to finely laminated flaggy beds. Some cross-lamination and possibly hummocky cross beds are present locally (Figure 55d). Soft-sediment deformation is manifest by small slump folds and disruption of thin cherty (tuff?) layers. A thin, impure, unfossiliferous limestone bed was observed in the middle of the section. Towards the top of the section, another thin altered basalt flow or sill crops out. The topmost rocks in the section form a ridge and consist of relatively siliceous, very thick-bedded, fine to medium-grained volcanolithic sandstone. At the base of the dip-slope to the south-west at MGA 761310 7449930, finely laminated, flinty siltstone, locally showing soft-sediment folds, crops out. The radiometric data suggest that the overlying siltstones to the south-west are part of the Back Creek Group, although the distinction from the Carmila beds is not obvious on the ground. Some of the siltstones in the upper part of the section may be waterlain tuffs, or transported relatively juvenile volcanic detritus.

West-south-west of Mount Benmore homestead, a similar sequence dominated by siltstone was observed. The rocks overlie and locally have been overthrust by the Mount Benmore Volcanics. The siltstones range from dark grey to greenish-grey, and from massive to finely laminated with low-amplitude soft-sediment folds. A grey, aphyric amygdaloidal basalt (?) flow, with strong carbonate alteration, was observed near MGA 762330 7442840. Some thin to thick-bedded, calcareous volcanolithic sandstone and siltstone also crop out in this area. The rocks are laminated and have low-amplitude to recumbent soft-sediment folds and sandstone dykes. In thin section, the laminated siltstones contain feldspar crystal fragments up to 0.1mm and variation in size and abundance of these defines grading. Some of the wavy laminations resemble small-scale hummocky cross-stratification.

Gogango Overfolded Zone
(Figure 35)

The Carmila beds have been recognised within the Gogango Overfolded Zone in a slice ~20km long and up to 1km wide, extending from the northern edge of the ROOKWOOD to near Langdale homestead. The slice can be recognised on the composite radiometric images as a dark purplish-brown belt. The rocks are interpreted to be thrust over the Boomer Formation and lower part of the Back Creek Group to the west and also appear to be partly faulted against the Boomer Formation on the east. Further north near Langdale, they are overlain to the east by the lower part of the Back Creek Group.

The belt shows a variety of rock types. In the south and north, it consists dominantly of grey siltstone and very fine-grained sandstone, locally containing carbonised remains and impressions of equisetalean stems. However, south from the old Marlborough–Sarina road in the western part of Develin Station, the rocks are predominantly coarse-grained volcaniclastic sedimentary rocks. These appear to underlie the siltstone-dominated interval. The volcaniclastic rocks are mainly very thick-bedded conglomerate and pebbly sandstone, consisting of subrounded to rounded felsic to intermediate volcanic pebbles and cobbles supported by a matrix of coarse to very coarse-grained quartz-poor, feldspatholithic sandstone. The matrix is moderately well sorted and the overall size distribution is bimodal. Beds of poorly sorted crystal-rich volcanic sandstone or tuff occur in places, and consist of abundant feldspar crystals and lithic clasts in a very fine-grained, possibly vitric matrix. Rare basalt outcrops are aphyric and consist of plagioclase laths, ophitic clinopyroxene and chlorite after pyroxene or olivine. They are probably flows, but could include dykes.

This belt appears to be another local thicker accumulation towards the southern end of the unit’s distribution. Although the Carmila beds have been mapped near Apis Creek homestead to the south-west, only 10–20m (at most) of siltstone have been observed between mafic volcaniclastic rocks of the Mount Benmore Volcanics and the fossiliferous basal Back Creek Group in the intervening area around the hinge of the Leura Anticlinorium.

About 2.5km south-west of Develin homestead, a small elliptical area of well-bedded siltstone ~1km long occurs in the hinge of an anticline. The rocks have been assigned to the Carmila beds because of the low radiometric response contrasting with the strong radiometric response of the overlying Back Creek Group.

West of the Connors Arch
(Figure 35)

The Carmila beds have been mapped around the southern nose of the Connors Arch, and extending along the western side, appearing to thin out just north of Macksford homestead. Along the road to Tartrus homestead, the unit is ~350m thick. The succession here is poorly exposed, but dark grey, thick to very thick, fissile mudstone and more resistant, thin to thick, dark grey, moderately calcareous siltstone to very fine-grained sandstone have been observed in gullies. The beds are locally laminated and contorted in places. Equisetalean stem impressions occur locally. Some intervals of conglomerate up to 30m thick are also present. The conglomerate contains subangular to subrounded granules and pebbles of siltstone and mafic volcanics in a coarse to very coarse-grained lithic sandstone matrix that is cemented by calcite.

In Yatton Creek at MGA 727900 7506100 and along the old Marlborough–Sarina road at MGA 726900 7507200, outcrops similar to rocks in the Carmila beds were observed between the Mount Benmore Volcanics and lowermost Back Creek Group (Yatton Limestone). The rocks include dark grey, medium to thick-bedded siltstone, very thick-bedded, medium to coarse-grained volcanic lithic sandstone and fissile mudstone. These rocks were not observed farther south and appear to be a small isolated basin. However, they are probably equivalent to parts of the Carmila beds or a thick lacustrine succession that is currently included in the upper part of the Lizzie Volcanic Group in the area west of Eungella Dam (Mount Coolon 1:250 000 Sheet area — Hutton & others, 1998).

Environment of deposition

Fielding & others (1997a) discussed the tectonic setting of the Carmila beds. They suggested that the Carmila beds and correlative units such as the upper part of the Lizzie Creek Volcanic Group and Youlambie Conglomerate were deposited in lacustrine and fluvial environments in rapidly subsiding tectonically and volcanically active basins during the early extensional phase of the Bowen Basin. Coarser-grained rocks appear to be more abundant to the north. In the Apis Creek area in the southernmost part, the Carmila beds are dominantly fine-grained, and are probably largely lacustrine. They terminate abruptly north of Leura homestead, and the underlying Mount Benmore Volcanics are directly overlain by mudstones of the Back Creek Group. The rapid thickness changes along strike are consistent with deposition in a rift setting.

Geophysical response

The sedimentary rocks in the Carmila beds show a varied low to moderate response in all three radiometric channels resulting in a mottled pattern of pink and pale bluish grey hues on composite images. At the southern end of the Connors Arch where the unit is mudstone dominated, the response is significantly different with low potassium and thorium responses and moderate uranium responses resulting in distinctly bluish composite hues. The basalt units show the typical low response in all channels resulting in dark purple to black colours on composite images. The areas of felsic volcanic rocks generally show moderate to strong potassium responses and moderate uranium and thorium producing pale pinkish composite hues.

The Carmila beds have predominantly a low, flat magnetic response in the airborne data that contrasts with most of the volcanic units, such as the underlying Mountain View Volcanics and Mount Benmore Volcanics, which have variable low to moderate responses. This is consistent with measured magnetic susceptibility measurements, in particular for the sedimentary rocks which are overwhelmingly $<10 \times 10^{-5}$ SI units. The volcanic units within the Carmila beds still have relatively low responses, but they are more variable and this has been used as an aid in mapping, particularly beneath Cainozoic cover. Outcrops still have relatively low magnetic susceptibility values. Basalts are predominantly in the range $10–50 \times 10^{-5}$ SI units with sporadic much higher values (to 2500). The more felsic volcanic rocks show a strong mode for values $<10 \times 10^{-5}$ SI units, but also have a tail of higher values to about 60 and then sporadic values up to 2000.

Geochemistry

Thirty-seven samples of volcanic rocks from the Carmila beds were analysed for a range of major and trace elements. The samples included twenty-one lavas and sixteen clastic rocks including some ignimbrite. The plot of total alkalis vs SiO_2 (TAS) in Figure 56 indicate that although basalt and basaltic andesite form the largest cluster, the analyses range through andesitic compositions to rhyolitic. Two of the andesites have high total alkalis and may be altered. They fall in the basalt-andesite rather than andesite field in the plot of Zr/TiO_2 vs Nb/Y after Winchester & Floyd (1977). The clastic rocks show a complete spread from basaltic andesite to rhyolite in both plots. No bimodality is evident.

Three samples of basalt were submitted for precise trace element analysis by laser ablation mass spectrometry, and the data have been used in the multi-element and rare-earth element (REE) plots in Figure 57a–f. The samples produce three quite different profiles in the REE plot and also in the high-field-strength elements (HFSE) in the multi-element plot. The profiles were compared with those from modern basaltic suites using the database compiled from literature by Murray & Blake (2005, appendix 1), and are difficult to explain. The three samples come from a relatively small area near Toolombah. IWSC0800 and IWSC0521 have the shallowest profiles and were collected ~10km apart from the same basalt unit. IWSC0232 is ~6km east of IWSC0521 from a separate basalt unit, probably at a higher stratigraphic level.

The shallowest profile is produced by IWSC0521, which has already been compared with a sample from the Mount Benmore Volcanics and basalt from the Collaroy Volcanics. Similarities with the Villarrica suite in the Southern Volcanic Zone of the Andes suggest that these are related to relatively thin crust compared with that associated with older volcanic units in the Connors Arch. However, the other two samples have steeper profiles suggesting that they may be associated with thicker crust. IWSC800 has a moderately steep slope and has been matched with basalts in the Tatara suite in the Southern Volcanic Zone of the Andes. This has a slightly shallower profile than the Peteroa suite to which most of the other volcanic units in the Connors Arch have been compared. IWSC0232 has the steepest profile and no good match could be found in the database.

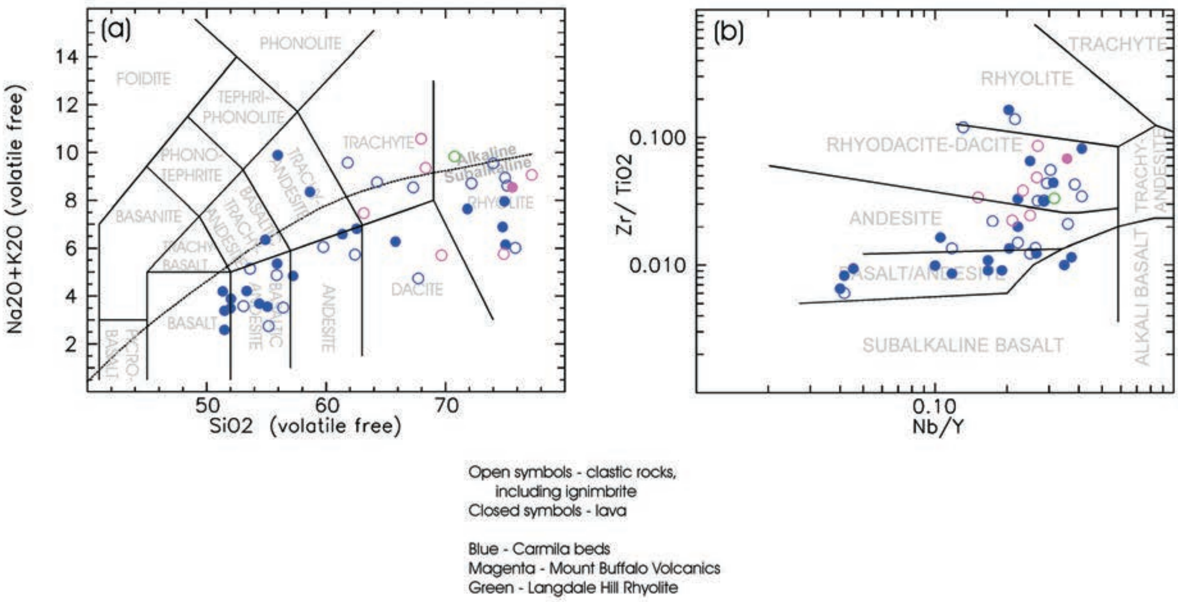

Figure 56. Geochemical classification of volcanic rocks from the early Permian Carmila beds (blue), Mount Buffalo Volcanics (magenta) and Langdale Rhyolite (green):
(a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986) and Irvine & Baragar (1971);
(b) Nb/Y vs Zr/TiO_2 showing the fields of Winchester & Floyd (1977).

The steepest profiles of rocks in the database are produced by the Casimiro suite in the Southern Volcanic Zone of the Andes, but the profile of this sample is even steeper. The Casimiro suite is associated with very thick crust (50–55km). Given that this sample may be stratigraphically higher in the Carmila beds, this seems inconsistent with a trend towards thinning crust evidenced in the progression from Coppermine Andesite through Mount Benmore Volcanics into the Collaroy Volcanics. It is farther east and it has already been noted that the basalt in the Wongrabry beds is similar to the Casimiro suite. Marked variation in thickness of the Carmila beds in the Tooloombah area suggest differential subsidence that may be related to rifting, but such dramatic variations in crustal thickness over such short distances seem unlikely.

In the Andes, significant geochemical variations can occur on a small scale in areas of similar crustal thickness and these are superimposed on the more regional trends (Hickey-Vargus & others, 1989). Hickey-Vargus & others suggested that the variations could represent individual magma batches that reflect heterogeneities in the lithospheric source or slab-derived fluids, which are not manifest in longer-lived volcanoes where extensive sub-crustal magma pooling and homogenisation by mixing occur. The geochemical variation in the Carmila beds, where the basalts are relatively thin compared with the thicker piles of volcanic rocks in the older units, could represent such processes, but more analyses are needed to properly resolve it.

Relationships

On the eastern flank of the Connors Arch in the Saint Lawrence 1:250 000 Sheet area, the Carmila beds in various places overlie the early Permian Mount Buffalo Volcanics, Mount Benmore Volcanics and Langdale Hill Rhyolite, and early Carboniferous Mountain View Volcanics. The relationship to the early Permian volcanics is probably unconformable at least locally. Along the eastern side of the Langdale Inlier, the Carmila beds progressively overlie older parts of the succession southwards.

Farther north in the Mackay 1:250 000 Sheet area, the Carmila beds are faulted against granitoids of the Urannah Batholith, but are probably mainly younger. There, they are intruded by numerous granitic plutons of probable Cretaceous age, including the Ben Mohr and Mount Bridgeman Complexes and Swayneville Granite. They are overlain by the late Permian Calen Coal Measures.

As noted, the Carmila beds have been mapped around the southern nose of the Connors Arch, and on the western flank, overlie the Mount Benmore Volcanics.

South from Saint Lawrence, the Back Creek Group overlies the Carmila beds, but the exact relationship is uncertain because of the lack of diagnostic fossils within the latter. Early Permian faunas occur in the basal Back Creek Group above the boundary. Although no angular discordance can be demonstrated, it is possible that the boundary represents a disconformity in places, *e.g.* around the Langdale Inlier.

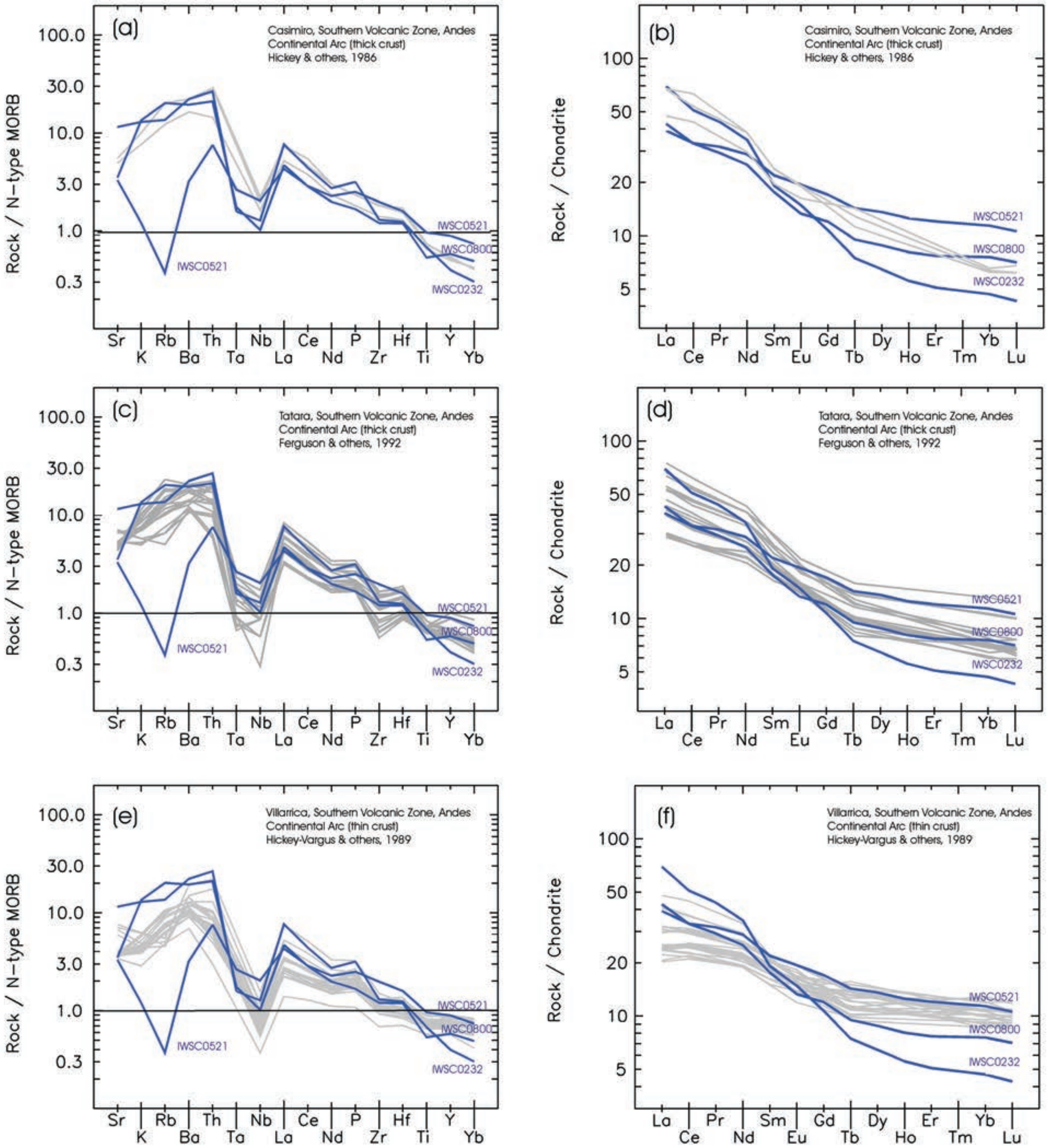

Figure 57. Multi-element plots of basalt or basaltic andesite samples from the early Permian Carmila beds — for comparison, patterns of modern basaltic suites as indicated are shown in grey:
(a, c, and e) N-MORB normalised multi-element plots (using values from Pearce, 1983);
(b, d, and f) chondrite-normalised REE plots (using values from Sun & McDonough, 1989).

The Langdale Inlier is a northerly-trending belt of volcanic rocks that crop out east of the main Connors Arch between Tooloombah homestead and the head of Apis Creek. It is ~10km long and up to 5km wide. The rocks within the inlier are probably partly equivalent to those within the Connors Arch. They are flanked to the west and separated from the main part of the Connors Arch by a 4km-wide belt consisting of a thick pile of sedimentary rocks and basalt flows assigned to the Carmila beds. These rocks dip eastwards towards the inlier, suggesting that its western margin is a fault. However, the Carmila beds thin dramatically around the southern margin and on much of the eastern margin they are absent, so that the Back Creek Group directly overlies the volcanic rocks. It is not yet clear whether this is due to uplift and erosion of the inlier between the deposition of the Carmila beds and the Back Creek Group, or whether the Langdale Inlier formed a positive feature during deposition of the Carmila beds. In the latter case, it is possible that the western bounding fault was a growth fault, and that the thick pile of Carmila beds to the west represents deposition in a rift, adjacent to a rising horst of basement. The rocks in the inlier become younger northwards. Farther north along the eastern margin, the Langdale Hill Rhyolite is again overlain by a thin succession of Carmila beds, comprising sedimentary rocks and basalt.

Such differential movement around the Langdale Inlier is consistent with the rifting model for the early history of the Bowen Basin (Fielding & others, 1997a). Farther south near Apis Creek, the Carmila beds also show rapid lateral changes in thickness and lens out abruptly.

Age

Plant fossils collected during the BMR–GSQ survey of the 1960s were described by White (1963a,b) and in Malone & others (1969). She reported a late Carboniferous–early Permian range. More recently, an ignimbrite from Dumbleton Rocks in the Pioneer River near Mackay yielded an early Permian SHRIMP age of 294±3Ma (Allen & others, 1998).

A sample of rhyolitic lava collected from the basal volcanic unit of the Carmila beds near Koumala (BB3050) gave a SHRIMP zircon age of 292.8±2.9Ma (10 analyses with a MSWD of 0.93, see Appendix). It also contained an older population of inherited grains that gave an age of 305.4±3.4Ma (7 analyses with a MSWD of 0.56).

The unit is, therefore, regarded as early Permian and equivalent in age to the more dominantly volcanic units in the Lizzie Creek Volcanic Group, although it overlies them in the south. In fact, the isotopic ages from the basal part of the unit overlap with and are within error of the ages obtained from the northern part of the Leura Volcanics. On the south-western flank of the Connors Arch, the Carmila beds overlie the Mount Benmore Volcanics, which in turn overlie the Coppermine Andesite dated by SHRIMP at 296.6±2.5Ma (Burch, 1999).

Early Permian marine fossils were reported from parts of the unit by Dickins (*in* Malone & others, 1969). However, it is doubtful whether these sites (near Tooloombah, Montrose and Prospect Hill homesteads) are actually part of the Carmila beds, and they are probably the basal part of the Back Creek Group. Rocks containing early Permian marine fossils south of Charon Point and previously assigned to the Carmila beds (Dickins *in* Malone & others, 1969; Fielding & others, 1997a) are now mapped as a new unit, the Wongrabry beds.

GOODEDULLA BEDS

Introduction

The Goodedulla beds were first named and described by Withnall & others (1998a). The name is derived from the Goodedulla National Park, in central ROOKWOOD. They crop out adjacent to the Mount Benmore Volcanics over ~30km^2 in the Melaleuca Creek area in central ROOKWOOD (Figure 65).

Type area

Because of the complex structure and difficult terrain, no complete section has been examined. Therefore, only a type area is designated along Melaleuca Creek between MGA 780700 7431300 and MGA 780500 7432300 where typical cleaved mudstone and siltstone and subordinate volcanolithic sandstone crop out.

Lithology

The unit is dominated by cleaved siltstone and mudstone and superficially resembles the Back Creek Group, but it has a low radiometric response similar to that of the Mount Benmore Volcanics (Figure 66). The rocks are generally yellowish-grey in outcrop and pale grey when fresh. This also distinguishes them the rocks of the Back Creek Group, which are generally dark grey and carbonaceous where unweathered.

Subordinate medium to coarse sandstone and granule to pebble conglomerate occur throughout the outcrop area. The rocks consist of subangular to subrounded intermediate volcanic detritus and generally subordinate plagioclase. No quartz is present. An unusual well-sorted sandstone from MGA 783030 7431760 consists almost entirely of plagioclase laths. Bedding ranges from very thin to very thick and the rocks are locally internally stratified, mainly by variations in grainsize, but locally well-defined planar and cross laminae. Swaly cross laminae resembling hummocky cross stratification were observed at MGA 780850 742920. The sandstones are generally moderately well-sorted. The conglomerates are generally matrix-supported with subangular to rounded felsic volcanic clasts in a lithic sandstone matrix.

An outcrop of ignimbrite, possibly forming a sheet several metres thick, was observed at MGA 780480 7428420 interbedded with sandstone and siltstone. It is rich in both lithic fragments (aphyric felsic volcanics to 1cm) and crystals (quartz and feldspar 1.5mm).

No other primary volcanic rocks were observed in the unit, although in Melaleuca Creek at MGA 783030 7431760, a concordant body of columnar-jointed, porphyritic dacite or andesite ~30m thick crops out. It is uncertain whether this is a sill or lava flow. Floaters, presumably from a similar body, were observed in the creek at MGA 783400 7431885, where an unusual conglomerate crops out. The conglomerate is very thick-bedded and internally massive, consisting of subrounded pebbles and cobbles of lithic sandstone, siltstone and aphyric andesite or dacite in a matrix of grey siltstone and locally very fine to medium-grained sandstone. Similar rocks were observed in the upper part of the Lizzie Creek Volcanic Group, along the pipeline road west of Eungella Dam in HILLALONG. Fielding & others (1997a) also refer to these rocks and suggest that they are subaqueous slide and mass flow deposits formed in a lacustrine deposit. Similar rocks have also been observed in the Carmila beds.

Geophysical response

The Goodedulla beds have a low radiometric response in all channels resulting in dark purple to grey composite hues similar to that of the underlying Mount Benmore Volcanics and distinguishing them from the mudstones of the Back Creek Group which have moderate to strong responses in all channels (Figure 66). No magnetic susceptibility measurements were made, but the unit has a low response in the airborne data.

Environment of deposition

The dominance of fine-grained sediments in the Goodedulla beds and their restricted extent is consistent with deposition in a largely lacustrine environment in a rift setting. Fossils are absent, although it should be noted that body fossils are also rare in much of the Back Creek Group, which is inferred to be marine. However, trace fossils, which are relatively common in the Back Creek Group, were not observed. The sporadic sandstone and conglomerate may represent alluvial fans, deltas and beach zones. Some of the conglomerates may be mass flow deposits related to slumping within the lake or from the adjacent terrain.

The dominance of volcanic detritus is consistent with local derivation from the underlying volcanic units, with possibly some contemporaneous volcanism indicated by the rare ignimbrite. The radiometric response is similar to the underlying largely andesitic/basaltic Mount Benmore Volcanics, suggesting a similar composition, although the lithic clasts in the sandstones and conglomerate appear to be more felsic, at least in hand specimen.

Relationships and Age

The Goodedulla beds are restricted to the Melaleuca Creek area, where they are inferred to overlie the Mount Benmore Volcanics and to be overlain by the undivided Back Creek Group. No fossils were found in the unit, but its stratigraphic position indicates that it is early Permian like the Carmila beds and Woolein Formation.

COLLAROY VOLCANICS

Introduction

The Collaroy Volcanics (first described by Hutton & others, 1999a) extend from south of Pint Pot Mountain to north of Undercliff Station forming a meridional belt ~50km long and up to 7km wide (Figure 37) and occupying a broad valley formed by Murray and Collaroy Creeks from which the name is derived. Outcrop is poor and thick black soil and alluvium cover the unit.

Type area

Because of the lack of structural information in the massive basalts and poor outcrop, no section was measured through the unit. The best outcrop is in the Chinaman Ridges west of Collaroy homestead where amygdaloidal basalts and marine sediments crop out and this is designated as the type area.

Lithology

The Collaroy Volcanics are mainly fine-grained, aphyric, locally amygdaloidal basalt or andesite flows and breccia. Possible pillow basalts have also been observed in Bull Creek at MGA 727370 7570700 (Figure 58a), and near Collaroy Creek at MGA 725500 7559975, a massive monomict breccia with mafic volcanic clasts may be quench-fragmented (Figure 58b). North of Collaroy homestead at MGA 725420 7563260, massive breccia comprises angular altered volcanic clasts, some of which are amygdaloidal basalt or andesite, in a coarse-grained matrix (Figure 58c).

Figure 58. Collaroy Volcanics
(a) Possible pillow structures in aphyric basalt. Bull Creek ~9km north-north-east of Collaroy homestead at MGA 727371 7570702 (LHC405)
(b) Basalt breccia, possibly quench-fragmented. Collaroy–Marylands road ~2km south of Collaroy homestead at MGA 725495 7559973 (RSC053)
(c) Breccia comprising angular volcanic clasts, including amygdaloidal epidotised basalt or andesite, in a coarse-grained matrix. Pit ~2km north-north-east of Collaroy homestead at MGA 725416 7563262 (LHC301)
(d) Moulds of shelly fossils including spinose productids, Eurydesma sp., bryozoans and crinoids. Southern part of Chinaman Ridge, 3.4km west-south-west of Collaroy homestead at MGA 722912 7559856 (RSC052)

A few small areas of felsic volcanic rocks crop out within the Collaroy Volcanics between Ridgelands and Undercliffe homesteads. These have been designated as unit **Pvc$_i$** and are interpreted to be possibly ignimbrite. They contain sparse feldspar crystal fragments and rare lithic clasts to 1cm in a very fine-grained to vitric matrix and appear to overlie the basalt.

Limestone, conglomerate and labile sandstone beds are interbedded with mafic volcanics and breccia in a few places. West of Collaroy homestead along Chinaman Ridges at MGA 722900 7559900, basalt lavas are interbedded with fossiliferous sandy limestone and coquinite and sparsely fossiliferous massive labile sandstone. Fossils include large bivalves like *Eurydesma*, pectens, gastropods, spiriferids, spinose productids and bryozoans (Figure 58d). These outcrops, which lie near the western margin of the unit, have a steeply dipping, NNW-striking fracture cleavage. It is possible that this cleavage is related to the fault system that occurs along the western margin of the Collaroy Volcanics. Other fossil localities occur east of Collaroy at MGA 727575 7561700 and north of Collaroy along the boundary fence with Ridgelands Station at MGA 725850 7563400.

Geophysical response

The Collaroy Volcanics are recognised by dark hues on composite radiometric images due to the low response in all channels. A few areas of high potassium response and pink to red hues on composite images are probably related to rhyolite plugs and possibly some felsic volcanic rocks as described above.

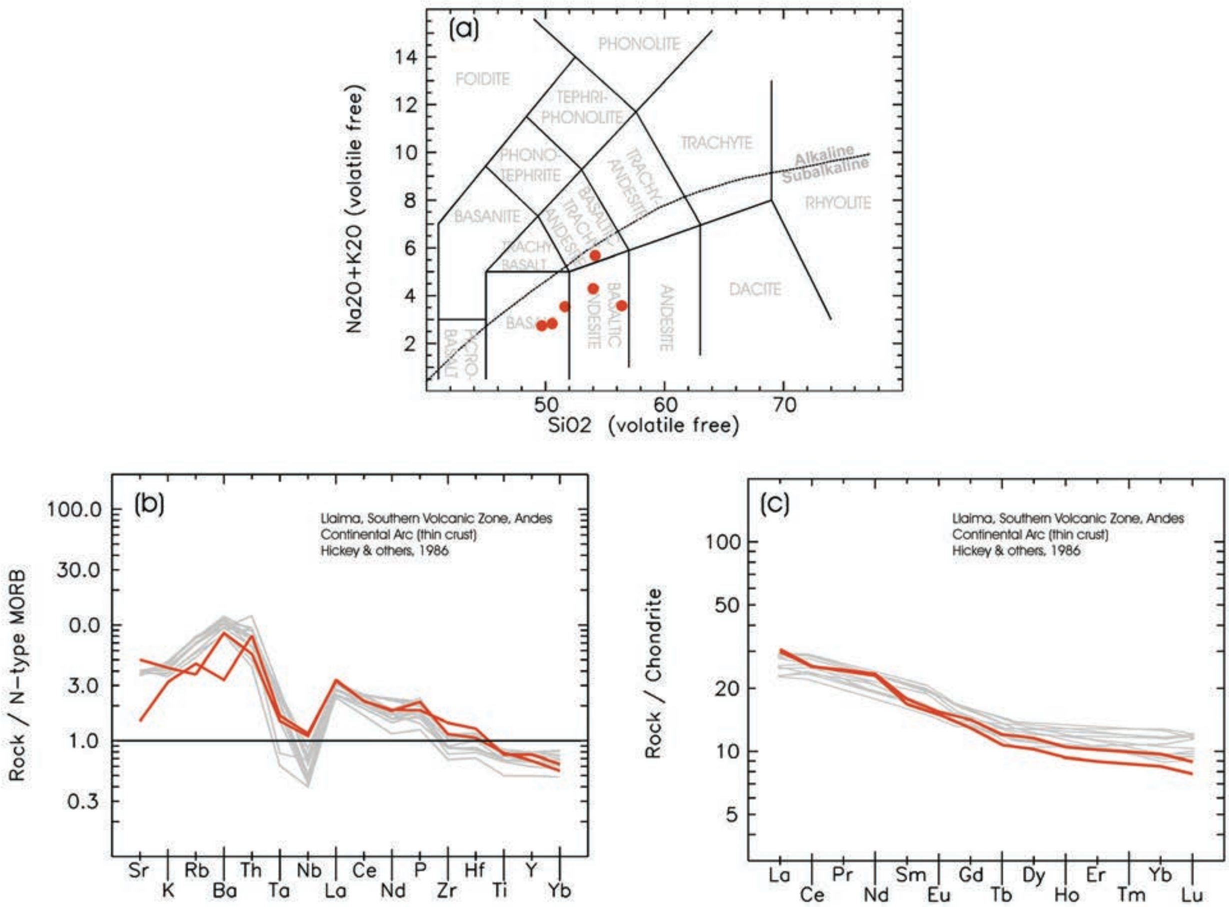

Figure 59. Geochemistry of the early Permian Collaroy Volcanics:
(a) total alkalis vs SiO_2 in weight percent showing the fields of Le Bas & others (1986) and Irvine & Baragar (1971);
(b) N-MORB normalised multi-element plot (using values from Pearce, 1983) for basalt samples;
(c) chondrite-normalised REE plot (using values from Sun & McDonough, 1989) for basalt samples. For comparison, basalts from the modern Andean Llaima suite are shown in grey.

The Collaroy Volcanics have a low magnetic response although the central part of the outcrop area north of Collaroy homestead has a series of conspicuous moderately magnetic curvilinear features of unknown origin. The overall low response is consistent with the magnetic susceptibility values which are mostly <100 x 10^{-5} SI units, with a mode at about 20. However, one basalt outcrop had values ranging from 260–2650 and although this outcrop is in an area of generally low response, the anomalous magnetic features may be due to particularly magnetic flows in the sequence.

Environment of deposition

The Collaroy Volcanics occupy a narrow meridional linear belt that may be a rift or half-graben (see below). The possible pillow structures and quench fragmentation suggest that the Collaroy volcanics were erupted subaqueously. The fossiliferous sediments that are interlayered with the volcanics indicate that this was probably in a shallow marine rather than lacustrine environment as suggested for the Carmila beds and locally for the Mount Benmore Volcanics.

Geochemistry

Six samples from the Collaroy Volcanics, all interpreted as lava, were analysed for a range of major and trace elements. The plot of total alkalis vs SiO_2 (TAS) in Figure 59 indicates that lavas are dominantly basalt and basaltic andesite.

Two samples of basalt were submitted for precise trace element analysis by laser ablation mass spectrometry, and the data have been used in the multi-element and rare-earth element (REE) plots in Figure 59b–c. The profiles of the two Collaroy Volcanics samples are slightly divergent towards the heavy REE, but overall produce a narrow parallel array.

The profiles were compared with those from modern basaltic suites using the database compiled from literature by Murray & Blake (2005, appendix 1). The profiles of the samples have a reasonable match with the REE profiles of basalts from the Llaima suite that developed on relatively thin crust (~35km) in the Southern Volcanic Zone of the Andes (Hickey & others, 1986). The multi-element profile also shows a reasonable match, although the Ta-Nb trough is not quite as pronounced. The shallower profiles contrast with those of the main group of samples from the northern part of the Mount Benmore Volcanics adjacent to the Collaroy Volcanics. They suggest that crustal thinning related to the extension that formed the Bowen Basin had certainly commenced during the eruption of the Collaroy Volcanics. This is consistent with the volcanics appearing to occupy a graben.

Relationships and age

Overall, the Collaroy Volcanics appear to occupy a broad synclinal structure, but much of the western margin of the unit appears to be faulted against the Leura Volcanics, with local thick wedges of polymictic conglomerate, suggesting that the volcanics were erupted into a developing half-graben structure. Along their eastern margin, they appear to unconformably overlie the Mountain View Volcanics. The relationship of the Collaroy Volcanics to the Mount Benmore Volcanics of the Lizzie Creek Volcanic Group is not known. Malone & others (1969) mapped them as Lizzie Creek Volcanics on lithological grounds but recognised that the faunas suggest that they may be slightly younger.

The Collaroy Volcanics are early Permian. The fossil assemblages were described by Dickins (*in* Malone & others, 1969, pages 99–100) as being Fauna I or Fauna II. They suggest that the Collaroy Volcanics are time equivalents of the Artinskian Buffel Formation, which overlies the Camboon Volcanics in the Auburn Arch (Flood & others, 1981; Briggs & Waterhouse, 1982) and the Tiverton Formation that overlies the Mount Benmore Volcanics in the Nebo area. They are therefore probably younger than the Mount Benmore Volcanics and Carmila beds.

UNASSIGNED SEDIMENTARY ROCKS, LIZZIE CREEK VOLCANIC GROUP

Introduction

Although most of the Lizzie Creek Volcanic Group has been subdivided as named formations, several small areas of sedimentary rocks at the base and top have not been assigned to a named unit. These comprise rocks mapped as $\mathbf{Pvz_{cg}}$ and $\mathbf{Pvz_{s}}$.

Lithology

In most places, the Leura Volcanics are overlain directly by the Mount Benmore Volcanics. However, at two localities, conglomerate and minor sandstone assigned to $\mathbf{Pvz_{cg}}$ were observed at the base of the Lizzie Creek Volcanic Group (Figure 53). One is along the access track west of Waitara homestead and the second along the Peak Downs Highway east of Burrenbring homestead. In both cases, the sedimentary unit is of limited lateral extent.

West of Waitara homestead, ~500m of polymictic pebble to cobble conglomerate is interbedded with beds of khaki coloured fine to medium grained lithic labile sandstone. In this area, the outcrop is dominated by pebble and cobble to pebble conglomerate, with clasts being mainly felsic volcanics. The conglomerate facies can only be traced for ~10km along strike, and has not been mapped east of Funnel Creek.

East of Burrenbring, ~800m of sedimentary rocks lie between the Leura Volcanics and the Mount Benmore Volcanics, and also appear to overlie unnamed granite of the Urannah Batholith. The sequence can only be traced for ~3km along strike. Outcrop is dominated by massive beds of poorly sorted, polymictic boulder to pebble conglomerate (Figure 60a). Clasts are mainly felsic volcanic rocks and some granite. Matrix in the conglomerate is medium to coarse grained feldspathic sandstone.

The conglomerate was probably deposited in a continental fluvial environment. Large thickness variations over short distances indicate that the conglomerate may have been deposited in small rifts or as valley-fill. Rifts would be consistent with the extensional setting which has been proposed for the onset of sedimentation in the Bowen Basin by Holcombe & others (1997a,b). The clasts were probably derived from the Urannah Batholith and Leura Volcanics.

The age of the conglomerate facies is not known directly. However an early Permian age is indicated from isotopic age determinations from overlying and underlying rocks. A SHRIMP age of ~293Ma has been

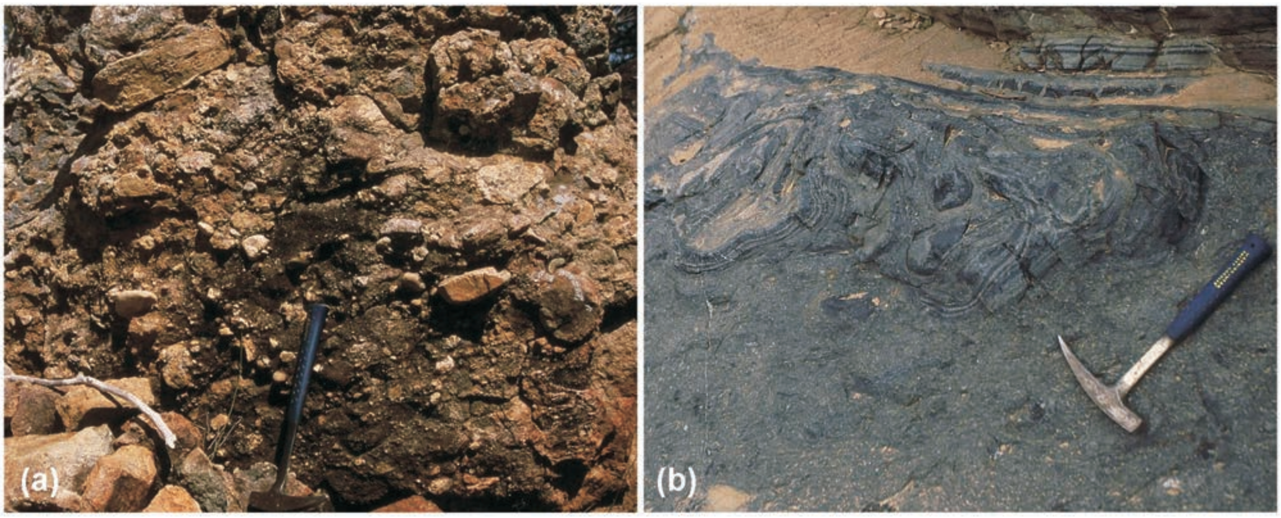

Figure 60. Unassigned sedimentary rocks — Lizzie Creek Volcanic Group
(a) Matrix-supported, pebble to boulder conglomerate containing subrounded clasts of mainly felsic volcanic rocks and minor granite. Along the powerline east of Burrenbring homestead, ~8km north of Nebo at MGA 675746 7608964 (LHC851)
(b) Soft sediment deformation in sandstone and siltstone in the upper part of the Lizzie Creek Volcanic Group. Near the Eungella pipeline road at MGA 636362 7657222 (RSC012)

determined from the Leura Volcanics east of Burrenbring, whereas an age of ~284Ma was determined from ignimbrite interlayered with the Mount Benmore Volcanics north of Eungella Dam.

Near Croydon homestead in southern CONNORS RANGE, fine-grained sedimentary facies overlies the Mount Benmore Volcanics. The rocks consist of very thick-bedded siltstone and some thin sandstone beds, and have been mapped along strike for about for ~12km. They may be equivalent to a thick early Permian lacustrine facies described by Hutton & others (1998) and referred to by Fielding & others (1997a, page 85) at the top of the Lizzie Creek Volcanic Group and beneath the demonstrably marine Back Creek Group in Hazlewood Creek in the Mount Coolon 1:250 000 Sheet area. They are also exposed on the pipeline road west of Eungella Dam (Figure 60b). Similar rocks overlying the Mount Benmore Volcanics and assigned to the Carmila beds crop out along strike to the south in southern MOUNT BLUFFKIN.

GEOLOGY OF THE MARLBOROUGH BLOCK

The Marlborough Block is located north of Rockhampton and straddles the boundary between the Yarrol Province and Bowen Basin. It contains the largest ultramafic mass in eastern Australia. The block is fault-bounded and has been interpreted as a near-horizontal, out-of-sequence, thin-skinned nappe sheet (Holcombe & others 1997a). It was originally outside the project area, although some of the rocks were examined briefly. The geology of the Marlborough Block, particularly of the mafic-ultramafic rocks was first described in detail by Murray (1969). More recent studies include those of Denton (1994), Muscio (1994), Paterson (1994), Bruce (1999), Bruce & others (2000), Bruce & Niu (2000a), Harbort (2001) and Harbort & others (2001). These were used to compile the MARLBOROUGH map along with additional airphoto and geophysical interpretation. Murray (2007) used the geochemical database of Bruce (1999) to examine the geochemical relationships between the mafic rocks and the enclosing serpentinised peridotite and reinterpret the genesis of the Marlborough Block. All of these studies were also used to compile the following description which is included in the report for completeness. Generalised geology of the western part of the Marlborough Block is shown in Figure 28.

The Marlborough Block consists of thrust-imbricated slices of an ultramafic-mafic complex, upper and lower greenschist facies metasedimentary units (quartz feldspar mica schist. banded quartzite), and lower amphibolite facies S-type metagranite, meta-sedimentary rocks and metabasite. Permo-Triassic I-type granites intrude these units. The metamorphic rocks and metagranite have been assigned to the Marlborough Metamorphics, which also includes the metabasite unit, the Nob Creek Amphibolite. A strong foliation in the S-type metagranites is attributed to deformation associated with intercalation of these rocks with the ultramafic-mafic complex, an event that occurred prior to final emplacement of the terrane during the Hunter-Bowen Orogeny. The lower grade metasedimentary units comprise rocks that are similar to the

Devonian Carboniferous accretionary coastal terrane units of the Curtis Island Group (Holcombe & others, 1997a). They are not described in this report.

Bruce & Niu (2000a) reported that the ultramafic-mafic complex is composed of rocks that represent the products of at least four tectonomagmatic events. The oldest event comprises elements of an ophiolite. These elements occur in four thrust sheets that are dominated by serpentinised mantle harzburgite with minor dunite and pyroxenite, podiform chromitite, isotropic gabbro and various basaltic intrusions. They are herein assigned to the Princhester Serpentinite. The rocks associated with the ‘younger’ events are discussed by Bruce & Niu (2000a) and Murray (2007) and are also described briefly below.

MARLBOROUGH METAMORPHICS

Introduction

The name Marlborough Metamorphics was used by Morand (1993a, 1998) for the metamorphic rocks in the Marlborough Block, although it has not been formally defined. It has since been used on the various 1:100 000 maps that cover the Marlborough Block, although Harbort (2001) referred to them informally as the “Windermere Metamorphics”. They also were studied by Muscio (1994) and Paterson (1994) in the Nob Creek area, north of Marlborough.

The metamorphic rocks crop out in several sinuous belts that trend north-west through the Marlborough Block from near Glen Geddes in the south-east to Marlborough. The total area is ~300km^2. They crop out poorly and mostly form relatively subdued topography in contrast with the Princhester Serpentinite. However, in the Nob Creek area, the unit contains several prominent, ridge-forming components.

The metamorphic rocks may include more than one package of rocks and need further study. Therefore no type locality is designated for them. The description given below pertains to only to those rocks cropping out in MARLBOROUGH. Rocks cropping out in RIDGELANDS will be described by the Yarrol Project Team (in preparation). They were only examined in a few road cuttings and outcrops along some of the major roads, and the descriptions here are based on those by Henderson & others (1993), Muscio (1994), Paterson (1994), and Holcombe & others (1997a,b).

Lithology

Muscio (1994) described the metamorphic rocks in the Nob Creek area as phyllite, pelitic schist, feldspathic schist and amphibolite (the latter being described here separately as Nob Creek Amphibolite).

The pelitic schist consists predominantly of quartz and biotite with minor muscovite, plagioclase ± garnet. It has a strong differentiated layering. Several penetrative fabrics were recognised by Muscio (1994). The early fabric S_1 is defined by aligned mica and quartzose laminae, but it is mainly overprinted by the stronger S_2 fabric that is defined by a differentiated layering, crenulation cleavage and alignment of mica. These are axial planar to tight to isoclinal folds that deform S_1. The later S_3 fabric is subtle and is axial planar to open folds of S_2.

The pelitic schist contains significant, but subeconomic, massive to disseminated base metal mineralisation adjacent to the Nob Creek Amphibolite. The mineralisation consists of pyrite, pyrrhotite, chalcopyrite and minor sphalerite and the gossan can be traced for ~4km. It was explored by Queensland Metals Corporation in the late 1980s (Milburn, 1992) and is regarded as being of the Besshi style of volcanogenic deposits (Paterson, 1994). Sulphides are medium to coarse-grained and have undergone the same metamorphic-deformational history as the silicate gangue. The sulphides show strongly annealed, polygonal textures and in some specimens show a preferred alignment of elongate grains.

The phyllitic quartzite forms cream to grey siliceous layers in the schist and consists of quartz and subordinate biotite, chlorite, muscovite and minor plagioclase and opaques. It is well-foliated, the main foliation being defined by aligned mica and quartzose layers. Muscio (1994) interpreted it as a crenulation cleavage and noted the presence of earlier biotite orientated in opposing directions to the main foliation. She also identified an L_2^1 intersection lineation.

The feldspathic schist contains feldspar, quartz, muscovite and biotite and has a schistose granitic appearance, suggesting a granitic protolith. It has 0.5–5cm-wide alternating leucocratic and melanocratic layers. Folded and boudinaged pre-metamorphic quartz veins are present. The main fabric has a similar orientation to that in the metasedimentary rocks and Muscio (1994) suggested that the protolith granite was produced by syn-tectonic magmatism during D_1 but that there was continued granite emplacement along F_2 structures.

Figure 61. Quartz-rich mica schist of the Marlborough Metamorphics. Note the strong differentiated layering or spaced foliation folded by open folds. Cutting on the Bruce Highway about 11km east-south-east of Marlborough at MGA 806803 7468964 (IWSC0509)

Muscio (1994) also described less deformed biotite granite in the Nob Creek area. It is equigranular and consists of quartz, plagioclase, perthitic K-feldspar, reddish brown biotite and minor muscovite and ilmenite. Quartz is partly recrystallised and is locally deformed and aligned. The rocks are peraluminous and corundum-normative.

The metamorphic rocks are exposed in some road cuttings along the Bruce Highway, east of the Cleethorpes Granodiorite. The mica schists are similar to those described by Muscio (1994). They are quartz-rich and have a strong differentiated layering or spaced foliation that appears to be axial planar to an earlier crenulated foliation and is itself folded by open folds (Figure 61). Some poorly exposed chlorite-actinolite schist is also present and may be related to the Nob Creek Amphibolite.

Rocks exposed near the old highway south-west of Marlborough include fine to medium-grained muscovite-biotite-feldspathic schist with a spaced laminar foliation. The schist is probably deformed granite similar to that described by Muscio (1994). The rocks continue for ~1km and pass into mylonite at the contact with the Princhester Serpentinite. Similar rocks are also exposed in a quarry or gravel scrape along the Coonumburra road ~2km south-west of Marlborough homestead. They consist of coarse-grained biotite-muscovite schist that is locally feldspathic, and could at least partly be derived from granitic rocks.

The rocks included in the Marlborough Metamorphics in the study area were probably originally a succession of quartzose sandstone, mudstone, mafic lavas and possibly chert intruded by granite.

According to Harbort (2001) the rocks were regionally metamorphosed under pressure-temperature conditions of ~450–550°C and 3.5–4.5Kpa. He suggested that the metagranitic rocks were derived from partial melting of the adjacent metasedimentary rocks.

Geophysical response

The radiometric response of the Marlborough Metamorphics is low to moderate in all three channels resulting in bluish grey to pinkish hues on composite images, contrasting markedly with the very low response of the ultramafic rocks. They also contrast with the moderate to high potassium response (and reddish hues) of the Cleethorpes Granodiorite.

The magnetic response of the unit is low, showing a sharp contrast with the ultramafic rocks and Permian plutons.

Relationships and age

The Marlborough Metamorphics form several imbricated thrust slices, interleaved with the Princhester Serpentinite. The bounding faults are steep and are interpreted to be rotated thrusts with kilometre-scale ductile response adjacent to them (Holcombe & others, 1997a,b). Muscio (1994) noted the similar orientation between the major thrust contacts and the prominent fabrics in the metamorphic rocks and deformed granites and described felsic mylonite and 'metasiltstone' (possibly phyllonite) in the contact zones. According to Holcombe & others (1997a), some contacts show clear thrust geometry and kinematics whereas others have more ambiguous dips or sense of shear. This is particularly the case near the foliated S-type granitoids and Holcombe & others suggested that these structures may be remnants of earlier extensional faults that developed during the granite emplacement.

The Marlborough Metamorphics are cut by several late Permian plutons, including the Cleethorpes Granodiorite, Og Syenite and Magog Gabbro.

The original ages of the metamorphic rocks and metagranites are uncertain. Holcombe & others (1997b) and Harbort (2001) correlated the metagranite and their schistose host rocks with the Broome Head Metamorphics, a high-grade, multiply deformed unit that crops out in the Shoalwater Bay area to the east (Morand, 1993a). The age of these is also uncertain, but they are generally regarded as higher grade equivalents of the Curtis Island Group, in particular the Townshend Formation that consists of metabasalt, chert and quartz-rich turbidites. However, the only isotopic ages available on these units are Permian to Early Triassic and are interpreted as cooling ages. Muscio (1994) derived a K–Ar biotite age of 268±3Ma from one of the least deformed foliated granites. Other ages presented by Harbort (2001) indicate that the rocks cooled through various mineral isotherms between 253 and 242Ma. Henderson & others (1993) reported a similar Rb-Sr biotite age of 245±2Ma from the Marlborough Metamorphics.

Given the Late Neoproterozoic age for the ophiolite (see below), it is possible, that the high-grade metamorphic rocks in the region are of comparable age and may correlate with the Anakie Metamorphic Group to the west and late Neoproterozoic to Early Cambrian rocks in the Townsville hinterland to the north (Withnall & others, 1995, 1996, 2002; Nishiya & others, 2003; Fergusson & others, 2001, 2005, 2007).

However, this is unlikely to be the case if the model of Murray (2007) for the formation of the 'ophiolite' is accepted. In this model, the peridotite was the result of partial melting at a Neoproterozoic oceanic spreading centre followed by pervasive reaction with Late Devonian supra-subduction zone magmas below an intra-oceanic island arc. The rocks are quartzose indicating that they are unlikely to be simply metamorphosed oceanic material and are probably derived from a siliceous source. They are therefore more likely to be Late Devonian.

NOB CREEK AMPHIBOLITE

Introduction

This name was used informally by Harbort (2001) for the prominent amphibolite that is associated with base metal mineralisation at the Nob Creek prospect north-east of Marlborough. The name has been adopted here and on the MARLBOROUGH map.

The unit forms a narrow band up to 300m wide that can be traced for ~6km. It forms relatively subdued topography adjacent to a prominent ridge of metasedimentary rocks.

Lithology

The Nob Creek Amphibolite was described by Muscio (1994) and Paterson (1994). Most of the rocks are dark green, fine-grained and well-foliated and strongly lineated. They consist mainly of nematoblastic actinolite or hornblende and albite with minor quartz, epidote, titanite and opaques. No relict mineralogy is preserved. The foliation is defined by alternating albite and amphibole layers.

Cream to pale pink calc-silicate bands consisting of albite, epidote and titanite occur through the outcrops and both pre- and post-date the foliation. They may represent zones of carbonate or epidote alteration.

Geophysical response

The radiometric response of the Nob Creek Amphibolite appears to be low in all channels, although because it crops out against prominent ridges, the data are somewhat degraded. It has a low magnetic response.

Relationships and age

The Nob Creek Amphibolite is presumed to form a stratigraphic unit within the original protolith of the Marlborough Metamorphics. It was interpreted by Muscio (1994) to represent submarine basaltic lava in a sequence of cherty pelitic sediments. According to Harbort (2001) it is metamorphosed, subalkaline, tholeiitic basalt. Like its parent unit, its original age is unknown, but is possibly Late Devonian. It is intruded by the Magog Gabbro.

PRINCHESTER SERPENTINITE

Introduction

Previous studies did not apply a formal name to the serpentinite in the Marlborough Block. The map by Harbort (2001) gave separate names to the serpentinite in each of the thrust sheets in the Marlborough Block, but because the map used the same geographic names for different units, as well as names that are unavailable because of prior usage, its nomenclature is not usable. Therefore the name Princhester Serpentinite (one of the names used by Harbort) is used for simplicity for all of the serpentinite that forms multiple thrust sheets. The names ‘Marlborough ophiolite’ and ‘Marlborough ultramafics’ have also been used by various authors, but the name ‘Marlborough Metamorphics’ has prior usage (see above).

The Princhester Serpentinite crops out over ~580km^2 as several sinuous belts in a roughly rectangular area that extends from near Marlborough in the north-west to Canoona in the south-east. The serpentinite crops out well and forms generally rugged, strongly dissected, hilly topography with steep slopes. It is thickly vegetated, commonly with *Acacia* scrub. Grasstrees (*Xanthorhoea*) are common in many areas.

No type locality is assigned to the unit at this stage.

Lithology

The Princhester Serpentinite has been regarded as an ophiolite by many authors (for example, Holcombe & others, 1997a; Bruce & others, 2000; Spaggiari & others, 2003), although it should be pointed out that it represents only the basal component of an ophiolite, the harzburgite tectonite. The higher level non-cumulate gabbros, diorites, plagiogranites, mafic sheeted dykes and mafic volcanic rocks are mostly absent, except as minor fault-bounded blocks.

Serpentinised harzburgite

According to Bruce & others (2000), serpentinised mantle peridotite comprises ~95% of the Princhester Serpentinite. Primary mineralogy has mostly been entirely replaced or pseudomorphed by serpentine with only scattered relicts remaining. However, a dominant tectonite harzburgite protolith is apparent from partially serpentinised peridotite with features characteristic of alpine-type peridotite (Thayer, 1967). Bruce & others (2000) estimated that the primary modal abundances for the harzburgite were olivine (~75%), enstatite (~20%, diopside (~4%) and chromium spinel (~l%). Murray (1969) also described minor pyroxenite cumulate and dunite in the harzburgite.

The serpentinite is largely massive with localised cleaved zones, mainly in regions disrupted by late (Cretaceous and Tertiary) normal faulting, and strongly schistose zones near the contacts with surrounding units. The bases of the serpentinite sheets are metamorphosed to upper greenschist and amphibolite facies and generally display high angle, ductile thrusting with east-over-west shear sense indicators.

Bruce & others (2000) divided the serpentinites into three classes on the basis of microscopic texture: pseudomorphic, transitional, and non-pseudomorphic (O’Hanley, 1995).

The pseudomorphic class is coherent serpentinite that retains the original serpentine mineralogy and has textures that pseudomorph the original ones. Mesh cells and ribbons of lizardite dominate the texture of these rocks. Mesh cells usually consist of low birefringent serpentine with relicts of igneous olivine present in some samples. Elongated laths of lizardite and chrysotile define the cell rims. Networks of magnetite grains around former olivine boundaries locally preserve the original granular texture. Enstatite bastites are typically 1–3mm in size and usually retain their pyroxene cleavages. Relics of clinopyroxene are also present in some samples. In most instances they appear to have survived serpentinisation but are strongly altered to talc and commonly display magnetite lamellae parallel to the original c-axis cleavage planes. Chrome spinel is present and commonly consists of unaltered cores surrounded by ‘ferro’ chrome rims.

In the transitional class, the serpentinites, although coherent, have undergone prograde metamorphism. They have hourglass textures composed predominantly of lizardite and chrysotile and interlocking textures of chrysotile and antigorite. Enstatite bastites are commonly pseudomorphed by plastically deformed ribbons of lizardite. Clinopyroxene crystals are altered to talc and enclose small magnetite grains in a poikilitic texture.

Locally, networks of magnetite grains rim former olivine crystals. Prismatic to acicular crystals of tremolite up to 2mm long (usually <0.5mm) are also present in some samples. Chrome spinel is variably altered to 'ferro' chrome compositions.

Locally schistose serpentinites display non-pseudomorphic textures with well-orientated blades of interpenetrating and or interlocking antigorite crystals. The antigorite is partially pseudomorphed by variable amounts of prograde, subrounded and elongated metamorphic olivine and talc. Bastites have commonly lost their original texture with triangular antigorite blades replacing lizardite. Clinopyroxene has been altered to talc and usually displays magnetite veining oriented along former c-axis cleavage planes. Needles of tremolite and anthophyllite are also common in these rocks. The relict chrome spinel is entirely altered to 'ferro' chrome compositions.

Podiform chromitite

Small chromite bodies are scattered throughout the serpentinite. They are generally massive and podiform in texture with chromite grains interspersed with gangue material. In thin-section, chromite is reddish-brown and highly fractured with opaque chromite defining the fracture zones. According to Bruce & others (2000), the compositions are well within the range for oceanic gabbros, and significantly higher in TiO_2 than in residual harzburgites. The gangue material makes up between <10% and 60% of the samples, and consists of serpentine ± talc ± tremolite occurring in stretching veinlets and interstitial patches between chromite grains. Serpentine is usually antigorite replacing lizardite after olivine, suggesting a chromite-olivine cumulate origin. Locally the gangue mineral is lizardite pseudomorphing pyroxene.

Metagabbro

Non-layered, medium to very coarse-grained, metagabbro occurs as fault-bounded blocks within the serpentinite. The primary igneous mineralogy is characterised by interlocking crystals of clinopyroxene (60–70%) and plagioclase (30–40%). Clinopyroxene retains partial to complete primary igneous textures, is diopsidic in composition and has compositions that lie in the field of oceanic gabbros (Bruce & others, 2000). Where primary, plagioclase is labradorite. However the gabbros are usually overprinted by a metamorphic assemblage of hornblende + actinolite + partially saussuritised albite ± prehnite pumpellyite ± chlorite ± carbonate ± quartz ± epidote ± titanite. Locally, anorthite veins crosscut the metagabbro, which grades into Ca-metasomatised rodingite with anorthite partially saussuritised and pseudomorphed by hydrogrossular.

Basaltic pockets occur in the metagabbro and were interpreted by Bruce & others (2000) to represent trapped melt. These enclaves are fine grained, volumetrically insignificant (<0.5m in diameter) and largely composed of metamorphic hornblende and plagioclase. Minor amounts of secondary actinolite, quartz, chlorite and titanite are present.

Basaltic intrusions

Fine- to medium-grained mafic dykes metamorphosed to amphibolite facies locally intrude the serpentinite. The amphibolites display total recrystallisation from original basaltic mineralogy to homogeneous subrounded grains of hornblende and tremolite alternating with layers of rounded quartz, calcite, plagioclase and minor amphibole. A foliation is evident under the microscope, but not always obvious in hand specimens. Metamorphism to amphibolite facies may have been caused by intrusion of nearby granitoid stocks.

Some fine-grained doleritic dykes also intrude the metagabbros. These dykes are also metamorphosed, and have a greenschist facies assemblage (hornblende + actinolite + albite + chlorite ± quartz ± carbonate ± titanite), with chromium spinel being the only relict igneous mineral.

Geophysical response

The Princhester Serpentinite is characterised by very low responses in potassium, thorium and uranium, appearing almost black on composite images. These contrast with the pale blue to pinkish hues in the metamorphic units and the reddish hues of the Cleethorpes Granodiorite.

The serpentinites also have a very strong magnetic response that contrasts with the very low response of the metamorphic units. Magnetic susceptibilities were measured on only two outcrops in the study area and are in the range 1000–6000 x 10^{-5} SI units.

Relationships

As already noted, the Princhester Serpentinite forms thrust-imbricated slices interleaved with upper and lower greenschist facies metasedimentary units (quartz feldspar mica schist. banded quartzite) that have been correlated with the Curtis Island Group, and lower amphibolite facies S-type metagranite, meta-sedimentary rocks and metabasite of the Marlborough Metamorphics.

Bruce & Niu (2000a) showed that the Princhester Serpentinite has been intruded by dykes that are the products of three Palaeozoic tectonomagmatic episodes that they designated V2, V3 and V4 and which are briefly described below (V1 referred to rocks in the 'ophiolitic substrate'). The V2 magmatic episode, represented by tholeiitic and calc-alkaline basalts and gabbros of island-arc affinities has been dated as Late Devonian, some 180 million years younger than the 'ophiolitic' rocks. The V3 magmatic episode includes tholeiitic and alkali basalts with enriched geochemical signatures characteristic of intraplate volcanism and is early Permian. The fourth magmatic event (V4) is represented by basaltic andesites and siliceous intrusives in its type locality in the Percy Isles. It is slightly younger, but also early Permian (Bruce & Niu, 2000b). The existence of this phase was questioned by Murray (2007).

The thrust-imbricated slices of the Marlborough Block are interpreted by Holcombe & others (1997a), Harbort (2001) and Harbort & others (2001) to represent a thrust duplex in an out-of-sequence nappe structure that was thrust over the rocks of the northern part of the Yarrol Province and adjacent Gogango Overfolded Zone. The Princhester Serpentinite around the northern and southern edges of the Marlborough Block is in faulted contact with the Rookwood Volcanics. It is not clear whether the contact along the north-western margin is a thrust. Where it crosses Pine Mountain, a topographic feature with 250m relief, the bounding fault appears to be steeply dipping to vertical. Therefore this margin could be a lateral ramp or bounding tear fault to the nappe. Henderson & others (1993) regarded it as the south-western extension of the Stanage Fault Zone. Holcombe & others (1997a) noted that "the basal thrust is a brittle structure with little deformation, even within metres of the contact". Internal faults within the block are associated with kilometre-scale ductile deformation, and although now steep, are thought to be rotated thrusts. The leading edge of the Marlborough Block to the west is concealed by Cainozoic deposits, but there the Princhester Serpentinite may be thrust over the Back Creek Group in the Gogango Overfolded Zone.

The Princhester Serpentinite is also intruded by late Permian granodiorite and gabbro stocks, including the Cleethorpes Granodiorite and Racecourse Gabbro. These constrain emplacement of the Marlborough Block at ~253Ma (latest Permian) or earlier.

Tertiary weathering produced lateritic cappings over the ultramafic rocks of the Marlborough Block and remnants of these are preserved on the crests and slopes of hills to the south of Marlborough (INAL Staff, 1975). They are locally enriched in nickel. After the initial deep weathering, parts of the area were subsequently overlain by sediments ranging from claystone through sandstones to coarse conglomerate and talus deposits.

Age

Bruce & others (2000) reported the results of Sm-Nd dating of mafic rocks of the complex. Five samples, a basalt, two dolerites and two gabbros from the 'ophiolite' complex were chosen. All had smooth N-MORB-like REE patterns. The Sm-Nd isotopic data defined a well-constrained (MSWD=0.21) isochron that yielded an age of 562±22Ma (late Neoproterozoic) that was interpreted as a crystallisation age. The ~560Ma age suggests that rocks of the Marlborough ophiolite are some of the oldest rocks so far identified in the New England Fold Belt. Ophiolitic rocks along the Peel Fault System are ~530Ma (Aitchison & others, 1992). Bruce & others (2000) presented mineralogical, geochemical and isotopic data that they interpreted as indicating that the ophiolite at Marlborough was formed at a sea-floor spreading centre. They pointed out that this interpretation was is in contrast to other occurrences of ophiolitic rocks found throughout the New England Fold Belt whose origins are interpreted to be associated with arc environments (Aitchison & others, 1992, 1994; Aitchison & Ireland 1995) or a back-arc basin (Yang & Seccombe 1997).

The mechanism of emplacement of the Princhester ophiolite is not certain. An early model put forward by Murray (1974), before the much older age was known, suggested a crude obduction mechanism driven by initiation of an early Permian subduction zone dipping beneath the continent. Bruce & others (2000) and Bruce & Niu (2000a) did not provide a detailed emplacement mechanism, but they discussed constraints on the timing of the ophiolite generation and emplacement. They suggested that a subduction zone was initiated at *ca* 580Ma and 'outstepping' or oceanward migration at *ca* 540Ma (as recorded by deformation and metamorphism in the Anakie Inlier — Fergusson & others, 2001) isolated the future ophiolite on the overriding plate and it was later passively accreted to the continent. They argued that if the V2 and V3 magmatic events represented island arc and continental intra-plate volcanism respectively, this accretion was constrained between 390Ma and 295Ma. The westward thrusting by the out-of-sequence thrust in the late Permian was a later event. This suggests a gap of at least 180ma between the formation of the oceanic lithosphere represented by the Princhester Serpentinite at 560Ma and its emplacement onto the continental margin in the Late Devonian.

Spaggiari & others (2003) produced a generalised tectonic reconstruction that linked the ophiolites of the New England Orogen with those of the Lachlan Orogen as reflecting a period of complex oceanic crust formation in an oceanic or back-arc position above an east-dipping subduction zone on the edge of Gondwana from 560–495Ma). Ophiolites were emplaced as both Tethyan types (in western Tasmania and the Delamerian Orogen) and as Cordilleran types in the Lachlan Orogen. However, no explanation was offered for the huge time-gap between the emplacement of the Lachlan ophiolites in the 515–440Ma interval and the New England Orogen ophiolites in the Carboniferous. This presents problems because it is difficult to envisage a tectonic scenario that would allow oceanic crust and upper mantle to avoid either subduction or renewed spreading over such extended periods of time. It would also have been difficult to detach a thin slice from an old lithosphere that had become cold and strong. Old dense oceanic lithosphere becomes denser and is easily subducted. Ophiolites can only form from young, hot and thin lithosphere and must be emplaced within a short time of their generation, typically 10ma or less (Dewey, 2003).

This would require the ophiolite to have been emplaced in the Cambrian. No data is available on the original age of the high-grade metamorphic rocks in the Marlborough Block, although the low-grade ones are thought to be equivalent to the Curtis Island Group. It is possible that some of the metamorphic rocks may be much older, and perhaps equivalent to the Anakie Metamorphic Group to the west and late Neoproterozoic to early Cambrian rocks in the Townsville hinterland to the north such as the Argentine Metamorphics and Halls Reward Metamorphics (Withnall & others, 1995, 1996, 2002; Nishiya & others, 2003; Fergusson & others, 2001, 2005, 2007). These units may have been deposited on a passive margin. All contain ultramafic rocks and these may represent fragments of Tethyan-type ophiolites that were emplaced onto the passive margin during the Delamerian Orogeny similar to those in western Tasmania (Spaggiari & others, 2003). The rocks in the Marlborough Block may represent a fragment of this margin that was split from the craton during the formation of the New England Orogen.

Murray (2007) used the data of Bruce (1999) to re-examine the geochemical relationships between the younger mafic rocks in the Marlborough Block (see below)and the enclosing Princhester Serpentinite. He concluded that the peridotite geochemistry is the result of partial melting at a Neoproterozoic oceanic spreading centre and that it was not part of the New England Orogen. He further postulated that in the Devonian, pervasive reaction of this Neoproterozoic oceanic crust with supra-subduction zone magmas of island arc composition, accompanied by a small degree of additional partial melting, occurred above an east-dipping subduction zone. This was based on the geochemistry of Devonian island arc basalts between Mount Morgan and Monto, which include compositions identical to dykes and gabbroic blocks within the Princhester Serpentinite. Blockage of the subduction zone by collision with the Australian continent during the Late Devonian led to slab break-off and the reversal of subduction direction, trapping the Late Devonian ophiolite in a forearc position. Its location, in a forearc setting above a growing accretionary wedge, conforms to the definition of a Cordilleran-type ophiolite. This interpretation is consistent with current views that most ophiolites are formed from young, hot and thin oceanic lithosphere at forearc, intra-arc and backarc spreading centres in a supra-subduction zone setting

The timing of final emplacement of the Marlborough duplex is provided by the age of late Permian sedimentary rocks in the underlying imbricate thrust stacks, and by the age of intrusive rocks that either are cut by the basal detachment or pierce both the detachment and the internal thrusts. Harbort & others (2001) referred to twenty previously published K–Ar ages and three Rb-Sr ages supplemented by twenty two $^{40}Ar/^{39}Ar$ step-heating results that constrained emplacement of the Marlborough Block to ~253Ma (late Permian). Emplacement of the duplex nappe sheet, and intrusion by a substantial granitic complex, occurred over an interval of <8my. The timing of emplacement of the Marlborough Block coincided with the rapid foreland loading of the Bowen Basin at the end of the Permian.

POST-PERIDOTITE MAFIC ROCKS

Introduction

Detailed petrological, geochemical and geochronological studies of rocks from the ultramafic mafic association in the Marlborough Block by Bruce & Niu (2000a) revealed three younger tectonomagmatic events within the ‘ophiolite’ substrate: V2 emplacement of a mafic suite of tholeiitic and calc-alkaline intrusives; V3 intrusion of tholeiitic and alkaline dykes; and V4 emplacement of suites of differentiated calc-alkaline granitoids and basaltic andesite dykes. Murray (2007) doubted the validity of this last suite.

Lithology

V2 intrusive rocks

Rocks from this group include both tholeiitic and calc-alkaline compositions.

Tholeiitic basalt to dolerite occurs as dykes and fault-bounded blocks in the Princhester Serpentinite. The dykes either intrude the serpentinite or are thrust-emplaced with it. The rocks are dark grey and the texture ranges from equigranular to plagioclase-phyric. Plagioclase phenocrysts are tabular to anhedral, greenish-white and up to 7mm. The rocks are invariably metamorphosed to greenschist facies and are composed mainly of small (<1mm) glossy black, elongated amphibole crystals in a fine-grained, greyish-white feldspar matrix.

In thin-section, relict igneous olivine, clinopyroxene (augite to salite), magnetite and ilmenite are overprinted by a metamorphic assemblage of hornblende + actinolite + albite ± chlorite ± prehnite/pumpellyite ± epidote ± carbonate ± titanite. Hydrogrossular is present in some metasomatised samples. The plagioclase phenocrysts in the porphyritic dolerites have been totally altered to chlorite and sericite assemblages.

Calc-alkaline rocks occur as gabbroic intrusions and fine-grained doleritic dykes cross-cutting and in structural contact with serpentinite. The dolerite dykes range from seriate textured to equigranular with plagioclase of andesine composition, clinopyroxene and relict igneous magnetite partially altered and overprinted by a metamorphic assemblage of hornblende + actinolite + chlorite ± prehnite/pumpellyite ± epidote ± titanite. The gabbros are commonly coarse grained (up to 6mm) with relict augite and hornblende crystals displaying intergranular texture with 0.5–1mm tabular partially saussuritised andesine crystals and minor metamorphic actinolite and prehnite. A finer grained gabbro dominated by a metamorphic assemblage of hornblende + actinolite + plagioclase + chlorite + epidote also occurs. Relict chromium spinel crystals in the gabbro have compositions typical of spinel in volcanic-arc rocks.

Bruce & Niu (2000a) presented geochemical data that indicate that the tholeiitic and calc-alkaline basalts are both of island-arc affinities. Murray (2007) agreed with this interpretation, but suggested a different subdivision of the V2 group into those suites. He demonstrated that the rare-earth element patterns of the enclosing peridotites were consistent with interaction between them and the V2 basalts by equilibrium porous flow, fractionating the REE by a chromatographic column effect. He suggested that this occurred in a supra-subduction zone setting in an intra-ocean island arc. Murray & Blake (2005, figure 23) had previously noted the close similarity of REE and HFSE compositions between one of the V2 tholeiite suites and basalts from the Late Devonian Mount Hoopbound Formation, Lochenbar Formation and Three Moon Conglomerate between Mount Morgan and Monto.

V3 intrusive rocks

Metamorphosed alkaline and tholeiitic dolerite dykes also intrude the ophiolite sequence. The alkaline dykes are relatively fine grained and equigranular in texture. They are commonly cross-cut by carbonate veins. In thin-section, they display relict igneous clinopyroxene and magnetite overprinted by secondary prismatic, equant and lath-like hornblende crystals, fibrous actinolite, tremolite and albite in a mesostasis of feldspar and quartz. Magnetite is ubiquitous but commonly rimmed by ilmenite. The tholeiitic dykes have a similar mineralogy to the alkaline dykes, the major difference being the presence of relict olivine crystals in the former.

The tholeiitic and alkali basalts have enriched geochemical signatures characteristic of intraplate volcanism (Bruce & Niu, 2000a).

V4 intrusive rocks

According to Bruce & Niu (2000a,b), this group includes basaltic andesite dykes, which are metamorphosed with their igneous mineralogy replaced by lath-like fibrous actinolite crystals embedded in a matrix of albite and chlorite with minor tremolite and secondary quartz. Diorite intrusions in fault contact with the serpentinite are also included in the group. The diorite displays intergranular textures, comprising primary hornblende and clinopyroxene crystals partially overprinted by an actinolite/hornblende + albite metamorphic assemblage. Locally plagioclase crystals are completely altered to chlorite. Relict chromium spinel is also present, but has been largely altered to ‘ferro’ chrome compositions. On the basis of geochemistry, Murray (2007) suggested that the samples from the Marlborough Block included in the V4 group by Bruce & Niu (2000a,b) appear to fit better within V2 and that the group should probably be abandoned.

Trondhjemite and tonalite dykes locally intrude the serpentinite and V3 rocks. The trondhjemite is medium-grained with a primary mineralogy of quartz and plagioclase, overprinted by a predominantly chlorite and sericite metamorphic assemblage. The tonalite has a similar mineralogy with less quartz and more plagioclase plus overprinting fibrous Mg-rich actinolite and tremolite. These lithologies are variably affected by Na-metasomatism resulting in dykes that are largely composed of albite and quartz.

The rocks are correlated with similar rocks on the Percy Islands off the coast from the Marlborough Block. These show strong volcanic arc signatures in geochemical plots and are similar to modern adakites and high-Al trondhjemite-tonalite-dacite suites (Bruce & Niu (2000a,b).

Relationships and age

As noted above, each of these suites of rocks intrude the Princhester Serpentinite, mainly as dykes, but are also present as fault-bounded blocks. The results of isotopic dating were presented by Bruce & Niu (2000a,b). Sm/Nd isotopes gave a whole-rock isochron age of 380±19Ma for the V2 magmatic episode, some 180 million years younger than the ‘ophiolitic’ rocks. A whole-rock Sm/Nd isochron age of 293±35Ma was obtained for the V3 magmatic episode The fourth magmatic event (V4) has its type locality in the Percy Isles, where it was dated by K–Ar on amphibole from a diorite intrusion at 277±7Ma (Bruce & Niu, 2000b).

STRATIGRAPHY OF THE EASTERN PART OF THE BOWEN BASIN

In the study area, the Bowen Basin succession is divided into the Back Creek, Blackwater and Rewan Groups.

The name Back Creek Group was first used by Derrington & others (1959) and Derrington & Morgan (1960) for the Permian succession in the Cracow–Theodore area. It was subsequently extended throughout the Bowen Basin (for example Mollan & others, 1969; Malone & others, 1969; Dickins & Malone, 1973) for the largely marine rocks that had been assigned to the “Middle Bowen Beds” of Jack & Etheridge (1892). In the northern part of the basin, Malone & others (1966) recognised a three-fold subdivision of the Group into the Tiverton, Gebbie and Blenheim Formations. Dickins & Malone (1973, page 37) raised these to subgroup status and extended them throughout the basin. However, various authors such as Staines & Koppe (1979, 1980), McClung (1981) and Waterhouse & Jell (1983) challenged the concept of basin-wide subgroups, because it was seemingly based on faunal affinities rather than lithological similarities. They suggested that the subgroups should revert to formation status and be restricted to the area in which they were first defined. This was the nomenclature used on the Bowen Basin Solid Geology Map (Geological Survey of Queensland, 1988), and the subgroup nomenclature, although defended by Dickins (1983), has fallen into disuse.

The Blackwater Group was proposed by Mollan & others (1969) for the succession of non-marine sediments recognised throughout the Bowen Basin between the marine Back Creek Group and the Rewan Formation (now Group), and previously referred to as the Upper Bowen Coal Measures.

The Rewan Group is an extensive unit cropping out across the entire Bowen Basin and into the Galilee Basin to the west and north. It was formerly named the Rewan Formation (Hill, 1957; Mollan & others, 1969, 1972; Whitaker & others, 1974), but was upgraded to group status by Jensen (1975).

BACK CREEK GROUP (SOUTH-EASTERN BOWEN BASIN)

BUFFEL FORMATION

Introduction

The Buffel Formation was originally included in the Oxtrack Formation by Derrington & others (1959), but was defined by Wass (1965) after recognition of a disconformity marked by an abrupt faunal change from assemblages typical of Fauna II of Dickins & others (1964) to those similar to their Fauna IV. Mapping by Dear & others (1971) and Gray & Heywood (1978) showed that the fossiliferous, calcareous and generally fine-grained rocks of the Buffel Formation are distinct from those of the redefined Oxtrack Formation.

Dear & others (1971) extended the known distribution of the unit from the Cracow area into the Monto 1:250 000 Sheet area to include discontinuous outcrops along the western flank of the Auburn Arch as far north as latitude 24°25’S. The best exposures are on a strike ridge 5km north-north-west of Mount Little Uncle Tom, at Mount Breast and in gullies ~3km north, and ~12km north-east of Banana. However, Dear &

others noted that the unit is best developed south-west of Biloela in the Prospect Creek Anticline, where it crops out as low limestone ridges. They also mentioned outcrops along the western edge of the Gogango Overfolded Zone and sheared limestone ~7km north of Drumberle homestead.

Flood & others (1981) redefined the formation in the Cracow area and erected two new units, the Pindari Formation and Brae Formation that occur in the upper part of the Buffel Formation as mapped by Wass (1965). They are in fact stratigraphically younger than the strata in Wass's type section, so Flood & others redefined the Buffel Formation to exclude the two formations. They, along with Briggs (1979) and Briggs & Waterhouse (1982), also recognised three unnamed members within the Buffel Formation. However, Waterhouse (1983) proposed a new nomenclature, naming the members as formations, the Fairyland Formation, Dresden Limestone and Elvinia Formation. He raised the Buffel Formation in status to Buffel Subgroup, to include the Pindari and Brae Formations. The formations were described relatively comprehensively by Waterhouse (1983, 1986) and briefly by Holcombe & Jell (1983).

The name Buffel Subgroup does not appear to have received wide acceptance. Green & others (1997) did not recognise any subdivisions in the subsurface Taroom Trough and reverted to the name Buffel Formation. The name Buffel Formation is therefore used in this report, and we regard the individual units as having member status. Briggs (1993, figure 1) also appears to have adopted this nomenclature in part, referring to the lower three units as members of the Buffel Formation. However, he followed Flood & others (1981) and restored the Pindari and Brae Formations as separate units, disconformable on the Buffel Formation, and forming part of a conformable sequence with the overlying Oxtrack Formation. Other workers in the area, for example Draper (personal communication, 2000), also regard the Brae Formation, and possibly the Pindari Formation as well, as simply part of the Oxtrack Formation.

Drilling of three fully cored stratigraphic holes west of Cracow homestead by the Department of Mines in 1983 was designed to establish the nature of the lithology of the components of the Back Creek Group and the nature of their contacts with each other and with the Camboon Volcanics. The results of the drilling were outlined by Holmes (1983) and palaeontological determinations were reported by Parfrey (1984a,b) and Wood (1984). However, due to the complexity of the stratigraphy in the holes, correlation with the surface exposures of the components of the Buffel Formation was poor and the nomenclature established for the surface units could not easily be applied to the cored sections. Consequently no formal stratigraphic subdivision of those sections was attempted.

Thus, the nomenclature of the unit is somewhat in a state of chaos. The problem has not been resolved because a study of the Buffel Formation was outside the scope of this project. No attempt to was made to map out any of the members or for that matter to map out accurately the extent of the unit as a whole. The members and even the whole formation are thin and difficult to represent on regional-scale maps. For completeness, the extent of the Buffel Formation as mapped by Dear & others (1971) and Whitaker & others (1974) has been basically retained (Figure 62), although the positions of the boundaries have changed slightly in places due to the use of more detailed aerial photography in the map compilation. One exception is in the Cracow homestead area, where mapping by Flood & others (1981) has been incorporated. Another is in the Drumberle area, where the Buffel Formation does not appear to be as extensive or as continuous as previously mapped. The following description is based mainly on the previous literature, apart from some new observations in the Drumberle and Prospect Creek areas.

Type section

Wass (1965) gave a type section west of Cracow homestead at Buffel Hill. However, Flood & others (1981, figure 2) showed that this section is incomplete and transects a folded sequence of limestone (now Dresden Limestone Member) in a partly faulted syncline. It does not include the lower sandstone (now Fairyland Member) or much of the upper siltstone (now Elvinia Member). They proposed a reference section on Buffel Hill from MGA 227100 7190200 to MGA 226700 7190200. This section includes all of the three members and is 130m thick. Waterhouse (1983, page 29) stated that the type sections for the three members are also on Buffel Hill. If the Pindari and Brae Members are considered to be part of the Buffel Formation, then to completely define the whole formation, a composite reference section can be erected to include the combined type sections of the Pindari Member and Brae Member (originally formations) as given by Flood & others (1981). This section is from MGA 226600 7191500 to MGA 226300 7191500 (Pindari Member) and from there to MGA 225800 7192000, the boundary with the overlying Oxtrack Formation.

Thickness

The total thickness of the Buffel Formation as represented by the composite section is 390m. However, if it is restricted to the lower three members, it is only ~130m thick. In most other areas, the unit is never thicker than this, and in many places it thins out completely. Green & others (1997) noted that in the subsurface to the west of the margin of the basin, the Buffel Formation is up to 100m thick.

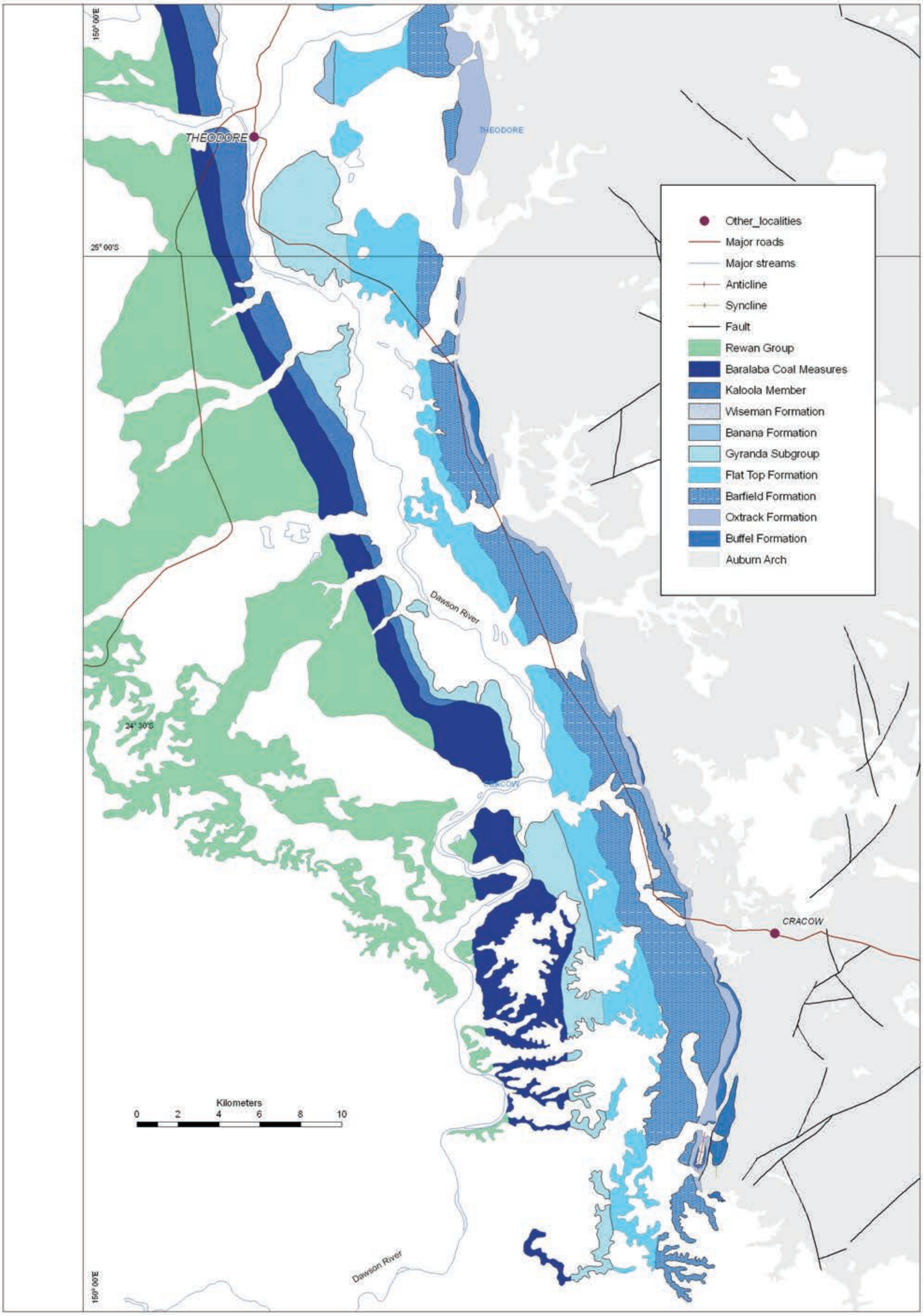

Figure 62. Permian–Triassic geology of the Theodore–Cracow area

Lithology

The Buffel Formation consists predominantly of fossiliferous limestone, siltstone and minor sandstone. As noted above, a five-fold subdivision was recognised in the area west of Cracow homestead (Flood & others, 1981; Briggs & Waterhouse, 1982; Waterhouse, 1983; Holcombe & Jell, 1983). However, this subdivision is not easily applicable elsewhere, given the discontinuous nature of the formation, and of the members within it.

The *Fairyland Member* is the basal sandy unit of the Buffel Formation in the type area. However, it is restricted in extent, and appears to have been deposited in a topographic depression ~2.3km long in the underlying Camboon Volcanics. Exposure is limited and usually restricted to float. It is mainly fine-grained volcaniclastic sandstone, commonly fossiliferous, and up to 45m thick. In places, somewhat calcareous silty beds rich in gastropods crop out. Briggs (1979) and Briggs & Waterhouse (1982) recognised three subunits within the unit. In GSQ Mundubbera 11, the basal section (subunits X, Y and Z) may correspond with the Fairyland Member. They mainly comprise lithic sandstone, siltstone and mudstone, but the lowermost unit also contains thin pyritic coal seams interbedded with tuff.

The *Dresden Limestone Member* forms a resistant unit cropping out along the eastern slope of Buffel Hill and also along the base of the eastern slope of Pindari Hills. It is up to 50m thick, and is predominantly limestone, ranging from calcilutite to calcirudite and is generally richly fossiliferous. However, in places it is extensively replaced by chert. Similar resistant, ridge-forming limestones elsewhere in the Buffel Formation may be equivalent to the member, and usually allow the presence of the unit to be identified by photo-interpretation. Draper (1988) described the petrography of the limestones in both the Buffel and Oxtrack Formations. He emphasised the similarities and he did not give separate descriptions. The dominant limestone facies is skeletal grainstone and lesser skeletal packstone and rare wackestone. Contacts with terrigenous sediments are gradational both vertically and horizontally. The bulk of the mud-sized component is terrigenous. Crinoidal remains are the dominant component, but bivalves and gastropods are also present. The bivalves are dominated by the thick-shelled bivalve *Eurydesma*.

The *Elvinia Member* is very localised in distribution and is best exposed on the western dip-slope of Buffel Hill. It is ~55m thick and consists mainly of fossiliferous silty to sandy limestone grading upwards into recessive calcareous siltstone in cycles 3–10m thick. The rocks are strongly bioturbated and are locally silicified, particularly towards the top of the unit. Some of the silicified beds have abundant spicules thought to be of sponges. A faunal gap near its base (Waterhouse, 1983) suggests that it may be disconformable on the Dresden Limestone Member.

The *Pindari Member* is exposed in the Pindari Hills, where it is ~100m thick, but northwards it thins to a few metres. The lower 50m on the eastern slopes of Pindari Hills are not well exposed, but include fine to coarse-grained quartzose to feldspatholithic sandstone. The upper 50m forms the ridge and western slopes, and consists of well-bedded, fine-grained, possibly tuffaceous, volcaniclastic sandstone and siltstone. Plant remains are present in the lower part of the member, and the younger beds contain fenestellids and abundant spines from brachiopods or sponges. In the absence of the Elvinia Member, it disconformably overlies the Dresden Limestone Member. Fossiliferous outcrops unconformably overlying the Camboon Volcanics at the Roses Pride mine, ~13km north of Cracow homestead, were equated with the unit by Waterhouse (1983).

The *Brae Member* crops out discontinuously west of Pindari Hills in gullies and areas of sheet erosion. It consists of ~160m of typically well-laminated green to buff mudstone and interbeds of strongly bioturbated sandstone. Marine fossils are patchily distributed towards the top of the unit and midway through the sequence is a rich shelly horizon. Waterhouse (1983) considered the unit more persistent than the underlying units, and he recognised it as far north as Thuriba homestead in DUARINGA. Flood & others (1981) applied the name ‘Brae Formation’ to many areas previously mapped as Oxtrack Formation, but devoid of the characteristic limestone. As already mentioned and outlined further below, the Brae Member is probably better considered part of the Oxtrack Formation.

Green & others (1997) noted that in the subsurface to the west, the Buffel Formation consists of sandstone, siltstone, shale and limestone, with the proportion of sandstone decreasing upwards. The sandstone is medium to coarse-grained with a clayey matrix and contains pebbles of quartz and tuffaceous siltstone and traces of mica. The medium grey to dark brown siltstone is tuffaceous, also contains minor mica and is slightly carbonaceous. The shale is slightly silty and contains carbonaceous material and minor shell fragments. The limestone is grey to white and contains abundant shell and crinoid fragments.

In the Prospect Creek Anticline, the base of the Buffel Formation is marked by a calcareous conglomerate that grades along strike through pebbly limestone into purple or grey limestone. Pebbles in the conglomerate are subrounded to rounded and appear to have been derived from the underlying Camboon Volcanics. The unit is

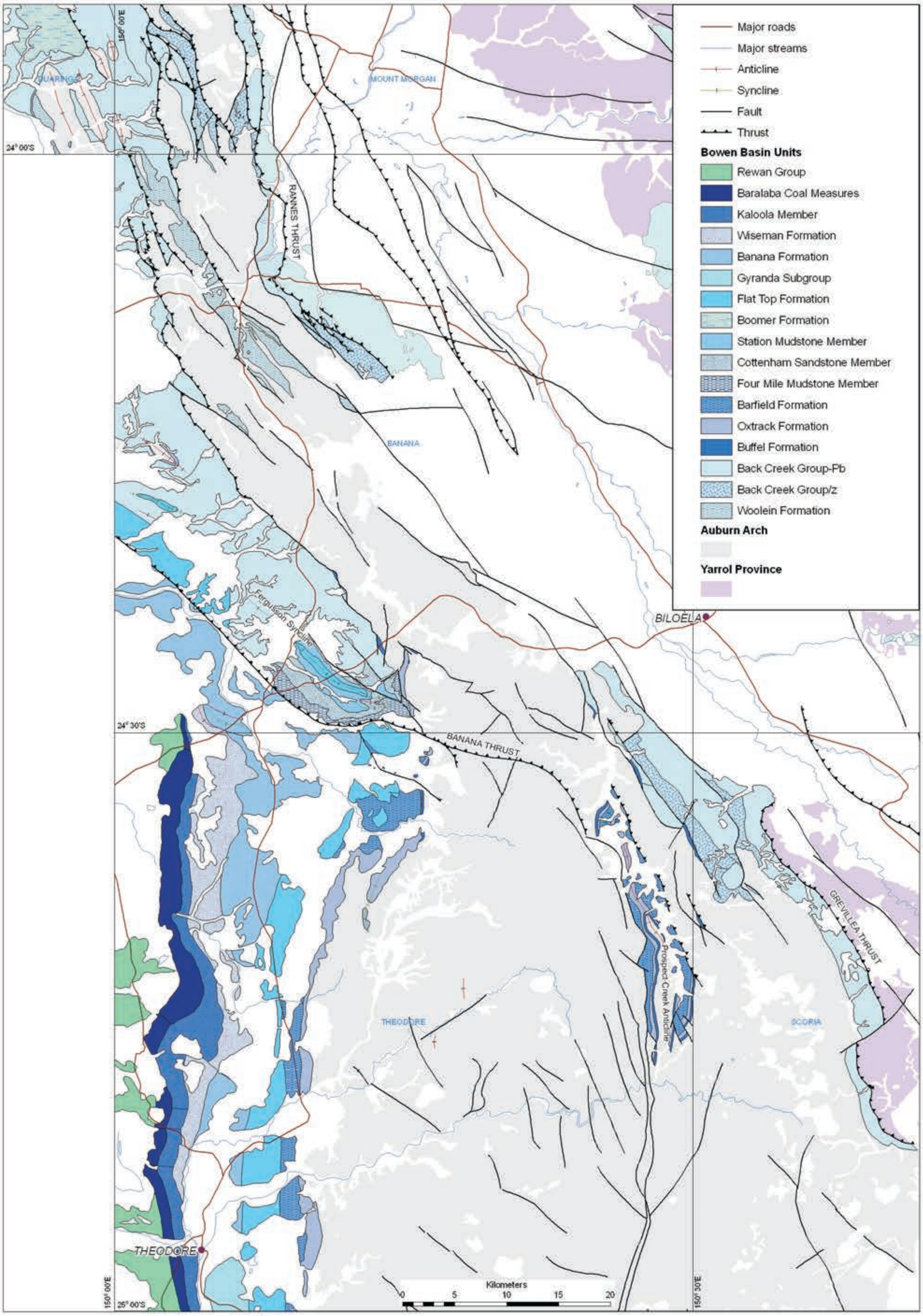

Figure 63. Permian–Triassic geology of the Theodore–Rannes area

generally no more than 30m thick and includes siltstone, mudstone, lithic sandstone, grey bioclastic limestone and dark blue to brown silty limestone containing brachiopods, molluscs and bryozoans.

Along the Thangool–Prospect Road at MGA 247700 7270200, light brown lithic sandstone that contains thin coquinitic limestone beds with abundant spiriferid and productid shells, occurs within the Camboon Volcanics. However, the sandstone is in fault contact to the east with volcanic breccia and aphyric porphyritic andesite and this is interpreted as a thrust that has juxtaposed Camboon Volcanics over Buffel Formation. Parfrey (1986) described the fauna from this locality, and considered it equivalent in age to the Buffel Formation. Nearby at MGA 244500 7268300, medium to thick-bedded, dirty, crinoidal limestone is interbedded with calcareous quartzose sandstone and overlies Camboon Volcanics that lie to the west. Other occurrences of fossils listed by Parfrey (1986) and apparently within the Camboon Volcanics could also have similar relationships.

On Mount Breast, the Buffel Formation is only ~10m thick, but Dear & others (1971) reported a transition upwards from the Camboon Volcanics, and the presence of some lava and tuff above the lowermost limestone of the formation. The upper part of the unit comprises purple and grey bioclastic limestone and conglomeratic limestone containing clasts of mafic volcanics.

South-east of Theodore, the Buffel Formation as mapped by Dear & others is atypical, because it contains no fossiliferous, obviously marine beds, and consists of ~100m of volcanic conglomerate, lithic sandstone and siltstone. The sandstones contain abundant plant fossil and may be freshwater deposits. It is possible that these rocks are simply part of the Camboon Volcanics or equivalents of the Woolein beds.

Depositional environment

Deposition of the Buffel Formation represents a major early Permian marine transgression that is also reflected in the Yarrol Formation in the Yarrol Province. The discontinuous nature of the Buffel Formation was considered by Dear & others (1971) to be due to erosion prior to the deposition of the Oxtrack Formation. However, Mollan & others (1972) and Waterhouse (1983) suggested that the unit was deposited in topographic lows on an erosion surface developed on the Camboon Volcanics. Flood & others (1981) suggested that the Buffel Formation was deposited as valley-fill with younger parts onlapping the basement volcanics, but probably while volcanism was still occurring elsewhere. The patchy distribution of the Buffel Formation could be due to its deposition in small sub-basins during the early extensional phase of Bowen Basin evolution (Draper, 1988). In the Rannes area, rocks of the newly recognised lacustrine Woolein beds overlie and possibly interfinger with the Camboon Volcanics in a sub-basin that may have formed during the same event.

Waterhouse (1983) also considered that volcanism was probably continuing elsewhere during deposition of both the Fairyland Member and Dresden Limestone Member. Gray & Heywood (1978) noted that sedimentary rocks were interbedded with andesitic volcanics in the bottom of GSQ Mundubbera 8, drilled north-west of Cracow. This and the relationships described by Dear & others (1971) from Mount Breast support the notion of continuous deposition with the Camboon Volcanics at least locally.

Draper (1988) suggested that the limestones were deposited during periods of lesser terrigenous input in a shelf-like environment ranging from nearshore to offshore in aspect. Wave and current activity was sufficient to disarticulate and transport skeletal material and locally intense enough to accumulate beds of broken skeletal debris.

The significance of the disconformity between the Buffel Formation and Oxtrack Formation is uncertain. In the northern part of the Bowen Basin, deposition appears to have been continuous during this interval. The initial subsidence in the south-eastern part of the Bowen basin could have been short-lived, and deposition ceased once the small topographic lows were filled after the initial flooding or was controlled by eustatic changes. Subsidence in the Auburn Arch may not have recommenced until the late Kungurian. Alternatively, subsidence and deposition did continue, but uplift and erosion at some time prior to deposition of the Oxtrack Formation removed the sediments.

Relationships

The exact nature of the contact between the underlying Camboon Volcanics and the Buffel Formation is uncertain, although there is no angular discordance. Green & others (1997) thought that an unconformable relationship was likely in the subsurface parts of the Taroom Trough, but as noted above, some authors have suggested that deposition may have been continuous in other areas.

Faunal evidence shows that the Buffel Formation is overlain disconformably by the late Permian Oxtrack Formation and, in its absence, by the Barfield Formation. However, as outlined below, there appears to be some uncertainty whether the break occurs at the top of the Brae Member or lower in the Buffel Formation above the Elvinia Member. The Oxtrack Formation is present over a greater area than the Buffel Formation, and in the absence of the latter, lies directly on the Camboon Volcanics.

Fossils and age

The Buffel Formation contains a rich marine fauna of brachiopods, molluscs, bryozoans, corals, pelmatozoa and sponges that was described by Wass (1965) and Briggs & Waterhouse (1982) and discussed further by Waterhouse (1983, 1986, 1987a,b). Dear & others (1971) also gave a faunal list, although many of the species have been subject to nomenclatural changes and reassigned to other genera.

According to Waterhouse (1983), the age of the fauna in the Fairyland Member is difficult to determine, and could even be basal Permian (Asselian). Palynomorphs in the coal from the base of the Buffel Formation in GSQ Mundubbera 11 indicate an age no older than stage 3 and therefore mid-Sakmarian or younger. The macrofossil assemblage determined by Parfrey (1984a) from this lower interval contains many species not recorded previously from Australian faunas, but one species *Terrakea pollex* has been recorded from the Tiverton Formation. Briggs (1993, figure 1) showed the Fairyland Member as part of his early Artinskian *Echinalosia curtosa* zone, and separated by a significant break from the Dresden Limestone Member and Elvinia Member that were assigned to his late Artinskian *E. preovalis* zone.

There appears to be some disagreement on the age of the upper units. Waterhouse (1983) regarded the fauna in the so-called Pindari Member at Rose’s Pride mine as ‘clearly correlative’ with the younger Tiverton fauna of the northern Bowen Basin. He also correlated it with that in the upper part of the Yarrol Formation. Both these units are agreed to be Artinskian. However, Briggs (1993, figure 1) showed the ‘Pindari Formation’ as mid-Kungurian, separated by a significant break from the Elvinia Member and part of a conformable sequence with the ‘Brae Formation’ and Oxtrack Formation. As noted above, ‘Pindari Formation’ in the type area has no distinctive fossils, and thins out rapidly to the north. The fossiliferous ‘Pindari Formation’ at Roses Pride mine, 13km north of the type area, may not be part of the same unit.

Briggs & Waterhouse (1982) and Waterhouse (1983) were less confident in the age of the fauna in the ‘Brae Formation’, which they could not match with any others in the Bowen Basin or elsewhere in eastern Australia. Waterhouse (1983) appears to have preferred a late Artinskian age, but admitted a definite possibility that the fauna could be a facies-controlled variant of that in the Oxtrack Formation. Like Briggs (1993), other workers (J.J. Draper, personal communication, 2000) now favour the latter possibility.

Subsurface samples from strata assigned to the Buffel Formation in HOM Alick Creek 1 contain palynoflora indicative of upper stage 4a (= unit APP32, Artinskian), which is consistent with the macrofossils.

OXTRACK FORMATION

Introduction

The Oxtrack Formation was named and defined by Derrington & others (1959) from Oxtrack Creek, north of Cracow. Wass (1965) restricted the name to the upper part of the unit of Derrington &others (1959) to include a succession of fossiliferous siltstone and limestone, the remainder being redefined as the Buffel Formation. The unit extends from Cracow Station in the south, and was mapped at least as far north as Banana by Dear & others (1971) and Whitaker & others (1974). Dear & others (1971) described the unit as forming an almost continuous strike ridge from the southern edge of THEODORE to east of Banana. They also mapped it north of Banana (in an anticline ~8km south of Mount Cooper) and in the Prospect Creek Anticline, south-west of Biloela. Malone & others (1969) also mapped it near Thuriba homestead in southern DUARINGA. Waterhouse (1983) noted that at some of these localities, it includes rock types typical of the Brae Formation, lending weight to the idea expressed above that the latter can be regarded as part of the Oxtrack Formation.

As for the Buffel Formation, study of the Oxtrack Formation was outside the scope of this project, and no attempt was made to resolve the question of whether the Brae Formation is conformable with and part of the Oxtrack Formation. Neither unit has been mapped out, and the extent of the Oxtrack Formation as mapped by Dear & others (1971) and Whitaker & others (1974) has mainly been retained (Figures 62 and 63). The following description is based mainly on a review of published literature.

Type section

The type section given by Derrington & others (1959) is in Oxtrack Creek, north of Cracow, where fossiliferous, brown to white banded limestone containing abundant crinoid ossicles is exposed. No top or bottom is exposed in this section, because of extensive alluvial cover. No more complete reference section has ever been designated, but Waterhouse (1983) noted that its lower contact is well exposed at several places, including Mount Breast, Rose's Pride mine and at the dam west of Pindari Hills.

Thickness

Dear & others (1971) reported that the Oxtrack Formation maintains a moderately uniform thickness between 60m and 100m throughout most of the Monto 1:250 000 Sheet area. An anomalous thickness of ~250m was reported from the Stockyard Creek area near Theodore.

Lithology

The Oxtrack Formation is characterised by grey bioclastic limestone, fossiliferous silty limestone, siltstone, mudstone and lithic sandstone. The silty limestones are brown to olive brown and have a characteristic flaggy weathering habit. The limestones were described by Draper (1988) along with those of the Buffel Formation and are dominated by skeletal grainstones. They are crowded with large crinoid stems and numerous brachiopods, bryozoans, bivalves and corals. The bioclastic limestones are dominantly crinoidal, but bryozoans are very common. The tabulate corals *Cladochonus* and *Gertholites* are common as isolated patches and also as beds of coral grainstone, suggesting that they grew as dense thickets. The solitary rugose coral, *Euryphyllum* is also present. The calcareous siltstones contain abundant fenestellid bryozoans. Draper (1988) also noted the presence of rare dropstones.

The description of Dear & others (1971) indicates that limestone is not developed everywhere, and where it is absent, the unit can be difficult to distinguish from the Barfield Formation. However, it is usually distinguished from the massive mudstones of the Barfield Formation by the presence of fine-grained sandstone and siltstone. Dear & others (1971) reported that limestone is the dominant rock type from Mount Breast northwards, but becomes progressively less prominent southwards. To the east of Theodore, the unit is composed mainly of siltstone, fine-grained lithic sandstone and mudstone and only scattered limestone lenses at the top of the unit. The sandstone and siltstone are mostly olive brown and green in stream exposures, but on ridges they are mostly leached and silicified, white to buff rocks. They are commonly burrowed. The mudstones are identical to those in the Barfield Formation, and locally have calcareous concretions containing *Cladochonus* and *Gertholites*. Flood & others (1981) regarded these rocks as part of their Brae Formation.

Limestone and silty limestone are again common farther south towards Cracow. Both are also dominant rock types locally on the western limb of the Prospect Creek Anticline and in the anticline south of Mount Cooper in BANANA.

The Oxtrack Formation as mapped by Malone & others (1969) was examined in the Thuriba Anticline where it overlies the Camboon Andesite and Woolein beds. Exposure is mostly poor. It consists of white, leached lithic sandstone, mudstone and discontinuous beds of bioclastic limestone. Most limestone is crinoidal and contains ossicles up to 2cm across. It ranges from relatively clean grainstones to wackestones and packstones that pass laterally into dirty limestone and calcareous sandstone and siltstone. At MGA 798100 7347900, some beds consist of densely packed *Cladochonus* and *Gertholites* in a lime mud matrix (Figure 64a). As noted by Draper (1988), such beds are typical of the Oxtrack Formation in the Cracow area, and have not been recorded in the Buffel Formation. Dickins (*in* Malone & others, 1969) assigned the fauna to Fauna IV and hence mapped the rocks as Oxtrack Formation. However, the presence in the fauna collected during this survey of *Sulciplica stutchburii,* which is known from the early Permian lower Tiverton Formation, suggests that a re-assessment of the faunas is needed. At least some of the rocks could be equivalent to the Buffel Formation. Both units could be represented. Briggs & Waterhouse (1982) and Waterhouse (1983) remarked on the similarity of rocks in the Thuriba area to the Brae Formation, but the exact locality was not specified. In some of the unnamed anticlines east of Thuriba, the lowermost part of the Back Creek Group overlying the Camboon Volcanics is locally a thin unfossiliferous interval of lithic sandstone and greenish laminated siltstone that also resembles descriptions of the Brae Formation. Rare sheared limestone lenses on Mundarra Station are close to contacts with the Camboon Volcanics.

Some or all of the rocks mapped in the Gogango Overfolded Zone as Subunit $\mathbf{Pb_z}$ of the Back Creek Group could be equivalents of the Oxtrack Formation (see page 180).

Although the Oxtrack Formation was previously recognised by wireline logs in UOD Cockatoo Creek 1 (Gray & Heywood, 1978), it is relatively thin and lacks any distinctive character in the cuttings descriptions. Therefore, Green & others (1997) inferred that the Oxtrack Formation is restricted mainly to outcrop.

The Oxtrack Formation has a variable radiometric response. In most areas it has a low response, probably reflecting the dominance of a mafic provenance from the Camboon Volcanics. However, in some places such as the Prospect Creek Anticline of Dear & others (1971), it appears to have a 'hotter' response, suggesting regional variations in provenance that could include the Torsdale Volcanics.

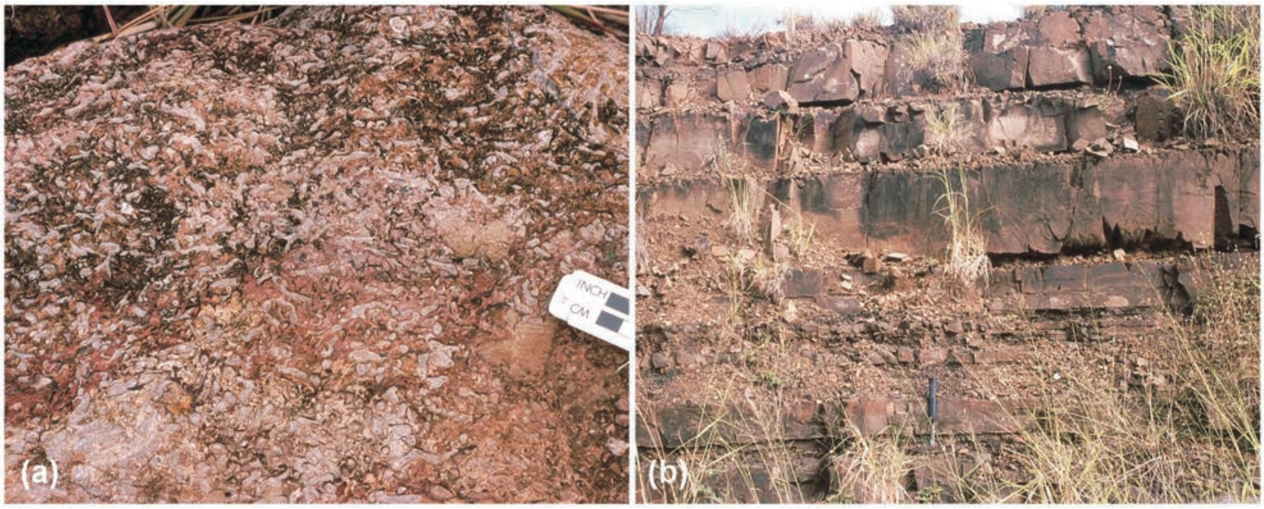

Figure 64. Back Creek Group
(a) Impure silty limestone of the Oxtrack Formation containing densely packed *Cladochonus*. About 5.5km north-west of Thuriba homestead at MGA 798114 7347906 (IWGG666)
(b) Thin to thick-bedded lithic sandstone and thin mudstone interbeds of the Cottenham Sandstone Member of the Barfield Formation. Dawson Highway~3km east of Banana township at MGA 212005 7291790 (IWGN457)

Depositional environment

Like the Buffel Formation, the Oxtrack Formation was probably deposited in shelf-like conditions that ranged from nearshore to offshore.

Relationships

The Oxtrack Formation, used in the sense of Dear & others (1971) and earlier workers, has long been recognised as being separated from the Buffel Formation by a significant faunal break. In many places, particularly in the Dawson Folded Zone, the Oxtrack Formation is transgressive over the Buffel Formation and directly overlies the Camboon Volcanics. However, as noted above, subsequent work in the Cracow area (Flood & others, 1981; Briggs & Waterhouse, 1982) identified mudstone, siltstone and some sandstone as belonging to a separate unit, the Brae Formation, between the Buffel Formation and Oxtrack Formation. They placed the unconformity at the top of the Brae Formation, although Waterhouse (1983) was less certain of this relationship. He noted that at the dam west of Pindari Hills, the contact between the Brae and Oxtrack Formations seemed to be conformable and ‘virtually transitional’ with limestone appearing and mudstone gradually diminishing. He also was uncertain of the existence of a faunal break at this boundary. Briggs (1993, table 1) showed the Oxtrack Formation and Brae Formation as conformable, and the break occurring below the Pindari Formation. Thus for simplicity, the name Brae Formation has been discarded, and following Dear & others (1971) all of the rocks are included in the Oxtrack Formation.

The Oxtrack Formation is overlain conformably by the Barfield Formation, and as noted above, in the absence of limestone, it is difficult in some places to distinguish them.

Fossils and age

The fauna in the Oxtrack Formation is characterised by *Echinalosia maxwelli* and *Terrakea concava* (Briggs & Waterhouse, 1982; Waterhouse, 1983). Correlation with similar faunas in the Sydney Basin and New Zealand dates it as younger Kungurian. The fauna is distinctive and not found elsewhere in the Bowen Basin and the interval is probably represented either by unconformity or beds with few marine fossils in the Gebbie Formation in the north and upper Aldeberan Formation in the south-west. The fauna in the Brae Formation, which is here considered to be part of the Oxtrack Formation, is also distinctive, and cannot be readily matched with any other fauna in eastern Australia. Briggs & Waterhouse (1982) and Waterhouse (1983) noted some similarities at the generic level with the fauna in the Oxtrack Formation, and suggested that they might represent almost contemporaneous faunas of two different facies.

Wood (1984) recovered a poorly preserved spore-pollen assemblage from silty sandstone at 266.63m in GSQ Mundubbera 9 and suggested an age not older than lower stage 5b (Ufimian or early Kazanian). Parfrey (1988) considered that the interval represents the Oxtrack Formation.

The Oxtrack Formation should correlate with the upper part of the Gebbie Formation in the north-eastern margin of the basin.

BARFIELD FORMATION

Introduction

The names Barfield Formation and Orange Creek Formation were introduced by Derrington & others (1959) for the mudstone, siltstone and sandstone sequence overlying the Oxtrack Formation in the Banana and Cracow areas respectively. Dear & others (1971) used the name Barfield Formation in preference to Orange Creek Formation throughout the region, and like Derrington & others, equated the overlying Flat Top Formation in the Banana area with the Acacia, Passion Hill and Mount Steel Formations in the Cracow area. However, Wass (1965), Mollan & others (1972) and Whitaker & others (1974) equated only the Mount Steel Formation with the Flat Top Formation, and regarded the other units as part of the Barfield Formation, along with the Orange Creek Formation. The stratigraphic drilling in GSQ Mundubbera 5 to 8 (Gray & Heywood, 1978) supported the latter interpretation. Gray & Heywood (1978) noted that the cored and wireline logged reference section mapped as Barfield Formation by Whitaker & others (1974) contains subunits that can be readily related to the three units introduced by Derrington & others (1959). The sequence mapped as Barfield Formation by Whitaker & others is a belt of low black soil country between strike ridges of their Oxtrack and Flat Top Formations, and has a similar expression to the Barfield Formation in the type area. The Barfield Formation has been mapped in the Cracow area as they showed it. With more detailed mapping, the units of Derrington & others could probably be defined as members.

Derrington & others defined five formations for the equivalents of the Barfield Formation north-east of the Banana Fault in the Fergusson Syncline. Dear & others (1971) redefined three of these as members of the Barfield Formation: the Four Mile Mudstone Member, Cottenham Sandstone Member and Station Mudstone Member (Figure 63). Two other units, the Neimen Formation and Fergusson Sandstone, were considered to be repetitions of the other units by folding and faulting on the structurally complex eastern limb of the syncline, and are now regarded as obsolete. Subdivision of the rocks in this area is difficult and the rocks are mapped as undivided Back Creek Group.

The Barfield Formation is poorly exposed and forms a belt of low-lying black soil country between ridges of the Oxtrack and Flat Top Formations. Outcrops are confined to gullies and areas of sheet wash, but concretions are common in the soil. East of Banana, the Cottenham Sandstone Member is better exposed and forms rounded strike ridges.

In this study, the Barfield Formation *per se* was only examined along the Dawson Highway, north-east of Banana, but much of the undivided Back Creek Group studied in the Gogango Overfolded Zone to the north is lithologically similar and probably equivalent to the Barfield Formation. The Barfield Formation was described comprehensively by Dear & others (1971), Whitaker & others (1974), Gray & Heywood (1978) and Green & others (1997).

Type section

Derrington & others (1959) specified a type area for the Barfield Formation as ‘near Barfield station’. Faulting complicates this area, and measuring sections in this and most other areas is difficult because of poor exposure.

Derrington & others (1959) also gave type sections for the units east of the Banana Fault that are now regarded as members of the Barfield Formation. These are all along the Dawson Highway and the composite of these sections can be regarded as a reference section for the formation. The type section of the Four Mile Mudstone is incomplete and lies between the Banana Fault at about MGA 210300 7291200 and MGA 211800 7291700, the base of the Cottenham Sandstone Member, which crops out from there to MGA 213300 7292300, the base of the Station Mudstone Member, which continues to MGA 214500 7292700 (the base of the Flat Top Formation). The mudstone members are not well exposed, but the Cottenham Sandstone Member is well exposed in the cuttings and consists of well-bedded lithic sandstone and mudstone.

The 814m-thick composite section derived by Gray & Heywood (1978) from core in GSQ Mundubbera 7 and 8 can also be considered a reference section. The lower, conformable contact with the Oxtrack Formation was intersected in GSQ Mundubbera 9 and 10. Parfrey (1988, figures 3 and 4) presented two measured sections from the upper, fossiliferous part of the formation along the road to Gyranda homestead and near the stockyards north of Mount Steel on Gyranda Station.

Thickness

Dear & others (1971) estimated that the Barfield Formation in the type area is ~480m thick and 840m on the western limb of the Fergusson Syncline. Farther south at Mount Steel and Back Creek, Whitaker & others (1974) estimated a thickness of 900m, consistent with the thickness in the composite reference section in GSQ Mundubbera 7 and 8. The formation is 714m thick in UOD Cockatoo Creek 1 (Green & others, 1997).

Lithology

The Barfield Formation is characterised by massive mudstone and subordinate siltstone, sandstone, tuff and conglomeratic mudstone and limestone.

In outcrop, the mudstone is olive brown to grey, weathering to yellowish grey, and is generally massive or only poorly bedded. It contains common dark bluish grey to olive brown calcareous to phosphatic concretions. Glendonites occur in some concretions, and towards the top of the formation, they also contain abundant fossils, particularly the corals *Cladochonus* and *Gertholites*. Some of the beds are burrowed.

Sandstone is distributed sporadically through the unit, but east of Banana, it is well developed towards the middle of the formation, where it characterises the Cottenham Sandstone Member. This member divides the formation into three, separating the essentially similar Four Mile Mudstone and Station Mudstone Members. The Cottenham Sandstone Member (Figure 64b) shows a strong resemblance to the Boomer Formation farther north.

The sandstone is thinly to thickly bedded and locally cross-laminated. Most beds are bluish grey, weathering to olive brown, fine to medium-grained, moderately sorted and slightly calcareous when fresh. Gray & Heywood (1978) reported the presence of graded bedding. Baker & others (1993) presented modal analyses of four quartz-poor, lithic sandstone samples from the Barfield Formation. Quartz (0–10%) was mostly monocrystalline and feldspar (10–45%) was dominantly plagioclase. Lithic grains (55–80%) were almost exclusively volcanic with only very minor (<2%) metamorphic rock fragments. The volcanic rock fragments are mostly felsic to intermediate.

Green & others (1997) also described tuff from the subsurface, as generally greyish green, tan, brown or white, medium to coarse-grained with a siliceous matrix. Several very thin to thick beds of probable tuffaceous rocks were observed in one of the cuttings along the Dawson Highway at MGA 215000 7293100 within the Station Mudstone Member. The rocks are bluish grey when fresh, weathering to yellowish grey and range from cherty siltstone to very fine-grained sandstone.

Whitaker & others (1974) described minor tuff with lapilli-sized fragments and volcanic pebble conglomerate in the upper part of the formation. They also described a vesicular and brecciated lava flow ~630m above the base of the formation at Back Creek and in a creek ~1.5km north of Mount Steel on the Cracow–Gyranda road.

Conglomerate was described by Green & others (1997) as consisting of granules and pebbles of argillite, quartz and quartzose sandstone in a silty matrix. This appears to be similar to the conglomerates in the undivided Back Creek Group in the Duaringa and Saint Lawrence 1:250 000 Sheet areas. Fielding & others (1997b) also referred to similar disorganised intraformational and extraformational conglomerates that form two intervals in the Barfield Formation and also occur in the Moah Creek beds. They are interpreted as sediment gravity flow deposits. As discussed later (page 182), this facies is widespread, and may reflect the onset of the pulsed foreland thrust loading that characterises the later history of the Bowen Basin.

East of Banana, the two mudstone members have a ‘hot’ radiometric response similar to the undivided Back Creek Group to the north, whereas the Cottenham Sandstone Member is ‘cooler’ with pinkish hues (similar to the response of the sandstone-dominated Boomer Formation). Farther south in CRACOW and THEODORE, the ‘hot’ response for the Barfield Formation is less obvious. This could be partly due to transported regolith from the ridges of Oxtrack and Flat Top Formations on either side of the generally recessive Barfield Formation. Alternatively, it may reflect provenance differences.

Relationships and boundary criteria

The Barfield Formation conformably overlies the Oxtrack Formation, or in its absence, disconformably overlies either the Buffel Formation or Camboon Volcanics. It is distinguished from these units by the change to massive mudstone from more diverse lithological assemblages. It is conformably overlain by the Flat Top Formation, which is recognised by the change from thick-bedded mudstone to sandstone and conglomerate.

North of the Fergusson Syncline, the Barfield Formation has not been mapped, but is probably represented by the rocks assigned to the undivided Back Creek Group. These rocks are described later (pages 173–179), but are dominated by cleaved mudstone. Farther north, the sandstone-dominated Boomer Formation has been mapped out within the Back Creek Group, and is similar lithologically to the Cottenham Sandstone Member, although it may not be a direct correlative. The Moah Creek beds in MOUNT MORGAN are probably also equivalent to the Barfield Formation (Fielding & others, 1997b; Yarrol Project Team, 1997, and in preparation; see pages 56–58).

Depositional environment

Marine conditions dominated the depositional history of the Barfield Formation. This is supported by the common marine macrofossils and spinose acritarchs recorded by Foster (1982). The abundance of mudstones suggests a moderate depth of water, and the graded bedding is suggestive of turbidity flows. The Barfield Formation along with the undivided Back Creek Group and Oxtrack Formation was interpreted by Fielding & others (1995, 1997a) as being deposited during the thermal subsidence phase in the evolution of the Bowen Basin.

Fossils and age

Marine fossils are present throughout the Barfield Formation, in contrast to the undivided Back Creek Group to the north, in which body fossils are rare. Dickins (1972) placed them in his late Permian Fauna IV. Dear & others (1971) listed fossils from THEODORE and BANANA. Parfrey (1988) reviewed the biostratigraphy of the upper Barfield Formation in detail from sites mainly in CRACOW. She showed that the faunal assemblage from the Barfield Formation and lowermost Flat Top Formation was closely comparable with that from the Ingelara and lower Peawaddy Formations in the south-western Bowen Basin. Tentative correlations were made with the Blenheim Formation in the northern Bowen Basin.

Results from palynological studies have been disappointing due to low yields and poor preservation. However, Foster (1982) attributed palynofloras from the upper part of the Barfield Formation in GSQ Mundubbera 6 to upper stage 5 (= unit APP5) and therefore late Permian. This is supported by determinations made by Wood (1984) of assemblages in the upper part of GSQ Mundubbera 9.

Draper & others (1990) showed the Barfield Formation as Ufimian to Kazanian.

FLAT TOP FORMATION

Introduction

The name Flat Top Formation was introduced by Derrington & others (1959) for the succession of feldspatholithic sandstone, mudstone and minor limestone overlying the Station Mudstone Member north-east of the Banana Fault and the Barfield Formation south-west of the fault. Derrington & others equated the Flat Top Formation with the Acacia Formation that they defined in the Cracow area. Dear & others (1971) equated the lower half with the Acacia Formation and the upper half with the Passion Hill and Mount Steel Formations. However, as noted above, Wass (1965), Mollan & others (1972) and Whitaker & others (1974) equated only the Mount Steel Formation with the Flat Top Formation, and regarded the other units as part of the Barfield Formation. The stratigraphic drilling in GSQ Mundubbera 5 to 8 (Gray & Heywood, 1978) supported the latter interpretation.

Dear & others (1971) extended the type Flat Top Formation to include an overlying marine fossiliferous, poorly outcropping part that Derrington & Morgan (1960) mapped as part of their Banana Formation. Dear & others (1971) based this on mapping by Glover (1954).

The Flat Top Formation as thus defined extends continuously apart from breaks in outcrop due to Cainozoic cover from south of Cracow to near Barfield Station. It again crops out east of Banana, in the core of the Fergusson Syncline, and in another syncline farther north near Wandoo Creek, but has not been recognised farther north. The lower half of the unit is well exposed and forms conspicuous strike ridges, but the upper half is generally less well exposed.

Type section

Derrington & others (1959) gave the type area as a prominent ridge along the Dawson Highway ~7km east of Banana. This section is in the core of the Fergusson Syncline and is not complete. The basal contacts with the Barfield Formation are at MGA 214490 7292710 and MGA 215020 7293090. The base is marked by a change from poorly exposed mudstone to resistant fine-grained fossiliferous sandstone and siltstone.

A complete reference section, 425m thick, is provided in GSQ Mundubbera 6 between 103–528m (Gray & Heywood, 1978). The top 35m was sampled in GSQ Mundubbera 5 from 879–914m (total depth) and the bottom 179m from 19–198m in GSQ Mundubbera 7. It was also intersected in Banana NS3 and 4 (Colton, 1970)

Thickness

In the Banana area, the Flat Top Formation as mapped by Dear & others (1971) ranges from 550–610m. In CRACOW, the formation is ~400m thick and it is 494m thick in UOD Cockatoo Creek 1.

Lithology

Dear & others (1971) described the lower half of the Flat Top Formation in the Banana area as consisting of fine-grained lithic sandstone, siltstone and interbedded mudstone, conglomerate, limestone and minor andesitic lava and tuff.

The sandstones are thin to thick bedded, and have local low-angle cross laminae and grading. They are bluish grey, weathering to olive brown or yellowish grey, and are feldspatholithic, consisting of plagioclase, intermediate volcanic lithics, siltstone and chert. Quartz is usually <15%. Most of the sandstones are well sorted, but some contain up to 15% matrix. The siltstones are bluish grey weathering to olive brown, yellowish grey or white. Dear & others reported the presence of devitrified glass shards in some siliceous siltstone, and local graded bedding, soft-sediment deformation and burrows. Calcareous concretions, many of which are fossiliferous, are common near the base of the formation. Coquinitic sandy limestone and bioclastic limestone overlie the basal conglomerate north of Wandoo Creek and are also well developed towards the middle of the unit west of Mount Little Uncle Tom near Kianga. According to Dear & others, the andesitic lava and tuff grade along strike into volcanic conglomerate at several localities, including the type section.

The upper half of the formation in the Theodore–Banana area consists mostly of poorly exposed olive brown siltstone and mudstone that contain fossiliferous calcareous concretions and are similar to the mudstones in the Barfield Formation. Fine-grained sandstone and siltstone again crop out towards the top of the formation and form a low strike ridge east of Theodore and Kianga. Marine fossils are scattered through these sandstones and siltstones, which are the uppermost fossiliferous marine strata in the Permian succession in the area.

In the Cracow area, Whitaker & others (1974) described the formation as consisting of “hard, buff and blue mudstone which grades laterally into buff-coloured argillite (siltstone?)”. Interbedded poorly sorted, lithofeldspathic sandy siltstone contains a high proportion of primary volcanic detritus. Contorted laminae due to slumping were reported in the mudstone in places. Mollan & others (1972) reported the common occurrence of wood impressions towards the top of the formation, but as noted below, these rocks are probably more correctly assigned to the Gyranda Subgroup. Marine fossils are present in the Cracow area, but they are not as common as in the Banana area.

In GSQ Mundubbera 6, the Flat Top Formation consists of siltstone and minor tuff (Gray & Heywood, 1978). The siltstone is brownish to greenish grey, sandy to muddy, mostly calcareous and a significant proportion is tuffaceous. Some beds are slightly cherty. Finely divided carbonaceous material, sparse leaf fragments and fine stringers and nodules of pyrite are present. Bedding is laminar to thin, and the rocks are extensively burrowed. Tuff beds are up to 0.5m thick, are pale green, cream and bluish grey, range from muddy through silty to sandy, and are calcareous.

Green & others (1997) summarised the lithology of the formation in the subsurface to the west, such as in UOD Cockatoo Creek 1. They recognised a three-fold subdivision. The lowermost is dominated by conglomerate and lesser sandstone and shale, the middle contains siltstone, shale and coal, and the upper is dominantly sandstone with lesser siltstone and shale.

Relationships and boundary criteria

In both GSQ Mundubbera 6 and 7, the contact with the underlying Barfield Formation appears conformable. The base of the formation is marked by a change from massive mudstone of the Barfield Formation to fine-grained sandstone and siltstone. Dear & others (1971) described basal conglomerate at Flat Top Mountain and in the Wandoo Creek area, but it is not common. The sandstone and siltstone are comparatively resistant, and the unit can be recognised on aerial photographs by the prominent strike ridges that contrast with the underlying recessively weathering mudstone of the Barfield Formation.

The boundary with the Banana Formation is taken at the top of the highest marine fossiliferous sandstone or siltstone. Dear & others also noted that the extensive bioturbation of the Flat Top Formation does not extend into the Gyranda Formation.

Gray & Heywood noted that the drilling indicated that near Gyranda in CRACOW, the upper 100m of the Mount Steel Formation as mapped by Glover (1954) and Flat Top Formation as mapped by Mollan & others (1972) and Whitaker & others (1974) consists of non-marine sedimentary rocks and should be included in the Gyranda Formation. This suggestion is adopted here, and the upper boundary of the Flat Top Formation in that area is placed ~1km farther east at the top of the ridge-forming siltstone.

Green & others (1997) noted that in the subsurface, the formation has a limited areal distribution and thins to the west, passing into finer-grained marine units. To the south, a succession of mudstone and sandy mudstone represents the combined Barfield and Flat Top Formations. The absence there of a distinctive sandstone/siltstone-dominated interval equivalent to the Flat Top Formation means that subdivision into these formations is not possible. Green & others considered this southern succession to be correlative with both formations. Similarly the undivided Back Creek Group to the north could also include correlatives of the Flat Top Formation as well as the Barfield Formation. It is also possible that parts of the Boomer Formation to the north could be equivalent to the Flat Top Formation rather than the Cottenham Sandstone Member.

Depositional environment

Green & others (1997) suggested that the Flat Top Formation was probably sourced from the east, because of its limited extent and thinning to the west. The lowermost subdivision represents deposition in a shallow sea as indicated by the marine fossils. The initial input of sediments was rapid as shown by the conglomerates that locally occur at the base of the formation. The presence of fossils in the conglomerates could either indicate shallow water or deeper water into which shallow water-derived sediments were transported by debris flows or turbidity currents. The coals in the middle interval in UOD Cockatoo Creek 1 indicate deposition in a fluviodeltaic environment. The scarcity of fossils in the upper part suggests deposition in a restricted shallow sea or nearshore environment. The overall depositional model suggested is an easterly or north-easterly sourced fan delta that rapidly prograded into a shallow sea.

Fossils and age

Dear & others (1971) noted that the lower half of the formation in the Banana area is richly fossiliferous, and they gave an extensive faunal list. These faunas were considered by Dickins (1964a) to be diagnostic of his Fauna IV and were assigned a late Permian (Kazanian) age. Parfrey (1988) described the faunal assemblage from the Barfield Formation and lowermost Flat Top Formation and considered it to be closely comparable with that in the Ingelara and lower Peawaddy Formations in the south-western Bowen Basin. The upper half of the formation is comparatively poorly fossiliferous, but scattered marine fossils persist to the top. Leaves of *Glossopteris* are also commonly associated with the marine faunas, attesting to a shallow marine, nearshore (fluvio-deltaic) environment. Palynofloras identified from GSQ Mundubbera 5 and 6 were referred by Foster (1982) to his *Dulhuntyispora parvithola-Triplexisporites playfordii Zone*, which is equivalent to APP5. A late Permian age is thus indicated. Draper & others (1990) showed the Flat Top Formation as Kazanian to Tatarian.

BACK CREEK GROUP
(CENTRAL EASTERN BOWEN BASIN)

RANNES BEDS

Dunstan (1901) first used the term “Rannes Altered Rocks” for cleaved rocks at Mount Rannes. Reid & Morton (1928) later used the name “Rannes Series” for rocks along the central railway line in the Gogango Range. Olgers & others (1964) subdivided the rocks in the Gogango Range into two units, a supposed older unit of slaty rocks referred to the “Rannes Beds”, and interbedded arenite and mudstone referred to the Back Creek Group. Malone & others (1969) also described the unit and, as well as the slaty rocks, included deformed and altered volcanic rocks and limestones that crop out in the southern part of the Gogango Range in the Rockhampton and Monto 1:250 000 Sheet areas. The rocks were thought to be mainly Permian, but Malone & others (1969) speculated about the presence of older rocks.

Therefore, as previously mapped by most of these workers, the Rannes beds became a general unit for any strongly deformed, mostly sedimentary rocks within the Gogango Overfolded Zone, although the original use by Dunstan was for deformed volcaniclastic rocks. Because of the different ways the name has been applied, no useful purpose would be served by retaining it for any of its components, and its use should be discontinued.

One intention of this mapping was to split the unit into its components and reassign them to the other units in the area. Most of the rocks are simply a more cleaved, generally mudstone-dominated part of the undivided Back Creek Group within the Gogango Overfolded Zone, having a similar ‘hot’ radiometric signature. The unit also includes deformed volcanic and volcaniclastic rocks that are now mapped as Camboon Volcanics and Woolein beds. One group of rocks of uncertain affinities occurs along the Leichhardt Highway between Wowan and Rannes and east towards Goovigen. The rocks are in contact with the Rookwood Volcanics and locally appear to be interleaved within them. However, the rocks are strongly deformed (locally mylonitic) and the contacts are probably tectonic. The rocks include chert, phyllitic mudstone and volcaniclastic sandstone and have a ‘hot’ radiometric signature like the Back Creek Group (see below). They could be sedimentary rocks within the Rookwood Volcanics, but are more likely a facies of the Back Creek Group.

UNDIVIDED BACK CREEK GROUP

Introduction

Rocks assigned to mostly unnamed divisions of the Back Creek Group were examined in a belt ~200km long from near Biloela to Saint Lawrence. The rocks were previously mapped as both undivided Back Creek Group and Rannes beds. As discussed above, it is contended that the most of the “Rannes beds” are simply more strongly cleaved parts of the Back Creek Group. Both the “Rannes beds” and rocks previously mapped as undivided Back Creek Group are characterised by a ‘hot’ radiometric signature (moderate to high in all three channels), appearing as whitish on composite RGB radiometric images (Figure 66). The term “undivided” indicates that the rocks cannot be definitely assigned to one or more of the named formations within the Back Creek Group, although several unnamed subunits (“$\mathbf{Pb_z}$” and “$\mathbf{Pb_s}$” and “$\mathbf{Pb_{cg}}$”) with most of the rocks simply being labelled “**Pb**” have been recognised (Figure 65). The first of the unnamed subunits has lower thorium and uranium responses and is represented by pinkish hues on composite radiometric images rather than appearing as white.

In the northern part of the outcrop area, a sandstone-dominated sequence that lies within “undivided” mudstone-dominated facies and also has lower thorium and uranium responses is assigned to a named unit, the Boomer Formation. It separates the “undivided” Back Creek Group into a lower and upper package. The Boomer Formation and unnamed subunits are described below under separate headings.

In BANANA, the radiometrically ‘hot’ undivided Back Creek Group is mapped south to near Banana township. Farther south, the Back Creek Group has been divided into the Buffel, Oxtrack, Barfield and Flat Top Formations. Over most of the area, the undivided Back Creek Group is dominated by mudstone, although some sandstone and other rock types are present locally, particularly in the subunits. The mudstone-dominated areas are probably mainly equivalent to the Barfield Formation.

Locally, restricted areas of rocks equivalent to the Buffel and Oxtrack Formations have been mapped. These include Buffel or Tiverton Formation equivalents in the Apis Creek area and on the eastern limb of the Leura Anticlinorium, and possible Oxtrack Formation equivalents near Thuriba homestead.

Lithology

South of Duaringa

The undivided Back Creek Group south of Duaringa is dominated by massive, mostly unbedded mudstone. Minor lithic sandstone occurs locally, but is subordinate overall. The mudstones are dark grey, weathering to yellowish-grey. Exposures in the deep cuttings along the Central railway line in the Gogango Range are pyritic and strongly carbonaceous. In most of the area, the rocks are cleaved, being defined by aligned phyllosilicates. In most outcrops, only one cleavage is present, but locally a second cleavage is present and defined by open crenulations and anastomosing seams of opaque minerals up to 1mm apart.

The rocks are unfossiliferous, apart from trace fossils. *Planolites* burrows are the most common, but *Scalarituba* and *Teichichnus* were also observed. Elliptical, phosphatic concretions are common (Figure 67d). They are mostly up to ~30cm, but in some places concertions up to 1m long have been observed. Most have a vague concentric structure, and in rare cases they contain shell fragments or burrows in their cores.

Farther south, the mudstone generally overlies or is overthrust by the Camboon Volcanics, but near Thuriba homestead a thin limestone-bearing sequence overlies the Camboon Volcanics. It was assigned to the Oxtrack Formation by Malone & others (1969) on the basis of a Fauna IV assemblage.

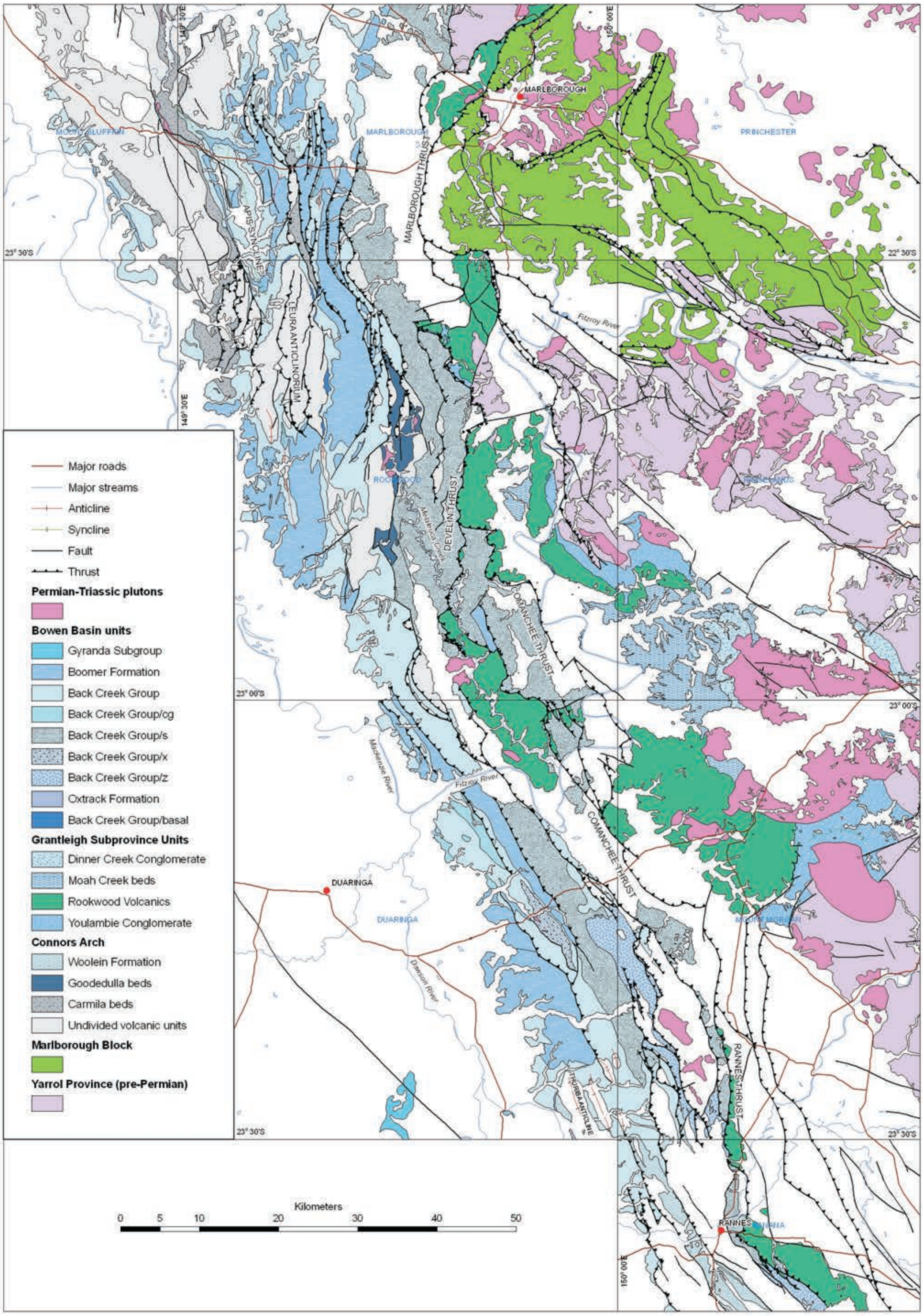

Figure 65. Permian geology of the Gogango Overfolded Zone

Most of the mudstone-dominated areas are relatively 'hot' on the composite radiometric images, although the belt along the eastern edge of the Gogango Overfolded Zone from the Capricorn Highway south to near the western side of Mount Wheal shows slightly pinkish hues. Some siliceous siltstone was observed locally in this belt (*e.g.* at MGA 205050 7365500 near McIntosh homestead) and some of the sandstones are interpreted as volcaniclastic. Therefore, although siliceous siltstone is not common, it is possible that this belt is related to the rocks in unit $\mathbf{Pb_z}$ (see pages 180–181).

Along the Leichhardt Highway north of Rannes, and between Rannes and Goovigen in northern BANANA, very strongly cleaved, phyllitic mudstones crop out locally with interbeds of siliceous siltstone or chert. The radiometric response of this belt is mostly 'hot'. These rocks are overthrust by the Rookwood Volcanics, and also appear to form a window in them, between Rannes and Goovigen. Southwards, these rocks pass into deformed lithic sandstone with a much lower radiometric response. The latter are tentatively equated with the Woolein Formation.

A belt of rocks ~1km wide with a 'hot' radiometric signature occurs in central SCORIA. Volcanic rocks assigned to the Camboon Volcanics occur to the east and west of the belt, which comprises slate and phyllite. Slaty cleavage dips 40–50° toward the east-north-east. It is probable that the eastern boundary of the undivided Back Creek Group in this area is a thrust from the east, resulting in repetition of the Camboon Volcanics. This interpretation is consistent with data from farther north where the undivided Back Creek Group is overthrust by the Rookwood Volcanics at the eastern edge of the Gogango Overfolded Zone. In places unit **Pb** is metamorphosed by granites of the Rawbelle Batholith. South of Mount Shaw at MGA 262210 7251613, cleaved greyish-black, very fine-grained sandstone contains aluminosilicate spotting.

Lower Back Creek Group (north of Duaringa)

The Back Creek Group in this area was referred to as the Apis Creek Formation by Laing (1960), but the name has not been used subsequently. The unit is again dominated by very thickly bedded to massive mudstone, and lithic sandstone is subordinate. The mudstones are identical to those described above. They again contain phosphatic concretions and are mostly unfossiliferous, apart from common trace fossils including *Planolites* and *Scalarituba* (Figure 67a). On the RGB composite radiometric images, the rocks have a 'hot' response, generally being white with pinkish to bluish hues (Figure 66).

In most of the area east of the Connors Arch, the rocks are cleaved (Figure 67b), and the cleavage becomes more intense eastwards. Because the mudstone is generally unbedded, mapping the structure is difficult, particularly where a strong cleavage overprints any subtle sedimentary parting that may have been present. Some outcrops display a crude parting oblique to the cleavage, and this may reflect bedding, although this can only be used with caution as multiple parting directions were observed in places.

Although the unit is mostly unfossiliferous, the basal succession east of the Connors Arch locally consists of fossiliferous calcareous sandstone and siltstone up to 10m thick, particularly between Tooloombah homestead and the old Bruce Highway. Along Apis Creek, just north of the old highway, a ridge-forming, volcaniclastic siltstone crops out at the base and consists of elongate laths of plagioclase in a silty or muddy matrix. Above this siltstone, distinctive, ferruginous, calcareous lithic sandstone crops out and is locally fossiliferous. It also contains rounded clasts of glauconite, which also rims some of the other clasts. Some of the observation sites from this survey correspond with those described by Dickins (*in* Malone & others, 1969, appendix 1). The most common fossils are brachiopods, bryozoans and the coral *Cladochonus.* At MGA 757400 7472350 in the headwaters of Apis Creek, the fossiliferous horizon is overlain by a thick bed of massive chert. In thin section, the chert contains brachiopod spines or sponge spicules and circular tests of radiolaria.

Along the eastern limb of the Leura Anticlinorium in the headwaters of Leura Creek and farther north, a succession <100m thick of calcareous sandstone and medium to thick discontinuous dirty limestone beds occurs at the base. The sandstones are generally well sorted, very lithic and relatively quartz-poor. They contain abundant felsic to intermediate volcanic lithic grains, plagioclase and bioclastic fragments. Quartz, where present, is unstrained and probably of volcanic origin. The limestone and sandstone contain large brachiopod shells (Figure 67c), bryozoans and corals that were examined by Dickins (*in* Malone & others (1969) and Parfrey (*in* Withnall & others, 1998a).

On the western side of the Connors Arch near Yatton Creek (for example at MGA 729200 7506500), the basal interval consists of limestone (bioclastic brachiopodal calcarenite and coquinite — Figure 68) and calcareous sandstone and siltstone. The succession is ~30–40m thick and forms a conspicuous strike ridge that can be traced south for ~14km. The rocks overlie mafic volcaniclastic rocks and lava of the Mount Benmore Volcanics. Limestone was also observed farther south at MGA 739200 7484100 forming a low ridge on the western side of Mount Bora (a Cretaceous or Tertiary microsyenite plug). Scattered outcrops of limestone and calcareous sandstone overlying the volcanics were also observed further north, between Croydon and Cardowan homesteads. Laing (1960) assigned these rocks to the **Yatton Limestone** (a member of his Apis

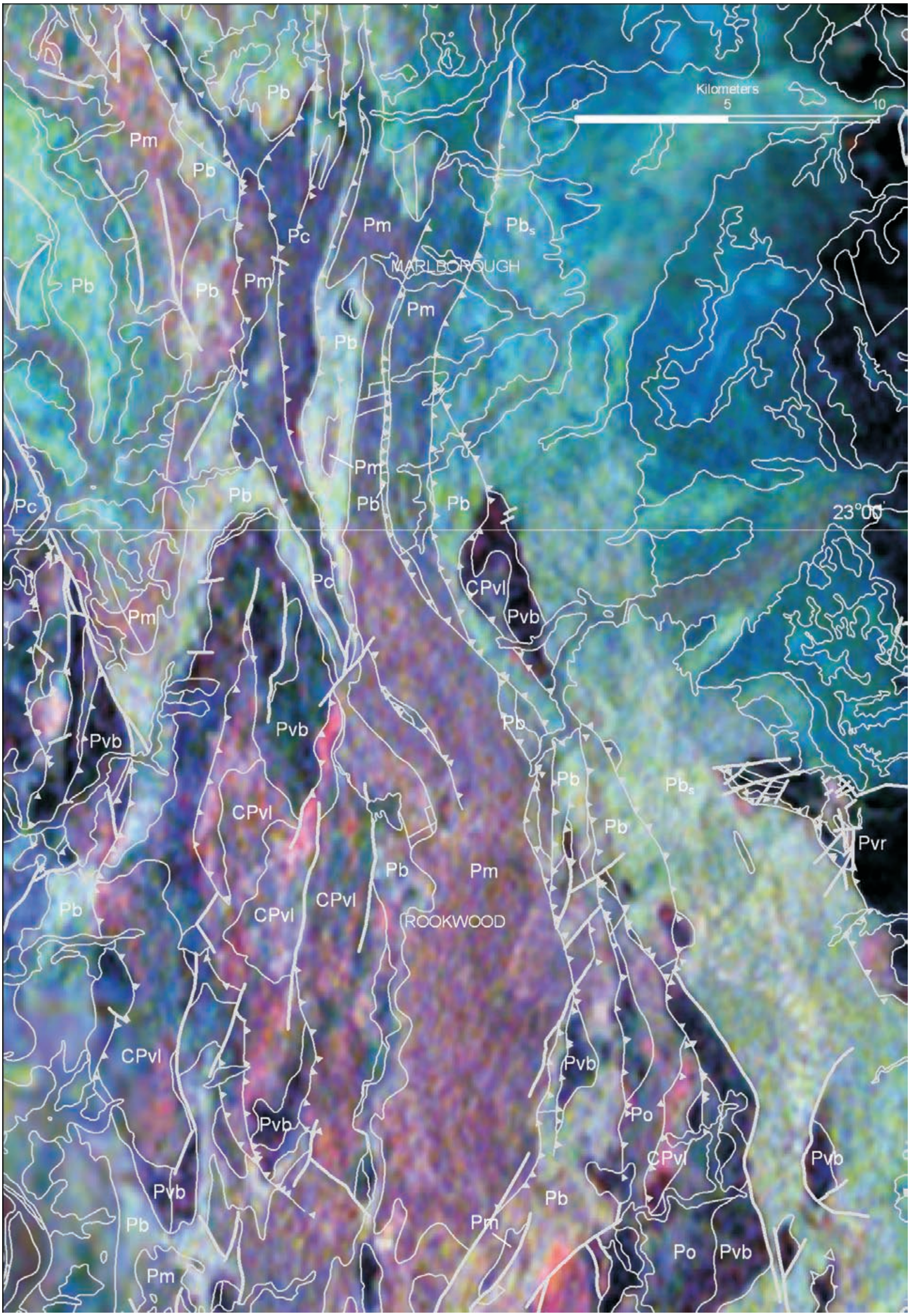

Figure 66. Radiometric image of the northern part of the Gogango Overfolded Zone showing the 'hot' radiometric response of the undivided Back Creek Group compared with the Boomer Formation. Symbols are CPvl — Leura Volcanics, Pvb — Mount Benmore Volcanics, Pvr — Rookwood Volcanics, Po — Goodedulla beds, Pb — undivided Back Creek Group, Pb_s — undivided back Creek Group (sandy facies), Pm — Boomer Formation

Figure 67. Undivided Back Creek Group

(a) Trace fossils (mainly *Scalarituba)* in mudstones of the undivided Back Creek Group. Leura Creek crossing on the Duaringa–Apis Creek road at MGA 763187 7434845 (IWGG004)

(b) Typical pencil cleaved, poorly bedded mudstone of the undivided Back Creek Group. Duaringa–Apis Creek road ~5km north of Leura homestead at MGA 763140 7439071 (IWGG006)

(c) Fossiliferous impure limestone containing abundant brachiopods (mostly *Tomiopsis profunda*) near the base of the undivided Back Creek Group. About 10km east-north-east of Leura homestead at MGA 773618 7438071 (IWGG128)

(d) Typical phosphatic concretion in massive mudstone. 6.5km north of Edungalba railway siding at MGA 790114 7380604 (IWGG603)

(e) Beds of grey (weathering to white) flinty tuffaceous(?) siltstone and fine-grained volcanilithic sandstone of subunit Pb_z and interbedded mudstone with a crosscutting cleavage. Access road from the Capricorn highway to the microwave station at MGA 797621 7368559 (IWGG535)

(f) Typical conglomerate of subunit Pb_{cg}, consisting of well rounded pebbles of siliceous siltstone, strongly indurated sandstone and lesser felsic volcanics supported by a matrix of grey mudstone (*c.f.* the diamictic conglomerate in the Moah Creek beds in Figure 22b). About 7km south of Morbank homestead at MGA 779114 7440011 (IWGG220)

Creek Formation) and that name is used on the MOUNT BLUFFKIN map. The rocks were described briefly by Malone & others (1969, page 33), and the fauna was assigned to Fauna II by Dickins.

The rocks overlying the basal calcareous interval west of the Connors Arch are poorly exposed, and were only examined at a few localities. However, they appear to be dominated by mudstone or siltstone containing concretions.

East of the old Bruce Highway in BOMBANDY, a sequence of fine to medium-grained, sublabile to labile sandstone, siltstone, shale and minor limestone (locally fossiliferous) is assigned to the undivided Back Creek Group. The rocks dip shallowly to the west. Volcanic rocks, tentatively assigned to the Lizzie Creek Volcanics crop out to the west, suggesting fault repetition.

Grey massive mudstone with minor sandstone crops out in the area between Saint Lawrence township and the Saint Lawrence–Ripplebrook road. Large concretions, possibly similar to those noted above, were noted south of Saint Lawrence township. Along the road into Ripplebrook, thick-bedded, course-grained sandstone to granule conglomerate is interbedded with khaki, fine-grained sandstone and thin to medium-bedded siltstone and shale. These rocks are locally fossiliferous with mainly brachiopod and pelecypod faunas assigned to either Fauna I or Fauna II by Dickins (*in* Malone & others, 1969).

The lower part of the Back Creek Group is probably ~150–250m thick in the Apis Creek Syncline and west of Langdale homestead. West of the Connors Arch in the Tartrus area, it is ~250–300m thick. The thickness in the Gogango Overfolded Zone is difficult to estimate, but is likely to be of a similar order, based on the sequence in a small anticline south-west of Develin homestead where the underlying Carmila beds are exposed. Along the eastern limb of the Leura Anticlinorium, between the basal calcareous sequence and the Boomer Formation, the mudstone-dominated facies is probably only 50–100m thick. However, on the western limb, south of Leura Station, it may be up to 500m.

Upper Back Creek Group (MARLBOROUGH and MOUNT BLUFFKIN)

East of the Connors Arch in the core of the Apis Creek Syncline, the Boomer Formation as now mapped is overlain by a further succession dominated by massive grey, cleaved mudstone. It has a strong radiometric response (white with a bluish tinge on the composite RGB image), and is essentially similar to the lower part of the Back Creek Group. Rare fossils (*Cladochonus* and *Atomodesma* moulds) were observed.

West of the Connors Arch to the north-west of Tartrus, a recessively weathering belt of rocks presumed to be the upper mudstone-dominated succession overlies the Boomer Formation. It was not examined in this survey. It is probably poorly exposed and disappears northwards under Cainozoic cover of the Duaringa Basin and Isaac River floodplain.

The thickness of the upper part of the Back Creek Group is difficult to estimate because of the lack of structural data. However, based on the few dips available and the width of the outcrop belt in the core of the Apis Creek Syncline, ~300m is exposed.

Depositional environment

Deposition of the basal part of the undivided Back Creek Group, along with the Buffel Formation and Tiverton Formation in the Bowen Basin and the Yarrol Formation in the Yarrol Province represents a major early Permian marine transgression. The discontinuous nature of the units could be due to erosion before the deposition of the overlying units or by deposition in topographic lows on an irregular erosion surface developed on the underlying rocks.

Although body fossils are rare in the rest of the succession, the common trace fossils indicate that the rocks are of marine origin. Fielding & others (1997a) interpreted an offshore shelf or ramp environment for most of them. The coarser sediments were possibly distributed as “turbulent underflows”. Intermittent shallower conditions may be indicated by rare hummocky cross-stratification. No basement-clast conglomerates that might indicate a basin margin or shoaling onto an emergent Connors–Auburn Arch, are evident. However, the eastward increase in sandstone into Subunit Pb_s (pages 181–182, is consistent with the dominance of westward-directed palaeocurrents on both sides of the arch (Fielding & others, 1997a), and suggests that the shoreline was to the east. The felsic volcanic provenance evident in the sandstones may not be represented by rocks now exposed onshore in Queensland. These comments also apply to the Boomer Formation.

The undivided Back Creek Group, along with the Barfield and Oxtrack Formations, was interpreted by Fielding & others (1995, 1997a) as being deposited during the thermal subsidence phase in the evolution of the Bowen Basin.

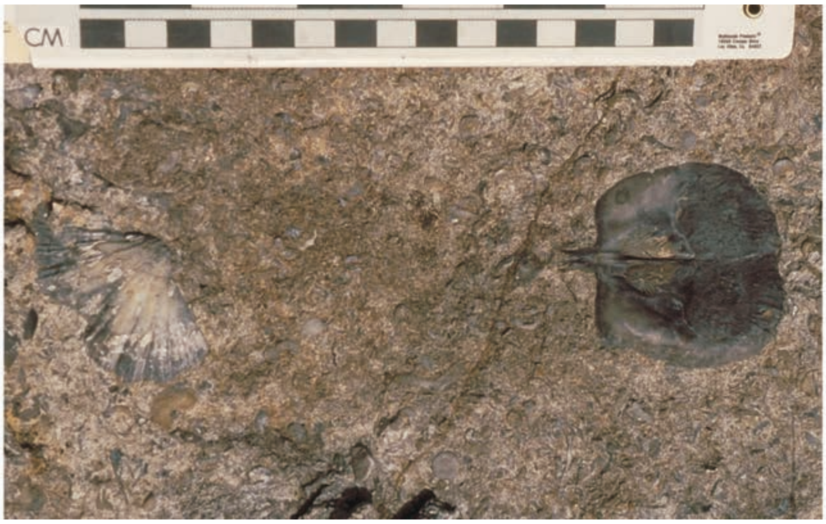

Figure 68. Well preserved shelly fauna in the Yatton Limestone including the productid *Taeniothaerus subquadratus*; ~11km north-north-east of Mount Bluffkin at MGA 730973 7502957 (IWSC1152)

Relationships

Where the base is exposed, the undivided Back Creek Group mostly overlies the Mount Benmore Volcanics west of the Connors Arch and the Carmila beds and Goodedulla beds to the east. In the south it overlies the Camboon Volcanics or Woolein Formation. In thrust slices in the Gogango Overfolded Zone in ROOKWOOD and DUARINGA, the rocks are conformably overlain by, and thrust against, the Boomer Formation, a sandstone-dominated package described below. On the eastern edge of the Gogango Overfolded Zone, the undivided Back Creek Group is overthrust by the Rookwood Volcanics. East of the Gogango Overfolded Zone, the Moah Creek beds are probable equivalents of the undivided Back Creek Group and overlie the Rookwood Volcanics.

Fossils and age

The most common fossils from the basal succession near Apis Creek are brachiopods assigned to *Anidanthus springsurensis* by Dickins (*in* Malone & others, 1969, appendix 1, pages 103–104), various spiriferids, bryozoans and the coral *Cladochonus.* Dickins assigned the faunas to part of his Fauna II. Farther north, Dickins (page 102) assigned locality Du 1000, ~500m south of Tooloombah homestead, to the Carmila beds. However, on lithological grounds, it may be part of the basal Back Creek Group. It contains common spiriferids and *Eurydesma.* Dickins assigned it to his Fauna I, suggesting it was older than the other sites described above, although Dear (1972) showed that most of the species present in Fauna I (which he called the Lizzie Creek Fauna) are also present in Fauna II (his Homevale Fauna). Some of Dickins' other sites to the north, such as near Prospect Hills homestead, are probably also basal Back Creek Group rather than Carmila beds.

Along the eastern limb of the Leura Anticlinorium in the headwaters of Leura Creek, the basal limestones and sandstone contain sporadic large brachiopod shells to 5cm across (mostly *Tomiopsis profounda,* Figure 67c). Other fossils identified include fenestellids, *Euryphyllum* and *Cladochonus*. The fauna, which Dickins (pages 105–106) assigned to Fauna II, is indicative of a late Artinskian age (Parfrey *in* Withnall & others, 1998a).

The fauna in the Yatton Limestone was examined by Dickins (pages 107–108) and also assigned to his Fauna II.

Various sites were recollected during this survey, but the faunas have not been examined. The samples are now in the collection of the Queensland Museum.

The basal successions in the undivided Back Creek Group probably correlate with the Buffel Formation near Cracow and Tiverton Formation in the northern Bowen Basin.

The overlying predominantly muddy succession in the Back Creek Group contains no diagnostic fossils. However, the lithological similarities with the Barfield Formation suggest an early late Permian age (Ufimian to Kazanian) for most of it, although some equivalents of the late Kungurian (late early Permian) Oxtrack Formation and Artinskian Buffel and Tiverton Formations may be present.

BACK CREEK GROUP (MAP-UNIT Pb_z)

Introduction

The unit has been mapped as a belt of rocks ~1–2km wide north-north-west for ~16km from near Drumberle homestead in SCORIA to near the Prospect Creek road in north-eastern THEODORE. It has a pinkish response on composite radiometric images that contrasts with the 'hotter' whitish response of most of the undivided Back Creek Group. The rocks were included in the Rannes beds by Dear & others (1971), and include cleaved mudstone, volcanilithic sandstone and rudite, and some lava.

This designation is also given to rocks in three other areas. One is south-east of Rannes, between the Rookwood Volcanics and Camboon Volcanics in northern BANANA. The second is west of Wowan, in the south-west part of MOUNT MORGAN and extending into northern BANANA. The other is a belt of rocks, 2km wide and extending for 12km south from the Central railway line on the western side of the Gogango Range.

Lithology

In the Drumberle–Prospect Creek area, the sandstones are moderately to well sorted and contain plagioclase crystal fragments as well as andesite lithic clasts. Quartz grains are very rare. Some rocks containing up to 60% plagioclase crystal fragments in a silty matrix may be crystal tuffs.

The lavas are mostly relatively felsic and may be andesite. They generally contain plagioclase phenocrysts in a groundmass that consists dominantly of feldspar and some iron oxides, chlorite and clinozoisite. They are locally amygdaloidal. Most outcrops are altered, strongly fractured and sheared and are commonly difficult to distinguish from volcanilithic sandstone except in thin section. Along Drumberle road at MGA 250300 7281600, poorly exposed basalt consists of saussuritised plagioclase laths to 1mm with interstitial, skeletal crystals of titaniferous augite, and is somewhat similar to some basalt within the Rookwood Volcanics.

Scattered lenses of sheared limestone are common within this belt, particularly on Drumberle and Woobulloo stations. No identifiable fauna is preserved other than crinoid stem fragments.

The belt is bounded to both the east and west, by radiometrically 'hot' rocks more typical of the undivided Back Creek Group. At least one of these contacts, probably the western one, is likely to be a thrust. Farther south, on the western part of Woobooloo Station at MGA 246950 7277300, the rocks are separated from the Camboon Volcanics by a narrow zone of fossiliferous siltstone, calcareous sandstone and thin to medium-bedded limestone ~300m wide. The fossils include spinose productids, spiriferids and bryozoans (similar to faunas in the Buffel Formation, although they have not been examined in detail). The fossiliferous rocks are not cleaved and may be separated from the more deformed rocks by a thrust. At the southern end of the belt, the rocks are in contact with the Camboon Volcanics. A complex interfingering relationship with the Camboon Volcanics just north of Drumberle homestead is probably due to folds and thrusts.

North-north-east of Drumberle, a second belt crops out to the east. It lies between rocks, clearly identifiable as Camboon Volcanics, and radiometrically 'hot' mudstone-dominated undivided Back Creek Group. This suggests that the rocks lie stratigraphically between these units and may correlate with the Buffel Formation or Oxtrack Formation or both. Crinoidal limestone and calcareous mudstone (locally containing fenestellids) crops out at MGA 251340 7277020. This is apparently at the base in an interval ~30m thick overlying the Camboon Volcanics.

Skarn assemblages noted at the Saunders copper mine (MGA 261110 7255000) west of Mount Shaw and at MGA 262765 7249980 were probably derived from calcareous rocks at the base of the Back Creek Group. Both of these localities lie near the western contact with the Camboon Volcanics.

Highly deformed rocks that have a similar radiometric response crop out south-east of Rannes, between the Rookwood Volcanics and Camboon Volcanics. The rocks include strongly cleaved or phyllitic mudstone and siltstone and volcaniclastic sandstone and conglomerate that consist of plagioclase crystal fragments and strongly elongate felsic volcanic lithics in a fine-grained matrix. The lithic clasts are strongly aligned in the foliation, which is defined by phyllosilicates and anastomosing concentrations of opaques and leucoxene. The rocks locally show S-C planes and asymmetry, consistent with proximity to a major west-over-east thrust. No limestones were recognised in this area.

West of Wowan, in the south-west part of MOUNT MORGAN and extending into the northern part of BANANA, lenses of strongly deformed crinoidal limestone also occur within rocks that are assigned to this unit, and which were previously mapped as Rannes beds. Apart from crinoids, no other fossils are identifiable. The limestone lenses mainly occur within strongly cleaved mudstone, but between MGA 205570

7347270 and MGA 206270 7347310, subordinate calcareous lithic sandstone is also present. Like the sandstones in the Drumberle area, they are quartz-poor and consist mostly of plagioclase and volcanic lithic clasts. This area has a low radiometric response similar to the Camboon Volcanics.

The 2km-wide belt of rocks extending for 12km south from the Central railway line on the western side of the Gogango Range has pinkish hues on composite radiometric images. The belt is dominated by cleaved mudstone and subordinate volcanolithic sandstone, but it locally also contains beds of flinty siliceous (possibly tuffaceous) siltstone that produce strong bedding trends on aerial photographs. Scattered darker, purplish areas in radiometric images may relate to lenses of tuff or volcanolithic sandstone.

A thin section of the siliceous siltstone from MGA 798090 7370240 contains only a very fine (mostly <0–0.05mm) mosaic of quartz and feldspar with subordinate phyllosilicates and epidote (?). The outlines of rare grains suggest that they were shards that have been replaced by silica, but this is not conclusive.

A sample of pale greenish-grey arenite from MGA 796575 7369520 in this unit, consists of 70% plagioclase crystal fragments (0.1–1.0mm) in a very fine-grained turbid matrix, and is probably a crystal tuff. Along the Capricorn Highway at MGA 796285 7371250, beds of volcanilithic sandstone and rudite consist of plagioclase crystal fragments (including laths to 3mm) and a variety of elongate, aligned andesite or dacite clasts up to 1cm in a very fine matrix. Similar rocks are well exposed along the access road from the Capricorn highway to the microwave station at MGA 797600 7368600. They are medium to thick-bedded, massive or weakly laminated and range from siltstone to medium-grained sandstone (Figure 67e). They have not been thin-sectioned, but appear to be quartz-poor, probably consisting almost entirely of felsic volcanic lithics or feldspar.

The clearly volcaniclastic nature of the rock in this belt contrasts with the more mixed provenance of other parts of the Back Creek Group. The apparent lack of limestone is an obvious difference to the rocks near Wowan and Drumberle.

Some other areas with pinkish hues on radiometric images occur to the south on DUARINGA. Although they have not been separated out, they possibly include rocks of this unit, interleaved with the more mudstone-dominated undivided Back Creek Group. Along the road to Thuriba homestead, a thin interval of volcanilithic rocks including siliceous siltstone was observed overlying the Camboon Volcanics.

Relationships and age

The affinities of the rocks assigned to this subunit are uncertain. They appear to be intermediate in age between the underlying Camboon Volcanics and the Back Creek Group and are probably early Permian. As already noted, they may be partly equivalent in age to the Buffel and Oxtrack Formations or they could represent a succession deposited in the interval represented by the unconformity between these two units. They are inferred to be separated from the less deformed Back Creek Group rocks flanking the Auburn Arch by thrusts, and could have been transported from farther east, where sedimentation may have been more continuous. The volcanilithic nature suggests that they might also correlate with the Berserker Volcanic Group to the east (Crouch & Parfrey, 1999).

The thickness is also unknown. The width of the belts suggests as much as 2000m, but there is likely to have been significant repetition by thrusting and folding as they crop out in the most intense part of the Gogango Overfolded Zone. On the eastern limb of the fold north of Drumberle, between the Camboon Volcanics and ‘hot’ Back Creek Group, a maximum of 500m is exposed, and is a more realistic thickness for the unit.

BACK CREEK GROUP (MAP-UNIT Pb_s)

Introduction

In the eastern half of ROOKWOOD, DUARINGA and extending into MARLBOROUGH as far north as Ogmore, extensive areas having the same ‘hot’ signature as the mudstone-dominated areas to the west contain a noticeable proportion of grey lithic sandstone, although mudstone is probably still dominant overall. The facies is exposed in the cuttings along the Central railway line and Capricorn Highway. The ‘hot’ signature of this sandier facies contrasts with the Boomer Formation (Figure 66). Previously, these rocks were mapped partly as Rannes beds and partly as Boomer Formation, probably because of the presence of at least some sandstone.

A narrow belt of generally strongly cleaved mudstone with subordinate sandstone and siltstone has also been mapped as subunit $\mathbf{Pb_s}$ in MOUNT MORGAN and BANANA adjacent to the Rookwood Volcanics.

Lithology

Examination of thin sections reveals that the sandstones are moderately well sorted, with little silt-sized or finer matrix and are essentially similar to those in the Boomer Formation (see pages 183–185) and probably had a similar provenance dominated by felsic volcanics with some plutonic and possibly metamorphic rocks. The sandstones are lithic, usually containing >50% fragments of very fine-grained felsic volcanic rocks or siliceous siltstone.

The sandstone beds range from thin to very thick, and are commonly massive. Internal structures mostly include planar laminations, but soft-sediment deformation features have been observed, and include low-amplitude slump folds and ball-and-pillow structures and load casts. Bioturbation mostly due to *Planolites* is common in the tops of sandstone beds.

The strong cleavage developed in much of the outcrop area has tended to obliterate any subtle structures, and in many exposures it is difficult even to determine the attitude of bedding. In thin sections, the cleavage in the sandstone is defined by discontinuous, anastomosing seams of semi-opaque minerals ~0.01–0.02mm wide and up to 0.5mm apart. More widely spaced fractures (up to 2cm) are evident in outcrop (Figure 150c). In the more intensely foliated rocks, the lithic clasts and any matrix have been replaced by a mass of fine-grained muscovite and chlorite aligned parallel to the foliation seams.

Relationships

The relationship of this facies to the mudstone-dominated facies is uncertain, but may grade laterally into it, although some mapped boundaries may be partly tectonic. The radiometric similarity suggests a similar provenance for the two facies, and the sandy facies may simply be more proximal. If so, its absence in the west of ROOKWOOD, and also in BANANA to the south, suggests that the source is to the north-east.

UNNAMED CONGLOMERATE IN THE LOWER BACK CREEK GROUP AND BOOMER FORMATION (MAP-UNIT Pb_{cg})

A distinctive facies that occurs in both the undivided Back Creek Group and Boomer Formation contains very poorly-sorted pebble to cobble conglomerates that commonly have a silty or silty sandstone matrix. It has been observed in areas mapped as undivided Back Creek Group and also in the Boomer Formation. This facies is similar to rocks described by Fielding & others (1997b) in the Moah Creek beds farther east. The main areas where it was observed are in the Morbank area at MGA 779110 7440010 (*e.g.* Figure 67f), in railway cuttings at MGA 791700 7374600 near Edungalba (on the main Central railway line) and at numerous localities farther north near Slaty Creek. Some outcrops were also observed south-east of Anchor homestead (*e.g.* at MGA 800500 7356800). In the Slaty Creek area, it seems to occur mainly within massive mudstones of the undivided Back Creek Group, but elsewhere it may be within or at the base of the Boomer Formation. At the foot of a ridge 1km east of Langdale homestead in MARLBOROUGH and along the old Bruce Highway between MGA 768600 7465600 and MGA 767800 7465700 it appears to crop out just below the base of the Boomer Formation. Malone & others (1969, page 33) also described siltstone containing rounded pebbles of quartz, volcanic rocks and siltstone in Sheepskin Creek and near Main Range Creek on the western side of the Connors Arch.

The conglomerates are characterised by very well rounded pebbles, cobbles and rare boulders of dark grey siliceous siltstone, strongly indurated sandstone and lesser felsic volcanics, supported by a matrix that ranges from mudstone to fine-grained silty sandstone. The conglomerates range from clast-supported to matrix-dominated (sandy mudstone or siltstone with sparse rounded granules and pebbles). The matrix itself is poorly sorted and contains subangular to subrounded quartz, feldspar, lithic fragments and rare echinoderm plates in a muddy matrix. The lithic fragments include felsic to intermediate volcanic rocks, mudstone, chert, fine-grained sandstone and quartzite.

The rocks are very thick-bedded and massive. Clasts are locally imbricated and some beds show reverse grading. Also present in the conglomerates in the Morbank area are slabs up to 1m long of intra-formational lithic sandstone. Disrupted beds of sandstone up to 2m long occur in mudstone in a cutting at MGA 79250 7374480 near Edungalba siding. Stem segments of crinoids are abundant in places along the old Bruce Highway.

Fielding & others (1997b) interpreted such conglomerates in the Moah Creek beds as debris flows due to submarine mass wasting. Fielding & others (1997a) recognised the presence of such conglomerates in at least two discrete intervals over ~350km north–south on both sides of the Connors–Auburn Arch within the thermal subsidence package. Their sporadic occurrence is consistent with them being separate lobes, although as Fielding & others (1997a,b) pointed out, their regional extent is consistent with a process operating on a basinal scale. They suggested that the rocks were induced by early stages of thrusting in the sub-surface, and reflect the onset of the foreland thrust loading that characterises the later history of the Bowen Basin. The change in facies from the mudstone-dominated lower Back Creek Group to the sandy Boomer Formation, which seems to occur at about the same interval as the conglomerates, may also be related to this process.

BOOMER FORMATION

Introduction

Malone & others (1969) defined the Boomer Formation from the Boomer and Gogango Ranges in the Duaringa 1:250 000 Sheet area. It was also mapped farther north into the Saint Lawrence Sheet area as a belt up to 10km wide between Clifton and Strathmuir homesteads. However, the unit is more extensive to the west, cropping out between Langdale and Apis Creek homesteads, where it is folded and interleaved by thrusting with the mudstone-dominated parts of the Back Creek Group.

Although not specifically included in the Back Creek Group by Malone & others (1969), Dickins & Malone (1973) included it in their Blenheim Subgroup. The subgroup nomenclature of the Back Creek Group is no longer in use (see McClung, 1981).

Type section

An incomplete type section was given in Leura Creek by Malone & others (1969, page 39), but the grid references given (in yards) probably contain a typographical error. The section marked on their Figure 5 is actually in a tributary of Leura Creek, and includes basal, massive mudstone (undivided Back Creek Group) as well as the Boomer Formation. The section is interpreted as being from MGA 773200 7439700, the base of calcareous rocks equivalent to the Buffel or Tiverton Formation, overlain by mudstone and minor sandstone of the undivided Back Creek Group at MGA 773700 7439500, and passing into the Boomer Formation at about MGA 774100 7439300. Outcrop of the Boomer Formation extends for ~4.5km south-east from here.

A more accessible reference section is given along Anglewood Road between MGA 763020 7468230 (base) and MGA 763010 7468720 (top), between the lower and upper parts of the Back Creek Group in that area.

Thickness

Where the overlying rocks are exposed north-west of Tartrus homestead, and in the Apis Creek Syncline, the Boomer Formation is only ~70–100m thick. It appears to thicken slightly to the north (300m thick along Tooloombah Creek and ~175m thick near Montrose homestead). However, further east, the thrust slices of Boomer Formation in the Gogango Overfolded Zone (for example near Develin and Clifton homesteads) appear to be up to 1000m thick, and in some cases the top is probably cut off by thrusts. Thus, although there may be some internal repetition within the major thrust slices as mapped, there appears to be dramatic thickness increase eastward from the Connors Arch at about the western edge of the Gogango Overfolded Zone. Conversely, there may be thinning over the Connors Arch.

Lithology

In the Gogango Overfolded Zone, there is some confusion between what was shown as Boomer Formation and undivided Back Creek Group on previous maps. However, in the western part of ROOKWOOD, the distinction is relatively clear. The undivided Back Creek Group consists dominantly of massive cleaved mudstone, whereas the Boomer Formation contains abundant lithic sandstone as well as cleaved mudstone and is radiometrically distinct (pink or brown on RGB composite images, rather than white, due to lower thorium and uranium responses — see Figure 66). This distinction has been applied to the areas farther east within the Gogango Overfolded Zone. On aerial photographs, the Boomer Formation in western ROOKWOOD and MARLBOROUGH is characterised by conspicuous strike ridges produced by differential weathering of the sandstone and mudstone.

The sandstone-mudstone facies in the Boomer Formation is superficially similar to the sandy facies in the undivided Back Creek Group in the eastern part of ROOKWOOD, but it is not entirely clear why the units are different radiometrically. Suites of samples from both units were collected for petrographic and geochemical studies to examine provenance differences. Petrographically, there seem to be little difference between the sandstones, and they cannot be separated geochemically. However, the sandstones from both units have distinctly lower K and Th than the mudstones, and it is likely that the radiometric differences reflect the abundance of sandstone. The Boomer Formation is probably dominated by sandstone, as the outcrop suggests, but in the so-called sandy facies of the undivided Back Creek Group, the sandstone, although conspicuous in outcrop, is probably less abundant overall than the more recessive mudstone.

Figure 69. Boomer Formation
(a) Medium to thick-bedded sandstone and mudstone typical of the Boomer Formation. Leura Creek ~7km south-west of Morbank homestead at MGA 774792 7441055 (IWGG145)
(b) Medium to thick-bedded sandstone and mudstone with crosscutting cleavage in the Boomer Formation. Cutting on the Rockhampton–Emerald Railway 4.5km east-north-east of Edungalba siding at MGA 794793 7376388 (IWGG507)
(c) Soft-sediment deformation in sandstone beds of the Boomer Formation. Cutting on the Rockhampton–Emerald Railway 6km east of Edungalba siding at MGA 796567 7375586 (IWGG502)
(d) Cuesta of resistant sandstone beds of the Boomer Formation. About 2.5km south-east of Langdale homestead at MGA 767800 7472200. (IWSC0502)

The sandstones are moderately well sorted, with little silt-sized or finer matrix. They are lithic sandstones, usually containing >50% fragments of very fine-grained felsic volcanics or siliceous siltstone. Other constituents are quartz (15–40%) and feldspar (15–30%). The quartz and feldspar (both plagioclase and K-feldspar) grains are subangular, and commonly have a low sphericity. The quartz is monocrystalline and most samples include grains with both straight and slightly undulose extinction. Some plagioclase twin lamellae are bent. Rare quartz tectonites are also evident. Muscovite is a common minor constituent. The petrography indicates a provenance dominated by felsic volcanics; the unstrained quartz may be volcanic, but the undulose grains and mica suggest that plutonic and possibly metamorphic rocks were also sourced.

The sandstones in the Boomer Formation are commonly thick to very thick-bedded (Figure 69a–b) and fine to medium grained. Most beds are massive with generally sharp bases and commonly diffuse tops. In many places, the diffuse tops are due to bioturbation and mixing of the sand with the overlying mud. The sandstones appear to show a greater variety of sedimentary structures than those in the undivided Back Creek Group. Grading is locally observed, and some beds contain massive sandstone passing upwards through laminations into cross-laminated tops. Low-amplitude soft-sediment folds commonly disrupt the laminated tops, and ball-and-pillows are also common (Figure 69c). Rip-up clasts occur towards the bases of some beds. Sole-markings, mainly load casts, are also present. Hummocky cross-stratification was noted by Fielding & others (1994, 1997a) along the Capricorn Highway, and was also observed at several other localities during this study. No body fossils were observed in the unit, but trace fossils are common in the mudstone and tops of sandy beds. Again these are dominated by *Planolites* but *Teichichnus* is also present and is probably more common than in the undivided Back Creek Group. Minor plant material is also present as coaly fragments on the tops of some beds.

Although most of the rocks are relatively fine-grained, intervals consisting of several thick to very thick beds of very coarse-grained lithic sandstone and granule conglomerate were observed at scattered localities in the northern part of the outcrop area. These extend from just north of the old Bruce Highway on the limbs of the Apis Creek Syncline to near the access road to Montrose homestead at MGA 761000 7495050. At the latter locality, the conglomerate consists of subangular to subrounded granules and lesser small pebbles of dark grey aphyric to porphyritic andesite or dacite (?) in a coarse to very coarse-grained, quartz-poor, feldspatholithic sandstone matrix. A relatively proximal volcanic provenance is suggested by the composition of the rocks. Some beds are also moderately calcareous and contain fragments of echinoderm plates to 1mm. At MGA 759045 7470405 near the head of Apis Creek, the conglomerate and sandstone are dominantly volcanilithic (*ca* 80% dacite/andesite), but in thin section (IWSC0164) also contains conspicuous clasts of pyroxene-bearing dolerite. At MGA 763300 7471700 along Anglewood Road, grey mudstone rip-up clasts to 50cm were observed towards the base of conglomerate beds that fined upwards into sandstone.

Depositional environment

Most of the comments by Fielding & others (1997a) regarding the undivided Back Creek Group apply also to the Boomer Formation. Thus an offshore shelf or ramp environment is interpreted for the unit. Many of the features of the sandstones are suggestive of turbidity flows with intermittent shallower conditions indicated by the hummocky cross-stratification. The provenance mostly seems to be similar to that of the undivided Back Creek Group.

Relationships and age

In the western part of ROOKWOOD, the Boomer Formation conformably overlies the massive mudstone of the Back Creek Group. This relationship is also evident in the thrust slices in the Gogango Overfolded Zone farther east, where packages of radiometrically ‘cool’ sandstone-siltstone overlie ‘hot’ mudstone, and are inferred to be thrust against the mudstone at the base of the next slice. In the Gogango Overfolded Zone, the Boomer Formation is evident on the composite radiometric images as linear belts of ‘cooler’ response that are 1–2km wide, alternating with the ‘hotter’ undivided Back Creek Group.

In much of the area, particularly in the Duaringa 1:250 000 Sheet area, the Boomer Formation is the uppermost exposed part of the Back Creek Group. However, in the Apis Creek Syncline and, north of Tartrus homestead on the western side of the Connors Arch, it is overlain by a further succession of massive mudstone.

The age of the Boomer Formation is probably late Permian. Possible correlatives of the Boomer Formation may be the Cottenham Sandstone Member of the Barfield Formation or possibly the Flat Top Formation that overlies the Barfield Formation. In the Banana area, both of these units contain sandstone and are characterised by similar radiometric responses to the Boomer Formation, particularly the Cottenham Sandstone Member. Fielding & others (1997a) included the unit within their thermal subsidence package, which is Ufimian to Kazanian.

BACK CREEK GROUP
(NORTHERN BOWEN BASIN)

TIVERTON FORMATION

Introduction

The Tiverton Formation is the oldest marine unit in the Back Creek Group in the north-eastern part of the Bowen Basin and has been recognised from near Emu Plains in the Bowen 1:250 000 Sheet area to near Mount Landsborough, 15km north-west of Nebo. South of here, the Back Creek Group is concealed by Tertiary basalt and alluvium. The formation was originally defined by Malone & others (1966). Dickins & Malone (1973) raised it to subgroup status and extended it throughout the basin. However, the concept of basin-wide subgroups was challenged by various authors such as Staines & Koppe (1979, 1980) and McClung (1981) and has fallen into disuse. Thus the name Tiverton Formation is used here and restricted to the area in which it was first defined. The unit forms soil-covered plains with sparse outcrop limited to gullies and some long, low strike ridges.

Type section

Malone & others (1966) designated a type section, ~225m thick, in a small creek 3.3km north-north-west of Blenheim homestead in the Mount Coolon 1:250 000 Sheet area. They also designated a type area that extended from this section along strike for ~16km south of Blenheim homestead.

Thickness

According to Malone & others (1966), the Tiverton Formation ranges from 225–630m in the type area near Blenheim homestead. In the Homevale area near Nebo, the unit is ~450m thick, but lenses out to the south.

Lithology

The lower half of the Tiverton Formation consists of marine, fossiliferous and coquinitic siltstone and fine to medium-grained greyish green, sublabile to labile sandstone that contains irregular carbonaceous streaks and is locally calcareous. The upper part of the formation consists of poorly exposed, apparently unfossiliferous siltstone and mudstone. Malone & others (1969) and Dickins & Malone (1973) suggested that these two recognisable subdivisions could be formally defined with further study, but this has never been done. In the current study area, the lower part is particularly well exposed on a low ridge north-east of Homevale homestead, close to the Nebo–Collinsville road. This locality has been long known and was described by Jack & Etheridge (1892, page 157). About 40m above the top of the Lizzie Creek Volcanic Group, numerous richly fossiliferous beds crop out, although some fossils are known from the basal beds. The fossiliferous beds can be traced for hundreds of metres. Between the overlying Gebbie Formation and the richly fossiliferous interval, which is ~50m thick, are ~360m of poorly exposed rocks.

Depositional and tectonic environment

No detailed studies have been done on the environment of deposition. In spite of the abundant shelly fauna, Malone & others (1966) commented on the lack of shallow-water sedimentary features and suggested that conditions were “moderately deep”. Deposition of the Tiverton Formation, along with the Buffel Formation in the south of the Bowen Basin and the Yarrol Formation in the Yarrol Province represents a major early Permian marine transgression. The discontinuous nature of the units could be due to erosion before the deposition of the overlying units or by deposition in topographic lows on an irregular erosion surface developed on the underlying volcanic rocks. However, it is probably more likely that the patchy distribution is due to deposition in a series of small sub-basins during the early extensional phase of Bowen Basin evolution (Draper, 1988; Fielding & others, 1997b).

Relationships and boundary criteria

The Tiverton Formation overlies the Lizzie Creek Volcanic Group and is overlain by the Gebbie Formation. The units are structurally conformable although a disconformity is possible. Malone & others (1966) stated that the two units are distinguished by the presence of more quartzose sandstone in the Gebbie Formation. The top of the Tiverton Formation is difficult to discern in the field, occurring in low-lying terrain with poor outcrop. As suggested by Waterhouse & Jell (1983, page 232) from their work near Exmoor homestead, a much more readily mapped boundary would be at the base of the Wall Sandstone Member. However, because mapping of the Bowen Basin units was strictly outside the scope of the project, the boundaries have been taken mainly from Jensen & others (1966) and the Bowen Basin Solid Geology Map (Geological Survey of Queensland, 1988).

The Tiverton Formation thins to the north and south and is overlapped by the Gebbie Formation although if the Wall Sandstone Member was taken as the base of the Gebbie Formation, the Tiverton Formation would continue farther north than currently mapped. South of Mount Landsborough in NEBO, the Back Creek Group is concealed by alluvium and basalt, and where it is again exposed in northern CONNORS RANGE, the subdivisions of the Back Creek Group cannot be readily distinguished, partly because of the poor outcrop. However, Malone & others (1964) tentatively recognised equivalents in a poorly exposed sequence of the Back Creek Group near Mount Flora. Around the southern end of the Connors Arch, fossiliferous rocks equivalent to the Tiverton Formation crop out discontinuously, but except for the Yatton Limestone, have been included in the undivided Back Creek Group.

Fossils and age

The early Permian faunal assemblage in the Tiverton Formation was described from the Homevale area by Waterhouse & others (1983) who also reviewed previous studies. The fauna is extremely rich and at least half of it remains undescribed. Four main faunal assemblages were recognised. The assemblage in the basal beds is characterised by *Tomiopsis elongata*. The richly fossiliferous intervals represent the type of the so-called

Fauna II of Dickins (1964a,b, 1966) and the first assemblage at the base includes *Strophalosia cf. subcircularis* and *Tomiopsis konincki* and probably correlates with the Allandale fauna of the Sydney Basin (Waterhouse & others, 1983). The overlying richest fauna is dominated by *Lissochonetes yarrolensis* and contains species of *Echinolosia*, *Megasteges*, *Attenuatella* and *Queenslandoceras*. The topmost fauna has numerous *Taeniothaerus* and is typified by *Wyndhamia brittoni*. Waterhouse & others (1983) considered the Tiverton Formation to be late Asselian to Sakmarian, but Draper & others (1990, figures 1and 4) and Briggs (1993), showed it as largely Artinskian. The ranges of *Tomiopsis elongata* and *Strophalosia* cf. *subcircularis* zones are shown as Sakmarian, and this implies that they may have been misidentified in the Homevale section. An Artinskian age is more consistent with the SHRIMP date of the underlying Mount Benmore Volcanics (284.7±4.4Ma, see page 126 and Appendix). In the south-eastern Bowen Basin, the Tiverton Formation correlates at least partly with the Buffel Formation.

GEBBIE FORMATION

Introduction

The Gebbie Formation was also defined by Malone & others (1966) and is traceable from ~10km north-west of Gebbie Creek in the Bowen 1:250 000 Sheet area to near Mount Landsborough in NEBO, where like the Tiverton Formation, it is concealed by Tertiary basalt and alluvium. The unit crops out as long prominent strike ridges separated by alluvial flats. As for the Tiverton Formation, the unit was raised to subgroup status by Dickins & Malone (1973) and extended throughout the basin. However, the name has since reverted to Gebbie Formation and restricted to the area in which it was first defined (Staines & Koppe, 1979; McClung, 1981).

Type section

Malone & others (1966) designated a type section in Gebbie Creek, ~1.6km upstream from the junction with the Bowen River, where the unit is 435m thick. The rocks in the type section were described briefly by McClung (1981). An interval of no outcrop above the Lizzie Creek Volcanic Group is overlain by a thin sequence of fine-grained sandstone and siltstone and then a prominent medium to coarse-grained, cross-bedded quartzose sandstone known as the Wall Sandstone Member (Reid, 1924; Malone & others, 1966). It is succeeded by interbedded sandstone, siltstone, carbonaceous mudstone and thin coal seams, followed by fossiliferous sandstone and then locally bioturbated sandstone and siltstone, and finally thin carbonaceous siltstone and mudstone. Javes (1972) and Waterhouse & Jell (1983) pointed out that the type section was not well chosen, because it shows a facies transitional between the Collinsville Coal Measures and marine beds. The section they described near Exmoor homestead (Waterhouse & Jell, 1983, figure 4) can be regarded as a reference section. As noted above, they suggested that the rocks below the Wall Sandstone Member should be included in the Tiverton Formation.

Thickness

Malone & others (1966) noted that the Gebbie Formation ranged from 435 to ~500m thick. If the Moonlight Sandstone Member and rocks below the Wall Sandstone Member are taken out of the unit as suggested by Waterhouse & Jell (1983), the thickness of the Gebbie Formation would probably be <300m.

Lithology

The Gebbie Formation comprises grey, micaceous, locally carbonaceous, fine to medium and locally coarse to granule-grained quartzose to lithic labile sandstone, siltstone, carbonaceous shale and coquinite lenses. Thin conglomerate lags, dropstones and ferruginous and calcareous concretions occur throughout the sequence. Bedding is thin to medium and locally thick. Clastic rocks are locally bioturbated, burrowed and contain scattered invertebrate marine macrofossils. The formation also contains rare fossil wood.

Lateral facies changes in the Gebbie Formation are marked, and the proportion of siltstone increases southwards and sandstone transitional between marine and freshwater in the north is replaced by marine sandstone in the south. In the north, the Gebbie Formation is laterally equivalent to the Collinsville Coal Measures.

Near Carinyah homestead in south-western MIRANI, McClung (1981) described the Gebbie Formation as consisting of a basal sequence of fine-grained, partly silty sandstone passing up into medium to coarse-grained, cross-bedded sandstone, a sequence of siltstone and thin, interbedded fine-grained sandstone, and an uppermost unit of thin-bedded fossiliferous sandstone. The lower coarse-grained sandstone was regarded by him as a continuation of the Wall Sandstone Member in the type section. The uppermost fossiliferous sandstone had been defined as a separate formation, the Moonlight Sandstone, by Runnegar &

McClung (1973), but McClung (1981) preferred to regard it as a member of the Gebbie Formation. However, as discussed further below, Waterhouse & Jell (1983) argued that it should be included in the Blenheim Formation. These subdivisions are not shown on the MIRANI and NEBO maps.

Depositional environment

The Gebbie Formation was probably deposited in a shallow marine environment offshore of a coastal plain and deltaic complex in which the Collinsville Coal Measures were deposited. Runnegar & McClung (1973) suggested that the two sandstone members represented nearshore shoals and that the intervening silts were deposited in deeper water on an open marine shelf.

Relationships and boundary criteria

The Gebbie Formation is distinguished from the underlying Tiverton Formation by the presence of quartzose sandstone, which is also generally coarser-grained. The precise relationship with the Tiverton Formation is uncertain and although structurally conformable the boundary could also represent a disconformity. As mentioned above, Waterhouse & Jell (1983) proposed some slight adjustments to the boundaries from their work near Exmoor homestead and suggested that placing the top of the Tiverton Formation at the base of the Wall Sandstone Member would enable field mapping to be more accurate and conform to natural sedimentary cycles. In the north, outside this study area, the Gebbie Formation as mapped by Malone & others (1966) overlaps the Tiverton Formation and rests directly and disconformably on the Lizzie Creek Volcanic Group.

The boundary with the Blenheim Formation is controversial and opposing views have been discussed at length by McClung (1981, pages 9–10) and by Waterhouse & Jell (1983, page 235). As originally defined by Malone & others (1966) in Gebbie Creek, the boundary was placed at the base of a thin conglomerate. In the Exmoor area, the base was placed at a base of a conglomerate within a sequence of labile sandstone and conglomerate below a bed containing Fauna IV and 17m below siltstones more typical of the Blenheim Formation. McClung (1981) suggested that the boundary between the units in the Homevale–Mount Landsborough area as mapped by Jensen & others (1966) was based to a large extent on the nature of the faunas rather than strictly lithological grounds. Runnegar & McClung (1973) mapped the Moonlight Sandstone in this area, and it included rocks originally in both the Gebbie and Blenheim Formations. McClung (1981) noted that the change from Dickins' Fauna III to Fauna IV occurs within this unit. McClung argued that problems, which would arise in future mapping if the boundary was based on faunas would be removed if the boundary was placed at the top of the highest quartzose sandstone typical of the Gebbie Formation in the Nebo–Exmoor area, *i.e.* the Moonlight Sandstone, which would be down-graded to member status. Waterhouse & Jell (1983) argued that the Moonlight Sandstone Member should be placed in the Blenheim Formation, because they observed a "considerable percentage of volcanic detritus" in it in the Exmoor sequence. However, Runegar & McClung (1973) in their original definition, described it as containing quartzose sandstone. Given the complex facies distribution and problems with the type section, further mapping is obviously needed before an adequate nomenclature can be applied to the whole unit. This was outside the scope of this project, and the boundaries were taken mainly from Jensen & others (1966).

Fossils and age

Most studies of faunas from the Gebbie Formation are from outside the study area, although near Carinyah homestead, Runnegar & McClung noted the presence of *Martiniopsis* (now *Tomiopsis*) *undulosa* in siltstones from the middle part of the Gebbie Formation and *M. isbelli* in the Moonlight Sandstone. McClung (1981) noted that the change from Dickins' Fauna III to Fauna IV occurs within the Moonlight Sandstone.

Waterhouse & Jell (1983, pages 236–240 and tables 2 and 4–8) discussed the faunas from the Gebbie Formation near Exmoor homestead which was regarded as the type for Fauna III of Dickins (1964a,b) and Runnegar (1969). Below the Wall Sandstone Member, rocks that Waterhouse & Jell placed in the Tiverton Formation are dominated by *Terrakea dickinsi* and *Tomiopsis plica*, and were considered to be late Sakmarian in age. The bivalve *Glendella dickinsi* is widespread in the middle of the Gebbie Formation proper, but although its age was considered open to question, a Baigendzinian age was considered likely. In the south-eastern part of the Bowen Basin, McClung (1981, figure 7) showed the Gebbie Formation correlating with the hiatus between the Buffel and Oxtrack Formations, whereas Waterhouse & Jell (1983, table 10) correlated it with the Oxtrack Formation. Draper & others (1990, figure 1) and Briggs (1993, figure 1) correlated it with the upper Buffel Formation through to the lower part of the Barfield Formation, ranging in age from late Artinskian to Ufimian.

According to Waterhouse & Jell (1983), beds at Exmoor considered to be equivalent to the lower part of the Moonlight Sandstone Member (but placed by them in the Blenheim Formation) had a fauna dominated by the bivalves *Merismopteria macrotera* and *Etheripecten plicata*. The upper part contained their *Wynhamia ingelarenisis* assemblage, which extended into the finer-grained beds of the Blenheim Formation. They argued that an Ufimian age was likely and suggested a correlation with the Freitag Formation of the Denison Trough. This is somewhat younger than the age and correlation suggested by other authors including McClung (1981), Dear (1972) and Briggs (1993) who correlated it partly with the Aldebaran Sandstone. These authors correlated the Moonlight Sandstone Member with the lower Barfield Formation in the south-eastern part of the Bowen Basin, .

BLENHEIM FORMATION

Introduction

The Blenheim Formation was also defined by Malone & others (1966) and was traced from near Mount Landsborough in NEBO to near Collinsville. They also considered it to continue south-east and south-west across the Mount Coolon, Clermont and Saint Lawrence 1:250 000 Sheet areas to the north-west part of the Emerald Sheet area. However, on the Bowen Basin Solid Geology Map (Geological Survey of Queensland, 1988), the extent of the unit on the western side of the basin is arbitrarily cut off at the same latitude as Mount Landsborough on the east, and rocks farther south are mapped as undivided Back Creek Group. As for the Tiverton and Gebbie Formations, the unit was raised to subgroup status by Dickins & Malone (1973) and extended throughout the basin. However, the name has since reverted to Blenheim Formation and been restricted to the area in which it was first defined (Staines & Koppe, 1979; McClung, 1981). The unit crops out as long, prominent strike ridges separated by alluvial flats.

Type section

Malone & others (1966) gave the type section as being in Blenheim Creek near where it is crossed by the Nebo–Collinsville road in the Mount Coolon 1:250 000 Sheet area.

Thickness

Malone & others (1966) reported that the thickness ranges from 700m in the type section to almost 1600m near Mount Landsborough.

Lithology

The Blenheim Formation consists of siltstone, pebbly sandstone to conglomerate and lithic to quartzose sandstone. The rocks are commonly fossiliferous and coquinite and limestone are locally present. Dropstones are common in parts of the formation.

Dickins & Malone (1973) recognised three unnamed subunits. The lower subunit consists of interbedded and pebbly and locally coquinitic mudstone, siltstone and sublabile sandstone. It is conglomeratic towards the base. According to Dickins & Malone (1973), the Blenheim Formation is characterised by felsic volcanic detritus, and Waterhouse & Jell (1983) noted that some sandstones in the lower part of the Blenheim Formation contain up to 40% volcanic fragments. In the northern part of the outcrop area, a prominent coquinite, which was originally informally known as the ‘Big *Strophalosia* Bed”, was named the Scottville Member by Runnegar & McClung (1973). The middle unit of the Blenheim Formation is mainly dark blue micaceous siltstone and the upper unit is a thin sequence of quartzose sandstone. No attempt was made to map out these subunits in the study area.

Depositional environment

The Blenheim Formation was deposited entirely in marine environments, and was formed during the thermal subsidence phase when the maximum flooding of the Bowen Basin occurred. Malone & others (1966) noted that unlike the Gebbie Formation, it contains no shallow-water structures.

Relationships and boundary criteria

The Blenheim Formation conformably overlies the Gebbie Formation on the eastern side of the Bowen Basin, but as noted above, the location of the boundary has been the subject of some debate. Where it is mapped in the western side of the basin, the Blenheim Formation unconformably rests on various basement units, including the Silver Hills Volcanics and Anakie Metamorphic Group.

Fossils and age

Again, most of the detailed faunal studies of the Blenheim Formation are outside the study area and Dickins (1966) listed fossils from only two localities from the Mackay 1:250 000 Sheet area. The formation is characterised by Fauna IV of Dickins (1964a,b) and Runnegar (1969), although the change from Fauna III occurs in the Moonlight Sandstone Member (McClung, 1981). Waterhouse & Jell (1983, pages 236–240 and tables 2, 4 and 9–10) listed three faunal assemblages in the Blenheim Formation (above the Moonlight Sandstone Member) at Exmoor and discussed their correlation with other zonal schemes. From base to top, the assemblages were the *Echinalosia ovalis*, *Wyndhamia clarkei* and *Martiniopsis pelicanensis*. The second of these is particularly significant because it forms the coquinite layer, originally termed the “Big *Strophalosia* Bed” and later formalised as the Scottville Member. It is not known whether this unit can be recognised in the study area. The faunas were interpreted as belonging to the Kazanian Stage of the late Permian by Waterhouse & Jell (1983), and they correlated the rocks with the upper part of the Barfield Formation and most of the Flat Top Formation. Draper & others (1990, figure 1) and Briggs (1993, figure 1) correlated them only with the upper part of the Barfield Formation.

EXMOOR FORMATION

Introduction

The youngest unit of the Back Creek Group in the northern part of the Bowen Basin is the Exmoor Formation, which was originally defined by Koppe (1974a) as a subdivision of the Blenheim Subgroup based on Departmental core-drilling. It overlies the uppermost of the three unnamed subdivisions recognised by Dickins & Malone (1973, page 57) in their Blenheim Subgroup. With the reversion of the subgroups to formation status, the Exmoor Formation should strictly have been reduced to member status as suggested by Staines & Koppe (1979), but most authors including Waterhouse & Jell (1983) and the Bowen Basin Solid Geology Map (Geological Survey of Queensland, 1988) have retained it as a formation, and that practice has been followed on NEBO.

The distribution based on drilling was given by Koppe (1974a) as being from Hail Creek on the eastern side of the basin around the northern hinge of the Nebo Synclinorium to Broadmeadow on the west. Although it has not been properly mapped from surface exposures, the distribution of the Exmoor Formation on the Bowen Basin Solid Geology Map mirrors that of the Blenheim Formation. The boundaries shown on NEBO are based on that map.

Type section

Koppe (1974a) gave the type section between 238–338m in Hillalong NS4 which was drilled near Exmoor homestead.

Thickness

Koppe (1974a) noted that the unit was relatively uniform in thickness throughout the defined area of extent and gave the variation from 60–110m discounting the various sills that are common in the drill sections.

Lithology

The Exmoor Formation consists of generally thinly bedded, micaceous sandstone, laminated siltstone and mudstone. Thicker sandstone beds are cross-laminated. The sandstone is grey, fine to medium-grained and moderately to poorly sorted. Clasts are angular to subangular. The unit becomes progressively more labile upwards, ranging from ~95% framework quartz at the base to 25% at the top. The rocks contain up to 10% feldspar, 30% clay matrix and the remainder consists of volcanic lithic fragments. In the type section, two thin coal beds occur in the upper 20m and plant fragments are common in the upper 70m. The sediments are visibly pyritic towards the base. Trails and burrows become more common down section and sparse brachiopods occur at the base.

Depositional environment

Koppe (1974a) noted that the Exmoor Formation displays several indicators of declining marine influence during its deposition and represents the transitional phase of the late Permian regression in the northern Bowen Basin. Most strikingly, there are marine fossils at the base and coal seams at the top. Bioturbation is progressively less abundant up-section whereas plant fragments are limited to the upper part of the formation, and pyritic sediments to the lower. Koppe suggested that the formation was probably laid down in a variety of near-shore environments including lagoonal, tidal flat, near-shore swamp and possibly fluvial.

Relationships and boundary criteria

The Exmoor Formation conformably overlies the Blenheim Formation and is overlain with apparent conformity by the Moranbah Coal Measures of the Blackwater Group. The distinctions are best identified from drill core. The lower boundary is marked by a change from interbedded dark grey mudstone, siltstone and lithic sandstone to a sequence consisting dominantly of quartzose sandstone in the upper informal subunit of the Blenheim Formation. The upper boundary lies at the top of the uppermost beds of dark grey micaceous siltstone or mudstone that have common bioturbation. It is also generally just below the lowermost significant coal seam in the Blackwater Group.

The unit can be recognised in gamma logs giving a consistently higher response than either the Blenheim Formation or Blackwater Group.

Fossils and age

Plant fragments in the unit include rare *Glossopteris,* and *Martiniopsis* has been tentatively identified from shell fragments near the base of the formation. A late Permian age is indicated and it may correlate with the lower part of the Flat Top Formation (Briggs, 1993, figure 1)

CALEN COAL MEASURES

Introduction

The Calen Coal Measures are an isolated area of early Permian coal-bearing sedimentary rocks north of Mackay. They are completely separated from the main part of the Bowen Basin in the Nebo Synclinorium to the west and the Strathmuir Synclinorium to the south. The term Calen Coal Measures was first used by Hill (*in* Hill & Denmead, 1960) for a unit described but not formally defined by Reid (1929). The rocks were described by Jensen & others (1966) and Clarke & others (1971). Early attempts to work the coal seams were described by Maitland (1889), Cameron (1903), Ball (1910) and Reid (1924, 1929). Coal was mined from two small collieries in the Calen area to the north of the study area from 1927 to 1939 for a return of ~9500t of high-ranking, non-coking, bituminous coal. The most recent exploration of the unit for coal was by BHP Company Ltd in 1964 (Faulkner & McKenzie, 1965) and Petrocarb Exploration NL (Bunny, 1971). The Department of Mines drilled two cored holes in the Calen Coal measures in 1973 and the results were reported by Koppe (1974b, 1975). The unit was also studied by Lo Grasso (1992) and Bloomer (1994).

The unit crops out in a narrow strip from near Elaroo Siding in the Proserpine 1:250 000 Sheet area to the Pioneer River in MIRANI. Most of the rocks crop out poorly in gently undulating plains, but the upper quartzose sandstone forms steep ridges near Calen and high, steep sided hills in the Mount Toby area north of the Pioneer River (Figure 70).

Type section

No type section was designated by previous workers, and insufficient work was done in this study to select a suitable section. However, the section in Hillalong NS5 (Koppe, 1974b, 1975) provides a reference section for part of the unit, although at least a third of the section is taken up by sills and dykes.

Thickness

Reid (1929) estimated that the Calen Coal Measures were ~300m thick, although this did not take into account repetition or loss of section by faulting. Faulkner & McKenzie (1965) showed a thickness of ~420m on their section in the Mirani–Kuttabul area, but their thickness of 3000–4500m in the Calen area would seem to be either a gross over-estimate or a drafting error.

Lithology

The Calen Coal measures comprise sandstone, siltstone, shale and coal. In the Mirani–Kuttabul area, Faulkner & McKenzie (1965) divided the unit into an upper and lower sequence. The lower part is ~150m thick and consists of medium-grained sandstone and sandy shale. One shale interval exposed in the vicinity of an adit south of Mount Toby is ~10m thick and has thin to very thin coal and carbonaceous shale bands. Unlike the Calen area farther north, no significant coal seams are known from the Mirani–Kuttabul area.

The upper part of the sequence begins with a prominent escarpment-forming quartzose sandstone 40–50m thick that appears to be a regionally extensive marker interval. It is mainly fine-grained with cross-bedding

Figure 70. Dip slopes of the upper escarpment-forming quartzose sandstone of the Calen Coal Measures viewed from the Mount Martin-Mount Charlton road.

and ripple marks. Above this sandstone is a 50m-thick flow-banded rhyolite, which was interpreted as a flow by Faulkner & McKenzie (1965), but is possibly a sill related to the Tertiary plugs and sill near The Leap. Above the ‘sill’, the upper sequence consists of ~200m of dominantly medium-grained, cross-bedded quartzose sandstone with minor shale. Faulkner & McKenzie (1965) noted that there are a few coal seams in the upper sequence, but that they are unlikely to be very extensive.

Koppe (1975) briefly described the petrography of the sandstones from Hillalong NS5. Quartzose sandstone is predominant with a lesser thickness of quartz-rich labile sandstone and one interval of quartz-poor lithic sandstone associated with carbonaceous rocks. The quartzose sandstone consists almost entirely of angular to subangular quartz with traces of chert and muscovite and a cement of silica and interstitial finely crystalline clay. In the quartz-rich labile sandstone, quartz still constitutes up to 50% of the clasts with indeterminate clouded labile clasts as the other main component. The lithic sandstones contain intermediate to acid volcanic rock fragments as the major clastic component along with minor plagioclase and only traces of quartz in a matrix of amorphous clay.

Environment of deposition

The Calen Coal Measures were probably originally continuous with the rest of the Bowen Basin before the deformation that developed the Connors Arch. Koppe (1974b, 1975) interpreted deposition as having occurred on a lower to upper delta plain with fluvial, overbank flats, swamps and channelled swamp environments. He suggested that some of the lithofacies were tidally influenced on the basis of numerous *Planolites* burrows and flaser bedding in the core, particularly in and above the quartzose sandstone marker. He noted that the composition of the sandstones shows a discernable relationship to the energy level of the depositional environment. The proportion of quartz is highest in the high-energy fluvial environments and lowest in the swamp environments. Bloomer (1994) disagreed with Koppe’s interpretation and argued that *Planolites* and flaser bedding are not necessarily diagnostic of a marine-influenced regime. Bloomer noted that the lack of marine body fossils and the widespread occurrence of siderite nodules, which cannot form in a marine environment, suggested that the environment was more likely to be non-marine. He recognised pebbly to sandy, low to high sinuosity braided streams and overbank and back-swamp facies. Palaeocurrents in the upper quartzose sandstone were from the south-east.

Geophysical response

The Calen Coal Measures have low responses in all radiometric channels, particularly in potassium, and has dark greyish to bluish hues on composite images. This contrasts with the somewhat higher potassium response in the Carmila beds due to their felsic volcanic component. Scattered areas of moderate to strong radiometric response are probably due to Tertiary felsic intrusive rocks.

The unit has a low magnetic response in the eastern part of the area. A moderate to high response in the western half may reflect a more magnetic basement or shallow intrusions.

Relationships and age

The Calen Coal Measures overlie the Carmila beds, but the exact relationship is unknown. The units are structurally concordant, but there may be a disconformity between them. The coal measures are intruded by a variety of felsic and mafic sills and dykes that are likely to have disrupted and metamorphosed any coal seams that are present. Reflectance determination reported by Koppe (1975) placed the coal well into the anthracite range.

In the Mirani area, the Calen Coal Measures have gentle dips ranging between 3–25° and Jensen & others (1966) suggested that the structure was possibly synclinal with a plunge to the north. In the Calen area, the dips are steeper (40–60°) and the unit appears to crop out on the eastern limb of a relatively tight syncline. The unit is extensively faulted.

Reid (1929) reported typical Permian plant fossils, such as *Glossopteris* and *Vertebraria* from the Calen Coal Measures. Several samples from Hillalong NS6 were processed for palynology, but all of the spores and pollen were intensely carbonised and could not be identified (Koppe, 1975). The unit is generally regarded as early Permian and correlated with the Collinsville Coal Measures. This is consistent with the lack of volcanic detritus and the quartzose nature of the sandstones in the unit.

BLACKWATER GROUP

GYRANDA SUBGROUP

Introduction

The Gyranda Formation was erected by Derrington & others (1959) for a non-marine succession between the top of the Back Creek Group and the base of the Baralaba Coal Measures, and was defined as the basal unit of the now obsolete Theodore Group. It was later included in the Blackwater Group by Dickins & Malone (1973). In the Banana area, Derrington & others divided the correlative succession above the Flat Top Formation into two units, the Banana Formation and the overlying Wiseman Formation. However, Dear & others (1971) preferred to group these two units regionally as the Gyranda Formation, although recognising that they are well-defined near Banana and that an approximate boundary could be drawn between the units through most of the Banana and Theodore areas.

The Gyranda Formation is herein raised in status to Gyranda Subgroup to incorporate the Banana and Wiseman Formations. The two units are easily recognisable in drillholes, but the subdivision is not always so easily recognised at the surface. Applying the name Gyranda Subgroup can satisfy the need for a name for such areas.

The Banana and Wiseman Formations have been mapped south to about Theodore, taking the boundary from the map of Derrington & Morgan (1960) and extrapolating it to the south, based on photo-interpretation. The lower boundary of the Wiseman Formation can be recognised from Banana as far south as Mount Wiseman as a prominent line of ridges that includes Mount Wiseman itself, and contrasts with the recessive topography of the Banana Formation. Farther south, the boundary is less clear, but locally is marked by a low ridge. South of Theodore the rocks are assigned to the undivided Gyranda Subgroup. In CRACOW, the Gyranda Subgroup is mainly recessive and poorly exposed, although some strike ridges of more resistant rocks occur towards the top of the unit in places, and probably represent the Wiseman Formation. Gray & Heywood (1978) recognised a two-fold subdivision in the Gyranda Formation in the core in GSQ Mundubbera 5, and suggested that they corresponded with the Banana and Wiseman Formations. The two units have also been recognised in UOD Cockatoo Creek 1 to the west (Green & others, 1997).

Type section

The type section of the Gyranda Formation as defined by Derrington & others (1959) is in Back Creek in CRACOW. Gray & Heywood (1978) suggested that the section cored in GSQ Mundubbera 5 from 214–879m could be regarded as a reference section for the unit and it is so designated here. It also provides reference section for the Banana and Wiseman Formations.

Thickness

Whitaker & others (1974) estimated the thickness as 480m, but this did not include part of the Flat Top Formation now assigned to the Gyranda Subgroup. A total of 665m was intersected in GSQ Mundubbera 5. Dear & others (1971) estimated a thickness of 914m for the unit near Theodore and Kianga.

Lithology

The Banana and Wiseman Formations are described below, and a full description of the lithology of the subgroup is given therein. What is now an undivided part of the subgroup was described by Whitaker & others (1974) in CRACOW as consisting of mudstone, lithic sandstone (locally calcareous), fine-grained tuff, minor siltstone and rare conglomerate and volcanic breccia. The mudstone is thinly laminated, green to brown and commonly has abundant carbonised plant debris. The sandstone is generally green to brown and is almost invariably trough cross-bedded. It is composed mainly of volcanic detritus. Modal analyses by Baker & others (1993) show the framework grains to consist entirely of volcanic lithics (45–65%) and subordinate plagioclase (20–30%).

Relationships and boundary criteria

The Gyranda Subgroup overlies the Flat Top Formation conformably and is overlain conformably by the Baralaba Coal Measures, which are marked by ridges corresponding with the tuffaceous Kaloola Member. According to Mollan & others (1972) and Whitaker & others (1974), hard, white and brown cherty tuff containing well-preserved leaf impressions is common at the top of the Gyranda Formation, but Gray & Heywood (1978) noted that this rock type is more characteristic of the Baralaba Coal Measures (specifically the Kaloola Member). Therefore it has been mapped as Kaloola Member and the boundary between the two units on CRACOW is placed ~1km east of that of Mollan & others (1972). The boundary of Whitaker & others (1974) appears to agree with that accepted here.

Fossils and age

Mollan & others (1972) gave a late Permian age based on floral evidence. This is in accord with the presence of palynofloras of unit APP5 (Green & others, 1997; Price, 1997). Webb & McDougall (1967) dated biotite from a tuff in the unit at 244Ma (recalculated), but this Early Triassic age is obviously a minimum.

BANANA FORMATION

Introduction

Derrington & others (1959) defined the Banana Formation cropping out in an arcuate belt from Kianga to Banana. As noted above, Dear & others (1971) preferred to group it with the Wiseman Formation into the correlative Gyranda Formation, which had been defined in the Cracow area. As also noted, the Banana and Wiseman Formations have been mapped as far south as Theodore. Farther south the rocks are assigned to the undivided Gyranda Subgroup. The Banana Formation can easily be recognised in stratigraphic holes and petroleum wells (Colton, 1970; Gray & Heywood, 1978; Green & others, 1997).

Type section

Derrington & others (1959) gave the type area as Banana township. The unit is faulted against the Back Creek Group along the Banana Thrust in this area, and a complete section is unlikely to be found, even if sufficient outcrop were available. Therefore the lower part of the Gyranda Subgroup intersected in GSQ Mundubbera 5 from 521–879m is designated as a reference section (Gray & Heywood, 1978). It consists of silty mudstone and shale with minor tuff.

Thickness

The Banana Formation is 358m thick in GSQ Mundubbera 5 and has a maximum thickness of 526m in UOD Cockatoo Creek 1.

Lithology

The Banana Formation crops out poorly, but is locally well exposed near Banana. As described by Derrington & others (1959), it consists dominantly of olive green mudstone and siltstone and lesser medium to coarse-grained feldspatholithic sandstone. Minor coal seams were intersected in water bores. Dear & others

(1971) refer to sandstone intervals up to 30m thick in places in the lower unit of the Gyranda Formation, but note that they are sporadic and less conspicuous than in the upper unit (Wiseman Formation).

In core, the siltstone is generally pale grey, poorly sorted, tuffaceous, locally calcareous and has carbonaceous material as disseminations and laminae. It is interbedded with shale, and slump structures are common. Thin beds and laminae of white to pale green, calcareous, silty tuff occur through the unit.

Depositional environment

Spinose acritarchs were recorded by Price (1981) and Foster (1982), and indicate brackish water or marine influences during deposition. The dominance of mudstone and siltstone indicates quiet water. No marine macrofossils have been found.

Relationships and boundary criteria

The Banana Formation overlies the Flat Top Formation conformably and is overlain conformably by the Wiseman Formation. The lower boundary of the Wiseman Formation can be recognised from Banana as far south as Mount Wiseman as a prominent line of ridges that includes Mount Wiseman itself (Figure 71), and contrasts with the recessive topography of the Banana Formation. To the south, the boundary is less clear, but locally is marked by a low ridge.

Fossils and age

Late Permian palynofloras belonging to unit APP5 have been recorded from the unit (Green & others, 1997; Price, 1997). Leaves of *Glossopteris* are found through the unit.

WISEMAN FORMATION

Introduction

Derrington & others (1959) defined the Wiseman Formation in the Banana area, but as noted above, Dear & others (1971) preferred to group it with the Banana Formation into the Gyranda Formation. As also noted, the Banana and Wiseman Formations have been mapped as far south as Theodore. Farther south the rocks are assigned to the undivided Gyranda Subgroup. The Wiseman Formation can be recognised in stratigraphic holes and petroleum wells (Colton, 1970; Gray & Heywood, 1978; Green & others, 1997).

Type section

Derrington & others (1959) gave the type area as Mount Wiseman (Figure 71). No outcrop sections have been published from this area and examining it was outside the scope of this project. Therefore the upper part of the Gyranda Subgroup intersected in GSQ Mundubbera 5 from 214–521m is designated as a reference section (Gray & Heywood, 1978). It consists of siltstone, sandstone and lesser silty mudstone.

Thickness

The Wiseman Formation is 307m thick in GSQ Mundubbera 5 and is 321m thick in UOD Cockatoo Creek 1.

Lithology

Dear & others (1971) described the upper part of the Gyranda Formation (Wiseman Formation) as consisting of lithic sandstone, thick interbedded successions of siltstone and mudstone and some pebble to granule conglomerate. The sandstones are mostly brownish to greenish grey, usually well sorted and many have abundant calcite cement. Cross-bedding is common. They are feldspatholithic with felsic to intermediate volcanic fragments and only minor quartz, consistent with the modal analyses of Baker & others (1993). Flakes of biotite are common in some specimens, particularly towards the top of the formation.

Siltstones and mudstones are mostly thinly laminated. Cone-in-cone limestone concretions are common. In the conglomerates, the pebbles are subrounded to rounded and are mostly volcanic rocks and indurated siltstone. Dear & others (1971) noted that many of the volcanics contain biotite flakes.

In GSQ Mundubbera 5, the siltstone is pale green and grey, and sandy to cherty in places. Carbonaceous shale laminae are common and small sedimentary dykes and flame and slump structures are present locally. The sandstone is light grey to greenish grey, very fine to coarse-grained, labile, calcareous and poorly to fairly sorted. It is partly micaceous and slightly tuffaceous. In the uppermost 40m, the sandstone becomes coarser

Figure 71. Mount Wiseman, the prominent cuesta that marks the base of the Wiseman Formation of the Gyranda Subgroup; viewed from the north-east along the Leichhardt Highway ~7km south of Banana township

and is locally conglomeratic with volcanic granules and pebbles. Coaly laminae and disseminated carbonaceous material occur throughout the sandstone. Bedding is thin to very thick and graded. Green & others (1997) reported a series of such coarsening-up and thickening-up cycles in the Wiseman Formation. Thin coal seams were reported at the top of some sandstone beds before a return to mudstone deposition.

Depositional environment

The Wiseman Formation is generally considered to have been deposited in a fluvial setting, based on the presence of medium to coarse-grained cross-bedded sandstone. However, Green & others (1997) point out that the coarsening-up and thickening-up cycles in GSQ Mundubbera 5 are more typical of progradational events in a delta system, the coaly beds at the top of the sandstone beds reflecting the presence of swamps on the top of the delta. Spinose acritarchs are only sporadically distributed through the unit compared with the Banana Formation (Foster, 1982), indicating a decreasing marine or brackish influence. The Wiseman Formation is the northern correlative of the subsurface marine Burunga Formation, and this is consistent with a southward progression from fluvial in the Banana area, through deltaic environments into a sea.

Relationships and boundary criteria

The Wiseman Formation overlies the Banana Formation conformably and in outcrop is distinguished from the it by the appearance of more resistant sandstone and siltstone beds. It is overlain conformably by the Baralaba Coal Measures. In the mapped area, the lower part of the latter is marked by the resistant ridge-forming Kaloola Member, which contains beds of hard white cherty tuff with abundant leaf impressions.

Fossils and age

Late Permian palynofloras belonging to unit APP5 have been recorded from the unit (Green & others, 1997; Price, 1997). Leaves of *Glossopteris* are found through the unit and Dear & others (1971) reported that fossil logs are common at several intervals.

BARALABA COAL MEASURES

Introduction

The name Baralaba Coal Measures was first used by Reid (1944) in describing the coal-bearing sequence at Baralaba, but was subsequently traced south-east by him into the Theodore area (Reid, 1945a,b). Mollan &

others (1972) extended the unit into CRACOW, where the rocks were previously named the Kia Ora Formation by Derrington & others (1959). Dear & others (1971) defined a tuffaceous unit, the Kaloola Member, forming the lowermost part of the Baralaba Coal Measures. The member forms a distinctive series of ridges, and has been photo-interpreted into CRACOW, although it was not recognised there by Mollan & others (1972) or Whitaker & others (1974) who specifically excluded the tuffs from the Baralaba Coal Measures. Outcrop is poor in the rest of the unit, the best exposures being in the Moura and Kianga opencut mines.

Type section

Being established before the advent of formal stratigraphic procedures, no type section ever appears to have been defined for the Baralaba Coal Measures. The rocks crop out poorly, and it would be difficult to designate a naturally exposed section. The lower 214m of the unit was intersected by GSQ Mundubbera 5 (Gray & Heywood, 1978), but there is no complete section. Logs and cuttings sections from UOD Burunga 1 and UOD Cockatoo Creek 1 provide complete sections (Green & others, 1997, figure 12).

Dear & others (1971, figure 10) gave a type section for the Kaloola Member in a tributary of Kianga Creek, east of Nipan. This unit is probably represented by the interval 79–214m in GSQ Mundubbera 5.

Thickness

Dear & others (1971) gave an estimate of up to 455m for the Baralaba Coal Measures, of which ~90–120m were tuffaceous rocks of the Kaloola Member. In the subsurface, the unit has a maximum thickness of 556m in UOD Burunga 1 and ~530m in UOD Cockatoo Creek 1.

Lithology

Dear & others (1971) defined the Kaloola Member as consisting of siltstone, feldspathic and lithic sandstone, tuff and conglomerate. The base is gradational with the Mount Wiseman Formation, but is marked by more resistant ridge-forming beds of white-weathering siltstone, fine-grained lithic sandstone and vitric tuff. Fossil logs are common and beds of silicified mudstone and siltstone crowded with leaves of *Glossopteris* (chert leaf beds) occur in the upper part of the unit (Rigby, 1972; Beeston, 1972). Many of the siltstones are tuffaceous and contain abundant devitrified glass shards and flakes of biotite. White to buff lithic, crystal and vitric tuffs and volcanic breccia of andesitic to dacitic composition are abundant. Where reworked, they grade into siltstone or sandstone. The thickest tuff bed recorded in GSQ Mundubbera 5 is 7m. Biotite is also a conspicuous constituent of the tuffs.

Sandstones are cross-bedded. Some of the beds intersected in GSQ Mundubbera 5 are up to 10m thick. They consist of felsic to intermediate volcanic rock fragments (40–80%), feldspar (20–50%) and subordinate quartz (5–10%) and conspicuous biotite. They are well sorted and have a fine clayey matrix or carbonate cement. Thin beds of granule and pebble conglomerate contain subangular to subrounded volcanic clasts as in the sandstone.

Carbonaceous mudstone is exposed in road cutting west of Theodore and thin poor quality coal seams grading into carbonaceous shale are locally present, although Goscombe (1968) recorded a seam nearly 2m thick in the unit ~6km south of Theodore.

The upper part of the Baralaba Coal Measures consists of lithic and feldspathic sandstone, siltstone, mudstone, conglomerate and coal. Tuffaceous rocks are present, but are less common than in the Kaloola Member. The sandstones are calcareous and many have a *fontainbleu* texture with framework grains ‘floating’ in coarse-grained calcite cement. Framework grains in the modal analyses given by Baker & others (1993) are plagioclase (7–47%), volcanic fragments (53–93%) and quartz (0–10%). Up to 20% carbonate or silica cement is present. The sandstones are prominently cross bedded, and excellent exposures occur in the highwalls of the opencut coal mines. Lensoidal channel forms up to 50m thick and 300m wide can be recognised. The only large clasts are logs and mudstone intraclasts. Thinly interbedded mudstone and siltstone contain a variety of structures, including flaser bedding, ripples, normal and reversed grading, loading and flame structures. They contain thin laminae of white tuff.

From three to ten coal seams >1m thick occur in the Moura–Kianga area and have been mined by a series of major opencut and underground mines since the late 1950s.

Depositional environment

Fluvial conditions prevailed during deposition of the Baralaba Coal Measures, although occasional incursions of brackish water are indicated by a few records of spinose acritarchs (Foster, 1979, 1982). Depositional models for the interseam intervals exposed in the Kianga and Moura highwalls were described briefly by Mallett & others (1983) and include a variety of facies including channel sands and muddy overbank, flood basin and lacustrine deposits. Deposition of the coal-bearing intervals was primarily peat swamp with periodic sediment influxes as channels migrated.

Relationships and boundary criteria

The Baralaba Coal Measures conformably overlie the Wiseman Formation of the Gyranda Subgroup. The basal Kaloola Member is recognised by the abundance of tuffaceous rocks, which are relatively less common in the upper part of the unit. The top of the Baralaba Coal Measures in many places is transitional with the overlying Rewan Group, the boundary in the subsurface being taken at the top of the highest coal seam. Towards the margins of the Taroom Trough, the relationship is considered to be unconformable (Fielding & others, 1990). In outcrop, west of the Dawson River in CRACOW, the base of the Rewan Group as mapped by Mollan & others (1972) and Whitaker & others (1974) is marked by a thick bed of pebble conglomerate and could reflect this unconformity.

Fossils and age

Late Permian palynofloras in the Baralaba Coal Measures are identified with unit APP5 passing into APP6 near the top (Price, 1997). The latter zone extends into the basal Rewan Group. Plant fossils, in particular *Glossopteris* and fossil logs are abundant in parts of the Baralaba Coal Measures, and were described by Rigby (1972) and Beeston (1972).

MORANBAH COAL MEASURES

Introduction

The Moranbah Coal Measures, which were named and defined by Koppe (1978, pages 444–45), form the basal unit of the Blackwater Group in the northern part of the Bowen Basin. The name was introduced for rocks previously included in the lower part of the Fair Hill Formation that lacked abundant tuffs. In the north-west the rocks were originally assigned to the Hail Creek beds by Jensen (1968), but Koppe extended the Moranbah Coal Measures to include them also. As defined by Koppe, the unit now extends from near the Peak Downs Highway south of Nebo around the apex of the Nebo Synclinorium and south to the Saraji area in the western part of the basin. In this study area, the rocks are limited to the western edge of NEBO. They were not examined and the mapped boundaries are based on a map produced by Lance Grimstone & Associates for Terence Willsteed & Associates (2001, figure 3). The unit was described by Hutton & others (1998) in the Mount Coolon area, immediately west of the study area.

Type section

Koppe (1978) designated the type section of the formation in the interval 152.4–411.1m in continuously cored Grosvenor NS14 which was drilled by the Department of Mines south of the Goonyella mine. Core is stored at the GSQ’s Zillmere Exploration Data Centre. A surface reference section was also designated in Rosella Creek in the northern part of the basin.

Thickness

The thickness in the type section is 259m and along the western part of the basin, the unit is 200–400m thick. It thickens considerably eastwards and is >760m thick at Kemmis Creek north-west of Nebo.

Lithology

The Moranbah Coal Measures are composed of lithic sandstone, siltstone, carbonaceous mudstone, coal, locally cherty mudstone and minor conglomerate. Orange to cream, micaceous, quartz-poor, lithic sandstone forms the major part of the outcrop. It is commonly medium to coarse-grained and locally granular. Koppe (1978) gave the modal composition of the sandstone as quartz (1–10%), feldspar (2–20%) and volcanic rock fragments (50–70%). Bedding thickness ranges from thin to thick, but commonly is medium to thick. Cross-bedding structures include small, medium and locally large scale low-angle trough, tabular and planar cross-stratification. Bedded sequences often thin and thicken laterally and fining and coarsening upward cycles are common. Mudstone rip-up clasts are locally common along bedding plane surfaces. Orange-yellow sideritic concretions occur locally in sandstone dominated sequences. Rare concretions are up to 2m wide and 30–50cm thick. However, they are more commonly <1m wide and 20cm thick.

Basal sandstones adjacent to the contact with the underlying Exmoor Formation are weakly burrowed. This indicates that local marine transgressions occurred during the initial phases of deposition of the Moranbah Coal Measures.

Koppe (1978) noted that conglomerate is a significant component of the unit on the eastern side of the basin. It crops out as thin to thick beds and lenses interbedded with thick-bedded sandstone and at the base of fining upward sequences. It contains mainly well-rounded pebbles of acid or intermediate volcanics, medium-grained granitoid and quartzite.

Siltstone and mudstone is light to dark grey, locally carbonaceous and fossiliferous with muscovite flakes common along bedding and lamination planes. Bedding is commonly thin and internally laminated. Fossil wood and, in particular, leaf impressions occur on bedding planes and partings.

Oxidized dull grey to dark brown coal is moderately common along the eastern side of the Nebo Synclinorium. Coaly intervals are thin to thick-bedded and locally contain mudstone, siltstone and carbonaceous mudstone intervals. Cream-coloured carbonate nodules and box veining are common. According to Koppe (1978), the coal is developed in as many as 24 individual seams with an aggregate thickness of 15–30m.

Fossil wood occurs locally in sandstone as fragments and logs. These are ferruginised and locally opalised, but well preserved opaline fossil wood is not as common in the Moranbah Coal Measures as in the Fort Cooper Coal Measures.

Although tuff beds are mostly insignificant, one major bed, mostly 1–1.5mm thick, has been recognised in the Moranbah Coal Measures and forms an important marker traceable for over 300km along strike. It was originally referred to as the “P Tuff”, but has been formalised as the Platypus Tuff Bed by Michaelsen & others (2001). It is described as a tuffaceous mudstone and contains 10–15% quartz crystal fragments that are up to 1mm and euhedral bronze biotite.

Environment of deposition

The Moranbah Coal Measures were interpreted by Johnson (1983) as having been deposited in a low relief, cold, fluviatile environment which also contained marshes, lakes and peat land. Falkner & Fielding (1990) suggested that the unit accumulated in an upper delta plain environment that passed southwards into a lower delta plain in which the German Creek Coal Measures were deposited. To the north, environments were more akin to alluvial plains. Falkner & Fielding described the depositional system in terms of seven facies that could be grouped into three facies associations — channel-fill, overbank and peat mires.

Relationships and boundary criteria

The Moranbah Coal measures conformably overlie the Exmoor Formation from which it is distinguished by the quartz-poor, labile composition of its constituent sandstones, the absence of quantitatively significant tuffs and the presence of major low-ash coal seams. The Moranbah Coal Measures are conformably overlain by the Fort Cooper Coal Measures, which contain abundant tuffs and inferior high-ash coal. In the south-west of its mapped extent, the unit grades laterally into the upper part of the German Creek Coal Measures and McMillan Formation.

Age

Fossil wood and in particular leaf impressions of *Glossopteris* sp., *Phyllotheca* sp., and *Sphenosteris* sp. (?*Libfokia*) occur on bedding planes and partings. According to Koppe (1978) the microfloral content of the formation is consistent with the younger part of upper stage 5 (now referred to as APP5 — Price, 1997). This is late Kazanian. Dating of the Platypus Tuff Bed by Michaelsen & others (2001) using the SHRIMP U-Pb method on zircon gave an age of 258.9±2.7Ma. Because of deficiencies in calibration of the late Permian stage divisions, they did not attempt to make a stage assignment for the unit on the basis of its geochronology, but noted that it was consistent with the palynological data.

FORT COOPER COAL MEASURES

Introduction

The Fort Cooper Coal Measures were named and described by Reid (1946) but not rigidly defined. Koppe (1978) extended the unit throughout the northern part of the basin and it can be traced from near the Peak

Downs Highway south of Nebo around the apex of the Bowen Basin to south of Saraji in the western part of the basin where it passes laterally into the Fair Hill and Burngrove Formations.

Type section

The type section of the Fort Cooper Coal Measures was given by Jensen (1975) and is in the headwaters of Hail Creek in HILLALONG, where the unit is ~400m thick and composed of conglomerate, green lithic sandstone, carbonaceous mudstone, coal and thin beds of greyish white cherty tuff containing abundant leaf impressions

Thickness

Koppe (1978) determined a thickness of 400m for the Fort Cooper Coal Measures, mainly from drillhole data.

Lithology

Regionally the sandstone is commonly brown to green, fine to medium and locally medium to coarse-grained, micaceous lithic (volcanilithic) in composition. Bedding is commonly thin to medium (flaggy) and locally thick. Medium to thick, locally interfingering, pebbly sandstone bodies also occur. Bedding contacts are locally erosional and outlined by small and medium scale scour and fill structures.

Internal bedding structures such as horizontal and ripple-cross lamination and small-scale cross-stratification are common in thin bedded sandstone. Medium and thick-bedded sandstone commonly has small to medium-scale planar and low-angle tabular cross-stratification. Cherty mudstone rip-up clasts and small pebbles locally form thin basal lag deposits in medium to thick beds. Sandstone also locally contains carbonaceous and coaly fragments. Sideritic concretions are common in sandstone of the Fort Cooper Coal Measures. These concretions are orange to yellow, commonly ovate in shape and up to 3m long.

Polymictic conglomerate and pebbly sandstone are composed of sub-rounded to well-rounded clasts of granite, fine-grained andesite, quartzite, cherty mudstone, lithic sandstone, ignimbrite and other fine-grained volcanics and fossil wood. Pebble conglomerate and pebbly sandstone are commonly thin and medium bedded, locally lenticular and occur at the base of fining-upward cycles. Conglomerate occurs as lags in lenticular sandstone bodies and in overbank sequences.

Tuffaceous and cherty mudstone is abundant in the Fort Cooper Coal Measures and is the most important feature distinguishing this unit from the other formations of the Blackwater Group. The tuff is cream-grey, commonly thin-bedded and occurs mostly within the coal seams where it occupies up to 50% or more of the total coal interval (Anderson, 1985). Tuff beds crop out poorly but are often interbedded with cherty mudstone. The mudstone is richly fossiliferous and contains abundant leaf and stem impressions. Locally, cherty and tuffaceous mudstone contains chloritised mudstone rip-up clasts at the base of beds.

Fossil wood is common in the Fort Cooper Coal Measures, particularly in sandstone beds. It occurs as branches and logs which are commonly parallel to bedding, but locally small logs in growth position crop out in argillaceous horizons. Fossil wood in this formation is more common, frequently better preserved, and more opaline and siliceous than fossil wood in the Rangal Coal Measures, as well as being less ferruginised than that in the Moranbah Coal Measures. In areas of poor outcrop, surface rubble containing abundant well preserved, highly siliceous and partially opaline wood commonly indicates subcropping Fort Cooper Coal Measures with a residual soil cover.

Coal seams crop out poorly, are commonly extensively oxidized, thin to medium-bedded and contain moderate quantities of non-coaly material such as mudstone, tuff, sandstone and tonstein. Seams are also commonly intruded and contain cream carbonate nodules and box veining.

Environment of deposition

The Fort Cooper Coal Measures are interpreted as deposits in a generally low-energy environment. Most sandstone beds and units are interpreted as overbank splays and channel sands. The interbedded nature of sandstone, mudstone, siltstone and mudstone suggest a depositional environment similar to a large peat swamp drained by a series of small to medium-sized channels and streams. The association of tuffs with the coals is due to their better preservation in the peat swamps rather than in the channels and overbank areas.

Relationships

The Fort Cooper Coal Measures conformably overlie the Moranbah Coal Measures and are overlain by the Rangal Coal Measures from which they are distinguished by having abundant tuff beds and thin, dirty, uneconomic coal seams.

The Fort Cooper Coal Measures are the northern Bowen Basin equivalent of the Burngrove and Fair Hill Formations (Koppe, 1978; Jensen, 1975).

Age

The stratigraphic position of the Fort Cooper Coal Measures indicates that they are late Permian and probably Kazanian to Tatarian.

RANGAL COAL MEASURES

Introduction

The Rangal Coal Measures are the uppermost part of the Blackwater Group and the youngest coal-bearing sequence in the Bowen Basin. They extend throughout most of the Bowen Basin except in the south-east where the rocks are assigned to the Baralaba Coal Measures. In the north-eastern part of the basin they were originally mapped as the Elphinstone Coal Measures by Reid (1946), but Koppe (1978) suggested that this name be discontinued in favour of the Rangal Coal Measures. In the study area, they are restricted to the western edge of NEBO. Outcrop is poor and limited by deposits of alluvium and colluvium.

Type section

Malone & others (1969) gave a type section in Deep Creek 5km west of Taurus homestead to the south of Blackwater.

Thickness

The Rangal Coal Measures are relatively thin and 100–300m thick.

Lithology

This formation is composed of sandstone, coal, siltstone, carbonaceous mudstone, mudstone (locally cherty), and rare pebbly sandstone. The sandstone is dominantly grey but locally is also brown to cream and green in outcrop, probably due to the presence of chlorite-rich volcaniclastic detritus. Sandstone is very fine to medium-grained, micaceous and lithic (volcanolithic) labile in composition. Pebbly sandstones contain clasts of granite, quartzite, intermediate volcanics, andesite, as well as intraformational clasts of carbonaceous mudstone and sandstone.

Bedding in the Rangal Coal Measures is thin to medium, but locally thick bedded lenses of sandstone do occur. These lenses, which commonly contain interbeds and lag deposits of pebbly sandstone, probably represent discrete channel systems. Sandstone beds exhibit a variety of internal bedding structures including small and medium-scale ripple-cross-lamination and small to medium-scale low-angle through and planar cross-bedding. Fining and coarsening upward cycles are preserved throughout, particularly at the top and base of thin sandstone units and in sandstone lenses.

Siltstone and mudstone range from grey-fawn to brown or dark grey where carbonaceous and are commonly micaceous. Cherty mudstone is cream, moderately indurated, and locally tuffaceous. The argillaceous sediments are commonly thin bedded and internally laminated with some ripple-cross laminations. Flaser bedding and starved ripples are locally evident in sequences associated with fine-grained sandstone.

Leaf and stem impressions occur throughout the Rangal Coal Measures along bedding and parting planes within argillaceous sediments. Fragments of partially opalised fossil wood occur in more arenaceous sequences. Fossil wood is not as common in the Rangal Coal Measures as it is in the other coal-bearing units.

Environment of deposition

Falkner & Fielding (1990) suggested that the Rangal Coal Measures were deposited on a vast alluvial plain crossed by deep channels that flowed axially within the basin. The entire basin at this time was covered by peat-forming wetland environments and associated drainage systems, and corresponded with a lull in volcanic activity in the east (Fielding & others, 1990). Mallett (1983) also discussed the depositional environments in the Rangal Coal Measures and came to a similar conclusion. Like the Moranbah Coal Measures, the depositional system can be described in terms of seven facies grouped into three facies associations — channel-fill, overbank and peat mires (Falkner & Fielding, 1990). Most of the sediments are fine-grained and were deposited distally to the channels and are a mixture of fine-grained overbank sediments and sandstone splays.

Relationships

The Rangal Coal Measures overlie the Fort Cooper Coal Measures in the northern part of the Bowen Basin, the latter being characterised by abundant tuffs and poor quality coal seams. The contact between the Rangal Coal Measures and the overlying Rewan Group is gradational. Some workers have placed the boundary at the top of the uppermost carbonaceous horizon, which is usually the uppermost coal unit (Quinn, 1985). However, Anderson (1985) suggested that the boundary be taken at the change in colour of the sandstone in core. The Rangal Coal Measures are almost exclusively grey, whereas the Rewan Group sandstones are green.

Age

The Rangal Coal Measures are late Permian (Tatarian) and have palynomorphs that can be assigned to the upper part of unit APP5.

REWAN GROUP

Introduction

The Rewan Group is an extensive unit cropping out across the entire Bowen Basin and into the Galilee Basin to the west and north. Green & others (1997) described the early nomenclature of the unit. It was formerly named the Rewan Formation (Hill, 1957; Mollan & others, 1969, 1972; Whitaker & others, 1974), but was upgraded to group status by Jensen (1975). None of the constituent divisions of the group are recognised in the study area, where it forms generally flat topography with a few gentle rises and strike ridges in the western part of THEODORE and CRACOW and also a small area in western NEBO. Exposure is generally poor and the unit is usually covered by deep soil that formerly supported extensive areas of brigalow scrub.

Type area

Mollan & others (1969) proposed a 515m-thick type section north of Rewan homestead in the Springsure 1:250 000 Sheet area.

Thickness

The top of the formation does not crop out in the study area, but the maximum thickness in petroleum wells in the area studied by Green & others (1997) is ~1400m.

Lithology

In general, the Rewan Group consists of fine to medium-grained, rarely coarse-grained lithic sandstone and reddish brown, green and khaki mudstone. In CRACOW, a volcanilithic pebble conglomerate forms the base of the unit and is overlain by pebbly lithic sandstone and brown mudstone. The sandstones commonly have calcareous cement.

Depositional environment

Kassan (1993) considered that the Rewan Group was deposited in a fluvial and lacustrine environment in an internally drained rapidly subsiding basin. The climate was warm with arid or strongly seasonal rainfall conditions accounting for the reddening of the sediments (Dickins, 1982). Minor occurrences of spinose acritarchs suggest occasional brackish influences in an otherwise terrestrial environment (de Jersey, 1979)

Relationships and boundary criteria

West of the Dawson River in CRACOW, the base of the Rewan Group as mapped by Mollan & others (1972) and Whitaker & others (1974), is marked by a thick bed of pebble conglomerate. This could reflect a local unconformity, although over most of the Taroom Trough, the relationship is conformable and the boundary is taken at the top of the highest coal seam. The boundary of the Rewan Group with the Clematis Group does not occur in the study area, but the Rewan Group is unconformably overlain by the quartzose sandstones of the Jurassic Precipice Sandstone in western CRACOW.

Fossils and age

The Rewan Group is latest Permian to Early Triassic (Scythian) and is generally associated with palynofloras assigned to APP6 and APT1 and APT2 (Price, 1997).

TRIASSIC VOLCANIC ROCKS

MOUNT EAGLE VOLCANICS

Introduction

The Mount Eagle beds were named and defined by Whitaker & others (1974) for volcanic and sedimentary rocks exposed west of the Burnett River between Yards Gully and Smalls Creek, 18km north-west of Eidsvold (Figure 72), and cropping out over ~50km^2. Because the unit is dominantly volcanic, the name is herein changed to Mount Eagle Volcanics. No significant changes to the previously known distribution have been made.

The topography is rugged with the volcanic rocks forming a plateau over the underlying recessive granitic rocks of the Rawbelle Batholith.

Type locality

Whitaker & others (1974) assigned a type locality in the gorge of Wuruma Dam. Typical rocks of the Mount Eagle Volcanics can be observed over several hundred metres of solid outcrop. The main rock type is a pale orange, welded, crystal-rich rhyolitic ignimbrite containing abundant K-feldspar and fiamme.

Lithology

The unit consists predominantly of lava flows, ignimbrite and volcanolithic sediments, mostly of felsic composition, which distinguishes them from the volcano-sedimentary rocks of the Nogo beds. They include pink to pale orange, crystal-rich, moderately lithic-rich rhyolitic volcaniclastic rocks; crystal-rich, fiamme-rich, mostly rhyolitic, ignimbrite; flow banded porphyritic rhyolite; spherulitic rhyolite; and volcanic breccias. The common K-feldspar phenocrysts and crystal fragments mostly have a reddish hue due to hematite alteration.

A typical crystal-rich, fiamme-rich, welded, rhyolitic ignimbrite crops out in Jackass Creek (Figure 73d). The fiamme are stretched and strongly elongated, and in places are 25–40cm long. The crystals are mostly red or pink K-feldspar; less common are clear quartz crystals. Lithic fragments include cream, flow-banded rhyolite and other aphyric volcanic rocks. The matrix is very fine, siliceous and is commonly purplish-grey to orange.

Strongly flow-banded rhyolite is also common. It typically has brownish cream, orange, reddish pink to purple hues.

Around Mount Eagle and west of Wuruma Dam near the Eagle gold prospect at MGA 295700 7211800, spherulitic rhyolite with sporadic layers of ‘thunder eggs’ up to 10cm were observed. At the prospect, brecciated, silicified rhyolite forms a zone with surface dimensions of 300m by 30m trending north-north-west. The altered zone occurs within rhyolitic tuff near the contact with the underlying Rawbelle Batholith and hornfelsed andesite of the Nogo beds. It is characterised by moderate to strong chalcedonic silicification and veining typical of near-surface hot-spring activity. Hydraulic fracturing caused by boiling is evidenced by breccias with lath shaped fragments in a chalcedonic microcrystalline quartz matrix. Several phases of post-brecciation, chalcedonic to microcrystalline quartz veining are evident. Disseminated fine-grained pyrite (to 5%) is commonly associated with the silica. Spheroidal structures in the silica that range in size from 1mm to several centimetres may be geyserite. Weak to moderate clay alteration forms a thin selvage around the silicification.

Brecciated porphyritic rhyolite is very common throughout the Mount Eagle Volcanics (Figure 73a). Most of these rocks are autobreccia, but some could be vent breccias. The clasts appear to be angular and locally show jigsaw fits, for example along Euroka Road at MGA 299730 7197580. Elsewhere, such as at the old boat ramp at Wuruma Lake at MGA 2969000 7212500, the larger clasts are sub-rounded and appear to have been milled.

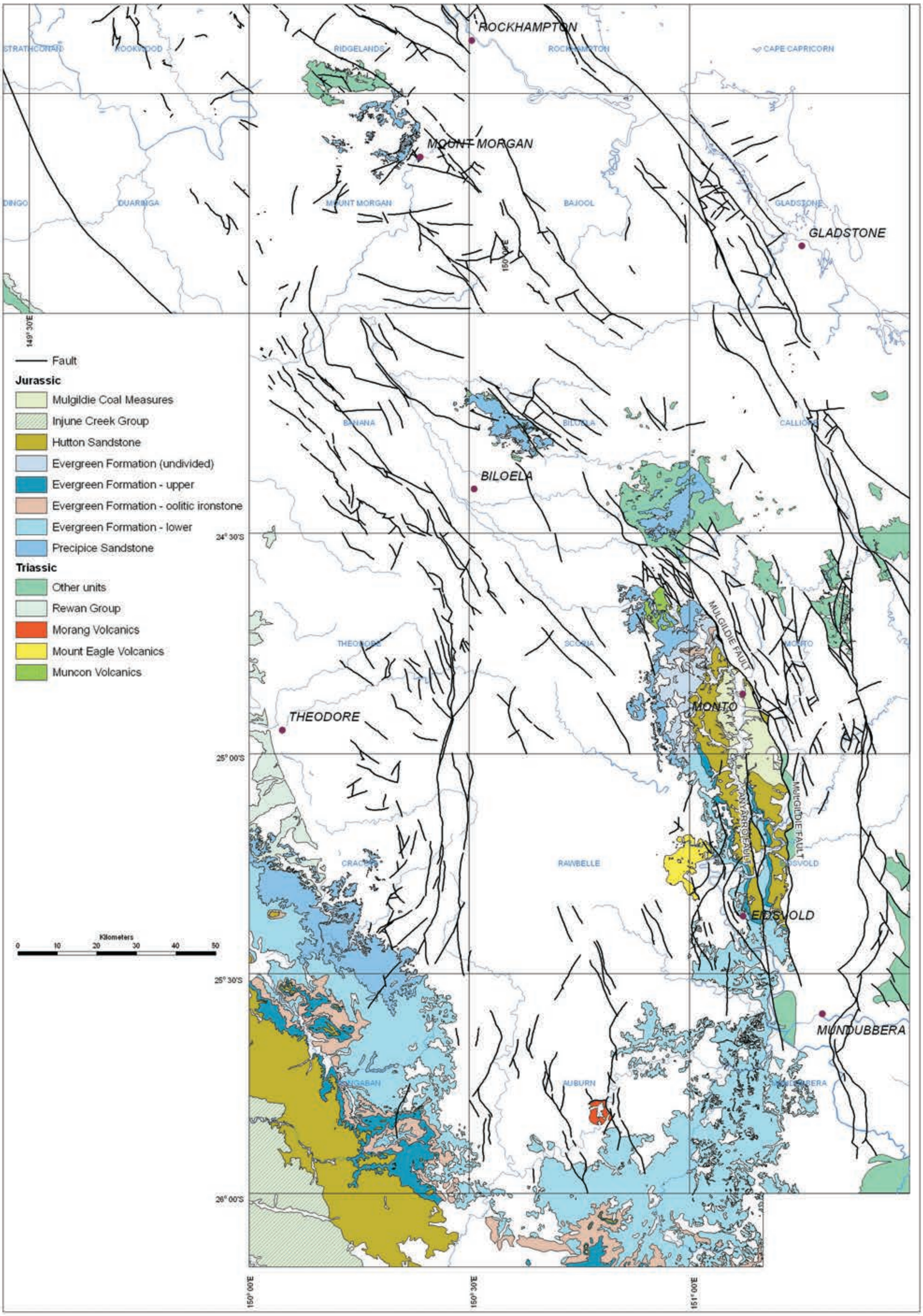

Figure 72. Distribution of Triassic and Jurassic units in central Queensland

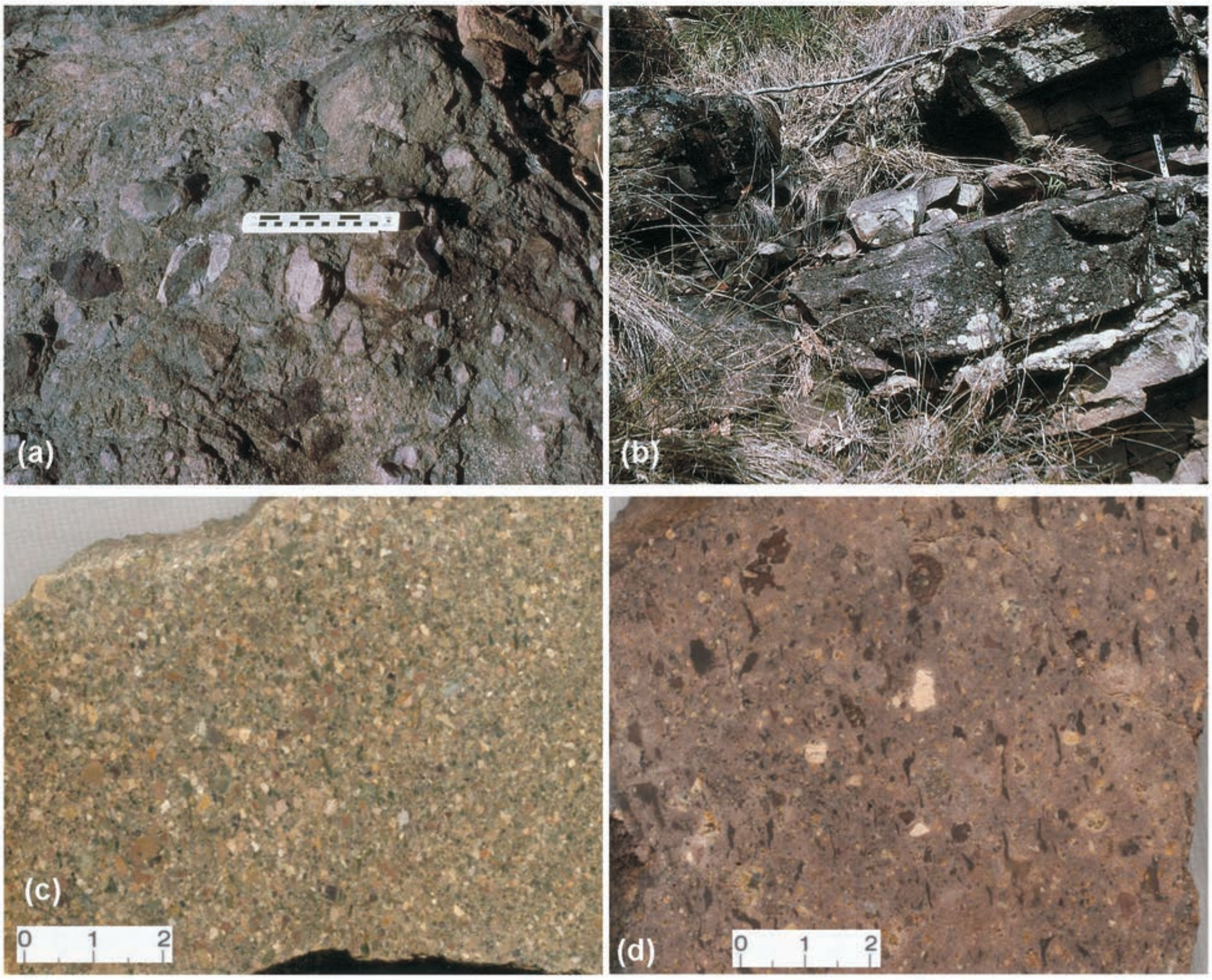

Figure 73. Mount Eagle Volcanics
(a) Poorly sorted rhyolitic volcanic rudite. Southern end of Wuruma Dam ~3km north of Mount Eagle at MGA 297146 7210486 (QFG2233)
(b) Well-bedded volcaniclastic sandstone. Jackass Creek about 4km south-west of Mount Eagle at MGA 294938 7204222 (QFG2926)
(c) Moderately sorted volcaniclastic sandstone from the outcrop in (b). Scale in (c) and (d) is 2cm.
(d) Rhyolitic ignimbrite with common fiamme and sparse crystal fragments and lithic clasts. Jackass Creek ~4km south-west of Mount Eagle at MGA 294819 7204617 (QFG2927)

Whitaker & others (1974) also described dacite consisting of phenocrysts of plagioclase, clinopyroxene and amphibole in an aphanitic quartzo-feldspathic groundmass.

Apart from the volcanic rocks described above, the south-western part of the Mount Eagle Volcanics consists of generally thick, flat-lying to shallowly dipping beds of arenite and rudite (Figure 73b–c). In Jackass Creek at MGA 294900 7204250, flat-lying, very thin to thin beds of crystal-poor to crystal-rich volcaniclastic rocks contain angular to sub-rounded intermediate to felsic lithic clasts. The crystal fragments are mostly feldspar, but some mafic minerals are present locally.

Dyke swarms within the Euroka Granite and the Culcraigie Granite consist of strongly flow-banded rhyolite containing abundant, cream to pink K-feldspar phenocrysts. The general appearance of these rocks is very similar to the rhyolites within the Mount Eagle Volcanics and they may be related.

Geophysical response

In general the Mount Eagle Volcanics show a low response on the magnetic images, consistent with the magnetic susceptibility readings which are mostly <500 x 10^5 SI units (average 235). The reason for a distinct magnetic high in the western part of the outcrop area could not be determined in the field. The radiometric response is higher in potassium and lower in thorium than that of the adjacent Euroka and Greystone Granites. On composite images it has pink hues that contrast with the yellow and brownish hues of those units.

Relationships and age

The Mount Eagle Volcanics overlie the granites of the late Permian to Early Triassic Rawbelle Batholith. No fossils are known and no isotopic dating has been done, but lithological and stratigraphic similarities suggest that the Mount Eagle Volcanics can be equated with the Aranbanga Volcanic Group to the south-east. This unit is of probable Late Triassic age.

MORANG VOLCANICS

Introduction

This name is given felsic to intermediate volcanics exposed west of Mount Saul homestead in the central southern portion of AUBURN (Figure 72). They were described by Whitaker & others (1974) but not named. The rocks form an area of low, moderately steep-sided, rounded hills over ~20km^2. A north-west-trending joint system is evident on aerial photographs.

The name “Rosehall Volcanics” was used informally by Peko-Wallsend Operations Ltd geologists (Bischoff & others, 1986; Wightman, 1992) during their exploration of the Rosehall prospect. The area was also studied by Newman (1988) and Morgan (1993).

Type locality

The type area is designated along the Auburn–Hawkwood Road from MGA 279300 7145850 to MGA 277900 7144450. This northern part of the unit seems relatively well exposed, and could lend itself to future facies analysis. Minor flow-banded rhyolite, upward-coarsening lapilli tuff and breccia, and minor intercalated dacite are exposed.

Lithology

Whitaker & others (1974) reported dominantly acid compositions, similar to that in the type area along the Auburn–Hawkwood Road, although the unit as mapped appears to include substantial amygdaloidal andesite. Whitaker & others estimated the thickness of the unit to be not greater than 300m and ascribed the irregular dips to an irregular depositional surface.

The southern portion of the unit, as exposed west of Mount Saul homestead (MGA 281400 7143200) on Barbours Road includes trachytic to rhyolitic lava flows and breccia, and spherulitic to locally commonly amygdaloidal andesite. The latter is not well exposed near the road. The succession seems to be interlayered at this site, but andesite clearly dominates east of the nearby reach of the Auburn River around MGA 279100 7142700.

Along the Auburn–Hawkwood Road, minor flow-banded rhyolite, upward-coarsening lapilli tuff and breccia, and minor intercalated dacite are exposed.

Geophysical response

The Morang Volcanics are weakly magnetic. Most magnetic susceptibility values are less than 50 x 10^{-5} SI units, with a mode of about 20. One dacite outcrop had values to 800. The low values are consistent with the low magnetic intensity recorded in the airborne magnetic data for the southern part of the outcrop area. A strong response in the northern part of the outcrop area suggests that Mount Saul Quartz Monzonite underlies this area, and is an annular intrusion, possibly into a ring fracture

The Morang Volcanics have moderate response in all three radiometric channels and are represented on composite images by whitish hues. They are less potassic than the Mount Saul Quartz Monzonite.

Relationships and age

The volcanics appear to be related to a sub-circular cauldron structure in aeromagnetic images. Whitaker & others (1974) suggested that the volcanic rocks are intruded by the Mount Saul Quartz Monzonite, and based a Triassic age on lithological correlation.

MUNCON VOLCANICS

Introduction

Originally referred to as the “Nobbies Basalt” by Dear (1963), the name Muncon Volcanics was established by Dear (1968) for a succession of siltstone, basic to intermediate lava, and “agglomerate” of Triassic age unconformably overlying Palaeozoic rocks near Mount Muncon, south of Cania in SCORIA (Figure 72). Previously the name had been used informally by McKellar (1967) for the basal part of a similar rock unit 29km north-east of Monto. The rocks were studied as part of the Yarrol Project and this description is based on their report (Yarrol Project Team, in preparation).

The Muncon Volcanics are exposed beneath escarpments of Jurassic Precipice Sandstone to the south and south west of Cania on either side of Three Moon Creek. Away from the escarpments, a very subdued topography has developed on the unit, as the rocks weather easily, and dips are mostly low. Weathering is usually extensive and fresh rock is rarely seen in outcrop. Near major faults, dips can be moderately steep, resulting in low strike ridge development.

Lithology

The lower part of the unit comprises interbedded volcaniclastic pebble conglomerate, tuffaceous sandstone, siltstone and minor basaltic to andesitic lava. The volcaniclastic pebble conglomerate is composed of poorly sorted, subrounded andesitic volcanic clasts in a greenish grey volcaniclastic matrix. The tuffaceous sandstone is greenish grey, fine to medium grained and composed of quartz, feldspar, biotite and minor fragments of andesitic lava. Dark grey to off-white tuffaceous siltstone has a similar mineralogical make up to the sandstone with the exception of having additional muscovite and varying proportions of carbonaceous detritus. Groundmass cement includes silica, calcite and iron oxides. Iron oxide is also commonly concentrated along bedding planes and joints in the sediments and along joint planes. On a branch of Oaky Creek at MGA 292575 7270970, the sandstone and siltstone contain plant remains.

The lavas are dominantly of basaltic andesite composition, based on geochemical analysis (Yarrol Project Team, in preparation). They are vesicular, fine-grained, and dark grey to black. Some contain euhedral to subhedral olivine phenocrysts now altered to iddingsite or bowlingite in a groundmass of plagioclase microlites, interstitial augite and very small opaque grains. The groundmass is commonly extremely altered to a felted matt of clay minerals, calcite, hydrated iron oxides and chloritic minerals. Other samples contain augite phenocrysts as glomeroporphyritic aggregates, and rare altered orthopyroxene, enclosed by strongly aligned plagioclase laths, interstitial to prismatic augite grains and opaque minerals. Andesitic lavas are similar to the basaltic andesite in both texture and mineral assemblage with the exception that augitic pyroxene becomes the dominant phenocryst phase and vesiculation of the lava is not as common. At the road crossing on Oaky Creek (MGA 291265 7271835) south of The Nobbies, relatively fresh basaltic andesite has been exposed in a low road cutting.

Higher in the sequence basaltic to andesitic lavas dominate, and are accompanied by tuff, volcanic breccia and minor pebble conglomerate. This conglomerate contains numerous clasts of white siltstone. The basaltic to andesitic lavas are similar in mineralogical composition to those previously described with the exception that some andesitic lava contains both biotite and rare hornblende as accessory minerals. The hornblende has been derived from the alteration of the augitic pyroxene during final cooling of the lava. Brown to purplish grey lithic tuff forms the majority of the tephra deposits. It contains angular to sub-rounded andesitic rock fragments along with minor angular grey siltstone fragments in an extremely fine grained matrix. The volcanic breccias appear to occur interspersed throughout the upper part of the sequence. At MGA 289250 7273700, clast-supported breccia with clasts to 30cm crops out as part of a low knoll. Many of the clasts are basaltic to andesitic and exhibit varying degree of vesiculation and flow banding. Minor sedimentary clasts, possibly derived from the Youlambie Conglomerate, also occur. The matrix material ranges from lapilli to fine ash. Near the very top of the exposed sequence, thin grey trachytic flows occur. These are composed of varying proportions of plagioclase, potash feldspar and quartz with accompanying accessory biotite, iron oxide and minor hornblende.

Thickness and structure

In general, the volcanics have a shallow dip, although in the vicinity of faults, the dip can be as great as 40º. The thickness is difficult to determine reliably with variability of dip and the poor outcrop. Dear (1968) estimated a thickness of ~150m for the Muncon Volcanics in the Cania area.

Geophysical response

The magnetic signature of the Muncon Volcanics is masked, to some extent, by more strongly magnetised rock types such as diorite and granodiorite of the northern end of the Rawbelle Batholith that underlies the volcanics and intrudes the Youlambie Conglomerate in the Cania area. The response is somewhat more ‘noisy’ than that of the batholith to the south suggesting the presence of moderately thick basaltic flows. Magnetic susceptibility readings were not systematically made but one outcrop of andesite had values from 500–2200 x 10^{-5} SI units.

The radiometric response is low in all three channels, although the potassium response is slightly elevated, so that on composite images the unit is represented by a deep purplish hue. The response is moderately low compared to the much higher response shown by the Wingfield Granite that the volcanics partly overlie. Adjacent to the overlying Precipice Sandstone and where debris slides from the sandstone partly cover the volcanics, the higher thorium response of the sandstone partly masks the radiometric response from the volcanics.

Stratigraphic relationships

The Muncon Volcanics unconformably overlie and are partly faulted against the early Carboniferous Rockhampton Group and the early Permian Youlambie Conglomerate to the north and east. They also overlie the Wingfield Granite and small unnamed diorite bodies that intrude the Youlambie Conglomerate and Rockhampton Group. They are unconformably overlain by the Jurassic Precipice Sandstone to the south and west. Towards the headwaters of Paddy’s Gully, the Muncon Volcanics have been intruded by a xenolith-bearing Tertiary basalt dyke.

Fossils and age

A collection of plant fossils was made from near the base of the formation on a branch of Oaky Creek at MGA 292575 7270970, south-south-west of Cania. Included in the assemblage are *Cladophlebis* sp., *Dicroidium odontopteroides*, *Dicroidium odontopteroides* var. *lancifolium*, *Czekanowskia* cf. *tenuifolia*, *Linguifolium* sp., *Elatocladus* sp., and indeterminate equisetalean plant stems. Dear & others (1971) found similar material and suggested that the assemblage represented an Early to Middle Triassic age. The Muncon Volcanics have been interpreted to be similar in age to the Native Cat Andesite and other scattered areas of mafic to felsic volcanic rocks in the Monto–Calliope area (McKellar, 1967; Dear & others, 1971; Yarrol Project Team, in preparation).

STRATIGRAPHY OF THE SURAT AND MULGILDIE BASINS

PRECIPICE SANDSTONE

Introduction

Whitehouse (1953) first used the name Precipice Sandstone for the lowermost formation of the “Bundamba Series”. It is the basal unit of the Early Jurassic succession and is extensive throughout the Surat Basin except on the eastern side around the southern end of the Auburn Arch in AUBURN and MUNDUBBERA, where the Evergreen Formation directly overlies the basement (Figure 72). It is well developed in CRACOW on the eastern margins of the Surat Basin, where it crops out over ~500km^2 from Quinns Gully north through Precipice Creek and along the Dawson River to near Cracow. It also crops out around the margins of the Mulgildie Basin in SCORIA and MONTO and EIDSVOLD. The unit forms isolated remnants in the Kroombit Tops area in BILOELA, just extending into BANANA, and near Mount Morgan (formerly the Razorback beds).

In the study area, the sandstone has been intersected in petroleum exploration wells in the Mulgildie Basin [APE Abercorn 1 (Hoyling & Stewart, 1964) and AP Mulgildie 1 (Stewart & Gough, 1963)] and GSQ stratigraphic drilling [GSQ Mundubbera 4 (Whitaker & others, 1974)].

In outcrop, the unit is characteristically cliff-forming along its margins and where incised by streams (Figure 74a). Elsewhere it forms very flat topography and is deeply weathered. In most areas, the lower boundary is easily photo-interpreted, except to the south of Cracow, where the silicified late Triassic weathering surface reported by Jensen & others (1964) is difficult to distinguish from the cliff formed by the sandstone. The overlying Evergreen Formation is bench-forming and has lighter tones on aerial photographs, but is difficult to distinguish where both units are weathered.

Type area

The type area is west of the study area and was defined by Whitehouse (1955) as "the sandstone cliffs in the gorge of Precipice Creek, a tributary of the Dawson River", ~50km north-east of Injune. Exon (1976) described a type section in this area.

Thickness

Mollan & others (1972) reported that in the western part of the Mundubbera 1:250 000 Sheet area, the Precipice Sandstone ranges from 30m to almost 150m in thickness. It thins out completely over the southern end of the Auburn Arch, which may have been a basement high. The maximum thickness intersected in the wells in the Surat Basin to the west is 106m in UOD Gurulmundi 1 in the axial part of the Mimosa Syncline (Green & others, 1997). Around the Mulgildie Basin, the thickness is highly variable ranging from 10m along the Monto–Biloela road to 60m in Cania Gorge. About 98m was intersected in APE Abercorn 1 and 76m in GSQ Mundubbera 4.

Lithology

Mollan & others (1972) described the Precipice Sandstone as consisting of white, thick-bedded, cross-stratified, fine to coarse-grained, pebbly quartzose sandstone with only minor lithic sublabile sandstone, siltstone and argillite. Exon (1976) subdivided the Precipice Sandstone into a lower coarser subunit and an upper finer subunit. Similarly, in the Mulgildie Basin in APE Abercorn 1, Hoyling & Stewart (1964) described mainly grey to white, fine to very coarse-grained porous sandstone containing subrounded quartz grains and small pebbles. Near the top of the interval they reported finer grained, clayey, micaceous sandstone and grey carbonaceous shale and micaceous siltstone. Dear & others (1971) described a similar succession from outcrop.

Geophysical reponse

On composite radiometric images, the clean quartzose sandstones have a dark bluish expression on composite images tending to dark green where deeply weathered due to very low potassium and low to moderate thorium and uranium. The labile Evergreen Formation has a much 'hotter' whitish response in composite images where relatively unweathered due to higher potassium, but has a similar response to the Precipice Sandstone where deeply weathered.

Depositional environment

Deposition of the Precipice Sandstone represents the start of the first major sedimentary cycle in the Surat Basin. Martin (1981) interpreted that the Precipice Sandstone was deposited in transverse bars in a braided stream system, with stream flow being from west to east. However, in the Yarrol Project area, palaeocurrent measurements from across the Callide Basin and near Mount Morgan are basically south to north (C.G. Murray, personal communication). Martin regarded the Precipice Sandstone as being a diachronous unit which transgressed to the west with deposition of the upper part on the Roma Shelf during the final stages. The sandstones on the Roma Shelf are finer-grained than in other parts of the basin and they represent a low-energy fluviatile meandering system. The uppermost, finer interval in the study area may represent a similar environment.

Relationships and boundary criteria

In the Surat Basin, the Precipice Sandstone unconformably overlies Triassic or Permian units of the Bowen Basin, Devonian to Permian basement rocks and some granites of the Auburn Arch. In the Mulgildie Basin, it variously unconformably overlies Devonian to Permian rocks of the Yarrol Province, the Triassic Rawbelle Batholith and Triassic volcanic rocks such as the Muncon and Winterbourne Volcanics. In the subsurface of the Mulgildie Basin, it unconformably overlies a thick succession of Middle Triassic Cynthia beds that occur in the Abercorn Trough (Whitaker & others, 1974). In APN Mulgildie 1, the Precipice Sandstone is separated by ~19m of unassigned greenish siliceous sandstone, micaceous and carbonaceous and carbonaceous siltstone and some mudstone as well as coarse-grained quartzose sandstone from the unconformably underlying Triassic rocks.

To the south of the study area, the formation grades laterally into the Helidon Sandstone of the Moreton Basin to the east. The top of the Precipice Sandstone is taken where the highest massive porous quartzose sandstone underlies the less porous sublabile sandstones and mudstones of the Evergreen Formation.

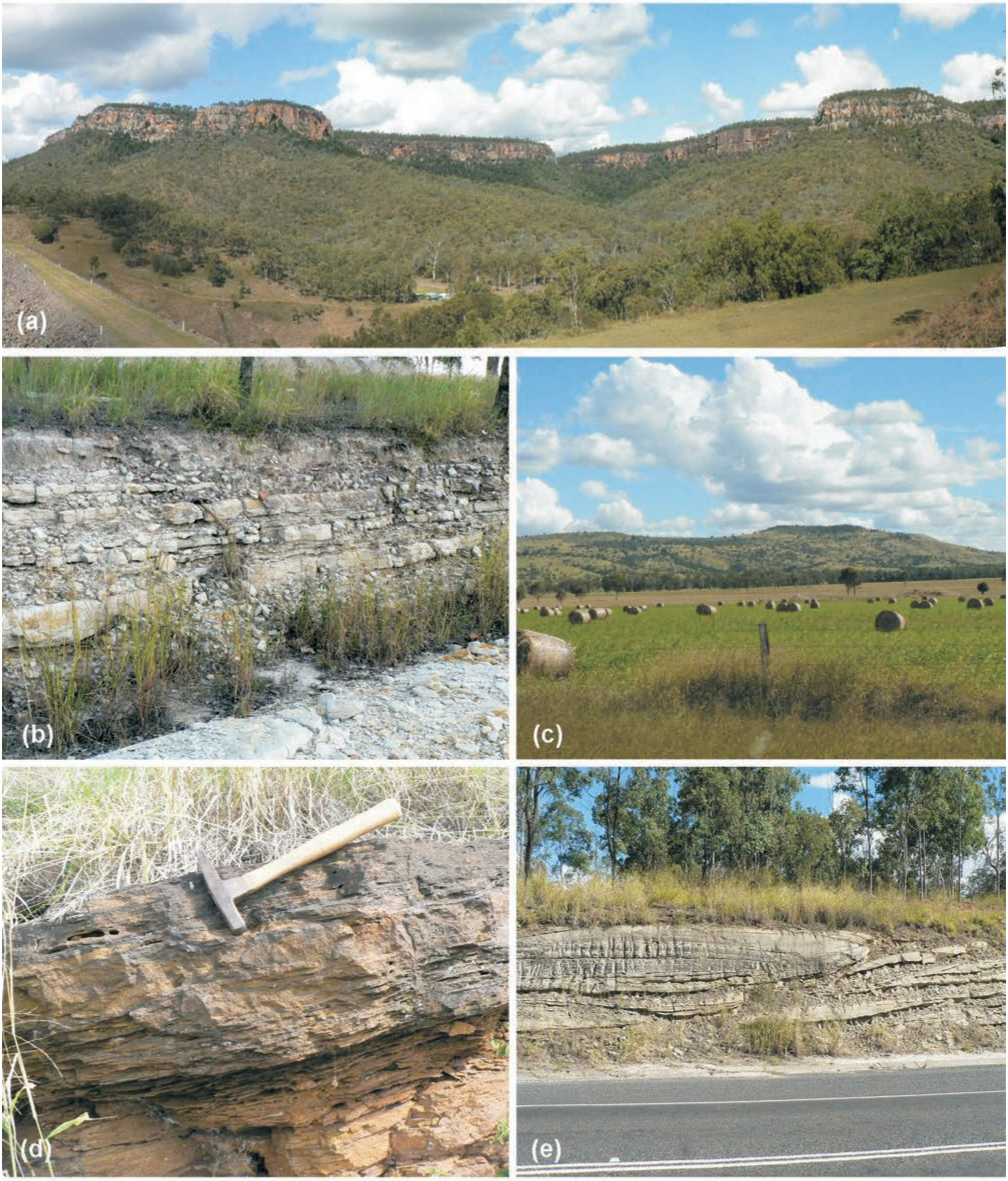

Figure 74. Jurassic units
(a) Mesas of cliff-forming quartzose sandstone of the Precipice Formation on the western edge of the Mulgilgie Basin. Viewed from near the main wall at Cania Dam
(b) Thin to medium-bedded, fine-grained labile sandstone and mudstone or siltstone in the lower part of the Evergreen Formation. Cania Road, 2km east-south-east of Cedar Creek at MGA 299190 7263890 (IWGN462)
(c) Hills of the lower part of the Evergreen Formation in the Mulgildie Basin, looking south from Cania Road near Moonford. Oolitic ironstone forms the top of the ridge — compare with the cliff-forming character of the Precipice Sandstone in (a)
(d) Outcrop of oolitic ironstone in the Evergreen Formation. Cania Road near the Moonford State School at MGA 301400 7260140 (IWGN463)
(e) Lenticular beds of fine to medium-grained labile sandstone and mudstone of the Hutton Sandstone in the Mulgildie Basin. Burnett Highway, 6.5km north-west of Monto at MGA 305150 7251400 (IWGN464)

Fossils and age

On palynological grounds the Precipice Sandstone is Early Jurassic and is generally attributable to units APJ1, APJ21 (Sinemurian–early Pliensbachian) and, in some areas at its upper limit, to APJ22 (Green & others, 1997; Price, 1997). The APJ21–APJ22 boundary is located either in the uppermost Precipice Sandstone or the lowermost Evergreen Formation. The Precipice Sandstone has few macrofloras apart from poorly preserved wood. However, small collections from Stuart Creek and Wycarbah in MOUNT MORGAN described and figured by Walkom (1915–1917) and Hill & others (1966) as from the Stanwell Coal Measures are probably from the Precipice Sandstone (C.G. Murray, personal communication). They were originally regarded as Jurassic and correlated with the Walloon Series.

EVERGREEN FORMATION

Introduction

Whitehouse (1955) applied the name “Evergreen Shales” to the recessive shaly interval between the Precipice Sandstone and the bluff-forming Boxvale Sandstone of Reeves (1947) in the valley of the Dawson River, north of Injune. Jensen & others (1964) defined the Evergreen Formation to include the “Evergreen Shales” as the lower unit, the overlying Boxvale Sandstone as a member and an upper unit of mudstone, siltstone and sandstone containing an oolitic member at its base. Mollan & others (1965) named and described the latter as the Westgrove Ironstone Member. Mollan & others (1972) confined the Westgrove Ironstone Member to the western side of the Mimosa Syncline as it was found to wedge out west-north-west of Taroom. In the Surat Basin on the eastern side of the Mimosa Syncline east of Taroom, a prominent oolitic ironstone member occurs at approximately the same stratigraphic level in the Evergreen Formation, but it has not been defined formally. This unit was recognised by Mollan & others (1972) in the study area south of Cracow, and is also well developed in the Mulgildie Basin (Dear & others, 1971; Whitaker & others, 1974). The Boxvale Sandstone Member has not been recognised in outcrop from the eastern side of the Mimosa Syncline (Exon, 1976), but Green & others (1997) have identified it in the subsurface.

In the southern part of Mundubbera 1:250 000 Sheet area, the Evergreen Formation crops out around the southern end of the Auburn Arch (Figure 72). The topography is typically very flat and the unit is deeply weathered and poorly exposed, except in creek beds where it forms low scarps. It also occurs in the Mulgildie Basin, where the topography is varied and ranges from cuestas and mesas (Figure 74c) (in particular in the Coominglah Range west of Monto where it is deeply weathered and lateritised) to valleys and flat river plains. Outcrop is mostly poor. The oolitic ironstone crops out as a low scarp or ledge up to 3m high on the slopes below the Hutton Sandstone and can be easily photo-interpreted in many areas.

Outliers of the Evergreen Formation overlie the rocks in the southern portion of the Rawbelle Batholith and Auburn Arch in many places. There is significantly more exposed than shown on the existing Mundubbera 1:250 000 geology sheet, mainly disposed as small ($<1km^2$) outliers. The subcrop gives rise to sandy to gravelly soils. Gravel lags also occur, providing evidence of the formerly more widespread distribution of the formation.

Type area

Mollan & others (1972) gave a type section for the lower part of the Evergreen Formation from the base to the top of the Boxvale Sandstone Member, 3km south-south-east of Fairview homestead in the Taroom 1:250 000 Sheet area. The upper part was measured from cores and cuttings in BMR Taroom 46 and 54.

Thickness

The thickness of the Evergreen Formation varies considerably over its outcrop extent. Mollan & others (1972) reported a thickness of 165m in the Cockatoo Creek area south-south-west of Cracow, but in places it does not exceed 30m. The maximum thickness of the Evergreen Formation intersected in the wells in the Surat Basin is 307m in GSQ Chinchilla 4, south of Miles (Green & others, 1997). The main axis of deposition is the Mimosa Syncline.

In the Mulgildie Basin, APE Abercorn 1 intersected a total of 208m (Hoyling & Stewart, 1964). GSQ Mundubbera 2 and 3 did not reach the base of the formation, but intersected 171m and 248m respectively, indicating a pronounced thickening of the formation eastward from the western edge of the Basin. AP Mulgildie 1 intersected 260m.

According to Urquhart (1962) the oolitic ironstone is 6–9m thick in the Cockatoo Creek area. In GSQ Mundubbera 2 and 3 it is ~3m thick. The upper Evergreen Formation is ~45m thick in areas mapped by Mollan & others (1972) and is ~30m thick in GSQ Mundubbera 2 and 3.

Lithology

In the western part of the Mundubbera 1:250 000 Sheet area and the Mulgildie Basin, the lower part of the Evergreen Formation consists mainly of light grey, micaceous and flaggy, fine to medium-grained, labile to sublabile sandstone (Figure 74b), becoming more quartzose towards the base and more massive towards the top. The rocks typically have an argillaceous matrix, although calcareous and ferruginous cements are common. The labile components range from feldspar to lithic fragments. South-south-west of Mundubbera, Whitaker & others (1974) described moderately well-sorted, medium to coarse-grained, partly pebbly iron-stained quartzose sandstone that is usually cross-bedded. Minor grey to dark grey, carbonaceous shale and siltstone containing plant fragments and thin coaly laminae were intersected in GSQ Mundubbera 2, 3 and 4, but these are rarely seen in outcrop.

The oolitic ironstone (Figure 74d) is yellowish brown and dominantly an oolitic or pelletal chamositic rock that crops out as oolitic limonite (Dear & others, 1971; Mollan & others, 1972; Whitaker & others, 1974). The rock ranges from a tightly packed aggregate of pin-head sized limonite or chamosite ooliths to fine-grained poorly sorted ferruginous sandstone containing small limonite pellets. Dear & others (1971) also report the occurrence of ferristilpnomelane and siderite as constituents of the oolites along with iron oxides and chamosite. The ooliths are generally spherical, concentrically zoned and uniformly ~0.5mm in diameter. Calcite occurs commonly in the cores as well as forming cement. Concretionary ironstone associated with the interval may have formed by replacement, because it contains rare relict patches of oolitic ironstone (Whitaker & others, 1974). In most areas, the oolitic and pelletal ironstone forms two or rarely three beds of variable thickness, interbedded with thin bedded, labile to sublabile sandstone and ferruginous mudstone and concretionary ironstone. Dear & others (1971) reported that in the Mulgildie Basin, another thin (30cm) bed occurs ~15m above the main interval. The oolitic ironstone in the Mulgildie Basin was investigated by Carpentaria Exploration Company Pty Ltd and contains ~40% Fe (Munt, 1962).

The upper part of the Evergreen Formation is very poorly exposed. Mollan & others (1972) briefly described green and purple calcareous “mudstone” and lustre-mottled siltstone and poorly sorted, sublabile calcareous sandstone with fossil tree trunks. In the Mulgildie Basin, the only complete section is in GSQ Mundubbera 2 and 3. In both holes the upper unit consists entirely of grey to dark grey laminated siltstone and shale and minor thin-bedded fine-grained labile sandstone.

Geophysical response

As noted above the labile Evergreen Formation has a much ‘hotter’ whitish response on composite radiometric images than the quartzose Precipice Sandstone where less weathered, but has a similar response to the Precipice Sandstone where deeply weathered.

Depositional environment

The Evergreen Formation below the Boxvale Sandstone Member is interpreted to have been deposited in freshwater lakes (Mollan & others, 1972) or by meandering streams in coastal plains and in deltas (Exon, 1976). Fielding (1989) concluded that during deposition of the Boxvale Sandstone, the Surat Basin consisted of a series of small lakes fed by fluvial systems with associated deltas. Green & others (1997) noted that the Evergreen Formation generally has more sandstone along its eastern and western margins, than elsewhere, and interpreted this to reflect the distance from the sediment supply. The coarser sediments were deposited at first around the edges of the basin and the finer sediments were transported to the centre.

Mollan & others (1972) interpreted that the Westgrove Ironstone Member was deposited under shallow marine conditions based mainly on the presence of the ironstone oolites. Cranfield & others (1994) showed the ironstone oolites in the Surat, Clarence–Moreton, Nambour and Maryborough Basins were deposited under lacustrine conditions. Bradshaw & Yeung (1990, 1992) and Bradshaw & Challinor (1992) associated a paralic environment with the ironstone oolite facies. They suggested that the rise of sea level to a peak in the mid-Toarcian caused the inflow of brackish water into the lacustrine (lagoonal) systems of eastern Australia, but the contribution of freshwater from the surrounding hinterland of rivers, lakes and coal swamps prevented marine conditions from fully developing. Green & others (1997) concluded that although such a scenario appears likely for the acritarch-bearing Boxvale Sandstone and Westgrove Ironstone Members (and adjacent acritarch-bearing strata of the Evergreen Formation), the occurrence of brackish, lacustrine-delta systems without connection to the sea cannot be discounted.

Relationships and Boundary Criteria

The Evergreen Formation conformably overlies the dominantly quartzose sandstones Precipice Sandstone and in some areas unconformably overlies pre-Jurassic basement. The formation is laterally continuous with the lower part of the Marburg Subgroup in the Moreton Basin to the east (Gray, 1975).

The top of the Evergreen Formation is taken where the labile sandstones, siltstones and mudstones of the Evergreen Formation are overlain by the sublabile porous and permeable sandstones of the Hutton Sandstone.

Fossils and Age

Palynofloras from the Evergreen Formation are largely Pliensbachian–Toarcian (Early Jurassic) and associated with units APJ21 (uppermost part, if present), APJ22, and APJ3, with the APJ3–APJ4 boundary, occurring within the lower to mid-Hutton Sandstone (Green & others, 1997; Price, 1997). The appearance of *Staplinisporites manifestus* (normally within the Westgrove Ironstone Member) delimits unit APJ32, which extends into the succeeding upper Evergreen Formation.

Although spinose acritarchs and leiospheres are common to abundant in the upper part of the unit associated with the Boxvale Sandstone and Westgrove Ironstone Members, (Paten, 1967; Reiser & Williams, 1969; McKellar, 1974), definite fossil indicators of a marine environment are absent.

Fossil wood and impressions of equisetalean stems are present locally.

HUTTON SANDSTONE

Introduction

The name Hutton Sandstone was first used by Reeves (1947) for sandstones north-west of Injune. He regarded the Hutton Sandstone as the top member of the “Bundamba Series”. Mollan & others (1965) raised the Hutton Sandstone to formation status. It is the most widespread Jurassic unit in the Great Artesian Basin and is continuous into, and forms the upper part of the Marburg Subgroup in the Moreton Basin to the east. The formation extends westward into the Eromanga Basin and overlaps basement rocks on the Walgett Shelf to the south-west. Dear & others (1971) and Whitaker & others (1974) also extended the name to soft-weathering sandstones that overlie the Evergreen Formation in the Mulgildie Basin.

In the study area, the Hutton Sandstone is limited mainly to the western margin of the Mulgildie Basin in MONTO and EIDSVOLD (Figure 72). In southern CRACOW, it forms a prominent mesa at Mount Moss. It is extensive in south-western BUNGABAN outside the area studied. It is generally poorly exposed and the common expression is as low sandy soil flats and low rounded hills and rarely cliffs. The sandstone usually has a low bluff at its base. Topography is more rugged in SCORIA, where it forms the eastern slopes of the Coominglah Range.

Type area

Mollan & others (1972) nominated a type section for the Hutton Sandstone near Hutton Creek, 19km east-north-east of Injune.

Thickness

In the Mulgildie Basin, the Hutton Sandstone was intersected between the surface and 232m in APE Abercorn 1 (Hoyling & Stewart, 1964). GSQ Mundubbera 2 and 3 also intersected part of the unit (126m and 79m respectively). Farther north, only ~72m was intersected in AP Mulgildie 1 between the Evergreen Formation and the Mulgildie Coal Measures (Dear & others, 1971).

In the south-western part of Mundubbera 1:250 000 Sheet area, Mollan & others (1972) recorded a thickness of 122m in the Cockatoo Creek area. The maximum thickness of the Hutton Sandstone intersected in wells in the Surat Basin is 266m in UOD Juandah 1, close to the axis of the Mimosa Syncline (Green & others, 1997). Throughout most of the basin it is between 120–180m thick (Exon, 1976).

Lithology

In outcrop in the Mulgildie Basin, Whitaker & others (1974) described the unit as being mainly fine to medium-grained, cream or brown, well sorted argillaceous, micaceous quartzose sandstone. It is interbedded with mudstone. The sandstone is generally well bedded and commonly lenticular and trough cross-bedded (Figure 74e).

Mollan & others (1972) described similar rocks from the western part of the Mundubbera 1:250 000 Sheet area. The upper half of the formation is dominated by fine-grained, porous, friable, generally thick-bedded, locally argillaceous quartzose sandstone.

In drillholes, the Hutton Sandstone consists mainly of sandstone with interbedded siltstone and shale and minor mudstone and coal (Green & others, 1997). The sandstone is white to light grey, fine to medium-grained, well sorted, sublabile to quartzose, partly porous with some pebble bands and shale and siltstone clasts in the lower part. Siltstone and shale are light to dark grey, micaceous, carbonaceous and commonly interlaminated with very fine-grained sandstone.

Geophysical response

On composite radiometric images, the response is similar to that of the underlying Evergreen Formation, probably reflecting its argillaceous nature, in contrast to the cleaner, more quartzose Precipice Sandstone.

Relationships and Boundary Criteria

The top of the Hutton Sandstone is taken at the top of the uppermost sublabile to quartzose sandstone below the sublabile to labile sandstones and mudstones of the Mulgildie Coal Measures or Eurombah Formation (basal Injune Creek Group in south-western BUNGABAN).

Depositional Setting

Deposition of the Hutton Sandstone represents the start of the second major sedimentary cycle in the Surat Basin. Exon (1976) interpreted that meandering streams on a broad floodplain deposited the Hutton Sandstone. The generally quartz-rich sediments were sourced primarily from the north-east, south-east and south-west. The groundwater in the lower part of the formation commonly has a high concentration of sodium chloride, calcium sulphate and sodium carbonate. This suggests that the lower part of the formation, at least, may have been deposited in brackish water (Mollan & others, 1972). Non-marine environments are indicated from palynology.

Fossils and Age

The Hutton Sandstone is Middle Jurassic. Palynofloral assemblages range from units APJ33 to APJ42 (Aalenian to Bathonian) (Green & others, 1997; Price, 1997).

MULGILDIE COAL MEASURES

Introduction

Reid (1927) first described the Mulgildie Coal Measures and correlated them with the “Walloon Series”. They were later described by Cameron (1960), Dear & others (1971) and Whitaker & others (1974). They occupy the axial region of the synclinal Mulgildie basin and extend from near Monto to Kapaldo in EIDSVOLD forming a belt up to 7km wide (Figure 72). They crop out extremely poorly and form low undulating hills with deep black and red-brown soils. The rocks are best known from APN Mulgildie 1 well (Stewart & Gough, 1963; Dear & others, 1971) and GSQ Monto 1-2R (Gray, 1972).

Thickness

Dear & others estimated the thickness of the Mulgildie Coal Measures to be ~350m. APN Mulgildie 1 intersected ~240m in the lower and middle parts of the unit, below unconsolidated Cainozoic sediments.

Lithology

The Mulgildie Coal Measures consists of sandstone, siltstone and mudstone. The sandstones are feldspathic sublabile, have a clayey matrix and low permeability. The mudstones are commonly carbonaceous and locally micaceous and sandy. Coal seams occur at numerous horizons, but the most important are in the middle part of the unit (intersected in water bores and the upper part of APN Mulgildie 1), and were designated as seams A to E by Reid (1927). The B seam is ~3.5m thick, although it contains numerous shale bands in the upper part. It was worked at the Selene coal mine south of Mulgildie until 1966.

Relationships and boundary criteria

The Mulgildie Coal Measures conformably overlie the Hutton Sandstone from which they are distinguished by the abundance of mudstone and the presence of coal seams. The only strata overlying them are unnamed freshwater Tertiary sediments. The unit is juxtaposed against the Evergreen Formation and Hutton Sandstone on their western side by the Anyarro Fault along the line of Three Moon Creek.

Depositional environment

Like the Walloon Coal Measures (McLean-Hodgson & Kempton, 1981), the Mulgildie Coal Measures were probably deposited by high sinuosity meandering streams associated with overbank deposits and the development of coal swamps.

Fossils and age

Reid (1927) recorded the presence of *Cladophlebis australis, Taeniopteris spatulata and Otozamites* sp., consistent with a Jurassic age. The unit is correlated on stratigraphic and lithological grounds with the Walloon Coal Measures.

INJUNE CREEK GROUP

Introduction

Rocks overlying the Hutton Sandstone in the south-west corner of the study area in BUNGABAN have been assigned to Injune Creek Group following Mollan & others (1972) and Whitaker & others (1974) (Figure 72). Only the lowermost part of the group is represented, corresponding to the Eurombah Formation and Walloon Coal Measures, but these have not been differentiated on the map. Green & others (1997) noted that the Eurombah Formation, which was defined by Swarbrick & others (1973), cannot be consistently differentiated from the Walloon Coal Measures and further work would be needed to determine its applicability. Therefore, in their study, they included it in the Walloon Coal Measures.

Outcrop is extremely poor and the unit is covered with a thick clay soil, which formerly supported a dense growth of brigalow scrub. Low cuestas, generally composed of calcareous beds, are the only features of appreciable relief.

Thickness

A complete section of the group is not present in the sheet area, but Swarbrick & others (1973) recorded 62m of Eurombah Formation in GSQ Mundubbera 1 (25.5–87.5m). Whitaker & others (1974) estimated that at least 150m of Eurombah Formation and Walloon Coal Measures are present in the south-west corner of BUNGABAN.

Lithology

Whitaker & others (1974) described the dominant rock type in the study area as sublabile to labile calcareous sandstone, containing ovoid sandy or silty concretions. The sandstone is medium to thick-bedded, but commonly poorly bedded, and in places is cross-bedded. Laminated to thin-bedded mudstone and siltstone are also present. Thin-bedded pebble or cobble conglomerate occurs at the base of the unit. Green & others (1997) noted that coals are located in the upper half of the unit, and therefore probably lie outside the study area.

Depositional environment

The Eurombah Formation was deposited in a fluviatile environment with periods of rapid deposition whereas the Walloon Coal Measures were deposited in a more sluggish, high sinuosity fluviatile environment dominated by meandering streams (Mollan & others 1972; Green & others, 1997).

Relationships and boundary criteria

The Injune Creek Group is approximately horizontal with a very shallow westerly dip and is regionally conformable on the Hutton Sandstone. The boundary is transitional and Mollan & others (1972) took the base to overlie the uppermost quartzose sandstone of the Hutton Sandstone, which generally underlies the lowermost calcareous bed of the Walloon Coal Measures.

Fossils and age

The age of the lower part of the Injune Creek Group is the same as that of the Walloon Coal Measures, which are late Middle Jurassic (Bathonian to Callovian), based on palynofloras attributed to units APJ42, APJ43 and APJ5 (Price, 1997).

CRETACEOUS TO CAINOZOIC STRATIGRAPHY

CRETACEOUS ROCKS

STYX COAL MEASURES

Introduction

The Styx Coal Measures are in an isolated block of Early Cretaceous sedimentary rocks termed the Styx Basin, a north-trending belt 50km long and ~10km wide extending south from Saint Lawrence to near Tooloombah Creek (Figure 75). Malone & others (1969) gave a summary of the geology on which this description is based. The rocks were first described by Rands (1892) after the discovery of coal in 1886. Dunstan (*in* Walkom, 1915) first used the term Styx Series for the rocks. Morton (1955) described them in detail, based on diamond drilling by the Department of Mines. A later program of drilling at Ogmore was reported on by Chiu Chong (1964) who also reviewed the geology of the coal measures. Production from four mines (mostly State-owned) from 1919 to 1961 produced 1.75Mt. Reserves of ~4Mt in the Tooloombah Creek area were proved by the drilling, but have not been exploited.

The western margin of the basin is marked by a line of east-sloping cuestas such as Mount Bison (Figure 76), but most of the belt underlies soil-covered plains where outcrop is very poor.

Rocks on Wild Duck Island ~40km north-east of Saint Lawrence have been equated with the Styx Coal Measures (White & Brown, 1963). Another small area of Cretaceous sedimentary rocks (labelled Ks) occurs in northern ROOKWOOD ~14km north of Redbank homestead (Malone & others, 1969).

Thickness

Drilling in the Tooloombah area revealed a total thickness of ~425m (Morton, 1955), but the unit may be thicker to the east. At Ogmore, the section intersected in the deepest drillhole was >360m, of which only the upper 250m were coal bearing.

Lithology

The Styx Coal Measures consist mostly of fine-grained, grey to green lithic sandstone, mudstone, conglomerate and thin coal seams. The green sandstone is distinctive and the colour is due to a green hydromica in grain interstices. The basal sandstone cropping out in the cuestas is a medium to coarse-grained, cross-bedded, pebbly quartzose sandstone that locally passes into pebble conglomerate.

Drilling identified three coal seams, each with a minimum thickness of 0.9m. The coal is of high volatile bituminous rank and non-coking to medium coking (Morton, 1955; Chiu Chong, 1964).

The rocks on Duck Island are siltstone and coarse-grained sandstone containing well-preserved fossil wood. The small outcrop area in northern ROOKWOOD consists of pebble conglomerate and subordinate sandstone and mudstone.

Depositional environment

The Styx Coal Measures are dominantly freshwater sediments, but microplankton discovered in one horizon (Cookson & Eisenach, 1958) suggests that the rocks were deposited on a coastal plain onto which the sea encroached at times.

Relationships

The rocks unconformably overlie the Back Creek Group and dip eastwards at ~5° towards a faulted eastern margin. The fault is interpreted to be a high-angle reverse fault that has uplifted Back Creek Group to the

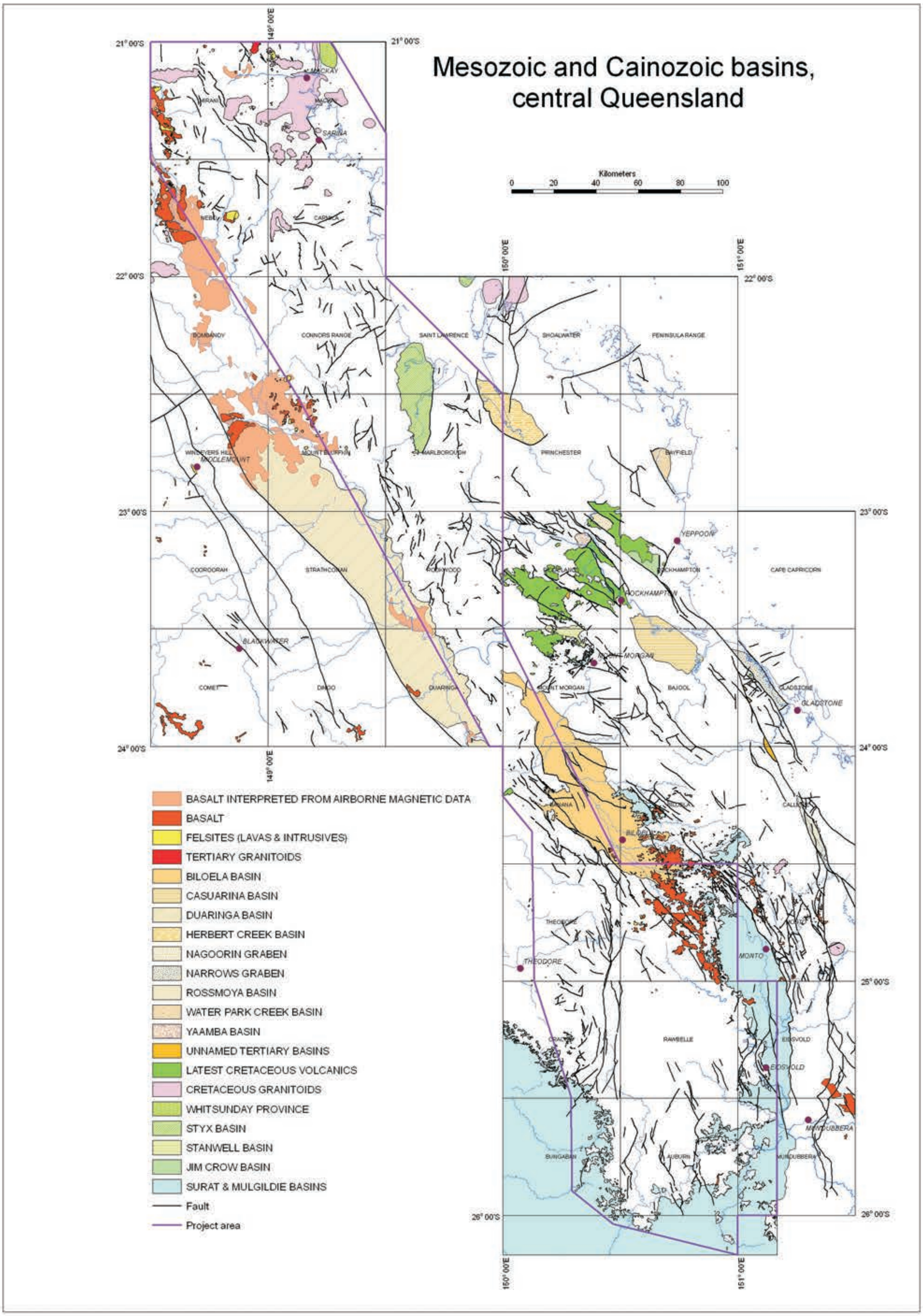

Figure 75. Distribution of Mesozoic and Cainozoic basins in central Queensland

Figure 76. Mount Bison, a cuesta formed by the basal quartzose sandstone of the Styx Coal Measures on the western margin of the Styx Basin; viewed from the north along Mount Bison Road.

east. The Styx Coal measures have been disrupted for some distance west of the fault (Malone & others, 1969).

Fossils and age

Walkom (1919) described Early Cretaceous plant fossils from the unit and Cookson & Dettmann (1958) determined an approximate Albian (Early Cretaceous) age from spores. The small outcrop area in northern ROOKWOOD contains Cretaceous plant fossils identified by White (*in* Malone & others, 1969, appendix 2).

WHITSUNDAY VOLCANICS

Introduction

The Whitsunday Volcanics were first defined and described in detail by Clarke & others (1971) from the Whitsunday and Cumberland Groups of islands offshore from Proserpine and were studied more recently by Ewart & others (1992) and Bryan & others (1997, 2000). Clarke & others suggested that it was reasonable to equate them with similar rocks cropping farther south on the Northumberland Islands offshore from Mackay and perhaps as far south as the Percy Islands. SHRIMP dating reported below and in the Appendix shows that rhyolitic ignimbrite near Slades Point, which had previously been mapped as Campwyn beds is Cretaceous and therefore the Whitsunday Volcanics do extend to the mainland and may extend as far south as Glendower Point (Figure 23 and 77a).

Type area

Clarke & others (1971) gave the type area as the exposures along the southern coastline of Whitsunday Island.

Lithology

In their main outcrop area, the Whitsunday Volcanics are volumetrically dominated by welded dacitic-rhyolitic lithic-rich ignimbrite, with some interpreted intra-caldera ignimbrite units up to 1km thick (Clarke & others, 1971; Ewart & others, 1992; Bryan & others, 2000). Coarse lithic lag breccias containing clasts up to 6m diameter (Ewart & others, 1992) commonly cap the ignimbrites in proximal sections and record the onset of caldera collapse. In addition to the thicker ignimbrite sheets, Clarke & others (1971) also described intermediate to basic volcaniclastic rocks as well as some rhyolite, andesite and basalt lavas. A thick interval of sedimentary rocks including feldspathic sandstone and carbonaceous mudstone was described from the Cape Conway area. Chemically, the suite ranges continuously from basalt to high-silica rhyolite, with calc-alkali to high-K affinities (Ewart & others, 1992).

In this study area, the best exposures are at Slade Point north of Mackay. The most prominent outcrops are of dark grey crystal-rich, lithic-rich dacitic ignimbrite (Figure 77b). It is at least 20m thick and forms the main bluff and wave-cut platform. Crystal fragments are solely plagioclase up to 2mm and fiamme up to 1cm are

Figure 77. Whitsunday Volcanics
(a) Exposures of Whitsunday Volcanics in coastal headlands viewed looking south from Slade Point
(b) Grey plagioclase-phyric, crystal-rich dacitic ignimbrite; Slade Point at MGA 731100 7669200 (RSC026)
(c) Poorly sorted, thin to very thick-bedded volcaniclastic conglomerate consisting of subangular to rounded feldspar-phyric to aphyric volcanic clasts and rare granite in a very fine-grained matrix; same locality as (b
(d))Thin to medium-bedded, internally laminated volcaniclastic sandstone that underlies the ignimbrite; same locality as (b)

common. In thin section the groundmass shows abundant outlines of partly flattened shards. Lithic fragments are mostly aphyric andesite or dacite.

Underlying the ignimbrite at Slade Point is a sequence of volcaniclastic sandstone and conglomerate. The sandstone (Figure 77d) is thin to medium-bedded, internally laminated and medium to coarse-grained consisting of angular quartz, feldspar and flattened pumice clasts in a fine-grained (ash?) matrix. The conglomerate (Figure 77c) is poorly sorted, thin to very thick-bedded and consists of subangular to rounded dark grey feldspar-phyric to aphyric volcanic clasts and rare granite in a matrix of very fine-grained siliceous ash and feldspar crystal fragments.

Geophysical response

The exposures are too small to show a radiometric response. The magnetic response appears to be low, consistent with the small number of magnetic susceptibility measurements taken that were mostly 10 x 10^{-5} SI units.

Environment of deposition

The abundance of thick ignimbrite, together with the lack of marine fossils in the sedimentary intervals, indicates that the Whitsunday Volcanics were formed in a continental environment. Bryan & others (2000) suggested that the Whitsunday Volcanics record a multiple vent, caldera-dominated, low relief volcanic region. Volcanism appears to have evolved from an early explosive phase dominated by intermediate compositions, to a later, bimodal effusive-explosive phase characterized by rhyolitic ignimbrites and primitive basaltic lavas/intrusives. Ewart & others (1992) and Bryan & others (1997; 2000) regarded the rocks as part of a silicic-dominated large igneous province related to the break-up of eastern continental Gondwana, and formation of the eastern Australian passive margin in the Late Cretaceous – Tertiary.

Relationships and age

In the main outcrops on the offshore islands, the ignimbrite-dominated sequences are intruded by gabbro/dolerite to rhyolite dykes (up to 50m wide), sills, co-magmatic granite (Ewart & others, 1992), and rarely in the intra-caldera sequences, by welded pyroclastic dykes, interpreted to be vents for some of the ignimbrite-forming eruptions (Bryan & others, 2000). At Slade Point, the ignimbrite is also cut by numerous fine-grained dolerite dykes. Relationships to older units farther inland are obscured by Cainozoic sediments.

K–Ar dating of hornblende from dacite from Carlisle Island gave an adjusted age of 115±3Ma (Webb *in* Clarke & others, 1971, appendix 9) and Ewart & others (1992) considered that the main period of volcanic activity occurred between 120–105Ma. SHRIMP dating of the ignimbrite at Slade Point, however, gave an age of 137.5±1.4Ma (MSWD = 0.89 from 17 of 18 analyses, see Appendix). The significance of this older age is uncertain. The volcanic activity may have spanned a much greater interval or it is possible that the younger K–Ar age is partially reset.

MOUNT COOPER VOLCANICS

Introduction

A small area of volcanic rocks forms Mount Cooper, a prominent topographic feature in the north-eastern part of BANANA (MGA 196235 7320760). They have not been named previously and Dear & others (1971) did not even describe them. They were recorded on the geological map as an undifferentiated Cretaceous volcanic unit. They are herein referred to as the Mount Cooper Volcanics. The late Dr Alan Robertson (formerly GSQ), who compiled the notes on which this description is based, mapped the unit, which is restricted to Mount Cooper.

The type area proposed for the Mount Cooper Volcanics is on the western side of Mount Cooper and extends from MGA 197225 7318625 to 196905 7320760 and includes the dome and ring-dyke.

Lithology

The Mount Cooper Volcanics were derived from a vent located at the western end of Mount Cooper. A lava dome, which approaches a granophyre in both composition and texture, now occupies the position of the vent.

Andesitic breccias and poorly exposed andesitic flows occur towards the base of the unit around the vent and on the western end of Mount Cooper. Andesitic lava, as clasts, is more prolific in these breccia beds than at higher levels in the eruption sequences, where trachyte and rhyolite dominate. The sequence is intruded by a feldspar-rich ring-dyke. Feldspar-rich veins, similar in composition to the ring-dyke intrude the whole of the sequence exposed at the western end of Mount Cooper.

The andesitic flows are dark green to black and are usually strongly altered. When texture and mineralogy can be observed, the rocks have phenocrysts of feldspar, augitic pyroxene and olivine. An opaque oxide (possibly magnetite) forms rare phenocrysts. The groundmass is mainly feldspar, pyroxene, olivine and opaque oxides (now hematite). Plagioclase is mainly altered to epidote and calcite, pyroxene to uralite and olivine to iddingsite.

All observed andesitic breccias are matrix supported. They also contain weathered grey to pink rhyolitic clasts as well as grey to black clasts derived from the underlying country rock. Colour depends on the percentage of andesite forming the clasts: a high andesite percentage gives a dominantly green hue, whereas increasing rhyolite content gives a mottled appearance. Clasts are dominantly subrounded and range from small cobbles to fragments up to 2m long.

The rock type forming the ring-dyke is composed of up to 95% fine to very coarse-grained, subhedral to euhedral feldspar in a groundmass of finer feldspar, sodium pyroxene and minor quartz. Opaque oxide (? altered magnetite), apatite and rare zircon are accessory minerals. Much of the feldspar is altered to a clay mineral. Variation in grain size through the dyke can be extreme. In general, grain size is finer at the margins of the dyke than towards the centre, indicating some chilling of the magma against the surrounding rock types. However, some areas within the dyke are coarse pegmatite.

The dome is variable in both composition and texture. The dominant rock has the composition and texture approaching that of a medium to coarse-grained granophyre. Fine-grained material resembles rhyolite with micro-phenocrysts of feldspar in a glassy to cryptocrystalline groundmass that contains up to 10% of altered sodium-rich pyroxene. Throughout the dome, irregular coarse-grained patches have the texture of a pegmatoid phase. This material contains a much higher proportion of feldspar and approaches the composition of the ring-dyke.

Towards the top of the sequence to the north-east, east and south-east, the Mount Cooper Volcanics are mainly rhyolitic and trachytic flows and thick beds of coarse breccias. Many of the rhyolite flows are fine-grained and fluidal in texture. They range from grey or cream when relatively fresh to mottled pink and purple when weathered. Sanidine and sodic feldspar are accompanied by minor amounts of an opaque mineral (? magnetite), and cryptocrystalline silica, usually forming irregular small patches throughout the groundmass. Apatite and zircon are accessory minerals.

Trachyte is mainly fine-grained and grey. Most of the exposed trachyte flows have been altered either by weathering or by mild hydrothermal activity and are now cream or buff. Where present, the phenocryst phases include sodic feldspar, sanidine and calcic anorthoclase. The groundmass mineralogy is similar to that of the phenocryst phases but may also contain minor altered biotite laths, opaque oxide, apatite and zircon.

Trachytic and rhyolitic breccias contain clasts similar in composition to the trachyte and rhyolite forming the flows. Within the trachytic breccias the clast sizes rarely exceed 0.5m, whereas in the rhyolitic breccias they can exceed 4m. Most of the observed trachytic breccias contain few other clasts. In contrast, the rhyolitic breccias contain various amounts of andesitic lava and underlying country rock.

A maximum thickness of 120m is estimated for the Mount Cooper Volcanics. Dips are difficult to measure but the general trend is outwards and away from the dome. Only adjacent to the dome do the strata dip inwards and the ring-dyke has a steep inward dip towards the dome.

Geophysical response

Aeromagnetic data shows a strong magnetic anomaly covering the western end of Mount Cooper. This anomaly has a steep magnetic gradient on its western side. To the east, the gradient is gradual under the eastern portion of Mount Cooper.

Composite radiometric images for the area show a ‘hot spot’ (potassium, uranium and thorium giving roughly equal detection responses) located at the western end of Mount Cooper. To the east, the rock types give a higher potassium response than either thorium or uranium, and therefore the area appears pink to red on the composite images.

Relationships and age

In the west, the Mount Cooper Volcanics intrude and unconformably overlie the Permian Back Creek Group. Adjacent to the vent the Permian rocks exhibit minor folding and faulting.

U-Pb zircon ages of 93.9±3, 93.4±5 and 77.7±4Ma were obtained from the volcanics (A. Robertson, unpublished data). The older ages of 93.9 and 93.4Ma were derived from zircon collected from the more mafic earlier eruption products. The younger age of 77.7Ma was derived from zircon recovered from the more felsic, final products of eruption. Whole rock samples collected from near the base of the volcanic pile gave a Rb-Sr isochron slope age of 139±3Ma. This Early Cretaceous age is at variance with the U-Pb Cretaceous ages of Albian to Cenomanian and Campanian derived from zircon. The possibility that eruption commenced in the Early Cretaceous and continued intermittently through to the Late Cretaceous cannot be dismissed. The youngest zircon age of 77.7Ma indicates that the Mount Cooper vent was active in the Late Cretaceous.

Cretaceous basalt

Several small plugs that were mapped by Whitaker & others (1974) as Cretaceous basalt have been delineated. Two of these plugs crop out on Rossmore Station in RAWBELLE. The plugs form rounded hills of moderate relief. The larger is Mount Runsome (herein named Mount Runsome Basalt) and the smaller is known to some locals as Little Mount Runsome at MGA 261400 7227600. A sample from this area was dated at 72Ma (recalculated) (Green, 1975). Sutherland & others (1989) reported that the rocks are *ne*-hawaiite and that they contain ultramafic upper-mantle inclusions.

The plugs contain olivine phenocrysts up to ~6mm across, and the sparse, generally altered, ultramafic inclusions are up to ~3cm across. Much of the bouldery rubble at both localities consists of broken columns. The basalt at Little Mount Runsome is characterised by the presence of spherical to cylindrical vesicles up to ~3cm across.

A smaller elongate basalt plug was also examined north of Kennedy Peak, on Red Range Station in AUBURN in the far south of the region. Basalt forming this plug is very fresh. Small olivine phenocrysts are common. The plug intrudes and has hornfelsed sandstone, siltstone and shale of the Early Jurassic Evergreen Formation.

In the Rookwood area, several areas of possible Cretaceous basalt were delineated, although in the absence of isotopic dating they could be Tertiary. One forms a small plug intruding the undivided Back Creek Group on the south-western corner of the Goodedulla National Park at MGA 783000 7411050 in ROOKWOOD. It forms a prominent knoll referred to as Mount Beardmore by Dunstan (1901). It consists of very fine-grained, columnar-jointed nepheline basalt with olivine phenocrysts.

Another plug occurs in the Grantleigh area at MGA 195100 7371200 near Westgrove homestead in south-western MOUNT MORGAN. The basalt contains olivine phenocrysts and sparse spinel xenocrysts. Farther south on the Grantleigh Road, at MGA 198600 7366230, a small area of basalt rubble contains inclusions of spinel and phlogopite up to 1cm across. Garnet fragments up to 1cm are present in the soils derived from the basalt and the site is popular with local gem hunters after rain. This site may be the remnant of a flow (A. Robertson, personal communication, 1997).

Airborne magnetic data suggest that basalt dykes cut the Back Creek Group. They generally trend north-north-west, parallel to the strike of the host rocks. Attempts to locate them in outcrop were unsuccessful. However, one weathered basalt dyke ~3m wide was observed in a cutting on the main Rockhampton to Emerald railway line at MGA 794800 7376400, but although strongly magnetic, it was not evident on the magnetic image.

EARLY TERTIARY (PALAEOGENE) BASINS

INTRODUCTION

In central Queensland, several narrow, but relatively deep, early Tertiary grabens developed on the Palaeozoic blocks and show the same overall north-north-westerly trend. They commonly have the form of half-grabens with a faulted westerly margin and an onlapping easterly margin. They first formed during the Paleocene in response to tension associated with the break-up of the Australian and Lord Howe Plates (Mutter & Karner, 1980) and were filled by oil shale and fluvial to lacustrine sediments in the Eocene followed by the development of a deep weathering profile during the Oligocene. In the study area, the basins are the Biloela, Duaringa and Herbert Creek Basins. Other basins to the east include the Nagoorin, Narrows, Casuarina, Rossmoya, Lowmead, Water Park Creek and Yaamba basins (Figure 75).

BILOELA FORMATION

Introduction

The Biloela Basin is one of the largest Tertiary basins in central Queensland. It is ~125km long and up to 35km wide, extending from south-east of Biloela near Thangool to north of the Capricorn Highway. The basin is bilobate, and water bore information indicates that the deepest lobe is to the north (Pearce, 1971). A saddle just north of Jambin separates the lobes. The basin is probably a half-graben like many of the other Tertiary basins, at least in its central part. Images of the airborne magnetic data show a well-defined western edge, where the magnetic response of the basement rocks is sharply truncated. However, the eastern margin is less well defined and the magnetic responses of the basement rocks fade gradually to the west. The western margin is also easily defined on aerial photographs, whereas the eastern margin is not.

The sediments of the Biloela Basin were named “Biloela Beds” by Kirkegaard & others (1966). However, later reports mapped them as unnamed Tertiary sediments (Kirkegaard & others, 1970; Dear & others, 1971). Grimes (1980) revived the name ‘Biloela Beds’ and Noon (1982a) defined them as the Biloela Formation.

Type section

The type section is in GSQ Monto 5 from 27.2–374m. The borehole is located near the eastern shore of Lake Victoria at MGA 224400 73392500.

Lithology

The sediments are usually extremely poorly exposed, and were only examined during this study at a few localities in scarps of duricrust mesas in the northern part of the basin near Wowan and north-west of Gogango, where they are deeply weathered and capped by thin ferricrete (Figures 78a–b). The exposure is better near the southern margin of the basin where the topography is more dissected (Figure 78c) Grimes (1988) described several weathered exposures of claystone, siltstone, pebbly sandstone and conglomerate in quarries and road cuttings.

The section in GSQ Monto 5, which is described in detail by Noon (1982a), comprises 335m of freshwater, lacustrine mudstone, siltstone, oil shale and sandstone, and minor lignite, carbonaceous mudstone and limestone. The bottom of the unit is shale that overlies basalt at 374m. The drillhole bottomed in the basalt at 390m and it is not known whether any older Tertiary sediments underlie it. The top of the section underlies poorly consolidated silty sand. A sill of basalt 11.7m thick occurs at 357.3m. The formation thins to the north and south and thickens to the west.

Several companies have explored the Biloela Basin for oil shale. EPMs 2634, 2635, and 2636 were explored by CRA Exploration Pty Ltd using core drilling. Eight holes were drilled for a total depth of 1 300m. Assays ranged from 2–180L oil per dry tonne. The best intersection was 3.2m of oil shale yielding 104.2L per dry tonne in drill hole Jambin 3C. The company considered that the potential for economic deposits was limited.

BP Australia Ltd explored the Biloela Basin in the 1980s under EPM 2664 and 2665 (1980). Twenty-five non-cored holes and six partly-cored holes were drilled on a 10 x 5km grid. Some kerogenous seams were intersected in several holes but none of these intersections was considered economic.

Australian Consolidated Minerals Limited explored the southern part of the basin during 1981 under EPM 2918. They drilled two holes in the area (Thangool 1 and Thangool 2). The maximum oil yield for these holes was 8L/t, and it was concluded that the oil shale horizons were either too thin or contained only low concentrations of kerogen.

Also in 1981, Clifford Minerals under EPM 3098 analysed water bore records, previous exploration drilling records, and core from GSQ Monto 5. Rocks from GSQ Monto 5 were thought to be similar to sedimentary rocks in the tenement area and were tested for oil yields. These tests returned results of up to 165L/t and many samples yielded >70L/t. The results from the study of water bore records, however, were less promising and indicated that the Biloela Basin shallowed markedly to the south of Biloela. The tenement was deemed to have little potential for a major oil shale deposit.

Overall the oil shale intervals are too thin and at depths too great to be developed by opencut methods. The sandstones contain sub-artesian groundwater in the Callide valley.

Environment of deposition

The Biloela Formation was deposited mainly in a freshwater lacustrine environment, but probably also contained some fluvial sediments towards the basin margins. Noon (1982a) suggested that initial ponding may have been in response to damming by the basalts that have been encountered by the drilling. Continued subsidence in response to tectonism accompanied the volcanism and allowed the development of a lake system. Bioturbation in the basal section, and presence of the freshwater gastropod *Planorbis* and ostracodes in the oil shale attest to shallow water conditions throughout the life of the lake. Carbonaceous and coaly sections indicate the development of localised swamps. Groundwater investigations (Pearce, 1971) indicate that the rocks are coarser grained in the southern part of the basin, suggesting that the rivers that fed the lake system flowed from the south.

Age

The Biloela Formation has not been studied palynologically, but is generally regarded as early Tertiary like the other Tertiary Basins of central Queensland. The ostracode fauna is similar to that studied in The Narrows

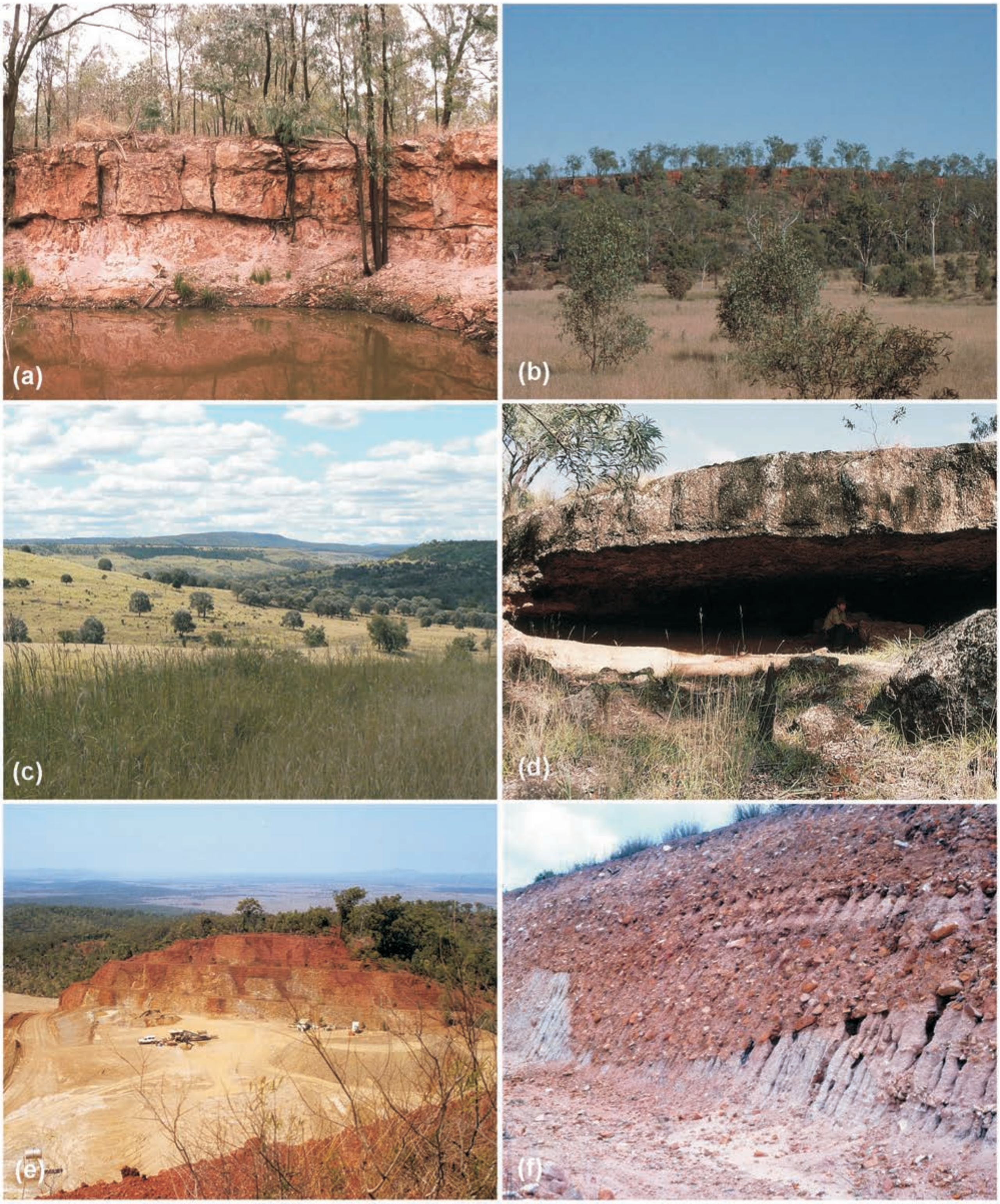

Figure 78. Tertiary deposits

(a) Typical leached and weathered exposure of the Biloela Formation. Old Burnett Highway, 9.3km north-west of Wowan at MGA 207196 7358980 (IWGG697)

(b) Lateritic capping developed on the Biloela Formation. About 3km west-north-west of Wowan

(c) Dissected sediments of the Biloela Formation forming benched flat-topped hills; Tertiary basalt caps the hills in the distance. Looking north from the Burnett Highway near Lawgi Hall at the southern end of the Biloela Basin.

(d) Resistant capping of indurated clayey gravel. About 2km south-west of Hawkwood homestead

(e) Deep weathering profile on the Princhester Serpentinite at the Gumigil Chrysoprase mine. About 17km south-south-west of Marlborough at MGA 791900 7457600

(f) High-level alluvial-fan deposits showing channels filled with cobbles and boulders of granite, rhyolite and some mafic volcanics, eroded into poorly sorted sandstone and thin conglomerate stringers. 3km south-west of Ballook Siding at MGA 702988 7594044 (BB3163)

beds and assigned an early Tertiary age by Palmieri (1975). An upper limit is provided by a K–Ar age of 25±4Ma on basalt from the Dawes Range south-east of Biloela.

DUARINGA FORMATION

Introduction

The sediments of the Duaringa Basin are here referred to as the Duaringa Formation, a name first used on the geological map of Queensland (Hill, 1953), although Malone & others (1969) later chose to leave them unnamed. The basin trends north-north-west from the south-east corner of the Duaringa 1:250 000 Sheet area, and is ~170km long by 35km wide. The basin has been described as a graben (Noon, 1984a,b), with most displacement occurring on the western margin, which is a normal fault (Kirkegaard, 1970). The eastern margin in places may be a simple onlap. Seismic data showed the basin to consist of a northern and southern depression separated by a saddle (United Geophysical Corporation, 1965). The presence of more than 1200m of Tertiary sedimentary rocks in the central part of the graben was demonstrated by drilling of GSQ Duaringa 1-2R and 3-5R (Noon, 1982b). West of the faulted margin and also to the north of the basin, widespread thinner deposits of sediments overlying the Bowen Basin rocks are equated with the Duaringa Formation.

Type section

The type section is herein designated in GSQ Duaringa 1-2R (Noon, 1982b), which intersected 1218.5m of mudstone, siltstone and subordinate sandstone, ironstone and some oil shale and lignite before intersecting basalt which was cored to the bottom of the hole at 1303m. GSQ Duaringa 3-5R also intersected 1224m of mudstone, siltstone and minor lignite is designated as a reference section.

Lithology

In outcrop, the Tertiary sediments are generally deeply weathered and capped by cliff-forming duricrust up to 10m thick, forming extensive tableland areas, generally <60m high, but up to 120m. Unlateritised sediments are poorly exposed, and as described by Malone & others (1970) consist mainly of poorly sorted sandy gravel, pebbly quartz sandstone and silty clay. The sandstone is cross-bedded in places. Ball (1928) described outcrops of fissile oil shale in the Dawson River, ~25km south of Boolburra. Reid (1939) recorded ~10m of diatomaceous earth 10km north-west of Junee homestead. Deeply weathered tuff also crops out locally, and is possibly derived from Oligocene felsic volcanism in the Peak Range near Clermont or Minerva area near Springsure. The altered tuff contains 30% kaolin cemented by secondary opaline silica and is mined near Duaringa at MGA 774300 7368700 and processed for use as an absorbent (Garrad & others, 2000).

Exploration for oil shale in the basin (almost exclusively by Southern Pacific Petroleum and Central Pacific Minerals) has indicated the presence of two oil shale seams over an area 100km x 20km north-west from Duaringa. The lower seam averages 14m thick, and the upper seam ~8m. Three main deposits have been identified within this belt and have a total resource of 4.2 billion barrels of oil at grades ranging from 72–82L/t (Garrad & others, 2000).

The rocks are mostly flat-lying. Malone & others (1969) noted the presence of dip slopes of <5° locally, but these may be remnants of an undulating weathering or duricrust surface.

Environment of deposition

Like the Biloela Formation, the sediments are probably largely lacustrine to fluviatile. Basalt flows are interbedded in places, and these may have locally dammed the streams and formed lakes.

Age and relationships

The sediments of the Duaringa Basin mainly overlie Permian rocks of the Bowen Basin, but locally up to 150m of Mesozoic sedimentary rocks are present in the middle of the basin (Swarbrick, 1974). Basalt flows are interbedded in places such as near Mount Sirloin, south-west of Duaringa. Basalt has been interpreted from airborne magnetic data underlying the Duaringa Formation near Balcomba homestead on the eastern margin of the basin and at the northern end of the basin in WINDEYERS HILL and the western part MOUNT BLUFFKIN (Figure 75).

Palynological studies by Foster (1980) indicated a middle or late Eocene age ranging to late Oligocene or early Miocene. Earlier studies by Hekel (1972) indicated an early Miocene age.

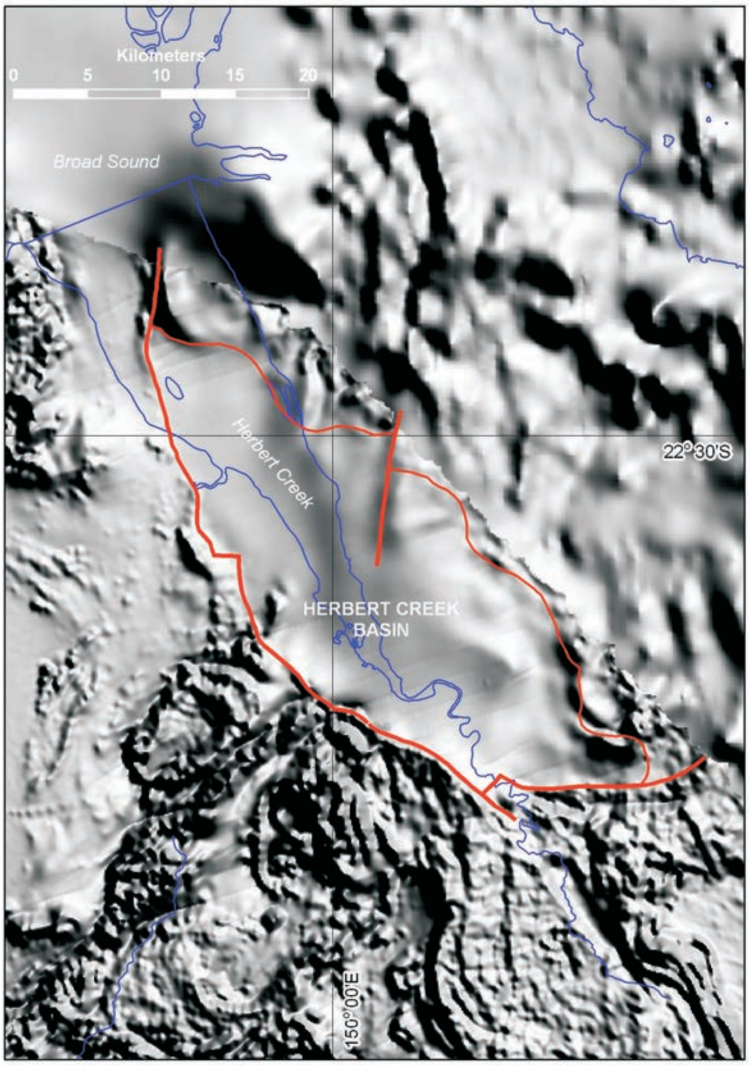

Figure 79. Total Magnetic Intensity image with a north-east sun-angle, showing the outline of the subsurface Herbert Creek Basin and its low magnetic response contrasting with the response of the surrounding older rocks. Note the sharply defined faulted western margin and the more diffuse on-lapping eastern margin.

HERBERT CREEK BEDS

The Herbert Creek Basin is located in the area of the Herbert Creek estuary into Broad Sound. It is ~45km long and 15km wide but apart from some deeply weathered exposures in lateritic profiles east of the estuary, is completely covered by late Cainozoic alluvial sand, gravel and clay or lies under Broad Sound. Like all of the Tertiary basins in central Queensland, the basin is faulted on its south-western side. The fault lies along the western edge of Broad Sound and is well displayed on magnetic images where it truncates the strongly magnetic rocks of the Marlborough Block (Figure 79). This faulted margin is thought to be on line with the Broad Sound Fault, a major regional structure that marks the western boundary of the Wandilla Province (or Coastal Block). The bounding fault appears to curve to the east at the southern end and truncates the basin. The eastern margin is probably just on the edge of the detailed airborne magnetic data and is poorly defined, lying east of the Stanage Bay road in the Shoalwater Bay Army Training Area. It is thought to represent onlap of the Tertiary sediments onto the Pyri Pyri Granite, because the magnetic signatures of the underlying rocks become progressively stronger to the east. The northern end of the basin lies between Woods Island and the mouth of the estuary.

The rocks in the basin are herein assigned to the Herbert Creek beds, but apart from some deeply weathered exposures in lateritic profiles east of the estuary, are completely covered by late Cainozoic alluvial sand, gravel and clay. The sequence is at least 800m thick and may be as much as 1300m (determined from drilling and geophysical modelling) and consists mainly of mudstone, sandy, micaceous shale and subordinate semi-friable lithic sandstone and pebble conglomerate; several intervals of oil shale are present.

The basin has been actively explored for oil shale and magnesite since 1979, but most of the data are still confidential and few details of the basin are available for publication. Some data for relinquished areas is available in the report by Peabody Australia Pty Ltd (1993). Oil shale resources with economic potential have been identified at two localities covered by the Block Creek and Boundary Flat Lagoons Mineral Development Leases.

Magnesite does not occur in the basin itself, but as nodules of cryptocrystalline material in clay and unconsolidated sand and gravel that blanket the Tertiary sediments and pre-Tertiary bedrock along the eastern flank of the Marlborough Block.

PLEVNA OIL SHALE

Tertiary sediments at Plevna, in the Crediton State Forest south-east of Eungella occur in the deeply incised valley of Hazlewood Creek. Overlying, mainly felsic Tertiary lavas have left only a small window of ~0.24km^2 of the sediments exposed (Jensen & others, 1966). They were first reported by Ball (1927) and later by Shepherd (1939). During World War II, a local syndicate drilled some bores and had shafts put down to test an oil shale member. Reid (1942) described these in some detail. Rock types logged included carbonaceous shale, tuffaceous shale, oil shale, siltstone, mudstone, fine sandstone, and tuff. According to Swarbrick (1974), oil shale crops out almost continuously for ~200m in the bed of Hazlewood Creek at the northern end of the window. The maximum known thickness of the succession is 96m. A dark grey fissile oil shale outcrop with dips of around 20° to the south-south-west was observed in a creek at MGA 658680 7644265 during this survey.

Hekel (1972) examined a sample from the basin and found abundant grains of the pollen genus *Nothofagites* and suggested an early Miocene age. The genus is indicative of a humid temperate to tropical highland climate. However, dating of basalt (QA218) that overlies the oil shale by Sutherland & others (1978) gave an Oligocene age of 28.4Ma (recalculated) suggesting that the oil shale is Oligocene or older. Sutherland & others (1978) further suggested that the oil shale formed in a restricted basin formed by damming of streams by the lower Eungella basalts in the early Oligocene (32–33Ma).

A survey by Austral Mining Qld Pty Ltd (1958) as a potential conventional petroleum prospect included the sinking of three shallow bores. Haoma Gold Mines NL reassessed the oil shale potential of the basin as part of A to P 2813M (Baker & Stuart, 1981). A resistivity survey was carried out to delineate the size of the basin. The prospect was considered to be too small to warrant further exploration.

Oil yields from the shale reported by Reid (1942) and Swarbrick (1974) ranged from 67–100L/t.

UNNAMED SEDIMENTARY ROCKS (Ts)

Whitaker & others (1974) mapped extensive areas of duricrusted sandstone, siltstone and claystone that are exposed as mesas and plateau over ~2600km^2 in the Mundubbera 1:250 000 Sheet area. They are best developed on the Auburn Plateau, although the duricrusted sediments are difficult to distinguish from deeply weathered granite and duricrusted granitic regolith. Where present, they consist of up to 15m of poorly consolidated, non-bedded, poorly sorted, clayey quartzose sandstone, siltstone and claystone, locally silicified. Sandstone commonly overlies granitic rocks, whereas the claystone overlies Palaeozoic and Mesozoic sedimentary and volcanic rocks. They are designated as **Ts** on the maps accompanying this report, and are usually covered by a veneer of sandy soil and shown as **TQr**.

Extensive areas of lateritised Tertiary sediments have been photo-interpreted west of the Marlborough Block, and also west of the Connors Arch along the catchments of the Mackenzie and Isaac Rivers. The latter are probably a northward continuation of the Duaringa Basin.

Around Lake Epson, south of the Peak Downs Highway near Mount Spencer on MIRANI, a discontinuous veneer of unbedded gravels and coarse semi-friable sandstones with abundant quartz and mica has been mapped. Some granitic subcrop is exposed within this unit.

In the Miocene and Pliocene, the mid-Tertiary land-surface was uplifted and eroded, and locally basalt volcanism occurred, burying the land-surface or filling valleys cut into it. Fluvial sedimentary rocks that define a palaeo-valley in the Rookwood area and to the west of Marlborough may have originated at this time. However, they have also been affected by deep weathering and are difficult to distinguish from the sedimentary rocks in the Biloela and Duaringa Basins and could be as old.

DEEP WEATHERING PROFILES

Extensive weathering during the Cainozoic probably produced deep weathering profiles over most of the region, but these have been subsequently removed by erosion in most areas.

The processes of deep weathering have been discussed by Senior & Mabutt (1979), Senior (1979) and McFarlane (1983). Where fully preserved, the profile consists of a thin loose sandy or silty soil overlying a ferricrete band (‘laterite’ *sensu stricto*) and below this a mottled zone followed by a pallid zone overlying the bedrock.

Extensive areas of deeply weathered rocks are preserved as mesas overlying the Biloela and Duaringa Basins and other areas of thin Tertiary sediments in BANANA, DUARINGA, MARLBOROUGH and MOUNT BLUFFKIN. Grimes (1988) described the profiles at several localities in the Biloela Basin. On the large red mesa 12km north-west of Wowan (MGA 207300 7364000), the profile grades from strongly weathered sandstone through a mottled zone to a uniform rich red ferricrete in the cliffs at the top. The cliffs have vermicular and nodular structures and occasional larger pipes. They are case-hardened and small caves have formed at the base. They are designated by the map unit **Td**.

Scattered swampy depressions a few hundred metres in diameter (mapped as **Qhw**) occur on the duricrusted surfaces in a few places, such as north-west of Wowan (Grimes, 1988, page 67) and on the plateau in western MOUNT BLUFFKIN. The depressions are usually floored by grey clay and are interpreted as having formed by lateritic solution in an analogous manner to solution dolines in karst terrains. They are common in northern Australia, but are less common in central Queensland (Grimes, 1988).

There are also very extensive areas in the southern part of the study area (RAWBELLE, AUBURN and CRACOW), where very few outcrops of unweathered basement rocks can be observed, and indeed decomposed basement is not widely exposed either. The most extensive relicts of deep weathering are on the Auburn Plateau, in the far east of CRACOW extending into western RAWBELLE. The bedrock consists, as far as can be determined, of granitic and silicic volcanic rocks, or poorly consolidated sandstone and claystone derived from these rocks. Many smaller relicts form low mesas scattered throughout the region.

Very little true ferricrete is present in the Auburn Plateau. The preserved part of the deep weathering profile in most outcrops examined consists essentially of a mottled zone, underlain in places by a pallid zone of variable thickness, the upper ferruginous zone having been eroded off. The intervening pallid material in the mottled zone has broken down to leave a soil with ferruginous pebbles and cobbles, which can be mistaken for ferricrete horizons. Minor true ferricrete occurs overlying some gabbroic units, such as on Rocky Springs Station. The thickness of the deep weathering profile is generally <20m.

Silcrete is also quite uncommon, and was mainly observed around the present Auburn River valley, for example along the Delubra homestead access road just off Hawkwood Road. A small area was also observed on Lakeview Station north of Rannes. Calcrete seems confined to more recent unmottled residual and transported deposits, provided they are calcic enough, such as colluvium derived from tonalite or mafic rocks such as andesite or basalt.

No significant areas of ferricrete are preserved on the Connors and Broadsound Ranges in the north of the project area, in spite of their elevation. However, areas of leached and mottled rocks representing the lower parts of the weathering profile have been observed along the crest of the range between Burwood and Marylands homesteads. Continued uplift of the region in the Neogene has probably caused the profiles to be removed in most of this area.

Tertiary weathering also produced lateritic cappings over the ultramafic rocks of the Marlborough Block and remnants of these are preserved on the crests and slopes of hills to the south of Marlborough. INAL Staff (1975) described the profiles as passing from surface rubble and pisolitic ferricrete through a limonite zone into saprolite and ultimately fresh bedrock. They noted some evidence for structural influence on the control of the deep weathering, the deepest profiles being developed along permeable fracture zones. After the initial deep weathering, parts of the area were subsequently overlain by sediments ranging from claystone through sandstone to coarse conglomerate and talus deposits. Because they were largely sourced from the underlying residual lateritised ultramafics, the sediments are difficult to distinguish from the latter. The sediments themselves were further lateritised and in places silicified forming a silica cap such as at Mount Slopeaway. Partial to complete silicification forming silica boxworks and massive jasper as well as the silica caps has affected almost all of the weathered profile and extends into the fresh bedrock in places. The silicification generally occurs as an irregular layer conformable with the base of the Tertiary sediments, but extends downwards along zones of shearing and faulting. The silicification may have occurred at multiple time intervals. The lower parts of the profile may have been silicified during the initial deep weathering and leaching of the serpentinite, whereas other silicification may have taken place during deposition of the sediments or during subsequent weathering. Recent weathering has produced a blanket of soil and rubble over the deposits and thick talus deposits blanket the slopes.

The age of the extensive weathering through the region cannot be ascertained with any accuracy. Profile development post-dated the youngest of the major faults in most of the region studied; the latest significant displacements on these probably occurred in the Late Cretaceous or Palaeogene. However, in the north, some of the movement may be younger, because profiles to the east of the study area in the Marlborough area have been displaced.

TERTIARY (PALAEOGENE TO NEOGENE) BASALT

MONTO–MUNDUBBERA AREA

Remnants of formerly more extensive flows of Palaeogene to Neogene (Tertiary) basaltic lava, forming part of the Monto Province described by Sutherland & others (1989), occur in the central part of the region from near Goovigen in BANANA to the northern part of CRACOW where they are present as rare, rubbly outcrops that form small, high-level, residual mesa cappings. Weathered basalts occur at the base of the Biloela Basin (Noon, 1982a; Grimes, 1988; see above). They are too altered to date, but Sutherland & others (1989) suggested that they might be similar to a dolerite dated south of Biloela at 48Ma (recalculated) by Green (1975). However, most of the basalts in the area are probably younger than the Biloela Basin sediments. They are mostly not lateritised, although locally some extensively weathered and locally lateritised basalts form residual plateaux and knobs.

The basalts are best preserved overlying the Rawbelle Batholith and Jurassic sedimentary rocks in SCORIA where they form extensive mesas and tablelands with steep scarps and dark brown to reddish, heavy soils. One of the most extensive is in the area west of Boolgalgopal Creek. The basalts are essentially flat-lying. They are aphyric to slightly porphyritic and show olivine phenocrysts (up to 10%) in a groundmass of plagioclase with intersertal pyroxene and glass. Vesicular and scoriaceous lavas are common. A scrape near Coominglah homestead at MGA 282200 7259450 shows sheets of aphyric basalt overlying vesicular basalt that has rounded ellipsoidal blocks of olivine basalt, up to 1.5m, in the top 2m. In some areas around Dawes Range and Cattle Creek, separate flows or levels of basalt can be recognised, but the lack of continuity prevents a regional subdivision. In places they are extensively weathered and locally lateritised. Sutherland & others (1989) reported that they are mainly alkali basalt and hawaiite, and suggested a late Oligocene (~27Ma) age, like similar basalts farther south in the Binjour Plateau and Mount Redhead areas. Sample DA-6 from the Dawson Highway at MGA 269900 7272900 on the Dawes Plateau was dated at 25.4±0.5Ma (Grimes, 1988)

Sutherland & others (1989) described unlateritised basalts at about the Oligocene–Miocene boundary (25Ma) in the Callide Valley in the northern part of the province, but these are mostly outside the project area. They reported that the thickest section of these in the Callide Valley has at least six flows totalling 270m in thickness. *Ol*- and *q*-tholeiitic basalts are typical amongst the basal flows whereas alkali basalt and hawaiite prevail in the upper flows.

A few plugs are known. The most conspicuous is Mount Scoria at MGA 256700 7284400, 7km south of Thangool (Figure 80a). The plug is ~150m high and covered by scree of basalt columns. Towards the top of the hill, the columns are vertical or rotated outwards by mass movement. Further down they dip downwards and out from the hill.

MACKAY – SAINT LAWRENCE AREA

Extensive basalt flows occur in the north-western part of MOUNT BLUFFKIN and south-western CONNORS RANGE. They were not examined except for a few outcrops along the old Marlborough–Sarina road. They are mostly covered by black soil and extensively cultivated. They may correlate with the late Eocene to Oligocene (41–27Ma) basalts of the Peak Downs region to the west (Veevers & others, 1964; Wellman & McDougall, 1974; Wellman, 1978; Knutson, 1989). Some may be interbedded with the Tertiary sediments at the northern end of the Duaringa Basin. Basalt has been interpreted from airborne magnetic data underlying the Duaringa Formation near Balcomba homestead on the eastern margin of the basin and at the northern end of the basin in WINDEYERS HILL and the western part MOUNT BLUFFKIN (Figure 75). The airborne magnetic data suggests different ages. Some basalts have normal polarity and some are reversed.

Figure 80. Tertiary flows and plugs
(a) Mount Scoria, a small basalt plug. 7km south-west of Thangool at MGA 256826 7284676 (RSC123)
(b) Rhyolitic or dacitic ignimbrite. Summit of Pine Mountain near Waitara at MGA 690236 7594437 (BB3039)
(c) Rhyolite flows and plugs forming Sydney Heads and Marling Spikes. About 30km north-north-west of Nebo.

Sutherland & others (1978) dated samples from ~12km south-west of Lotus Creek Roadhouse. A weathered flow of olivine tholeiite is overlain by three trachybasalt flows. A sample of partially glassy tholeiite (QA236) gave a recalculated minimum age of 26.5Ma and a fresh, slightly glassy trachybasalt (QA235) gave a recalculated age of 29.1Ma, suggesting an Oligocene age consistent with the deep weathering and lateritisation that have affected the rocks.

The possible presence of older basalt flows is suggested by an early Eocene recalculated age of 50.7Ma for an alkali olivine basalt plug just south of the old Yatton Creek goldfield at MGA 739200 7507300 (QA230; Sutherland & others, 1978). Some of the flows near Yatton Creek may be related to this plug.

Farther north in western MIRANI and NEBO, olivine basalt crops out as remnants of more extensive lava flows. Basalt occurs in, and to the south of, the Crediton State Forest capping the Clarke Range and filling old valleys of Hazlewood Creek to the west. Sutherland & others (1978) recognised at least four flows consisting of alkali basalt, hawaiite and transitional basalt in order of eruption. They reported ages of 31–33Ma (early Oligocene — samples QA215-217).

Basalt flows filling former valleys underlie the rhyolitic rocks in the Diamond Cliffs area and were correlated petrographically with the rocks in the Crediton area by Sutherland & others (1978). Rhyolites also intrude and overlie a flow of alkali basalt at the Marling Spikes. A sample of this flow from near Sydney Heads gave a recalculated age of 35.1Ma (QA232; Sutherland & others, 1978).

Basalt to the west of Nebo gave minimum ages in the range 25–29Ma and Sutherland & others (1978) suggested an early Oligocene age for the succession. At Mount Fort Cooper, weathered basalt of this sequence is overlain by thick, coarse-grained, basaltic rocks ~150m thick that form a prominent mesa ~1.5km across. The rocks were described by Sutherland (1981) and briefly by Rienks & others (1984, pages 22–24). The body is composite ranging from micro-porphyritic basanite near the base to coarse-grained, pegmatoidal alkali basalt to gabbro near the top. The coarse-grained material is heterogeneous in grainsize and composition and includes minor irregular mafic and leucocratic layers 3cm to 4m thick and lenses, veins and patches of pegmatoidal material. A crystallised volcano feeder or lava lake has been suggested as a possible origin for Mount Fort Cooper. An age of 17Ma (re-calculated) was obtained for the coarse-grained basalt by Sutherland & others (1978), but because of the presence of a zeolitic mesostasis in the sample (QA241), it is unlikely to be a reliable age.

PALAEOGENE SILICIC VOLCANIC AND HIGH-LEVEL INTRUSIVE ROCKS

Silicic volcanic and high-level intrusive rocks are scattered through the area, particularly in the Saint Lawrence and Mackay 1:250 000 Sheet areas. They have not been dated, but are probably Tertiary and could correlate with the Oligocene felsic rocks of the Peak Range in the Clermont Sheet area to the west (Wellman & McDougall, 1974; Wellman, 1978).

DIAMOND CLIFFS – NEBO AREA

These felsic rocks were described by Jensen & others (1966), Sutherland & others (1978), Sutherland (1981) and briefly by Rienks & others (1984).

The Diamond Cliffs are a 4km-long east-west trending series of escarpments that mark the edge of a high plateau formed by felsic volcanic rocks, in south-west MIRANI. The cliffs are up to 80m high and around 900m in elevation. The plateau surface is rough and broken and evidence of its former size can be seen in smaller remnants, for example Sydney Heads and the Marling Spikes, which now stand as conical hills isolated from the main plateau (Figure 80c). Rhyolitic breccia and poorly-bedded rhyolitic tuff are exposed around the Diamond Cliffs area (MGA 661970 7636950), commonly overlying basalt. Rhyolitic breccia with blocks up to several metres across is associated with fluidal rhyolite and glassy black obsidian and pitchstone. They are likely to have been erupted from multiple vents including dykes and plugs. The Marling Spikes consist of fine-grained flow-banded rhyolite or trachyte and are interpreted as volcanic plugs, and may be feeders for various flows in the area. The plugs have well-developed columnar joints, steep to vertical flow banding and steeply dipping brecciated margins. Sutherland & others (1978) dated glass and sanidine from a sample of pitchstone (QA231) from a dyke west of Marling Spikes giving recalculated ages of 30Ma and 34.2Ma respectively. They speculated that the sanidine may have contained excess argon and considered that the rock should be regarded as being early Oligocene in the range 30–34Ma consistent with the age of the basalt underlying the rhyolite at Sydney Heads (see above).

At Mount Britton, 4km south of the Marling Spikes, a thick succession of volcaniclastic rocks (including ash-flow deposits) and rhyolite lavas is exposed. Dykes and plugs intrude the volcaniclastic rocks and the underlying basalt. A slightly altered trachyte (QA256) from a dyke gave a recalculated age of 30.2Ma (Sutherland & others, 1978).

Mount Landsborough, 15km north-west of Nebo, is formed by a thick sheet of autobrecciated rhyolite overlying basalt, and is capped by a thin unit of siltstone.

Scattered outcrops of silicic volcanic and high-level intrusive rocks are present in the south-east of NEBO, where they form Mount White and Pine Mountain (north of Waitara). These rocks form prominent topographic highs, with abundant bouldery rubble, numerous rocky outcrops and, locally, cliffs. Vine scrub and lantana grow profusely in areas underlain by these rocks, making access very difficult.

Pine Mountain, ~18km east-south-east of Nebo, consists of ~200m of dark grey, densely-welded, crystal-poor, dacitic(?) ignimbrite (Figure 80b), with well developed columnar jointing in places (e.g. in the summit area). The ignimbrite in the summit area is lithic rich, with fragments (up to 10cm across but mostly <3cm) consisting mainly of aphyric to porphyritic dacite and rhyolite (?), with minor andesite and/or basalt (some amygdaloidal). Highly flattened pumice lapilli define a prominent eutaxitic foliation in places. Elsewhere, the ignimbrite is very lithics poor. The ignimbrite sequence overlies ~60m of poorly exposed basalt, which in turn overlies granites of the Urannah Batholith. The rocks are probably Tertiary, although ignimbrite is not typical of the Tertiary volcanic rocks elsewhere in the area.

The summit area of Mount White, ~8km farther east, consists of buff, moderately porphyritic microgranite, with numerous small quartz and feldspar phenocrysts in a very fine-grained, granular groundmass. The rock is interpreted as a high-level intrusive. In contrast, the upper southern flank of the mountain consists of slightly porphyritic rhyolite, which may represent the remnants of an older (Tertiary) lava flow.

Several hills comprising dacitic to possibly trachytic ignimbrite overlie the Collaroy Volcanics south of Undercliff in southern CARMILA. The age of these volcanic rocks is uncertain, but they are tentatively assigned to the Tertiary.

CARDOWAN – MOUNT BORA AREA

Several rhyolite bodies form large hills along the western flank of the Connors Arch in CONNORS RANGE. These include Meiklejohn Hill near Cardowan, Mount Raddle, Iron Pot Mountain and Mount Bora. These hills comprise generally massive white to cream aphanitic rhyolite or trachyte. Their age is uncertain but they appear to form massive rhyolitic sheets and domes overlying or intruding the early Permian volcanic and sedimentary rocks.

Mount Bora is a large plug of microsyenite ~1.5km^2 in area intruding the Back Creek Group. Several smaller plugs of rhyolite or trachyte occur in the vicinity, but some of these may be Permian.

Massive flow-banded and autobrecciated rhyolite bodies occur elsewhere in the Mount Benmore Volcanics. However, no definitive field criteria have yet been established to distinguish the early Permian rhyolites from the Tertiary volcanic rocks except where they clearly intrude or overlie the Permian Back Creek Group. Examples of the latter include Mount Bora and rhyolite or trachyte flows at Bar Mountain and Mount Bluffkin.

MACKAY – SARINA AREA

Tertiary silicic volcanic rocks were described around The Leap and Yakapari, north-west of Mackay by Reid (1931) and Jensen & others (1966). The Leap was described as consisting of thick flows of columnar-jointed trachyte overlying altered sedimentary rocks which are intruded by thick trachyte sills and some dykes of green perlitic pitchstone that contain phenocrysts of quartz and feldspar and needles of sodic amphibole. Reid described “immense sills” of trachyte intruding the Permian rocks at Yakapari.

Mount Hector, a small hill on the coast north of Sarina, comprises fragmental and well-bedded felsic volcanic rocks (MGA 735200 7646250). Light grey rhyolite intrusive into the Campwyn Formation was also seen.

OTHER CAINOZOIC DEPOSITS

Cainozoic deep weathering and sedimentary deposits are extensive throughout the region, particularly in the south. Over the southern part of the Auburn Arch and Rawbelle Batholith, their distribution is considerably greater than shown on the existing Monto and Mundubbera 1:250 000 geological maps. However, because the Cainozoic deposits were essentially outside the scope of the investigation, little time was spent studying them. They range in age from Recent to Tertiary.

HIGH LEVEL ALLUVIAL FAN/TALUS DEPOSITS

High-level alluvial-fan and talus deposits apparently unrelated to present-day drainage systems cover extensive areas adjacent to the old Bruce Highway, between the Sarina Range and Wandoo homestead in north-western CARMILA and adjacent NEBO (Figure 78f). Some of these deposits have maximum exposed thicknesses of >10m. They are probably Tertiary. Rock types include poorly consolidated conglomerate, sandstone, siltstone, mudstone, and shale, as well as coarse gravel, sand, and silt. The deposits are extensively weathered (bleached and locally ferruginised). Many of the granite clasts in the conglomerates are also extensively ferruginised. The data imply that these deposits pre-date a period of deep weathering in the Tertiary.

Noteworthy features of the deposits are the abundance of conglomerates and the coarse size of many of the clasts. They range from medium to thickly bedded and most are massive with no evidence of grading. Clasts range from less than 3cm up to ~2m across and are mainly unsorted; a few deposits are characterised by poorly developed normal grading. Most of the boulders are well rounded to subrounded (particularly the larger ones), but angular clasts are common in some deposits.

The fabric ranges from matrix- to clast-supported. Aphyric to sparsely porphyritic, and locally flow-banded, rhyolitic volcanic rocks form by far the predominant clast type in most deposits. They also generally form the largest clasts, except for the rare boulders of silicified (petrified) wood. The rhyolites are pale to dark grey, aphyric to sparsely porphyritic, and locally flow-banded. They were probably derived from Tertiary volcanic sequences, which have been extensively eroded. Rhyolitic volcanic rocks similar to those forming the clasts have not been found in situ in the study area. Scattered boulders of extensively weathered (ferruginised) granite generally accompany the rhyolite clasts. Some deposits also contain scattered clasts of porphyritic dacite and/or quartz.

On parts of the eastern flanks of Black Mountain and Blue Mountain south-west of Sarina, granite forms the dominant clast type reflecting the fact that granite is one of the main rock types exposed on both mountains. Boulders of gabbro and several types of dyke rock are also present in the deposits at the foot of Blue Mountain. *In situ* outcrops of such rocks have been found on the flanks of Blue Mountain. The deposits form a very extensive terrace adjacent to Stony Creek. The terrace is characterised by an irregular, hummocky, bouldery surface. Similarly, clasts in the deposits exposed in the railway cutting at MGA 725400 7607400 consist mainly of crystal-rich ignimbrite. The clasts are mainly angular and were derived from nearby silicic volcanic units in the Carmila beds exposed further upslope.

The matrix in most of the conglomeratic deposits is medium to coarse-grained, poorly sorted, feldspatholithic sandstone. Locally, the matrix is rich in pale brown clay. Some of the deposits contain scattered lenses (up to ~1.5m thick) of poorly sorted, fine to coarse-grained, feldspathic sandstone and siltstone.

Some of the deposits display evidence of extensive penecontemporaneous erosion. Channels up to ~2m deep, for example, have been eroded in a sequence of poorly sorted, feldspathic sandstone and conglomeratic sandstone exposed at MGA 703000 7594100 (Figure 78f). The channels are filled with boulder conglomerate.

COLLUVIAL AND RESIDUAL DEPOSITS

Areas of slope wash and thick soil cover are mostly designated as **Qr**. These include aprons of clay and sand deposited below the scarps of the mesas of deeply weathered and duricrusted sediments in the Biloela and Duaringa Basins.

More extensive areas of soil cover, particularly those that define older, dissected surfaces, are designated as **TQr**. Subscripts are used in some places to denote compositional variations, such as dominance of sand or gravel and red or black soils derived from basalt and other mafic rocks. Most Cainozoic deposits delineated on the Auburn Plateau, as well as smaller areas elsewhere in the Mundubbera 1:250 000 Sheet area, have been included in this unit. They include residual and, to a much lesser extent, transported soil, sand, and gravel, as well as some alluvial deposits that overlie remnants of deep weathering profiles and poorly consolidated massive sandstone and minor siltstone and claystone that have been mapped as **Ts** (Figure 78d).

ALLUVIAL AND COLLUVIAL DEPOSITS

Alluvial deposits are developed along most of the major watercourses throughout the project area, generally as discontinuous flats. They have not been studied in any detail, but some observations were made that allow some subdivision of the deposits on aerial photographs. The youngest units mapped are the active stream-bed alluvium and lowermost terraces along the major rivers (delineated as **Qha**). Most alluvial tracts are simply mapped as **Qa**, and mostly comprise the modern flood plains, although some higher terraces may be included. Extensive flood plains have been developed along the modern Fitzroy, Don, Dawson, Isaac and Mackenzie Rivers and Callide Creek. Adjacent to these flood-plains, remnants of higher alluvium are characterised by extensive development of 'melon holes' or gilgai that give a dimpled appearance on aerial photographs. The development of these depressions indicates a significant length of time since floods inundated them, and the deposits probably extend back to the Pleistocene at least. They have therefore been designated as **Qpa**.

South-west of Auburn homestead, tributaries of Johnson Creek give the impression that it once drained south-west (particularly Washpool Creek and some other creeks draining the range to the west). This impression, along with the change in direction of the Auburn River near Auburn homestead, suggest that the river once flowed south-west near the present course of Johnson Creek, but abandoned this more southerly course or was captured to adopt its present north-easterly flowing course.

Other alluvial units include fan deposits (designated **Qf** or **TQf** if they are suspected to be older) adjacent to some of the higher topographic features such as the Banana Range near Biloela and the Connors and Broadsound Ranges in the north. In the Biloela Basin, extensive fans have been mapped extending out from some of the larger plateaux of duricrusted and deeply weathered Biloela Formation. Talus aprons (labelled

Qr^{t}) consisting of gravel grading down-slope to lower-gradient alluvial fans and outwash deposits have been recognised adjacent to some of the steeper escarpments.

Extensive areas of older alluvium in the western part of THEODORE and BANANA and also in ROOKWOOD west of the Fitzroy River probably extend back to the Pliocene, and have been designated as **TQa**. Older areas of semi-consolidated deposits have been designated **Ta**. Some of these may include outliers of Palaeogene sediments deposited in the Biloela and Duaringa Basins, although most, such as those adjacent to the modern Dawson River, are probably younger (Neogene). Some are mottled and appear to have been through a deep weathering cycle.

COASTAL DEPOSITS

Coastal deposits are best developed in the Broad Sound area near Saint Lawrence, although narrower deposits also occur along the coast south from Mackay. Broad Sound is an estuarine complex characterised by shallow water, a large tidal range (up to 10m) and strong tidal currents. It includes the funnel-shaped mouth of Herbert Creek, as well as the mouths of the Styx River, The Hoogly and Waverley and Saint Lawrence Creeks. Cook & Mayo (1977) studied the region in detail and used a five-fold classification of the environments into shallow marine, open intertidal, mangrove channel, mangrove swamp and supratidal.

The shallow marine environment is entirely subtidal and not represented on the maps accompanying this report. The sediments range from sand in areas flanking the intertidal sand ridges, to gravel (with significant mud and sand) in the more seaward parts of the sound. The gravels are composed mainly of calcareous nodules and shell debris overlying an indurated pavement thought to represent relict pre- or early Holocene sediments formed under subaerial conditions. The nodules are probably relic pedogenic carbonate from the indurated surface.

The open intertidal environment is dominated by fine to medium-grained, well-sorted sands composed of ~40% shell debris. A few relict gravels are also present, and some mud occurs in areas where there is active erosion of adjacent mangrove swamps. Features of the sand include mud-balls and intraformational breccias, cross-beds, current and oscillation ripples, and megaripples that generally show an ebb-orientation perpendicular to the sand ridges. The sands are strongly bioturbated, particularly by crabs. High in the intertidal zone are some coarse-grained beach deposits, cemented in places to form beachrock. The intertidal deposits are shown on the map as unit **Qhe**$_{s}$. Their extent is based on air-photo interpretation, as fortuitously, the Fitzroy Project 1:25 000-scale coloured photos that cover Broad Sound were taken at or near low tide.

Mangrove channels are mainly within the intertidal zone, although they extend into the supratidal zone in places. They characteristically have steep v-shaped profiles. Sediments are generally mud and sandy mud. The mangrove swamp environment, ranges from high in the intertidal zone into the supratidal zone. It commonly forms narrow belts flanking the mangrove channels, but in places forms areas several kilometres wide, particularly on the eastern side of Herbert Creek. The sediments are mainly slightly calcareous mud, but sandy mud and sand are locally present on the seaward side. They are strongly bioturbated by infaunal and root activity. The mangrove swamp and channel environments are grouped together as unit **Qhcm**.

On the landward side of the mangrove swamps are supratidal environments that are inundated only during spring tides or storm tides. The sediments are predominantly fine mud (unit **Qhe**$_{m}$), but some sand and gravel occur on the landward edge, washed in during the wet season. Because of the hypersaline conditions, gypsum crystals are common. Algal fibres are important sediment binders. The mud is only slightly calcareous, although dolomitic nodules have formed. Continued seaward progradation of the coastal plain finally results in removal of the supratidal flats from the marine regime and they are then colonised by grasses to form coastal grasslands. Farther inland they are overlain by fluvial sands and gravels, which can be distinguished by their open tree cover.

The coastal grasslands are best developed upstream along Waverley and Saint Lawrence Creeks. Many of these lie within the extratidal zone, subject to inundation by seawater only during exceptional conditions, such as cyclones. The coastal grasslands are flooded with freshwater during the wet season. Removal of some of the former supratidal and extratidal areas from marine influences has been accelerated artificially in the Glenprairie area along the western side of Herbert Creek. Extensive dams or bunds have been constructed across the tidal channels and flats to exclude seawater and extend the coastal areas suitable for grazing. The coastal grasslands have a thin soil (<30cm) and are underlain by intertidal to supratidal sand and mud.

The supratidal flats and extratidal coastal grasslands have not been differentiated, because their study was outside the scope of the project and in some areas are difficult to distinguish on the aerial photographs. They have been mapped as unit **Qhe** (undivided estuarine deposits). In the Waverley Creek area, the boundary between the two environments is clearer and has been shown as a trend line.

Cook & Polach (1973) described cheniers on the western side of Broad Sound at the mouths of the Styx, The Hoogly and Waverley estuaries. Individual cheniers are up to 5km long, 50m wide and 2m high, and are composed mainly of coarse-grained shell debris. They commonly support a dense tree cover, in contrast to the treeless supratidal flats and grasslands. They are mostly too narrow to show as a map unit, but have been outlined as trends within unit **Qhe**. Some wider belts of several closely spaced cheniers have been mapped as unit **Qhcb**. The cheniers are thought to have formed in response to fluctuating sediment supply. A decrease in supply led to coastal erosion and death of the mangroves. The cheniers formed seaward of the old mangrove swamps by winnowing of shelly material.

Radiocarbon dating of the cheniers was reported by Cook & Mayo (1977). It showed that the Broad Sound shoreline has prograded rapidly over the last 6000 years (since sea-level stabilised) at ~1.2km per 1000 years on the western side and 1.7km per 1000 years on the eastern side, where there is evidence of uplift.

PLUTONIC ROCKS OF THE AUBURN PROVINCE AND RAWBELLE BATHOLITH

EARLY CARBONIFEROUS PLUTONS

DONORE GRANITE GNEISS

Introduction

The Donore Granite Gneiss is a new unit in southern RAWBELLE (Figure 81) that was previously mapped by Whitaker & others (1974) as undifferentiated granite within the Rawbelle Batholith. The rocks are mapped over an area of $50km^2$. The name is derived from Donore Station on which much of the unit crops out.The area consists of undulating topography with a moderate degree of dissection resulting in good outcrop in creeks.

Type area

The type area of the Donore Granite Gneiss is centred around MGA 279700 7188400 on the northern side of the Eidsvold–Cracow road ~1.8km east of the turnoff to Carinya and Wathonga homesteads. Platform outcrops display the diversity of rock types in the unit. They include medium to coarse-grained well-banded to almost migmatitic biotite gneiss; foliated, fine to medium-grained biotite granite with streaky banding and local xenoliths of amphibolite or diorite (in places strongly elongated and possibly boudinaged); and dykes and veins of aplite, microgranite and pegmatite.

Lithology

The Donore Granite Gneiss appears to be a complex of variably foliated (from weak to very strong), fine to medium-grained, equigranular biotite granite grading into orthogneiss (Figure 84a–c) and intermixed with more migmatitic gneiss that may include paragneiss. Dykes and veins of aplite, microgranite and pegmatite are also common.

A typical orthogneiss crops out near the Eidsvold–Cracow road east of St Johns Creek crossing at MGA 276900 7188500. It consists of medium to coarse grained, muscovite-biotite granitic gneiss with enclaves of foliated microgranite and foliated fine-grained dark greenish-grey amphibolite pods, cut by pinkish-grey fine-grained microgranite and pegmatite dykes. The foliation in the orthogneiss is defined by flattening of quartz grains and alignment of biotite, which is concentrated into lenticles giving a streaky layered appearance.

The migmatitic rocks commonly show leucosomes and melanosomes on a millimetre to centimetre scale. The leucosome bands dominantly contain plagioclase, microcline and quartz, whereas the melanosome bands are rich in coarse black biotite. Some melanosomes also contain subordinate hornblende and titanite.

Geophysical response

The radiometric response for this unit is similar to that of the Coonambula Granodiorite and moderate in uranium and potassium and high for thorium, resulting in mottled pale pinkish grey to pale greenish hues on the composite images (Figure 99). It appears to be somewhat higher in thorium than the Coonambula Granite.

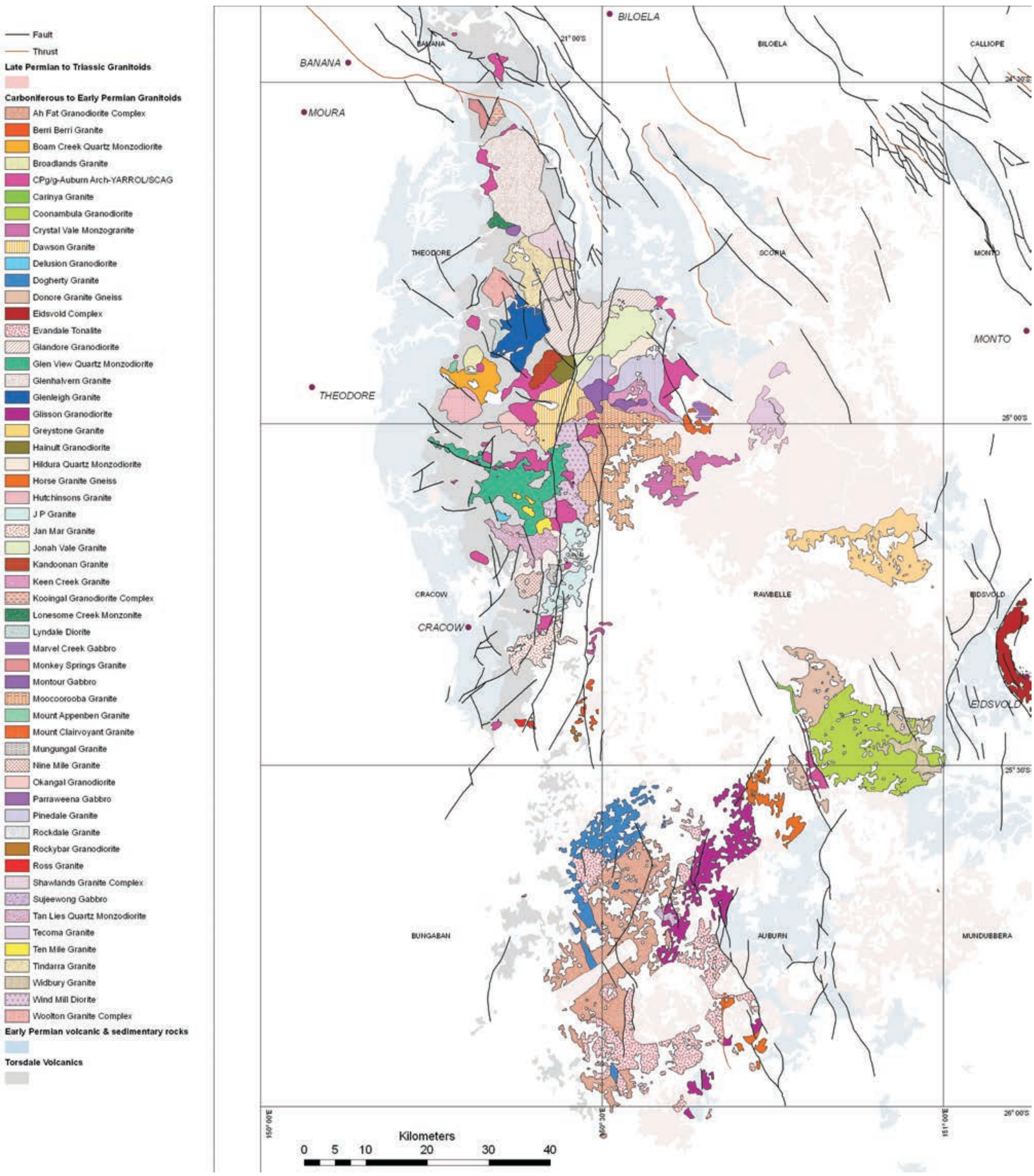

Figure 81. Distribution of Carboniferous to Early Permian plutonic rocks in the Auburn Arch

It contrasts with the more strongly potassic Culcraigie Granite to the north-east and north-west, and the Yerilla Metamorphics that appear to be lower in all channels.

Magnetic susceptibilities measured on the diverse range of rocks in the field are variable, but the data show a strong mode for values <100 x 10^{-5} SI units with a tail of values extending to about 1400. This is consistent with the airborne magnetic data in which the unit has a generally low response with some north-north-west-trending linear features that elevate the overall response and distinguish it from the adjacent Morrow Granite that lacks such features (Figure 100).

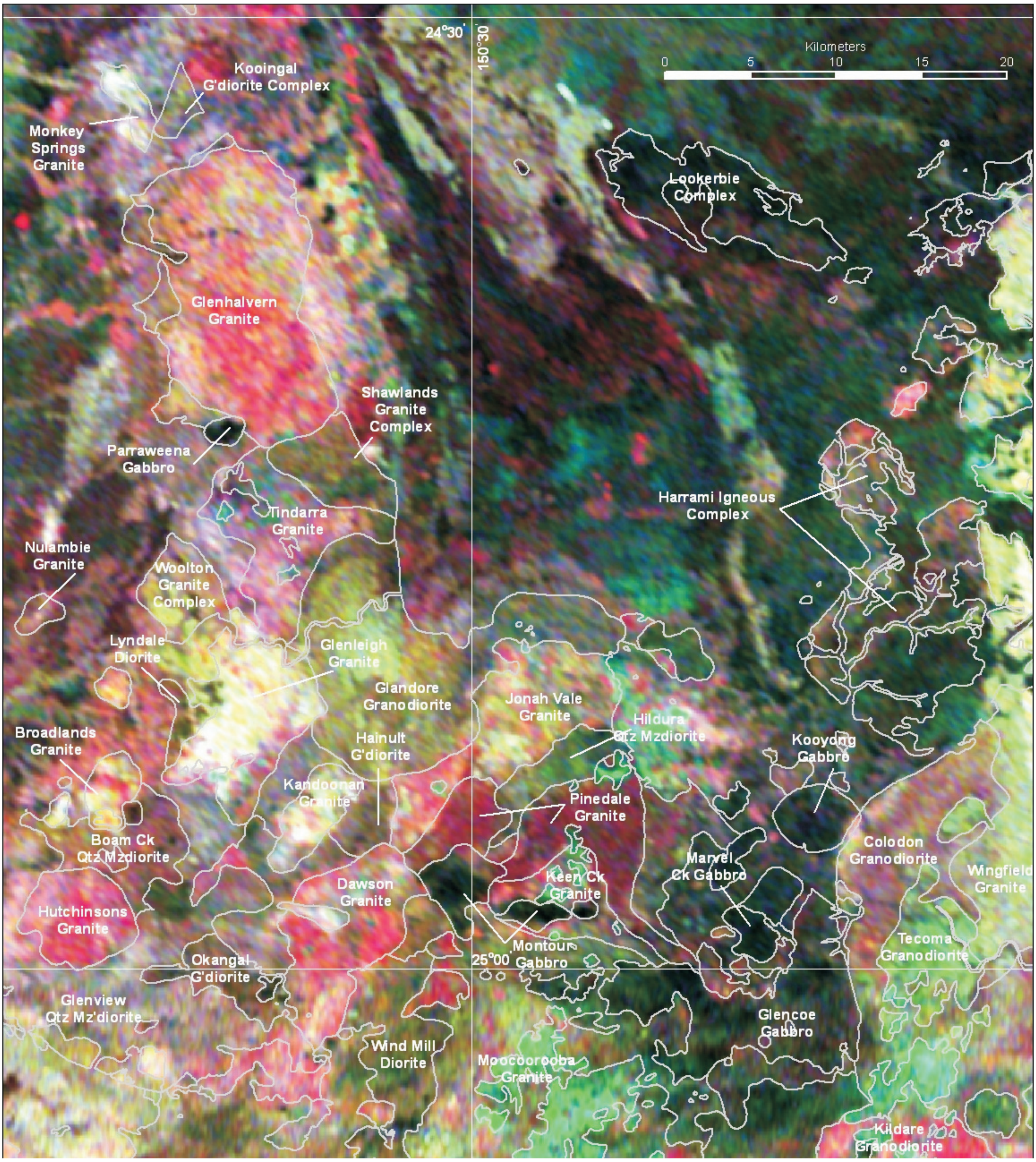

Figure 82. Radiometric image of the northern part of the Auburn Arch showing selected units

Relationships and age

The relationships of the Donore Granite Gneiss to the adjacent units are not clear. As noted the unit appears to be a complex of variably foliated biotite granite and more gneissic rocks. The latter do include some orthogneiss, but may also include zones of metamorphic rocks like those in the Yerilla Metamorphics so that the distinction from the latter unit is not altogether clear. It is possible that the Donore Granite Gneiss simply represents a transition between dominantly granitic and metamorphic terrains. Geochemically the Donore Granite Gneiss is distinct from the late Carboniferous granitoids of the Auburn Arch. It generally has higher FeO_{total}, TiO_2 and Zn and generally lower CaO, Sr and Na_2O and is distinctly peraluminous (Figures 88 and 89). The Coonambula Granodiorite is similar, but is thought to be much younger (early Permian).

K–Ar dating of biotite from two biotite gneisses and one biotite granite from within this unit was reported by Whitaker & others (1974). The ages (233, 234 and 234Ma) are Middle Triassic, but probably have been reset

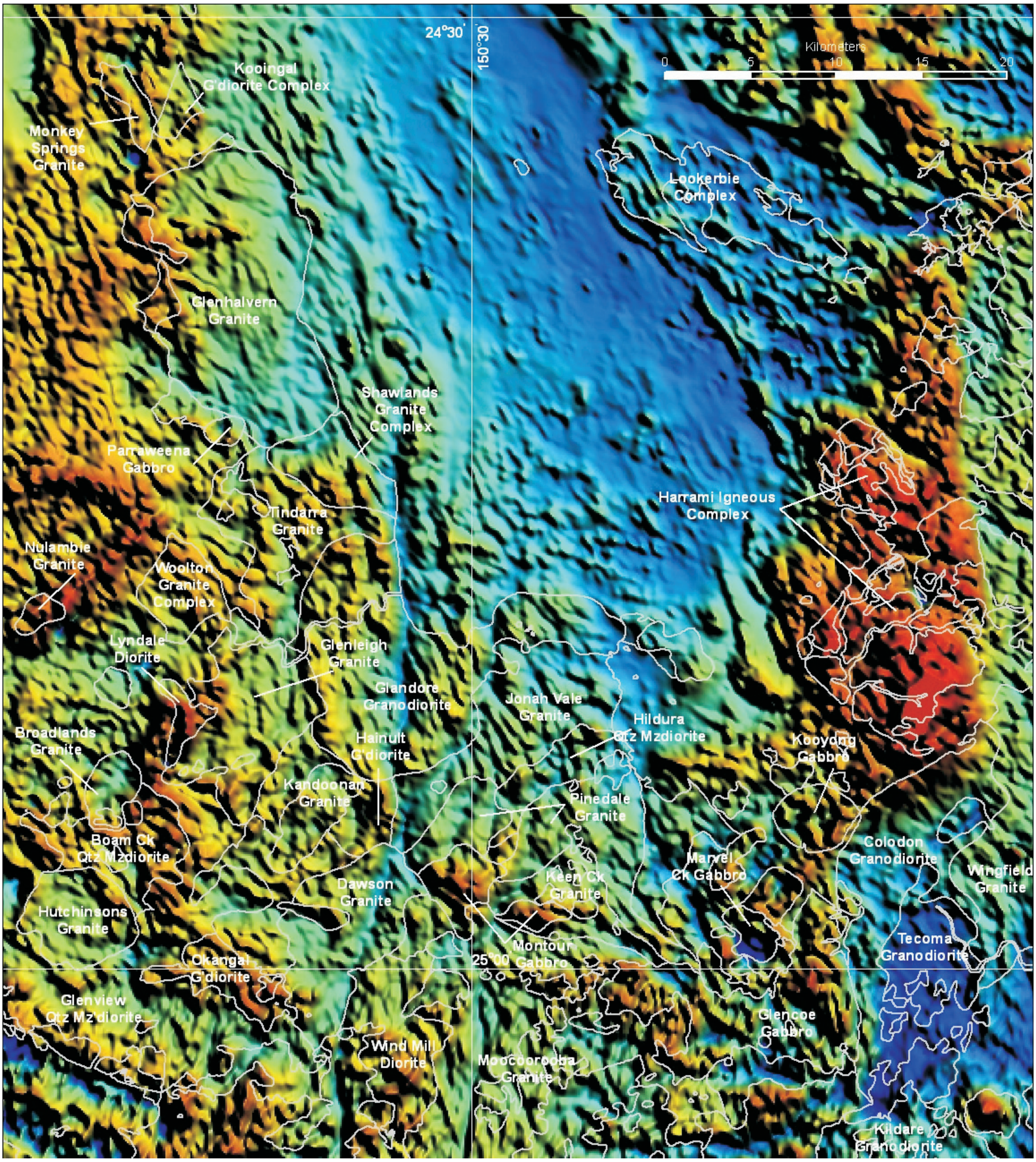

Figure 83. Magnetic image of the northern part of the Auburn Arch showing selected units

during emplacement of the bulk of the Rawbelle Batholith. A sample of orthogneiss from the western margin of the unit near the Eidsvold–Cracow road east of St Johns Ck crossing at MGA 276900 7188500 was dated using the SHRIMP U-Pb zircon method and gave an early Carboniferous age of 342.5±4.0Ma (see Appendix). This is the oldest age obtained for granites in the Auburn Arch.

HORSE GRANITE GNEISS

Introduction

The Horse Granite Gneiss is a new unit in northern AUBURN within the Yerilla Metamorphics (Figure 81). It was previously mapped by Whitaker & others (1974) as undifferentiated granite within the Rawbelle Batholith. The name is derived from Horse Creek, a tributary of Cheltenham Creek in northern AUBURN.

Figure 84. Deformed Early Carboniferous granitoids of the Auburn Arch
(a) Gneissic biotite granite of the Donore Granite Gneiss. About 250m east of the crossing of South Branch of St John Creek near the Eidsvold–Cracow road at MGA 276930 7188457 (RSC164)
(b) Scanned slab of a specimen from the outcrop in (a). This sample was dated by SHRIMP to give an age of 342.5±4.0Ma
(c) Foliated biotite granite of the Donore Granite Gneiss containing biotite-rich schlieren and cut by a leucogranite dyke. Eidsvold–Cracow road 3km east of the crossing of the South Branch of St John Creek at MGA 279688 7188401 (QFG2974)
(d) Strongly foliated biotite leucogranite of the Horse Leucogneiss. The leucogranite occurs as dykes cutting biotite gneiss of the Yerilla Metamorphics. Near the Auburn River ~9.5km east-north-east of Auburn homestead at MGA 269255 7131577 (IRAU661)
(e) Gneissic biotite granite of the Horse Leucogneiss. About 7.3km north-west of Yerilla homestead at MGA 271505 7174527 (IRAU624)

The unit crops out over an area of ~30km^2. Scattered areas of gneissic granite farther south have also been assigned to the Horse Granite Gneiss, and are generally associated with areas of metamorphic rocks, for example along the Auburn River, 10km north-east of Auburn homestead. The unit crops out poorly and is mainly distinguished from the surrounding Yerilla Metamorphics on the basis of its radiometric response. Outcrops of orthogneiss widespread throughout the Yerilla Metamorphics are probably related to the Horse Granite Gneiss, but are too small in area to map out. Conversely, outcrops within areas mapped as Horse Granite Gneiss commonly include paragneiss, schist and amphibolite. The irregular boundary between the Horse Granite Gneiss and Yerilla Metamorphics as mapped is consistent with a complex interfingering relationship.

Type area

The type area is designated along a track north-west from Yerilla homestead from MGA 272500 7171650 to MGA 271900 7172850. Although there are sporadic outcrops of younger diorite, the Horse Granite Gneiss in this area consists of buff to pink or light grey leucocratic biotite-bearing orthogneiss or foliated leucogranite, that ranges from being equigranular to locally containing K-feldspar or plagioclase augen up to 2cm long.

Lithology

Throughout its outcrop area, the Horse Granite Gneiss is similar to the rocks in the type area and is clearly of granitic origin and mostly leucocratic containing 1–5% biotite and minor secondary muscovite.

The rocks generally have a strong planar foliation, although locally it is anastomosing and wraps around K-feldspar or plagioclase augen or quartz-feldspar lenses (Figure 84d,e). The foliation is defined by alignment of biotite and also by flattening of quartz grains and in some rocks, thin anastomosing bands of granulated quartz and feldspar (mortar texture). The foliation is mostly steeply dipping, but locally it is relatively shallow and has been deformed by small-scale open folds. Commonly no obvious lineation is associated with the foliation, suggesting that deformation mainly involved pure shear. However, in the type area at MGA 271500 7174550, a weak lineation is associated with asymmetric feldspar porphyroclasts and S-C planes that suggest south-east over north-west shear sense.

Geophysical response

In the radiometric data, the Horse Granite Gneiss is distinguished by its moderate potassium, high thorium and moderate uranium responses that result in a pale greenish hue on composite images. This contrasts with the generally lower response in all channels and dark hues of the surrounding Yerilla Metamorphics. It is somewhat similar to the Donore Granite Gneiss although the latter is more mottled with pinkish grey hues.

It has a low magnetic response indistinguishable from the surrounding metamorphic rocks and consistent with the magnetic susceptibility values that are mostly $<30 \times 10^{-5}$ SI units with a large proportion of outcrops having a zero response.

Relationships and age

The Horse Granite Gneiss intrudes the Yerilla Metamorphics, which are of uncertain age, and is unconformably overlain by the early Permian Narayen beds. Its age is therefore uncertain. The strong deformation suggests that it may be similar in age to the Donore Orthogneiss which is early Carboniferous. The Horse Granite Gneiss is similar to many of the rocks described in the Donore Orthogneiss and appears to have a similar interfingering relationship with the Yerilla Metamorphics. However, the samples that have been chemically analysed mostly cannot be distinguished from the main suite of Auburn Arch granitoids (Figures 89 and 90), whereas, as noted, the Donore Granite Gneiss has distinctive geochemistry.

CARINYA GRANITE

Introduction

The Carinya Granite forms an elongate north-trending body that crops out over ~3km^2 in southern RAWBELLE. Whitaker & others (1974) incorporated these rocks into an undifferentiated Palaeozoic unit (Pz) with gneiss and schist now mapped as Yerilla Metamorphics. The name is derived from Carinya Station that adjoins and lies to the south of Donore Station in southern RAWBELLE.

Type locality

The type locality of the Carinya Granite is designated along the Eidsvold–Cracow road at MGA 274600 7190200. At this site a light grey, fine to medium-grained saccharoidal biotite leucocratic granite crops out.

Lithology

Most other outcrops within this unit are strongly weathered, but are typically weakly to moderately foliated, fine to coarse-grained, equigranular, leucocratic biotite granite. Biotite hornblende granodiorite and diorite were also recognised within the outcrop area, but it is uncertain whether they are related to the leucocratic granite.

Geophysical response

On radiometric images the Carinya Granite has a moderate response in most channels, although potassium is somewhat higher resulting in pale pink to reddish hues on the composite images. This contrasts with the higher response in thorium of the Donore Granite Gneiss (producing pale greenish hues), the red to bright pinks of the Culcraigie Granite, and the dull-pinks and browns of the Yerilla Metamorphics.

Magnetic susceptibilities mostly range from 0–50 x 10^{-5} SI units although locally they are up to 600. On the airborne magnetic data the Carinya Granite has a low response similar to most of the neighbouring units.

Relationships and age

The Carinya Granite intrudes the surrounding Yerilla Metamorphics, and may be intruded by the Culcraigie Granite. The age is not known precisely, but the presence of a foliation suggests that it is relatively old and may be early Carboniferous like the Donore Granite Gneiss and probably the Horse Granite Gneiss. In some respects it is lithologically similar to the latter although the radiometric response is different and it is generally not as strongly foliated. Geochemically, the one sample analysed is like the other later Carboniferous granites.

MOUNT CLAIRVOYANT GRANITE

Introduction

The Mount Clairvoyant Granite is a new unit which crops out over ~6km^2 in northern RAWBELLE and southern SCORIA (Figure 81). It forms one main, irregularly-shaped body around Mount Clairvoyant (from which the unit is named) and several smaller bodies to the north. Whitaker & others (1974) incorporated the rocks in the Crystal Vale Adamellite. Outcrop is scarce and mostly decomposed, but bouldery outcrop occurs on the north-western flank of Mount Clairvoyant.

Type locality

The type locality of the Mount Clairvoyant Granite is at MGA 261200 7231600 on the north-western flank of Mount Clairvoyant itself. It comprises foliated medium-grained porphyritic biotite granite with pink K-feldspar phenocrysts. It is strongly recrystallised with sugary texture. In places the quartz has an opalescent bluish appearance due to strain. Biotite is also recrystallised and concentrated in thin lenticles.

Lithology

The Mount Clairvoyant Granite consists of foliated medium-grained biotite granite as at the type locality. The foliation is variable in intensity and where stronger, the rocks grade into orthogneiss, with discontinuous biotite-rich layers and lenticles.

Geophysical response

On radiometric images the Mount Clairvoyant Granite has a moderate potassium and low to moderate thorium and uranium response, resulting in pinkish hues on composite images that contrast with the low-response of both the adjacent unnamed metamorphic rocks and Glencoe Gabbro.

Magnetic susceptibility readings were recorded at only three localities and range up to ~500 x 10^{-5} SI units. On the airborne magnetic data the granite lies in an area of generally moderate to high intensity and cannot be easily delineated.

Relationships and age

The Mount Clairvoyant Granite intrudes unnamed gneiss and schist that may be a continuation of the Yerilla Metamorphics. The age is uncertain, but a Carboniferous age is likely. The granite could be related to the Donore Granite Gneiss in southern RAWBELLE and other foliated granites but geochemically it is unlike the Donore Granite Gneiss and mostly plots with the rest of the Auburn Arch granitoids (Figures 89 and 90). The unit is in contact with the Glencoe Gabbro to the south. This is inferred to be late Permian or Early Triassic and may account for the recrystallisation of the Mount Clairvoyant Granite.

CARBONIFEROUS TO EARLY PERMIAN PLUTONS

AH FAT GRANDIORITE COMPLEX

Introduction

This name is given to a unit in the southern part of the Auburn Arch (Figure 81). It forms a large irregular mass that extends for ~30km south from the southern end of the Auburn Plateau and is up to 15km wide. The name is derived from Ah Fat Well on Evandale Station in western AUBURN. Total exposed area is ~200km^2. Outcrop is mostly poor although there are scattered boulders and local whaleback outcrops. Topography is gently undulating to hilly with moderate relief, the latter at least locally related to the presence of swarms of Permo-Triassic dykes. It was previously mapped as part of the Kilbeggan Adamellite of Whitaker & others (1974). The name is shown as Ah Fat Granite Complex on the AUBURN map, but is herein changed to reflect more accurately the dominant rock type in the complex.

Type locality

As the name suggests, the unit shows some variation and it is difficult to specify a single type locality. Therefore two reference localities are given. One is near a station track at MGA 255250 7153250, 3km west of Sujeewong homestead. It is pinkish grey, medium-grained, equigranular hornblende-biotite granodiorite (Figure 85a) consisting of quartz (25%, to 3mm), poikilitic K-feldspar (20%, to 5mm), plagioclase (50%, to 4mm, oligoclase), reddish brown biotite (5%, to 2mm), anhedral to prismatic hornblende (1–2%, to 5mm) and common opaque oxides with traces of titanite and allanite.

A second reference locality is in the northern part of the complex, where pinkish orange to grey, medium-grained, equigranular to slightly porphyritic (hornblende)-biotite granite is exposed as a line of moderate-sized tors at and around MGA 252450 7161000 ~7km north-north-west of Evandale homestead. It consists of quartz (25–30%, up to 3mm, forming some coarse intergrowths with K-feldspar), perthitic K-feldspar (30%, to 1.5mm), plagioclase (40%, to 3mm — slightly turbid oligoclase), biotite (1–2%, to 1mm) and sporadic opaque oxides. Only rare hornblende was observed in thin section, but sparse prismatic crystals to 6mm were observed in outcrop. Minor epidote was observed and the biotite is partly chloritised. Sporadic rounded xenoliths of microdiorite are present in the outcrop.

Lithology

The Ah Fat Granodiorite Complex consists mainly of pinkish grey to grey, medium to coarse-grained, equigranular to seriate or slightly porphyritic biotite granite and hornblende-biotite granite to granodiorite similar to these outcrops described above. Apart from some local outcrops of hornblende quartz monzodiorite, the rocks are relatively leucocratic with biotite as the dominant mafic mineral and hornblende subordinate to absent. Titanite is rare and where present appears to mainly rim grains of opaque oxides. Quartz and K-feldspar form coarse graphic intergrowths. Plagioclase commonly shows normal to oscillatory zoning from sodic andesine to oligoclase. Feldspars are commonly turbid or partly altered to sericite and clay minerals, and biotite is altered to chlorite and epidote.

Geophysical response

The Ah Fat Granodiorite Complex has a variable radiometric response, presumably reflecting some regional differences in rock types that could probably be better delineated with more detailed mapping and if exposure was better. In the south, it has a moderate to high potassium response and moderate uranium and thorium resulting in pale pinkish composite hues. The central part of the complex has low to moderate potassium and thorium and low uranium, resulting in mottled brownish hues on composite images. An area of higher potassium in the north has overall reddish pink hues.

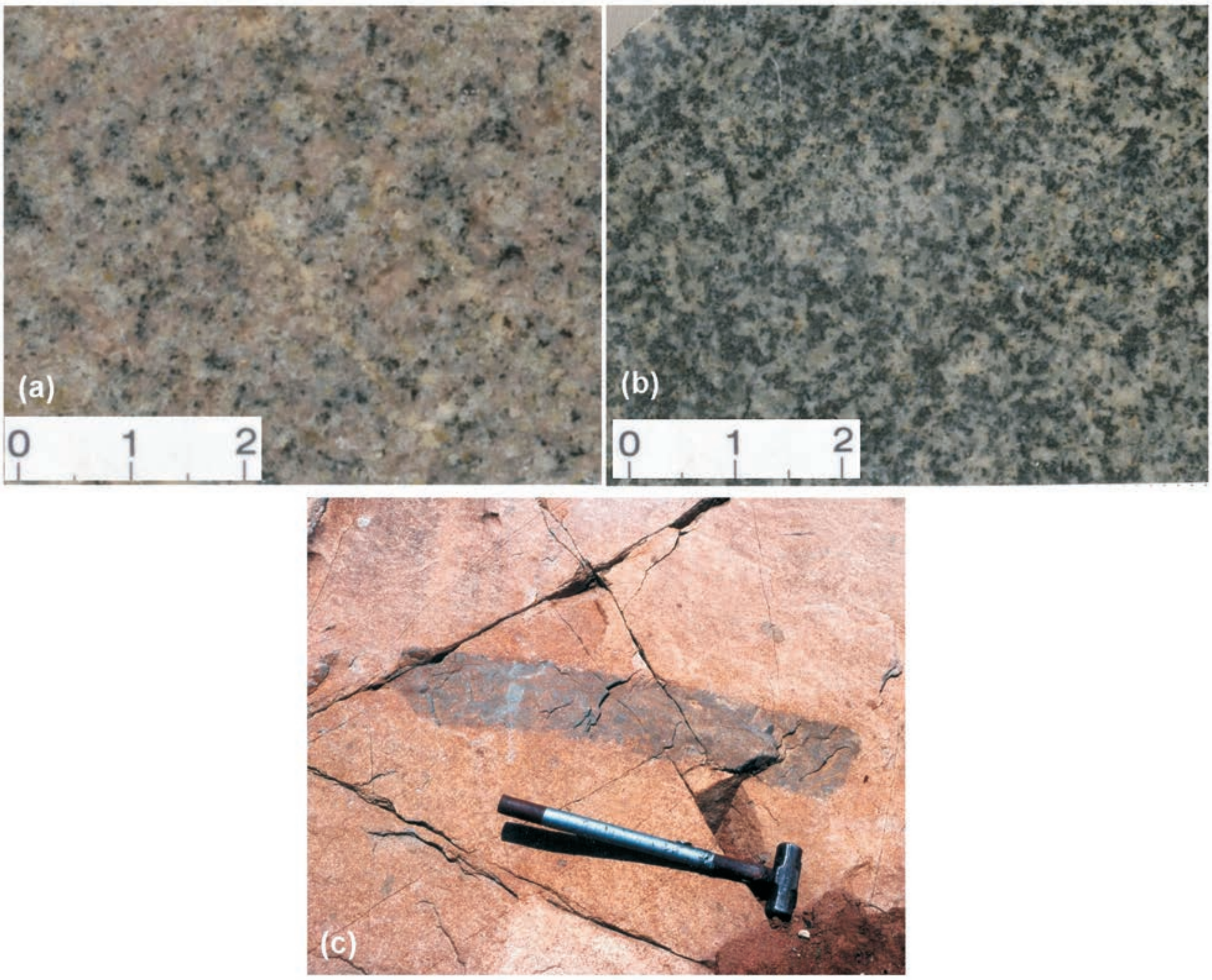

Figure 85. Granitoids of the Auburn Arch – Ah Fat Granodiorite Complex, Boam Creek Quartz Monzodiorite and Delusion Creek Granodiorite.
(a) Pink, equigranular biotite granite of the Ah Fat Complex. 3km south-west of Sujeewong homestead on the road from Dunrobin to Cockatoo Creek at MGA 256511 7150632 (RSC219). Scales in (a) and (b) are 2cm.
(b) Hornblende-biotite quartz diorite or quartz monzonite of the Boam Creek Quartz Monzodiorite. Boam Creek crossing on the Theodore–Eidsvold road (Defence Road) at MGA 224276 7240691 (RSC148)
(c) Biotite granodiorite with an enclave of feldspar-phyric felsic volcanic rock. Type locality in Delusion Creek east of Mount Kitchener homestead at MGA 233663 7217031 (BB3003)

The unit has a low to moderate magnetic response although, as for the other granitic units in the area, the pattern is complicated by the presence of north-west-trending magnetic linear features that are probably due to the swarms of andesite to dacite dykes that are ubiquitous in the area. Magnetic susceptibility values show a skewed distribution in the range 0–2150 x 10^{-5} SI units with a prominent mode at 600.

Relationships and age

The relationship of the Ah Fat Granodiorite Complex to the surrounding plutonic units of the Auburn Arch is not known. It is mapped in contact with the Evandale Tonalite, Glisson Granodiorite and Dogherty Granite. It probably intrudes the Torsdale Volcanics to the west, but the contact is obscured by the unconformably overlying Jurassic Evergreen Formation. Like the other units, it is also intruded by swarms of andesite to dacite dykes that are probably late Permian or Triassic. A north-east-trending body of late Permian to Triassic granitoid was mapped mainly from airborne magnetic evidence, but it may be another dyke swarm of mainly felsic dykes. The unit is also unconformably overlain by extensive unnamed Tertiary sediments that form the Auburn Plateau to the north.

A late Carboniferous age similar to that of the Evandale Tonalite is assigned to the unit although it has not been dated isotopically. In the airborne magnetic data, it has a similar irregular pattern with poorly defined margins to that of the Evandale Tonalite and Glisson Granodiorite suggesting that they are all of similar age. By contrast, the known younger plutons are generally clearly defined circular to elliptical bodies.

BERRI BERRI GRANITE

Introduction

The Berri Berri Granite forms several scattered outcrop areas (total area ~4km^2) separated by Cainozoic deposits, in south-eastern CRACOW (Figure 81). The granite is extensively weathered and poorly exposed, and forms undulating country, with local outcrops of scattered boulders. The unit is named after Berri Berri Creek, which drains part of the unit.

Type locality

The type locality is proposed at MGA 247920 7186380, south-east of the main Eidsvold–Rockybar road. The unit is relatively well exposed at this locality as scattered boulders.

Lithology

The unit at the type locality consists of pale grey to very pale pink, medium to fine-grained, uneven-grained to slightly porphyritic (hornblende-) biotite monzogranite. Biotite (~6–7%) is much more abundant than hornblende which is present as traces. The main accessory minerals are opaques, titanite, zircon, allanite and secondary epidote, sericite, and chlorite.

Rounded to elongate inclusions, up to ~40cm across, of mainly dark grey, fine-grained, even-grained ‘diorite’ are common. Some of the larger inclusions are characterised by highly irregular contacts with the enclosing granite. The granite is cut by thin aplite dykes up to ~1cm wide.

Where examined elsewhere the granite is deeply weathered and partly to extensively decomposed, with sparse relict boulders exposed locally, and deep weathering profiles preserved in places. A relatively leucocratic (~3% mafic minerals) coarser grained, porphyritic variant, with pale pink K-feldspar phenocrysts up to ~2cm long, is poorly exposed along the abandoned telegraph line (*e.g.* around MGA 245410 7184860), west of the main Eidsvold–Rockybar road.

Geophysical response

The unit is characterised by high potassium and low to moderate thorium and uranium airborne radiometric responses resulting in pink hues on composite images that are identical to the response of the adjacent Flat Range Granodiorite. The pink hues contrast markedly with the blue and green hues of the overlying Cainozoic cover deposits.

The unit is characterised by low to moderate responses on magnetic images, and is characterised by moderately high magnetic susceptibilities; measurements taken at the type locality range from 565–12508 x 10^{-5} SI units (average of 24 readings = 830 x 10^{-5} SI units).

Relationships and age

The Berri Berri Granite is inferred to intrude the Torsdale Volcanics and to be intruded by the Flat Range Granodiorite. It is overlain by extensive Cainozoic deposits (including duricrust).

The age of the unit is uncertain. A late Carboniferous – early Permian age has been tentatively assigned but it could be late Permian – Early Triassic like the nearby Flat Range Granodiorite.

BOAM CREEK QUARTZ MONZODIORITE

Introduction

The Boam Creek Quartz Monzodiorite occurs in the western part of the Auburn Arch cropping out over ~25km^2 to the east of Woolton homestead in south-eastern THEODORE (Figure 81), in the valley of Boam Creek, from which the unit is named. It appears to be one of the older granitoids in the region as it is intruded by the Hutchinsons Granite and the Mount Appenben Granite. The Torsdale Volcanics adjacent to the Boam Creek Quartz Monzodiorite are hornfelsed.

Type locality

The type locality of the Boam Creek Quartz Monzodiorite is on the track to Kandoona homestead on the south bank of Boam Creek at MGA 228200 7239600. Here a medium to light grey, medium grained, biotite-amphibole quartz monzonite comprises oligoclase, large, erratically distributed, poikilitic K-feldspar, brownish-yellow biotite, pale masses of very fine-grained amphibole (after pyroxene), quartz, and some opaques.

Lithology

Although the unit is shown as Boam Creek Granite on the THEODORE, the quartz and K-feldspar content of the rocks is relatively low and the name is herein changed to Boam Creek Quartz Monzodiorite. The unit comprises mainly green to grey, fine to medium-grained hornblende-biotite to biotite quartz monzonite to quartz diorite (Figure 85b). At the Boam Creek crossing on Defence Road, medium-grained quartz diorite comprises minor quartz, andesine, biotite, pale green amphibole after pyroxene and minor opaques. Biotite appears to be the dominant mafic mineral in some outcrops. Mafic xenoliths are rare. The unit has commonly undergone sericitic and chloritic alteration. Hornblende is usually a minor component but the amounts are variable and may be masked by the alteration.

Geophysical response

The Boam Creek Quartz Monzodiorite has low to moderate response in the potassium channel and low responses for thorium and uranium, producing mottled pink to brown hues on composite radiometric images (Figure 82).

Magnetic susceptibility was measured on a few outcrops and ranged from 1000–3600 x 10^{-5} SI units, consistent with strong response on images of total magnetic intensity (Figure 83).

Relationships and age

Petrographically, the Boam Creek Quartz Monzodiorite is similar to samples from the Lyndale Diorite to the north suggesting that the two units may be related. It is intruded by the Broadlands Granite. A sample from the Boam Creek Quartz Monzodiorite from east of Woolton homestead was used, together with granites from other parts of the Auburn Arch, to yield a Rb-Sr whole-rock isochron age of 311±29Ma (Webb & McDougall, 1968). Although this method of deriving an isochron is no longer considered reliable, the unit is probably late Carboniferous.

BROADLANDS GRANITE

Introduction

The Broadlands Granite forms a small pluton cropping out over ~9km^2, east of the Mount Appenben Granite (Figure 81), from which it is separated by a screen of rocks mapped as Torsdale Volcanics. It is one of a series of fractionated granite bodies in the Auburn Arch in the southern part of THEODORE.

Type locality

The type locality of the Broadlands Granite is south of a dam on southern Broadlands Station (from which the unit takes it s name) at MGA 228100 7244400, where pale red, medium grained biotite granite crops out.

Lithology

The unit comprises pink, fine to medium-grained biotite granite. Poor outcrop over much of the unit precludes a more detailed study of any variation that may occur.

Geophysical response

The Broadlands Granite is similar to the nearby Mount Appenben Granite and also the Glenleigh Granite to the east. All have a similar radiometric response, being high in all channels and displaying white to yellow colours on composite radiometric images and may be closely related. A reddish band on the composite radiometric image corresponds to a band of poor outcrop and may be a zone of potassic alteration (Figure 82).

No magnetic susceptibility measurements in the Broadlands Granite were recorded, but the unit has a slightly lower response that the surrounding Torsdale Volcanics or Boam Creek Quartz Monzodiorite (Figure 83).

Relationshipss and age

The Broadlands Granite intrudes the Boam Creek Quartz Monzodiorite and Torsdale Volcanics. Its relationship to a diorite body to the south-east is unclear. The age is uncertain, but a late Carboniferous to early Permian age is assigned.

CRYSTAL VALE MONZOGRANITE

Introduction

This unit was named and defined by Whitaker & others (1974) as the Crystal Vale Adamellite, herein modified to Crystal Vale Monzogranite. The unit crops out in two small, irregular shaped, areas totalling ~35km^2 in north-western RAWBELLE. The eastern area is centred on Crystal Vale homestead, from which the name of the unit is derived. The western area was added to this unit, but as discussed later the range of rocks present and isotopic dates cause some uncertainty in this assignment. Some smaller units previously mapped as the Crystal Vale Adamellite farther north have been assigned to a new unit, the Mount Clairvoyant Granite.

The topography within the area of the Crystal Vale Monzogranite is typically undulating with dykes within the monzogranite producing resistant ridges. Outcrop is poor and occurs mainly as small boulders. The monzogranite readily weathers to a pale sandy soil.

Type locality

A type locality is here designated in a gravel scrape near the road from Glencoe homestead to Mount Clairvoyant at MGA 261400 7224800. The gravel scrape exposes medium to coarse-grained hornblende-biotite monzogranite and pink medium to very coarse-grained muscovite leucogranite. A typical sample of the monzogranite contains alkali-feldspar (~30%), quartz (~45%), andesine (~20%), minor biotite and hornblende (up to ~5% together) and some opaques (mainly magnetite, <1%).

Lithology

As reported by Whitaker & others (1974), the monzogranite in the eastern outcrop area typically consists of alkali-feldspar (~30%), quartz (~50%), andesine (~20%), minor biotite and magnetite. Grey medium to coarse-grained hornblende-biotite granodiorite was also observed and contains common rounded fine-grained xenoliths (up to 50cm) of dioritic composition. In places it shows a saccharoidal texture due to extensive recrystallisation of medium-grained interstitial quartz grains. It is locally foliated (being described in field notes as gneissic), and some coarse-grained biotite gneiss is also present (for example at MGA 262200 7228300). Pegmatite and aplite dykes are common. Locally, fine to medium-grained dolerite dykes cut the granite.

The unit as now mapped, particularly the western outcrop area, incorporates a range of other rock types, including hornblende gabbro, diorite and tonalite. Also a medium-grained melanocratic granodiorite, consisting of andesine (An_{28}–An_{40}; ~35%), quartz (15%), K-feldspar (15%), biotite and hornblende (together 35%) and accessory minerals such as magnetite (for example at MGA 256400 7221900). The hornblende and biotite are partially altered to uralite and chlorite and the feldspars typically show minor alteration to sericite and saussurite.

Geophysical response

The radiometric responses for the eastern outcrop area are moderate to low in most channels resulting in purplish-brown hues on the composite images that contrast only slightly with the darker brown hues of the Glencoe Gabbro which is low in all channels. The western outcrop area is more varied and includes some areas of moderately high potassium and higher thorium.

The magnetic susceptibilities measured in the field are quite varied and range up to ~1800 x 10^{-5} SI units, but are mostly <1000. The eastern pluton has a distinctly lower magnetic response to the surrounding Glencoe Gabbro and Moocoorooba Granite, but the western outcrop area is indistinguishable from them.

Relationships and age

Whitaker & others (1974) assigned a Permo-Triassic age to the Crystal Vale Monzogranite because it was interpreted as intruding the Carboniferous Moocoorooba Granite and the gabbro now assigned to the Permo-Triassic Glencoe Gabbro. However, they did not give specific evidence.

Two K–Ar ages reported by Green (1975) and Whitaker & others (1974) were determined on a sample from the western outcrop area, which at the time was interpreted to belong to the “Glandore Granodiorite” The sample gave a biotite age of 246Ma, whereas hornblende gave an age of 319Ma. Both dates have been adjusted to revised IUGS constants (Steiger & Jäger, 1977). This indicates that at least part of the western outcrop area is Carboniferous and may be related to the Moocoorooba Granite. As apparent from the above description, the western outcrop area is heterogeneous, both lithologically and geophysically, and probably should not have been included in the Crystal Vale Monzogranite.

However, the presence of foliated, gneissic rocks and recrystallised granites within the eastern outcrop area suggests that it too may be older than previously supposed and may include elements similar to the Coonambula Granodiorite or even the Donore Granite Gneiss. The recrystallisation also suggests that by the Crystal Vale Monzogranite may be intruded by the Glencoe Gabbro, rather than *vice versa*. Therefore it is now considered likely that the Crystal Vale Monzogranite is Carboniferous rather than Permo-Triassic.

The Crystal Vale Monzogranite is intruded by a Late Cretaceous olivine basalt plug, the Mount Runsome Basalt.

DOGHERTY GRANITE

Introduction

This name is given to a unit in the southern part of the Auburn Arch. It has been mapped as several irregular masses separated by the Glisson Granodiorite and has an exposed area of ~75km^2 at the southern end of the Auburn Plateau. The name is derived from Dogherty Creek in north-western AUBURN. Outcrop is poor and commonly deeply weathered in mostly gently undulating country with scattered remnants of the Tertiary sedimentary cover that forms the plateau to the north. It was previously mapped as part of the Kilbeggan Adamellite by Whitaker & others (1974).

Type locality

The type locality is designated MGA 254660 7173930 along a track south-west from Redbank homestead, where several rock types crop out. Pink medium to coarse-grained, porphyritic biotite syenogranite contains subhedral, equant to tabular, poikilitic K-feldspar phenocrysts up to 1.5cm across. The rock is leucocratic with only ~1% biotite. Grey, fine to medium-grained hornblende-biotite granodiorite also crops out and is cut by epidote-chlorite veinlets. Pink to grey, fine to medium-grained, slightly porphyritic biotite granite or granodiorite and pink aplite are also exposed.

Lithology

Because of the weathered nature of the unit and poor outcrop, the unit has mainly been mapped from its uniform geophysical response which suggests that it is a discrete unit. However, there is some uncertainty about the main rock type. The observed rock types include leucocratic biotite granite and hornblende-biotite granite or granodiorite as at the type locality, although the former appears to be the most common. However, most of the observations were made in peripheral areas and may not be representative of the unit as a whole, particularly as the magnetic susceptibility measured on these outcrops is not consistent with the response in the airborne data. As noted below, granodiorite may actually be more abundant than granite.

Geophysical response

The Dogherty Granite has a relatively uniform radiometric response compared with some of the other units in the southern Auburn Arch. It is characterised by moderate potassium and low thorium and uranium so that is represented by pinkish hues on composite images.

The overall magnetic response is moderate. However, measured magnetic susceptibility values are not consistent with this response as they are mostly in the range 0–500 with a prominent mode for values at about 10, although there are sporadic values up to about 1850, especially for granodiorite outcrops. At the type locality, the ranges are 4–200 x 10^{-5} SI units for the syenogranite, 250–850 for the fine-grained granite and 800–1850 for the granodiorite. Given the moderately magnetic response in the airborne data, this suggests that granodiorite could be the dominant rock type in the unit.

Relationships and age

The relationship of the Dogherty Granite to the surrounding plutonic units of the Auburn Arch is not known. It is mapped in contact with the Evandale Tonalite, Flat Range Granodiorite and Ah Fat Granodiorite

Complex. It probably intrudes the Torsdale Volcanics to the west, but the contact is obscured by the unconformably overlying Jurassic Evergreen Formation. Like the other units, it is also intruded by swarms of andesite to dacite dykes that are probably late Permian or Early Triassic. A north-east-trending body of late Permian to Early Triassic granitoid was mapped mainly from airborne magnetic evidence, but it may be another dyke swarm of mainly felsic dykes. The unit is also unconformably overlain by extensive unnamed Tertiary sediments that form the Auburn Plateau to the north.

A late Carboniferous age similar to that of the Evandale Tonalite is assigned to the unit although it has not been dated isotopically. In the airborne magnetic data, it has a similar irregular pattern with poorly defined margins to that of the Evandale Tonalite, Glisson Granodiorite and Ah Fat Granodiorite Complex suggesting that they are all of similar age. By contrast, the known younger plutons are generally clearly defined circular to elliptical bodies.

DAWSON GRANITE

Introduction

The Dawson Granite has an area of ~42km^2 and crops out as an elongate, northerly aligned pluton, in north-eastern CRACOW and adjoining south-eastern THEODORE. The unit forms low hilly country, which is largely undeveloped (because of the poor quality of the soils developed on the granite). The granite is generally poorly exposed and strongly weathered. The unit is named after the County of Dawson.

Type locality

The type locality is proposed on the eastern side of a station track at MGA 239600 7203260. The granite crops out as large boulders at this locality.

Rock types

The unit at the type locality consists of pale pink, medium-grained, slightly porphyritic biotite monzogranite. Most groundmass grains are >1mm across, but some are <0.5mm, the average being ~2.5mm. The monzogranite is leucocratic and contains scattered, slender, pale pink K-feldspar phenocrysts up to ~1.5cm long. Biotite (~2%) is the main mafic mineral, forming relatively small grains, which are confined to interstices. The biotite flakes have been extensively replaced by chlorite, locally accompanied by minor epidote and secondary titanite. The main accessory and secondary minerals are opaques, zircon, primary titanite (rare), epidote, sericite, and chlorite. Rare hornblende laths, up to ~2cm long, are present in a few samples examined from elsewhere in the pluton.

The monzogranite has been slightly to moderately deformed. Quartz grains show highly undulose extinction and local subgrain development. Sparse, rounded mafic inclusions up to ~10cm in diameter are present.

The unit is cut by pods and dykes of aplite, aplitic microgranite, and pale pink leucogranite in places.

Scattered boulders of highly porphyritic microgranite exposed ~550m west-south-west of the type locality, but are most probably not part of the Dawson Granite. The microgranite has not been delineated as a discrete unit on the Cracow 1:100 000-scale geological map, because its extent is unknown due to the very poor outcrop. The microgranite is texturally distinct. It contains numerous phenocrysts of feldspar (up to ~1.5cm long) and deeply embayed quartz (up to ~1cm across) as well as sparse phenocrysts of completely altered biotite and hornblende (?) (up to ~5mm across). The quartzofeldspathic groundmass is very fine-grained.

Geophysical response

The unit is distinguished from adjacent units by bright pink to red hues on composite airborne radiometric images (reflecting a high potassium and low thorium and uranium responses) (Figure 82).

It is characterised by low to moderate responses on total magnetic intensity images. Magnetic susceptibility readings range from 0–950 x 10^{-5} SI units, show a skewed distribution with a mode at ~300 x 10^{-5} SI units, and are consistent with the responses shown on images of total magnetic intensity (Figure 83).

Relationships and age

The Dawson Granite intrudes the Torsdale Volcanics and is also interpreted to post-date the Okangal and Hainault Granodiorites, Pinedale and Jonah Vale Granites, Montour Gabbro, Glen View Quartz Monzodiorite, and Wind Mill Diorite. It is intruded by unnamed unit **CPir**, and probably also pre-dates unnamed units **CPbx**, **CPg_{mg}**, and **CPg_{g}** .

The age of the unit is uncertain, but it is tentatively interpreted to be late Carboniferous – early Permian.

DELUSION GRANODIORITE

Introduction

The Delusion Granodiorite forms a small (~2km^2), ovoid pluton in the central-northern part of CRACOW (Figure 81). Mount Kitchener homestead is located on the granite, and consequently the unit is readily accessible. It is well exposed compared to most of the granites in CRACOW, and forms low undulating to rocky, hilly country. The unit is named after Delusion Creek, the upper reaches of which traverse the granodiorite.

Type locality

The type locality is in the bed of Delusion Creek at MGA 233665 7217040, east of Mount Kitchener homestead. There are extensive rock pavements at this locality.

Lithology

At the type locality, the unit consists of grey, fine-grained, highly porphyritic, biotite-hornblende granodiorite. The granodiorite contains numerous plagioclase phenocrysts up to ~1cm long, in a fine-grained (quenched) groundmass (average grainsize ~0.2mm) of mainly quartz and K-feldspar. Hornblende is much more abundant (~3%) than biotite (traces) and, locally forms euhedral laths up to ~1cm long. Many of the hornblende grains have been replaced by fibrous aggregates of pale green actinolite.

Accessory and secondary minerals include opaques, actinolite, sericite/muscovite, chlorite, prehnite, and epidote. The rocks are commonly moderately to extensively altered, and cut by veinlets consisting mainly of prehnite (characterised by a radiating fabric). Prehnite also replaces calcic cores of plagioclase phenocrysts.

Inclusions up to ~1.5m across of partly recrystallised dark grey intermediate–felsic volcanic rocks are very common (Figure 85c). The other noteworthy feature is the presence of numerous white to pale pink alteration zones up to ~2cm wide.

The granodiorite is only slightly porphyritic north-west of Mount Kitchener homestead, where it forms a small cliff in the northern bank of Delusion Creek (at MGA 232665 7217680). The granodiorite at this locality is characterised by a slightly coarser grained groundmass (~0.3–0.4mm) and smaller phenocrysts (up to ~2mm long) of plagioclase and brownish green hornblende compared with the samples examined in the type area. Hornblende grains are mainly unaltered. Rare titanite was detected in thin section. Chlorite, sericite, and epidote are the main secondary minerals. Inclusions are also much scarcer and smaller (up to ~5cm across), and consist mainly of ‘diorite’.

Very fine-grained, porphyritic, biotite-hornblende quartz diorite crops out beside a station track at MGA 233880 7217350. It is texturally similar to the granodiorite in the type area (~400m to the south-west), but is much richer in mafic minerals, much poorer in K-feldspar, and little altered. The relationship between the two is unknown. The fact that the quartz diorite is not as altered as the granodiorite may indicate it is a younger intrusion, and should not be included in the unit. The quartz diorite contains abundant biotite (as small flakes in the groundmass), as well as subordinate hornblende (as scattered small phenocrysts), and minor clinopyroxene (as small phenocrysts, generally with rims of brownish green hornblende).

Geophysical response

The unit is distinguished from the enclosing Torsdale Volcanics by dark brown to dark purplish hues on a composite radiometric image due to low responses for all three radioelements. The adjacent Torsdale Volcanics show mainly pale pink hues.

The Delusion Granodiorite is characterised by relative high responses on images of total magnetic intensity, but is not readily distinguished from the enclosing Torsdale Volcanics. Magnetic susceptibility readings at the type locality range from 865–1980 x 10^{-5} SI units (average of 26 readings = 1443 x 10^{-5} SI units). Readings on an outcrop of diorite are in the range 1852–5200 x 10^{-5} SI units.

Relationships and age

The Delusion Granodiorite intrudes the Torsdale Volcanics and contains numerous large inclusions of partly recrystallised volcanic rocks adjacent to the contacts. The enclosing Torsdale Volcanics have also been hornfelsed and partly recrystallised. The granodiorite is cut by dykes and pods of more felsic, pale pink biotite granite near the north-western margin of the pluton (*e.g.* at MGA 232365 7218075).

The age of the unit is uncertain, but it is tentatively interpreted to have been emplaced in the late Carboniferous – early Permian.

EVANDALE TONALITE

Introduction

This name is given to a unit in the southern part of the Auburn Arch. It forms a large irregular mass that extends for ~30km north from near Auburn homestead and is up to 20km wide. Several smaller isolated outcrop areas within the area of the Ah Fat Granodiorite Complex have also been assigned to the Evandale Tonalite based on similar lithology (Figure 81). These include the outcrops near Evandale homestead itself, such as at MGA 254300 7154550. Total exposed area is ~150km^2. Outcrop is moderate to poor with scattered boulders and local whaleback outcrops in gently undulating to hilly country, which is associated with remnant mesas of overlying Jurassic and Tertiary cover rocks. The unit was previously mapped partly as Kilbeggan Adamellite and partly as “undifferentiated Rawbelle Batholith” by Whitaker & others (1974).

Type locality

The type locality is designated at MGA 261950 7128850 along the road between Auburn and Mount Auburn homesteads where pale grey, medium-grained, equigranular biotite-hornblende tonalite intruded by a dacite dyke crops out. The tonalite or quartz diorite contains quartz (~15%), plagioclase (60–70% as weakly zoned laths of andesine), minor K-feldspar (<5%), partly chloritised biotite (5–10%), anhedral hornblende (~5%, commonly with clinopyroxene cores), minor opaque oxides and accessory titanite.

Lithology

The Evandale Tonalite mostly consists of pale grey, medium-grained, equigranular biotite-hornblende tonalite, but the compositional range extends to granodiorite and rarely monzogranite with up to 25% microcline in places. The rocks cropping out near Evandale homestead appear to be somewhat lower in quartz and range from quartz diorite to quartz monzodiorite. Plagioclase is mostly andesine showing oscillatory zoning and is locally replaced by myrmekitic intergrowths where in contact with microcline. Both hornblende and biotite are ubiquitous in the unit totalling up to 15%. The hornblende commonly contains cores of clinopyroxene and biotite is commonly partly altered to chlorite. At least traces of titanite are present in all samples and it is locally visible in hand specimen forming mainly anhedral grains up to 2mm.

The Evandale Tonalite is mostly not foliated, but it does appear to be deformed in the south-eastern part of the area. About 5km south of Auburn homestead at MGA 261860 7122830 outcrops of tonalite have a pronounced rodding or lineation, defined mainly by alignment of enclaves. At MGA 268900 7131300 ~9km north-east of Auburn, near the eastern contact with the Yerilla Metamorphics, the tonalite has a conspicuous foliation defined by biotite and hornblende that form discontinuous stringers anastomosing around the plagioclase crystals. The biotite and hornblende are locally concentrated into schlieren up to 10cm long. The foliation is parallel to a distinct banding defined by variations in content of mafic minerals (Figure 86a). In thin section, the plagioclase has bent twin lamellae, the biotite is kinked and quartz is strongly strained and recrystallised as subgrains and partly defines a mortar texture.

The reason for the foliation is not known. The association with compositional layering suggests that it may be partly an igneous foliation, although the deformation textures indicate subsolidus deformation. This might still be relatively soon after cooling. The foliated rocks are close to the contact and the deformation was perhaps related to diapiric emplacement. Alternatively, it may be related to later deformation. A series of anastomosing north-north-east-trending lineaments is evident in the magnetic data and could indicate a zone of deformation. One of these has been interpreted as a west-dipping thrust.

Geophysical response

The Evandale Tonalite shows mainly moderate responses in all three radiometric channels resulting in yellowish hues in the composite images.

Figure 86. Granitoids of the Auburn Arch — Evandale Tonalite
(a) Blasted outcrop of biotite-hornblende tonalite showing a diffuse compositional banding. Near the Auburn River ~9km east-north-east of Auburn homestead at MGA 268905 7131277 (IRAU662)
(b) Scanned slab of biotite-hornblende tonalite from the type locality. Road from Auburn homestead to Mount Auburn Outstation at MGA 261953 7128842 (RSC211). Scale is 2cm.

The unit as mapped is mostly moderately magnetic in the regional airborne data, although the pattern is complicated by the presence of north-west-trending magnetic linear features that cut across most of the granitic rocks of the Auburn Arch and obscure the boundaries between units. These features are probably due to the swarms of andesite to dacite dykes that are ubiquitous in the area. Magnetic susceptibility values are in the range 500–3000 x 10^{-5} SI units with a mode at 1250.

Relationships and age

The Evandale Tonalite intrudes the Yerilla Metamorphics and is faulted against the early Permian Narayen beds. Its relationship to the Ah Fat Granodiorite Complex and Glisson Granodiorite is not known, but it appears to be intruded by the late Permian Impey Granodiorite as well as swarms of andesite to dacite dykes that are probably late Permian or Triassic. The tonalite is unconformably overlain by the Jurassic Evergreen Formation and unnamed Tertiary sediments.

Zircon from a sample of hornblende-biotite quartz diorite (IRAU481) collected from the small outlier near Evandale homestead was dated by the SHRIMP method, but the results are imprecise. The data had excess scatter with an MSWD of ~3, but arbitrarily trimming the data gave one interpretation of 319±7Ma with an MSWD of 1.7. However, the zircon population appears to be complex and 'unmixing' suggests that the sample may have a magmatic age of ~300Ma with significant inheritance of 325Ma zircon (see Appendix). Although the data is imprecise, it does suggest a late Carboniferous age or early Permian age for the unit.

GLANDORE GRANODIORITE

Introduction

The Glandore Granodiorite as defined by Dear & others (1971) covered an area of ~650km^2 principally in the Monto 1:250 000 Sheet area, but was extended by Whitaker & others (1974) into the Mundubbera 1:250 000 Sheet area. Mapping during the current project has resulted in subdivision of this unit into many granitoid units, and the redefined Glandore Granodiorite is restricted to an area of ~110km^2 around Glandore homestead in eastern THEODORE (Figure 81) with a lobe extending east towards Jonah Vale homestead in SCORIA.

Type locality

The type locality of the Glandore Granodiorite is along the Biloela–Camboon road immediately east of Glandore homestead at MGA 244500 7248300. Grey to pink, medium grained, even grained to rarely porphyritic granodiorite (Figure 87a) comprises quartz (15–20%), large poikilitic K-feldspar (15–20%), oligoclase to andesine (45–50%), hornblende (5–7%), biotite (4–5%), opaques and titanite.

Lithology

Petrographically, the Glandore Granodiorite is similar to the Hainault Granodiorite and the Hildura Quartz Monzodiorite. Around Glandore homestead it comprises grey to pink, medium-grained, hornblende-biotite quartz monzonite, granodiorite and possibly granite. West of Glandore homestead, grey, medium-grained quartz monzonite to quartz monzodiorite comprises quartz, large poikilitic K-feldspar megacrysts containing chadacrysts of plagioclase, andesine, hornblende, biotite, and traces of titanite and opaques.

The mafic-rich phase around the northern margin of the unit comprises grey, medium-grained diorite containing brownish green hornblende and andesine. Some granodiorite was also observed in this area.

Medium-grained reddish-orange biotite granite and pink to red, medium-grained fractionated granite crops out in the core of the Glandore Granodiorite west-north-west of Glandore homestead. The reddish-orange granite intrudes pink and grey medium grained biotite-hornblende granodiorite, similar to the granitoid at Glandore homestead.

Between Jonah Vale homestead and the Lone Hand mine, similar quartz monzodiorite forms an eastern lobe to the pluton, although it is unclear if this granitoid is part of the Glandore Granodiorite or if it is a separate but similar pluton. South of the Lone Hand mine, altered granitoid comprising quartz, slightly turbid K-feldspar, sericitised plagioclase, chloritised biotite and hornblende may be a more quartz-rich variant.

The unit is intruded by numerous northerly-trending fine-grained rhyolite and porphyritic dacite dykes.

Geophysical response

The main part of the unit has moderate potassium response, moderate thorium and low uranium responses, producing mottled brown and yellow hues on composite images (Figure 82). The small central granite phase has high thorium and moderate to high potassium response and has strong yellow hues on composite images. The eastern lobe and northern marginal mafic phase has lower responses in all channels.

Magnetic susceptibility values mostly range up to 2000 x 10^{-5} SI units, with a bimodal distribution having a strong mode for values <100 and another at 1200. The low values were measured on granite outcrops. The higher values are consistent with the moderate to strong response on total magnetic intensity images (Figure 83). The small central granite phase has a low to moderate response. The overall unit is cut by a prominent north-trending linear zone of demagnetisation ~500m wide.

Relationships and age

The relationships of the Glandore Granodiorite to surrounding granites are not clear, but it intrudes the Torsdale Volcanics. A sample from the type locality was dated by the K–Ar method on hornblende and biotite that yielded adjusted ages of 300–306Ma (Webb & McDougall, 1968). However, a sample from the same outcrop was dated using the SHRIMP U-Pb method on zircon at 323±4Ma, (see Appendix). The unit is therefore early late Carboniferous.

GLENHALVERN GRANITE

Introduction

The Glenhalvern Granite is a large pluton cropping out over ~170km^2 in the Banana Range in the north-eastern part of THEODORE (Figure 81). The name is derived from Glenhalvern Station. Outcrop is generally poor in spite of the relatively rugged topography.

Type locality

The type locality of the Glenhalvern Granite is defined in the State Forest on top of the Banana Range, ~10km east of Glenhalvern homestead at MGA 236600 7271700. Large boulders of white and pink, medium to coarse

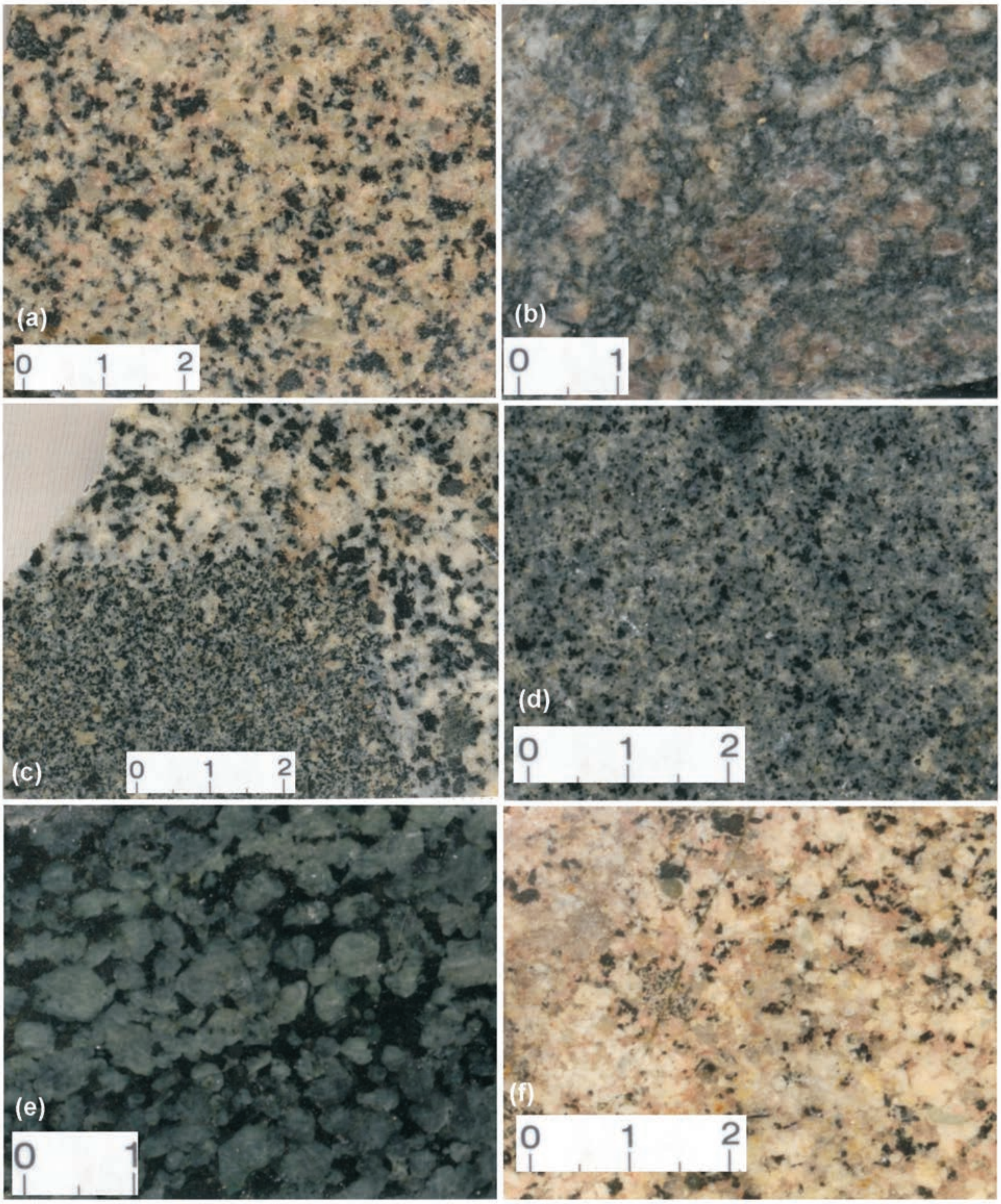

Figure 87. Other granitoids of the Auburn Arch. Scale is shown in centimetres.
(a) Scanned slab of medium grained, even grained hornblende-biotite quartz monzonite from the type locality of the Glandore Granodiorite. Biloela–Camboon road near Glandore homestead at MGA 244518 7248287 (RSC137)
(b) Scanned slab of slightly porphyritic biotite granodiorite of the Glisson Granodiorite. Redbank – Rocky Springs road at MGA 270809 7167113 (RSC220)
(c) Scanned slab of hornblende-biotite granodiorite and a microdiorite xenolith from the type locality of the Hainault Granodiorite. Biloela–Camboon road 8km north-north-east of Mount Kandoonan at MGA 242957 7243147 (RSC139)
(d) Scanned slab of biotite-hornblende quartz monzodiorite of the Okangal Quartz Monzodiorite. Wooloon–Camboon road 3km north-west of Mount Coangal 236330 7231475 (RSC151)
(e) Scanned slab of medium to coarse grained hornblende-plagioclase gabbro of the Parrawee Gabbro. Along the road east of Parraweena homestead at MGA 234008 7264530 (RSC147)
(f) Medium-grained hornblende-biotite monzogranite of the Rockdale Granite. Defence Road ~400m north of the JP Creek crossing near Rockdale homestead at MGA 239570 7204411 (RSC156)

grained, biotite granite comprise quartz (~30%), K-feldspar (~40%, locally perthitic) plagioclase (~25%), biotite (~3%) with minor epidote and opaque oxides. The granite contains rare enclaves of dark grey diorite.

Lithology

The Glenhalvern Granite comprises pink to white, medium to coarse-grained biotite granite. Similar rocks to the type locality occur along Banana Creek in the north and on Parraweena Station to the south. On eastern Parraweena Station, a sample consisting of about equal amounts of quartz, K-feldspar and plagioclase, contains extensive granophyric intergrowths.

The granite is variably altered with some areas of potassium feldspar granite possibly being altered versions of the main granite. Pink to red microgranite on the south-western flank of the pluton is mapped as a separate phase of the main pluton.

Small, unnamed diorite to quartz monzodiorite bodies, some up to 2km long, are interpreted as intruding the pluton particularly around the margins and in the north-west, and may be related to isolated microdioritic outcrops which occur throughout the pluton. It is difficult from available outcrop to determine whether these represent enclaves or dykes.

Geophysical response

The Glenhalvern Granite has a strong potassium response and low to moderate responses for uranium and thorium, resulting in overall pinkish hues on composite radiometric images (Figure 82). A large more pinkish area defines a central core to the pluton that appears to be related more to a lower thorium response rather than elevated potassium. The microgranite on the south-western flank of the pluton is relatively strong in all channels and has a ‘hotter’ (whitish) response on the composite radiometric images than the rest of the pluton.

Magnetic susceptibilities throughout the unit susceptibilities are mostly 100–350 $x10^{-5}$ SI units consistent with the low response on total magnetic intensity images (Figure 83).

Relationships and age

The Glenhalvern Granite is inferred to intrude the Torsdale Volcanics around most of its perimeter. Rhyolite, assigned to the Torsdale Volcanics along the eastern side of the pluton has a similar radiometric response suggesting possible co-magmatism. In the north-east, the granite is unconformably overlain by the Mount Bulgi Conglomerate Member, which is basal to the early Permian Camboon Volcanics. The Torsdale Volcanics are mostly late Carboniferous, although some rocks assigned to them in the Banana Range are early Permian, so a late Carboniferous to early Permian age is assigned to the Glenhalvern Granite. The relationship of the Glenhalvern Granite to the Lonesome Creek Quartz Monzodiorite and the Shawlands Granite Complex in the south is unclear.

GLENLEIGH GRANITE

Introduction

The Glenleigh Granite crops out over ~46km^2 as a roughly rectangular pluton mainly south of Castle Creek and centred ~30km east-north-east of Theodore in south-eastern THEODORE (Figure 81). The name is derived from Glenleigh Station. The granite forms topographically high, dissected country, but crops out poorly.

Type locality

The type locality of the Glenleigh Granite is beside a track, 6km south-west of Glenleigh homestead at MGA 236700 7246500. Greyish-white to pink, medium to coarse grained biotite-hornblende granite comprises quartz (25–30%), K-feldspar (40–45%), plagioclase (15–20%), hornblende (~5%), biotite (2–3%), with traces of allanite, titanite, apatite and opaque oxides. It is intruded by dacitic to rhyolitic dykes.

Lithology

Most of the outcrops observed are similar to that described above, but any variations within the Glenleigh Granite are likely to have been masked by poor outcrop. Much of the pluton is intruded by dacitic to rhyolitic dykes and these make up most of the outcrop. In the south-west of the pluton, pink to red granite appears to be a more fractionated (or possibly potassically altered) variety and granodiorite or monzonite was observed along the south-eastern margin of the pluton.

Geophysical response

The radiometric response of most of the unit is uniformly high in all channels, resulting in ‘hot’ whitish hues on composite images (Figure 82). The granodiorite and monzonite in the south-east correspond with lower values in all radiometric channels and are more magnetic.

Magnetic susceptibility readings at the type locality are mostly in the range 350–900 x 10^{-5} SI units, consistent with the moderate response in total magnetic intensity images (Figure 83).

Relationships and age

The Glenleigh Granite intrudes the Torsdale Volcanics on most sides, commonly resulting in extensive hornfelsing. Its relationship to the Glandore Granite to the east is unclear, but the shape of the mapped contact suggests that it is younger than the latter. The Glenleigh Granite is one of a series of highly fractionated granites (including the Broadlands Granite and the Mount Appenben Granite) that intrude the Auburn Arch north-east of Theodore.

The age is uncertain but is probably late Carboniferous to early Permian as for similar units in the Auburn Arch.

GLEN VIEW QUARTZ MONZODIORITE

Introduction

The unit crops out in north-eastern CRACOW, forming an irregular shaped pluton (~115km^2) with an overall northerly elongation with a north-westerly trending apophysis (Figure 81). The Glen View Quartz Monzodiorite is a mainly recessive unit and forms gently undulating to low hilly country, with scattered boulders and pavements. The terrain is characterised by the development of extensive, fertile, red-brown soils, and has been selectively cleared of much of the original native vegetation. Several prominent bouldery knolls near the south-western margin of the unit are known as The Sisters. The unit is named after Glen View pastoral holding, which encompasses much of the country underlain by the pluton.

The unit incorporates the Boughyard Quartz Diorite and Tan Lies Quartz Monzodiorite depicted on the first edition 1:100 000-scale geological map and Central Queensland GIS (Withnall & others, 2007). Subsequent examination of thin sections and geochemical data indicated that the three subdivisions are very similar.

Type locality

The designated type locality is at MGA 232090 7224270, where the unit forms low hilly country and is relatively well exposed.

Lithology

The unit is somewhat heterogeneous. It consists mainly of pale to dark grey or pinkish grey to pale pink, fine to medium-grained, even-grained to highly porphyritic (mainly plagioclase) quartz monzodiorite, quartz diorite and diorite. Minor gabbro and granodiorite (?) have also been recorded.

The dominant rock type at the type locality is pinkish grey, medium-grained, even grained, (epidote-) chlorite-actinolite-titanite-biotite-hornblende-clinopyroxene quartz monzodiorite. The quartz monzodiorite is characterised by the presence of sparse interstitial granophyric intergrowths between quartz and K-feldspar.

The main mafic minerals are hornblende, clinopyroxene, and biotite. The relative proportions of these minerals show a considerable range from one area to another. Epidote, sericite and chlorite are common secondary minerals. Some rocks are characterised by the presence of relatively abundant, pink feldspar grains, in particular, those exposed in the north-westerly trending apophysis. Most of this feldspar is altered plagioclase rather than K-feldspar. Traces of pyrite and rare chalcopyrite are present locally.

The unit in the area around MGA 2361000 7208160 consists of grey, fine-grained, very porphyritic quartz monzodiorite. The rocks contain numerous euhedral–subhedral calcic plagioclase phenocrysts (up to ~1.5cm long but most much smaller), together with subordinate and smaller (to ~3mm across) clinopyroxene phenocrysts. Groundmass grains (average size ~3mm) consist mainly of calcic plagioclase, with minor biotite, hornblende, clinopyroxene, quartz, K-feldspar (slightly turbid) and opaques. Biotite forms discrete, well-formed grains and small decussate aggregates of fine flakes. Traces of orthopyroxene (faintly pleochroic) and cummingtonite (pale green grains with fine, polysynthetic twinning) have also been identified in one thin section. Quartz and K-feldspar are relatively abundant, and commonly form small granophyric intergrowths in interstices between plagioclase laths. Actinolite, chlorite and sericite are the main secondary minerals (minor). Joint planes are lined with chlorite. Rounded, dark grey, mainly slightly porphyritic inclusions up to ~10cm in diameter of dacite–rhyodacite are common.

The granitic rocks at MGA 240090 7212885 are pale pinkish grey to pale grey, medium-grained (average grainsize ~1.5mm) and somewhat uneven grained, with a well-developed intergranular texture. Calcic plagioclase is the dominant mineral present. Mafic minerals (total ~20%) in decreasing order of abundance are biotite, hornblende, and clinopyroxene. Most clinopyroxene grains are rimmed and partly replaced by green hornblende. Minor amounts of quartz and K-feldspar crystallised relatively late, mainly in interstices between plagioclase laths. Opaque oxide, as relatively abundant, anhedral granules (up to ~0.3 mm across), is the main accessory mineral. Traces of zircon (as relatively large, zoned grains) are also present (mainly as inclusions in biotite flakes). The rocks are little altered, with only traces of sericite (after plagioclase) and chlorite (after biotite).

Hornblende is slightly more abundant than biotite at many localities, and clinopyroxene is absent locally (*e.g*. at MGA 236615 7213695). Traces of titanite (primary) were detected in a few samples (*e.g*. at MGA 237905 7213270, where it forms relatively coarse, interstitial grains). Rarely, quartz and K-feldspar form granophyric intergrowths (*e.g*. at MGA 233310 7214275 and MGA 231140 7220590). Some samples (*e.g*. from MGA 237395 7214060) contain relatively large, anhedral, poikilitic K-feldspar grains (oikocrysts) and are probably quartz monzonite rather than quartz monzodiorite. Quartz may be sufficiently abundant in a few places for the rocks to be classified as granodiorites.

Diorite (?) exposed at MGA 236260 7226250 contains numerous hornblende laths up to ~2cm long.

Some samples are relatively coarse grained and extensively altered. Sericite and chlorite, locally accompanied by minor epidote and/or actinolite, are the main secondary minerals.

The rocks contain scattered mafic inclusions up to ~5cm across. Locally, (*e.g*. at MGA 237550 7220990), they contain large inclusions of pale pink, medium-grained, slightly porphyritic, tourmaline-bearing biotite leucogranite. The rocks are commonly cut by thin (up to ~5cm wide), dyke-like alteration zones containing significant amounts of epidote, chlorite, altered plagioclase (commonly pink), sericite, ± hematite ± pyrite.

Geophysical response

The unit is characterised by low to moderate potassium and thorium and low uranium responses resulting in mainly brownish pink to dark brown hues on composite images (Figure 82). The variation in hues on the radiometric image implies parts of the unit are more mafic than others. In the south, areas characterised by green hues (reflecting a relatively higher thorium response) may correspond to extensively weathered zones with deep soils.

The unit has a relatively high response on total magnetic intensity images (Figure 83), consistent with the magnetic susceptibility values, which show a skewed distribution (with most values between 1000 and 5000 x 10^{-5} SI units and a mode at 2100). Local, extensively altered zones tend to yield lower values.

Relationships and age

The Glen View Quartz Monzodiorite intrudes the Torsdale Volcanics, and is tentatively inferred to post-date the Wind Mill Diorite. In addition, it is inferred to pre-date the Ten Mile Granite, Ravenscraig Gabbro, and unnamed units CPg_{lg}, CPg_{mg}, CPg_{gd}, CPg_{b}, and CPbx. These postulated relationships are mainly based on curvilinear outlines of individual plutons and are, therefore, somewhat speculative. The highly irregular outline of the pluton may also indicate that the unit pre-dates the Nine Mile, Mungunal, and Rockdale Granites. However, few contacts have been found with adjacent units.

The unit is cut by mafic to intermediate dykes in places. The samples examined in detail consist of fine-grained, porphyritic dolerite (with clinopyroxene phenocrysts), hornblende andesite, porphyritic andesite? (with phenocrysts of plagioclase and clinopyroxene), porphyritic dacite (with phenocrysts of plagioclase and scarce, deeply embayed quartz), and aplitic biotite granite. The dykes are up to ~ 1m wide (most < 30cm).

The unit has yielded K–Ar isotopic ages of 265±8Ma (hornblende) and 290±9Ma (biotite) (Whitaker & others, 1974; original ages adjusted using revised IUGS decay constants as detailed by Steiger & Jäger, 1977). It has, therefore, been assigned a late Carboniferous – early Permian age.

GLISSON GRANODIORITE

Introduction

This name is given to an irregular mass that extends for ~30km north from near Sujeewong Creek and is up to 10km wide. Total exposed area is ~100km^2. It lies at the south-eastern end of the Auburn Plateau (Figure 81). Outcrop is poor with scattered boulders and is the unit is commonly deeply weathered. It forms gently undulating to hilly country, the latter being associated with remnant mesas of the Tertiary cover rocks that form the main plateau to the north. It was previously mapped as “undifferentiated Rawbelle Batholith” by Whitaker & others (1974).

The name is derived from Glisson Creek in western AUBURN. It should be noted that the name is misspelt ‘Glissons’ on the AUBURN map.

Several areas of relatively leucocratic biotite granite and granodiorite near Auburn have also been assigned to the Glisson Granodiorite for convenience.

Type locality

The type locality is designated near the Auburn–Sujeewong road at MGA 257700 7147200 where tors of brownish grey, medium grained, porphyritic biotite granodiorite to monzogranite crop out. In thin section the rock consists mostly of quartz (25%), slightly perthitic K-feldspar (25–30% to 4mm), plagioclase (45–50%, mostly 1–3mm and zoned from oligoclase to andesine), fresh dark brown biotite (~5%, 1–3mm) and very minor hornblende. No titanite was observed in thin section. Rare prismatic crystals of hornblende are present in the outcrop as well as plagioclase phenocrysts, both up to 1cm. Porphyritic andesite dykes crop out nearby.

Lithology

Outcrops in the southern part of the unit between the type locality and Glisson Creek appear to be similar to that described above, consisting of pale pink to white or pale grey, medium to coarse-grained, equigranular to slightly porphyritic biotite granodiorite (Figure 87b) with variable but minor amounts of hornblende and titanite. Although usually strongly weathered, fresh rocks are relatively unaltered containing dark brown, only slightly chloritised biotite. Plagioclase is mostly oligoclase with weak oscillatory zoning.

The northern part of the unit is commonly deeply weathered and crops out very poorly. Fine-grained, porphyritic to seriate biotite granite that crops out along the road between Yerilla and Redbank homesteads is assigned to the Glisson Granodiorite. However, outcrops near the eastern contact ~5km south-west of Rocky Springs homestead consist of grey, medium to coarse-grained, equigranular hornblende-biotite tonalite or granodiorite and seem to be more like the Evandale Tonalite. In thin section, they consist of quartz (10%), plagioclase (75%, to 5mm, andesine), K-feldspar (~5%), fresh biotite (5–10%, to 2mm), hornblende (5–10%, with cores of clinopyroxene) and common titanite. The rocks are weakly foliated like parts of the Evandale Tonalite. The full extent of these rocks is not known, but as noted below, the radiometric data also suggests that this area should possibly be mapped as Evandale Tonalite.

Geophysical response

The Glisson Granodiorite as mapped has a variable radiometric response. The southern part of the area between Sujeewong and Glisson Creeks has moderate response in potassium and low to moderate responses in the other two channels, resulting in mottled greyish pink hues on composite images. However, the area south-west of Rocky Springs has moderate potassium, high thorium and moderate uranium, resulting in pale yellowish composite hues similar to parts of the Evandale Tonalite, suggesting that it is probably a continuation of that unit as suggested above. West of Yerilla homestead, the response is again similar to that in the south, consistent with field observations of biotite granite cropping out there.

The magnetic response is mostly moderate and indistinguishable from the Evandale Tonalite, given the complicating factor of overprinting magnetic dykes and demagnetised fault zones. Magnetic susceptibility values are complexly distributed, mostly in the range 0–2850 x 10^{-5} SI units with several peaks between 550 and 1800. Although values at the type locality are at the low end of the overall range (465–660 x 10^{-5} SI units) breaking the data up by area makes little difference to the pattern.

Relationships and age

The Glisson Granodiorite intrudes the Yerilla Metamorphics and is faulted against the early Permian Narayen beds. Its relationship to Ah Fat Granodiorite Complex and Evandale Tonalite is not known. The Jack Shay Gabbro that crops out along the eastern margin of the unit in the Jack Shay Mountain area has a late Permian or Early Triassic K–Ar age and probably intrudes the Glisson Granodiorite. Outcrops of hornblende gabbro or diorite scattered through the unit may be of a similar age. It is also intruded by swarms of andesite to dacite dykes that are probably also late Permian or Triassic. The granodiorite is unconformably overlain by extensive unnamed Tertiary sediments that form the Auburn Plateau to the north.

A late Carboniferous age similar to that of the Evandale Tonalite is assigned to the unit although it has not been dated isotopically. In the airborne magnetic data, it has a similar irregular pattern with poorly defined margins to that of the Evandale Tonalite and Ah Fat Granodiorite Complex, suggesting that they are all of similar age. By contrast, the younger plutons are generally clearly defined circular to elliptical bodies.

HAINAULT GRANODIORITE

Introduction

The Hainault Granodiorite is a roughly ovoid pluton, cropping out over ~11km^2 north of Hainault homestead in south-eastern THEODORE (Figure 81). The name is derived from Hainault pastoral holding.

Type locality

The type locality is along the Biloela–Camboon road on northern Hainault holding at MGA 243000 7243200. Here dark grey medium-grained hornblende-biotite granodiorite or quartz monzodiorite (Figure 87c) comprises quartz (15–20%), large poikilitic K-feldspar (~20%), andesine (40–45%), biotite (5–7%), green hornblende (8–10%), opaques and epidote.

Lithology

The unit consists mostly of granodiorite or quartz monzodiorite as at the type locality. On the road to Hainault homestead a pinkish-grey medium-grained quartz monzonite comprising quartz, large K-feldspar grains (with chadacrysts of plagioclase), andesine, hornblende, biotite and opaques is a variant from the more dominant granodiorite. The quartz monzonite resembles the Glandore Granodiorite to the north.

Geophysical response

On total magnetic intensity images, the unit appears to be continuous with and indistinguishable from the Glandore Granodiorite, but the radiometric response is different (Figures 82 and 83). The radiometric response of most of the unit is low to moderate in all channels resulting in greyish brown hues on composite images.

Magnetic susceptibility readings at the type locality are mostly in the range 1000–2000 x 10^{-5} SI units, consistent with the moderate to strong response in total magnetic intensity images.

Relationships and age

The relationship of the Hainault Granodiorite to surrounding granitoids is not clear.

A tentative late Carboniferous to early Permian age was assigned on the published map but it may be mid-Carboniferous like the Glandore Granodiorite.

HILDURA QUARTZ MONZODIORITE

Introduction

The Hildura Quartz Monzodiorite is a complex unit that crops out over ~15km^2 as a north-east trending slightly arcuate pluton ~9km long and averaging ~1.5km wide, in the south-western part of SCORIA (Figure 81). Rock types range from gabbro to granite, but their relationships are uncertain, and poor outcrop precludes mapping out of the different phases. The name is derived from Hildura Station. It is shown on SCORIA as Hildura Granodiorite, but the name is herein varied to Hildura Quartz Monzodiorite to reflect the dominant lithology.

Type locality

The type locality of the Hildura Quartz Monzodiorite is along the Hainault/Hildura boundary fence at MGA 250000 7244300. White to grey, medium grained quartz monzodiorite comprises quartz (10–15%), large poikilitic K-feldspar (15–20%), andesine (35–40%), biotite (15%), hornblende (8%), pyroxene, titanite apatite, epidote and opaque oxides.

Lithology

In southern Hildura medium and light grey, medium grained hornblende-biotite granodiorite or quartz monzodiorite crops out, but in many places the unit is quite heterogeneous, with quartz monzonite, quartz monzodiorite and granodiorite appearing to be the dominant rock types with local granite and gabbro.

Adjacent to the type locality, medium grained hornblende-biotite granite comprises quartz (~25%), K-feldspar (~30%), plagioclase (~35%), biotite (~10%), hornblende (~5%), with minor opaque oxides and titanite.

Near Rainbow Dam at MGA 250400 7243100 a light grey to black, medium-grained hornblende-biotite quartz monzonite comprises quartz, large K-feldspar grains (with chadacrysts of plagioclase), andesine, biotite, hornblende with pyroxene cores, and traces of titanite, apatite, epidote and opaque oxides. This rock is petrographically similar to the Glandore Granodiorite and parts of the Hainault Granodiorite. Biotite is the dominant mafic mineral, locally occurring in large coarse clumps.

Medium-grained gabbro north of Rainbow Dam at MGA 250400 7244000 comprises labradorite to bytownite (~70%), hornblende (~15%), chlorite (~10%), with minor pyroxene, opaques, quartz, calcite and possibly K-feldspar.

Geophysical response

The Hildura Quartz Monzodiorite is well-delineated from adjacent plutons by its radiometric response. It has similar low to moderate potassium and low uranium, but higher thorium than the Pinedale Granite, resulting in pale green to brownish hues that contrast with the deep pink of the latter (Figure 82). The Jonah Vale Granite to the north has moderate to high potassium, thorium and uranium resulting in overall mottled pinkish to whitish hues.

The unit has a moderate magnetic response that is indistinguishable from surrounding units (Figure 83). Magnetic susceptibilities of the quartz monzonite are in the range 590-1800 x10^{-5}SI units. Gabbro at Rainbow Dam ranges from 1680–2500 x10^{-5} SI units, whereas diorite at another locality is in the range 100–1600 x 10^{-5} SI units.

Relationships and age

The relationships of the Hildura Quartz Monzodiorite to the Jonah Vale Granite to the north and the Pinedale Granite to the south are uncertain. A tentative late Carboniferous to early Permian age is assigned.

HUTCHINSONS GRANITE

Introduction

The Hutchinsons Granite forms a semicircular pluton of ~26km^2 in the southern part of THEODORE (Figure 81).

Type locality

The type locality is along Hutchinsons Road (from which the unit is named) at the Woolton/Camboon boundary at MGA 227600 7236100. Pink to red, medium grained biotite-hornblende granite comprises quartz, anhedral K-feldspar, sericitised plagioclase, hornblende, biotite (mostly altered to chlorite) and opaque oxides.

Lithology

The Hutchinsons Granite comprises pink to red, medium grained biotite-hornblende granite as at the type locality. At the northern end of Hutchinsons Road, biotite granite crops out. The western part of the pluton crops out poorly, but outcrops of microgranite are present, some with miarolitic cavities. This is mapped out as a separate phase of the pluton.

Geophysical response

The Hutchinsons Granite has high potassium, low thorium and low to moderate uranium responses that result in bright pink hues on composite images (Figure 82) that contrast with the surrounding Torsdale Volcanics and Boam Creek Quartz Monzodiorite and facilitate the mapping of the pluton. The microgranite phase in the west is characterised by stronger potassium, thorium and uranium responses than the rest of the pluton and has paler pink composite hues.

The pluton is moderately magnetic although not as magnetic as the Boam Creek Quartz Monzodiorite except along the north-eastern margin. Magnetic susceptibility measurements from three outcrops were in the range 35–904 x 10^{-5} SI units.

Relationships and age

The shape of the mapped contact suggests that the unit intrudes the Boam Creek Quartz Monzodiorite. Slightly recrystallised Torsdale Volcanics flank the granite to the east, west and south. The age is uncertain, but a late Carboniferous to Permian age is assigned.

JAN MAR GRANITE

Introduction

The Jan Mar Granite crops out as an irregular north-easterly aligned pluton covering ~28km^2, 8–16km south-south-east of Cracow (Figure 81). The granite is deeply weathered and forms undulating country with few outcrops. The unit is named after Jan Mar pastoral holding, which encompasses most of the pluton.

Type locality

The type locality is a cutting on the Eidsvold–Theodore road, at MGA 236850 7197685.

Lithology

The unit consists mainly of white to pale brown, or red (extensively weathered), medium-grained, even-grained to slightly porphyritic, leucocratic biotite monzogranite. Outcrops examined consist mainly of crumbly, decomposed granite, locally with remnants of a deep weathering profile preserved. No thin sections from the unit have been examined. The monzogranite is cut by aplite dykes in places.

Geophysical response

The unit has high potassium, moderate thorium and low to moderate uranium radiometric responses that result in pink hues on composite images that are not particularly distinctive from the surrounding Torsdale Volcanics.

Moderately high magnetic responses characterise most of the unit on total magnetic intensity images but these are not particularly distinctive from the surrounding rocks either. No magnetic susceptibility values are available.

Relationships and age

The Jan Mar Granite intrudes the Torsdale Volcanics. Volcanic rocks adjacent to contacts with the granite have been hornfelsed and extensively recrystallised. The unit is interpreted to pre-date unnamed unit CPg_{gd} and unit $CPvc_{al}$ of the Camboon Volcanics, although contacts between these two units and the granite were not found.

The granite has not been isotopically dated and its age is thus uncertain. It is tentatively interpreted to be late Carboniferous – early Permian.

JONAH VALE GRANITE

Introduction

The Jonah Vale Granite forms an irregular wedge shaped area of ~32km^2 trending south-west from near Jonah Vale homestead across the boundary between southern THEODORE and SCORIA (Figure 81).

Type locality

The type locality of the Jonah Vale Granite is beside Jonah Vale homestead at MGA 252300 7250600. Pink to grey medium grained, hornblende-biotite granite comprises quartz (~35%), perthitic and locally poikilitic K-feldspar (~35%), plagioclase (~20%), biotite (~3%), hornblende (~2%), and opaques (~3%).

Lithology

The Jonah Vale Granite has similar rock types throughout its outcrop area, and is mainly pink to white, medium to coarse-grained, horneblende-biotite granite comprising quartz (~25%), K-feldspar (~45%), plagioclase (~25%), biotite (~5%), hornblende (~2%), with minor titanite, opaques and zircon.

Near the eastern edge of the pluton on Runaroo Holding, the granite is intruded by grey porphyritic granite dykes that make up much of the outcrop there.

Geophysical response

Radiometric response throughout the Jonah Vale Granite is generally uniformly high in potassium, moderate to high in thorium and moderate in uranium, indicating that the granite is relatively fractionated. On composite images the granite has mottled pink and pale yellowish hues (Figure 82).

The unit has a moderate magnetic response that is somewhat lower than the adjacent Glandore Granodiorite, but is similar to the Hildura Quartz Monzodiorite and Pinedale Granite. Measured magnetic susceptibilities are in the range 12–1750 x 10^{-5} SI units with a mean of about 400 and a mode at about 300.

Relationships and age

The relationship of the Jonah Vale Granite to the adjacent Pinedale Granite and Glandore Granodiorite is unknown due to poor outcrop. A late Carboniferous to early Permian age is assigned.

J P GRANITE

Introduction

The J P Granite crops out in the far east of CRACOW (Figure 81), as an irregular northerly trending pluton of ~34km^2. The granite forms undulating to low hilly country, and is generally poorly exposed and deeply weathered. The unit is named after J P Gully, which drains part of the pluton in the south.

Type locality

The designated type locality is beside the Defence Road, at MGA 240170 7201660, near the southern margin of the pluton. Outcrops are readily accessible in this area.

Lithology

The samples examined from the type locality consist of pale grey, medium to fine-grained, uneven grained to slightly porphyritic, biotite-hornblende monzogranite. Hornblende appears to be slightly more abundant than biotite (total mafics content ~10%). Granophyric intergrowths between quartz and K-feldspar are common. Opaques and zircon (as relatively coarse, zoned grains) are the most abundant accessory minerals. Traces of titanite, epidote, chlorite and sericite and rare allanite are also present.

The monzogranite contains scattered rounded inclusions, up to ~15cm across, of grey, extensively recrystallised, porphyritic rhyolite. These inclusions may have been derived from the Torsdale Volcanics, which crop out nearby. Scarce, much smaller, ovoid inclusions of fine-grained hornblende diorite up to ~2.5cm across are also present locally. The monzogranite is cut by thin dykes of pink aplite.

Outcrops are characterised by the presence of thin, tabular alteration zones concentrated along joint planes. Monzogranite in these zones is moderately altered. Epidote, chlorite, and sericite are the main secondary minerals. Hornblende is generally unaltered. In contrast, most of the biotite flakes are partly to completely replaced by chlorite ± epidote. Many plagioclase grains are turbid due to extensive sericitisation.

Monzogranite from the northern part of the pluton at MGA 243656 7212577 is more leucocratic than that exposed in the type area. It contains ~4–5% biotite. The biotite forms discrete flakes, some of which have been partly to completely replaced by chlorite ± epidote. Hornblende and titanite were not detected. Granophyric intergrowths between quartz and K-feldspar are also not as extensively developed.

The unit is deeply weathered and covered by extensive residual deposits, commonly with a basal deep weathering profile developed.

Geophysical response

The J P Granite has high potassium, moderate thorium and low to moderate uranium radiometric responses that result in pink hues on a composite radiometric image.

It has low to moderate responses on total magnetic intensity images consistent with measured magnetic susceptibilities, which show a strongly skewed distribution with a maximum mode at ~50 x 10^{-5} SI units, a smaller mode at 450 x 10^{-5} SI units, and values tailing off to ~1500 x 10^{-5} SI units.

The unit is difficult to distinguish from the adjoining Rockdale Granite on the geophysical images examined. Parts of the Rockdale Granite show slightly darker pink tones and higher magnetic intensities.

Relationships and age

The unit is interpreted to post-date the Torsdale Volcanics, Wind Mill Diorite, and to pre-date the Rockdale and Moocoorooba Granites, and unnamed units $\mathbf{CPg_b}$ and $\mathbf{CPg_{gd}}$. However, exposures of contacts between the J P Granite and the adjacent units were not found during the fieldwork, so the relationships postulated above are speculative.

The age of the unit is uncertain. The granite was most probably emplaced in the late Carboniferous – early Permian. The adjacent Rockdale Granite is intruded by the Mungunal Granite which has yielded a K–Ar biotite age of 307±6Ma (Webb & McDougall, 1968).

KANDOONAN GRANITE

Introduction

The Kandoonan Granite crops out on eastern Hainault and northern Kandoonan stations in south-eastern THEODORE (Figure 81). It forms an ovoid shaped outcrop area of ~12km^2. Outcrop is very poor.

Type locality

The type locality is along a station track on the eastern part of Hainault Station at MGA 240000 7243000. Grey to pink, medium-grained granite comprises quartz (~25%), K-feldspar (40–45%), oligoclase to andesine (20-25%), biotite (~5%), hornblende (~3%), titanite and opaque oxides.

Lithology

The few other outcrops seen in the Kandoonan Granite during this survey are all hornblende-biotite granite similar to the type area. Pink granite to the north of the type locality may be a more altered or fractionated variant.

Geophysical response

The Kandoonan Granite has a high radiometric response in the potassium, thorium and uranium channels, showing up as a white area on composite radiometric images (Figure 82).

The pluton has a moderate to high magnetic response indistinguishable from the surrounding granitic and volcanic rocks. Magnetic susceptibilities measured on five outcrops ranged from 4–1641 x 10^{-5} SI units with a mean of 660.

Relationships and age

The Kandoonan Granite has hornfelsed the Torsdale Volcanics to the north and west. Its relationship to unnamed diorite and Hainault Granodiorite is unclear, but it appears to cut across the former. A tentative late Carboniferous to early Permian age is assigned.

KEEN CREEK GRANITE

Introduction

The Keen Creek Granite is a triangular pluton covering ~22km^2 in the headwaters of Keen and Marvel Creeks on southern Hainault Station and north-eastern Camboon Station in south-eastern SCORIA (Figure 81). It crops out poorly and is locally deeply weathered and capped by duricrust.

Type locality

The type locality is on a track on northern Camboon Station at MGA 250700 7237600, where grey, fine to medium-grained, biotite granite forms large outcrops. It comprises quartz (~35%), poikilitic and perthitic K-feldspar (~40%), plagioclase (~20%), biotite (~5%), and minor opaques.

Lithology

Only four outcrops were examined in the unit, which was delineated from the radiometric data. They were pale grey to pale pink, fine to medium-grained biotite granite. On southern Pinedale Station, the Keen Creek Granite is strained and recrystallised and a sample comprises strained and recrystallised quartz (~30%), microcline (~40%), plagioclase (~30%) with minor biotite and a trace of muscovite. A sample from along the boundary fence between Camboon and Hainault stations shows less recrystallisation and contains quartz (~35%), poikilitic K-feldspar (~40%, mostly microcline with perthite strings and beads), plagioclase (~20%), biotite (~5%) and minor opaque oxides.

Geophysical response

In the radiometric data, the potassium response is moderate to high and thorium and uranium are moderate, resulting in pale pink hues on the composite images (Figure 82), which contrast with a much deeper pink hue for the Pinedale Granite that has lower responses in all three channels.

Magnetic susceptibilities were only measured at two outcrops and were quite variable and in the range 30–1400 x 10^{-5} SI units. On total magnetic intensity images, the granite has a moderate response, indistinguishable from surrounding units.

Relationships and age

The Keen Creek Granite appears to intrude the Pinedale Granite mainly on the basis of the shape of its contact as mapped from the radiometric data. It is intruded by the Montour Gabbro and a tentative age of late Carboniferous to early Permian is assigned.

KOOINGAL GRANODIORITE COMPLEX

Introduction

The Kooingal Granodiorite Complex forms a small pluton of ~5km^2, centred ~7km south-west of Torsdale homestead. It mainly crops out recessively along the valley of Prairie Creek on the eastern side of the Banana Range (Figure 81). The unit is shown as Kooingal Granite Complex on the THEODORE map, but is modified herein to reflect the dominant rock type.

Type locality

Two mingled granitoid types are well exposed beside a station track at MGA 231800 7283100. The main type is white to grey, medium-grained, biotite-hornblende granodiorite containing enclaves of grey, fine to medium-grained, porphyritic diorite.

Lithology

The Kooingal Granodiorite Complex comprises at least two magma types but the relationship between them is unclear. White to grey, medium-grained hornblende-biotite granodiorite is mingled with porphyritic grey diorite that appears to form xenoliths. The two magma types may have been emplaced synchronously. Similar magma mingling is seen in the Shawlands Granite Complex.

Outcrops of the two rock types along Prairie Creek are generally highly fractured and have various degrees of potassic, sericitic and chloritic alteration. In the hilly country south of Prairie Creek, dark grey porphyritic diorite appears to be the dominant rock type.

Geophysical response

The Kooingal Granodiorite Complex has high potassium and uranium responses and a low to moderate thorium response resulting in mottled pink and whitish hues indistinguishable from the surrounding Torsdale Volcanics (Figure 82).

The magnetic response is moderate and also largely indistinguishable from the surrounding Torsdale Volcanics. Magnetic susceptibilities were measured at only two outcrops. The diorite and granodiorite are indistinguishable and have values in the range 670–1368 x 10^{-5} SI units.

Relationships and age

The relationship of the Kooingal Granodiorite Complex to the surrounding Torsdale Volcanics was not seen, but is probably intrusive. The Kooingal Granodiorite Complex is overlain disconformably by the Mount Bulgi Conglomerate Member of the Camboon Volcanics.

The Kooingal Granodiorite Complex is probably late Carboniferous. Webb & McDougall (1968) plotted analyses of a sample of the unit on the same Rb-Sr isochron as the Boam Creek Quartz Monzodiorite, yielding an age of 311±29Ma).

LONESOME CREEK QUARTZ MONZODIORITE

Introduction

The Lonesome Creek Quartz Monzodiorite is a small pluton of ~5km^2 that crops out in the headwaters of Lonesome Creek on the western foothills of the Banana Range (Figure 81). The name Lonesome Creek Monzonite has been used on the THEODORE map, but is herein changed to more accurately reflect the dominant rock types.

Type locality

The type locality is along a station track in northern Parraweena Station at MGA 231900 7266200 where the unit is well exposed. Pale pink, green and grey, medium-grained, hornblende-biotite quartz monzodiorite or quartz monzonite consists of quartz, typically in micrographic intergrowth with turbid K-feldspar, oligoclase to andesine, hornblende, altered biotite, opaques and zoisite. About 500m away, a red to green syenitic rock may be a potassically altered variety.

Lithology

Main rock-types include pale pink and green hornblende-biotite monzodiorite, greyish white and green medium-grained granodiorite, and orange-pink and green, medium-grained hornblende-biotite monzonite to syenite.

Geophysical response

The unit has moderate responses in potassium and thorium and low to moderate in uranium that produce pale yellowish green hues on composite images similar to those in the Glandore Granodiorite 12km to the south-east. Although the rock types are superficially similar to those in the Shawlands Granite Complex 4km to the south-east, they have a different radiometric response and are mapped as a separate unit.

The unit has a moderate magnetic response indistinguishable from that of the Torsdale Volcanics, but higher than that of the Glenhalvern Granite to the east. The magnetic susceptibility was measured at three localities and was in the range 313–2470 x 10^{-5}SI units (average 1405).

Relationships and age

The shape of the mapped contact suggests that the Lonesome Creek Quartz Monzodiorite is intruded by the Parraweena Gabbro. The relationship to the Glenhalvern Granite is unclear. A late Carboniferous to early Permian age is assigned, but the unit is more likely to be late Carboniferous because of its similarity to the Glandore Granodiorite.

LYNDALE DIORITE

Introduction

The Lyndale Diorite crops out over ~5km^2 south of Castle Creek and ~28km north-east of Theodore in south-central THEODORE. It forms an elongate north–south pluton intruded along the western contact of the Glenleigh Granite with the Torsdale Volcanics (Figure 81).

Type locality

The type locality is on eastern Lyndale Station (from which the unit takes its name) at MGA 232200 7247900. Here good outcrop of fractured greenish-grey, medium to fine grained, two-pyroxene diorite comprises oligoclase to andesine (~58%), clinopyroxene (~15%), orthopyroxene (~7%), poikilitic K-feldspar (~5%), biotite (~3%), quartz (~3%), chlorite (~2%), and opaques (~7%).

Lithology

Rock types throughout the Lyndale Diorite are similar to the type locality, generally comprising fine to medium-grained, greenish-grey diorite. About 1km south of the type locality, an outcrop is petrographically similar except that pyroxene has been altered to a pale green amphibole. It comprises oligoclase to andesine (~70%), pale amphibole, commonly cored by pyroxene (~15%), biotite (~5%), poikilitic K-feldspar (~2%), quartz (~2%), and opaques (~5%).

Geophysical response

The radiometric response is relatively low in all channels, particularly uranium, resulting in dark greenish hues on composite images (Figure 82).

No magnetic susceptibility measurements were made on the Lyndale Diorite, but it partly corresponds with a very strong anomaly on the total magnetic intensity images (Figure 83).

Relationships and age

The Lyndale Diorite forms an elongate pluton that intrudes along the contact between the Torsdale Volcanics and the Glenleigh Granite. It is one of a series of diorite/gabbro bodies in the Auburn Arch, although most are small and are not named.

Petrographically, the Lyndale Diorite is similar to granodiorite in the Boam Creek Quartz Monzodiorite that lies to the south, except that the latter contains more K-feldspar and quartz. Amphibole in both units is pale green and cored by pyroxene. The two units are possibly part of the same magmatic suite.

A late Carboniferous to early Permian age is tentatively assigned to the Lyndale Diorite but the unit may be early Carboniferous due to the similarity to the Boam Creek Quartz Monzodiorite.

McKONKEY GRANODIORITE

The name McKonkey Granodiorite was applied on the first edition of the Auburn Special 1:100 000 map for an area with an unusually low radiometric response in all three channels that contrasted with moderate responses of the surrounding Coonambula Granodiorite. However, re-examination of the data indicates that the radiometric response is more likely due to a thin cover of Tertiary alluvial deposits that locally host alluvial gold in the area. Outcrops in the area are described as dark grey, mesocratic muscovite-biotite granite with schlieren and diffuse metasedimentary enclaves in places. This fits the description of part of the Coonambula Granodiorite or Widbury Granite.

MONKEY SPRINGS GRANITE

Introduction

The Monkey Springs Granite crops out as an elongate intrusion ~5km long and 1–2km wide trending north-north-west along the crest of the Banana Range ~9km west-south-west of Torsdale homestead (Figure 81). Topography is relatively rugged.

Type locality

The type locality of the Monkey Springs Granite is on the top of the Banana Range at MGA 229200 7280400, north of the track connecting Torsdale and Brookleigh homesteads. Reddish-orange, medium-grained, biotite granite crops out.

Lithology

Because of the rugged topography, the granite was examined in only two localities. The two sites examined are both pink to red, medium-grained fractionated granite and the radiometric response suggests that it is likely that this represents most of the outcrop. This granite is similar to clasts observed in rhyolitic ignimbrite in the Torsdale Volcanics to the south-west.

Geophysical response

The Monkey Springs Granite has a high radiometric response in potassium, uranium, and thorium appearing white on the composite radiometric images (Figure 82), consistent with its fractionated appearance. This contrasts with the pinkish hues of the Torsdale Volcanics and allows the pluton to be easily delineated.

The pluton has a moderate magnetic response indistinguishable from the Torsdale Volcanics. Magnetic susceptibilities at the two localities are in the range 3–425x10^{-5}SI units (average 153).

Relationships and age

The relationship of the Monkey Springs Granite to the surrounding Torsdale Volcanics is unclear. In eastern Monkey Springs, the granite is adjacent to recrystallised rhyolitic volcanics suggesting that it intrudes them. However, Torsdale Volcanics in the adjacent area contain granite clasts similar to the Monkey Springs Granite. If these clasts are from the Monkey Springs Granite, then it predates or is possibly co-magmatic with the Torsdale Volcanics. Consequently, a late Carboniferous age is assigned.

MONTOUR GABBRO

Introduction

The Montour Gabbro comprises three bodies forming a west-north-west line across the south-west corner of SCORIA and the south-east corner of THEODORE (Figure 81). The largest and westernmost of these bodies is ~10km^2, and straddles the boundary between THEODORE and SCORIA. The other two bodies are 3km^2 and 1km^2 respectively. Outcrop is very poor. The distribution of the gabbro bodies was determined mainly from red soils on the air-photos and corresponding areas of low radiometric response on the composite radiometric images. The name is derived from Montour Creek.

Type locality

The type locality of the Montour Gabbro is in the middle of the three bodies beside a station track in the northern part of Camboon Station at MGA 250100 7236100. Dark green and white, medium-grained gabbro comprises plagioclase (~45%), hornblende (~35%, commonly ophitic with plagioclase inclusions), clinopyroxene (~10%, commonly as cores to hornblende), orthopyroxene (~2%) and opaque oxides (~8%), some of which form complex symplectic intergrowths with clinopyroxene and plagioclase within hornblende grains.

Lithology

Only four outcrops were found in the current study. Dark green fine-grained gabbro at MGA 246900 7237800 is the only outcrop found in the larger western body. The only outcrop observed in the easternmost body at MGA 253900 7235700 shows variation in the hornblende content at the outcrop scale, probably due to layering and differentiation within the pluton. Greenish grey, medium-grained leucogabbro is layered with more hornblende-rich varieties, and comprises labradorite to bytownite (80–85%), hornblende (~5%) and fibrous uralite (10–15%).

Geophysical response

The radiometric response is very low in all channels, resulting in very dark greenish blue to black hues on composite images (Figure 82).

The gabbro at the type locality is highly magnetic, with susceptibilities in the range 4500–11700 x 10^{-5} SI units. Outcrops in the eastern body have values in the range 4000–7000 x 10^{-5} SI units. The leucogabbro in the eastern body is non-magnetic, although the overall body has a very strong response like the other two.

Relationships and age

The Montour Gabbro appears to have been intruded late in the magmatic cycle forming discrete bodies within different granitoid plutons. It could be early Permian and related to basalts in the Camboon Volcanics or part of the late Permian to Early Triassic suite of gabbros.

MOOCOOROOBA GRANITE

Introduction

This unit was named and defined by Whitaker & others (1974) as the Moocoorooba Adamellite and changed here to the Moocoorooba Granite. Much of the former unit, particularly in its western half has been subdivided and assigned to new units. As now mapped, it is exposed over an area of ~150km^2, lying across the junction of RAWBELLE, CRACOW, THEODORE and SCORIA (Figure 81). The Moocoorooba Granite readily weathers to a sandy soil, and generally forms gently undulating country with little relief. The unit is poorly exposed with outcrop mainly confined to creek outcrops.

Type locality

The type locality is given at MGA 248150 7230900, where low rubbly outcrops of pink medium-grained equigranular (hornblende)-biotite granite are exposed.

Lithology

A typical lithology for this unit is a pale to moderate pink medium-grained equigranular (hornblende)-biotite granite. The granite contains biotite (~5%) and green hornblende (variable, from traces to 10%). Magnetite and apatite occur as accessories and the feldspars show varying degrees of alteration to sericite and saussurite. Both biotite and hornblende are partly altered to chlorite; some uralite is present. In places the granite appears to have a weak foliation.

Outcrops of quartz diorite have been observed within the mapped area, but their relationship to the granite is not known.

Geophysical response

The radiometric response for this unit is high for potassium and only moderate for thorium and uranium resulting in pinkish hues on the composite images (Figure 82).

The overall response in the airborne magnetic data is moderate to high, and the unit is cut by a north-trending lineament marked by a narrow zone of demagnetisation (Figure 83). The few magnetic susceptibilities measured in the field range from 900 to 3000, consistent with the airborne magnetic data.

Relationships and age

The Moocoorooba Granite is mapped in contact with numerous other granitoid and gabbro units, most of which are probably Carboniferous. The relationship to these is uncertain. It is probably intruded by the Glencoe Gabbro. The unit is overlain unconformably along its eastern boundary by Cainozoic deposits.

Carboniferous isotopic ages were by reported by Whitaker & others (1974) and Webb & McDougall (1968) for the Moocoorooba Granite, but none of these lie within the unit as now mapped. However, a late Carboniferous age is still likely.

MOUNT APPENBEN GRANITE

Introduction

The Mount Appenben Granite crops out over ~3km^2 north of the Defence Road and east of Woolton homestead on the western slopes of Mount Appenben in southern THEODORE (Figure 81).

Type locality

A type locality is defined ~1km south of Mount Appenben at MGA 225000 7240600 where fine to medium-grained biotite granite crops out.

Lithology

The unit comprises pink to grey, fine to medium-grained biotite granite. At Mount Appenben, the granite is capped by (and may intrude) grey rhyolitic breccia.

Geophysical response

The granite is probably fractionated and is represented on the composite radiometric images by ‘hot’, whitish hues due to a strong response in all channels (Figure 82).

No magnetic susceptibility measurements were made on the Mount Appenben Granite. It has a slightly lower response the total magnetic intensity images than the Boam Creek Quartz Monzodiorite to the south.

Relationships and age

The Mount Appenben Granite appears to intrude the Boam Creek Quartz Monzodiorite but no contacts were observed. It is separated from the lithologically and radiometrically similar Broadlands Granite by a septum of Torsdale Volcanics ~1km wide and may be an apophysis of the larger pluton. The age is uncertain, but a late Carboniferous to early Permian age is assigned by association.

MUNGUNAL GRANITE

Introduction

The Mungunal Granite crops out as a small (~4km^2), northerly aligned, elongate pluton adjacent to the Defence Road, ~15km north-east of Cracow (Figure 81). The pluton forms undulating country with scattered bouldery rises and low ridges. The unit is named after the nearby Parish of Mungunal.

Type locality

The type locality is at MGA 240480 7207400, on the western side of Cracow Creek. The unit forms large rounded boulders in this area.

Lithology

The unit at the type locality consists of pale pinkish brown to pale pink, medium-grained, uneven-grained to slightly porphyritic (in K-feldspar), leucocratic biotite monzogranite. Biotite is the main mafic mineral and forms small, discrete flakes, some of which have been partly or completely replaced by chlorite. Feldspar grains are commonly turbid as a result of alteration. The granite also contains minor chlorite (after biotite) and sericite (after plagioclase), as well as rare allanite. A noteworthy feature is the presence of abundant granophyric intergrowths between quartz and K-feldspar. Accessory and secondary minerals recorded include zircon, apatite, epidote, opaque oxide and pyrite.

The monzogranite is locally cut by aplite dykes up to ~10cm wide. It shows minor alteration, expressed mainly as thin (<5cm), dyke-like, reddened zones along joint planes.

The grainsize of the groundmass constituents decreases significantly towards contacts with the Rockdale Granite, and the texture becomes porphyritic. Granophyric intergrowths between quartz and K-feldspar are also common in the finer grained variants. Porphyritic microgranite from the contact with the Rockdale Granite at MGA 240920 7207820 is grey rather than pink and has a very fine-grained (average grainsize ~0.3mm) granophyric groundmass. The groundmass contains minor pale green hornblende, as well as biotite, and traces of titanite. Plagioclase is the dominant phenocryst phase in contrast to other samples examined, in which K-feldspar is the main phenocryst phase. The sample analysed from this locality contains ~69% SiO_2, reflecting the relatively mafic character of the microgranite. In contrast, the remaining samples analysed from the unit have SiO_2 contents of between 75–76%. The mapping was not sufficiently detailed (and the outcrop too poor) to determine whether or not the microgranite represents a quenched, relatively mafic marginal phase of the Mungunal Granite or forms a discrete intrusion (dyke or pod). The microgranite is currently included in the Mungunal Granite.

Geophysical response

The unit has high potassium and moderate thorium and uranium radiometric responses that result in pink hues on a composite radiometric image. These tones are slightly paler than those displayed by the adjacent Rockdale Granite.

On total magnetic intensity images the Mungunal Granite is characterised by a moderate response, essentially similar to that shown by the adjacent Rockdale Granite. No magnetic susceptibility measurements were made.

Relationships and age

The Mungunal Granite is interpreted to intrude the enclosing Rockdale Granite, because its grainsize decreases significantly towards contacts with the latter.

The unit has been assigned a late Carboniferous age, based on a K–Ar biotite age of 307±6Ma (Webb & McDougall, 1968; adjusted using the revised IUGS decay constants of Steiger & Jäger, 1977).

NINE MILE GRANITE

Introduction

The Nine Mile Granite forms a roughly circular pluton (~11km^2), ~10km north-east of Cracow (Figure 81). It forms mainly relatively low undulating country, interspersed with low rises and ridges. Outcrops consist of bouldery rubble and small pavements. The unit is named after Nine Mile Creek, which traverses the central part of the pluton.

Type locality

The designated type locality is in a small gully at MGA 237300 7206610, on the western side of a station track.

Lithology

The unit consists mainly of pale pink to dark reddish pink, pale brown or, rarely, pale grey, fine to medium-grained, slightly porphyritic, leucocratic biotite granite. Biotite (~2–3%) is the main mafic mineral. Traces of pyrite are also commonly present.

The only sample examined in detail, from the type locality, is characterised by abundant granophyric intergrowths between quartz and K-feldspar. Phenocrysts up to ~1cm across are common and comprise plagioclase and quartz (euhedral to rounded, some with bipyramidal habit, and commonly embayed). K-feldspar is much more abundant than plagioclase, and is particularly common in the groundmass.

The unit is commonly slightly to moderately altered. K-feldspar grains are turbid, most plagioclase grains have been partly replaced by sericite, and biotite has been partly replaced by chlorite. Many outcrops are cut by thin quartz veins up to ~1cm wide.

Relict deep weathering profiles are preserved on the granite in places.

Geophysical response

The unit has high potassium and moderate thorium and uranium radiometric responses, which result in pink hues on composite radiometric images.

The unit shows low to moderate magnetic responses, which are slightly lower than those displayed by the Torsdale Volcanics and significantly lower than those characterising the Glen View Quartz Monzodiorite. Magnetic susceptibility readings are low (most are $<140 \times 10^{-5}$ SI units, and at some outcrops the readings were $<10 \times 10^{-5}$ SI units).

Relationships and age

The Nine Mile Granite intrudes the Torsdale Volcanics, Glen View Quartz Monzodiorite, and probably the Rockdale Granite. The Nine Mile Granite is a high-level intrusion, possibly related to the Torsdale Volcanics. The unit has not been isotopically dated, but it tentatively assigned a late Carboniferous – early Permian age.

OKANGAL QUARTZ MONZODIORITE

Introduction

The Okangal Quartz Monzodiorite (~15km^2) crops out as an irregular, elongate, north-westerly aligned pluton in north-eastern CRACOW and extends into adjoining THEODORE (Figure 81). The unit is deeply weathered and poorly exposed, and is characterised by extensive development of dark red-brown soils. It forms low, undulating country with broad rises. The unit is named after the Parish of Okangal, and was shown as Okangal Granodiorite on the first edition 1:100 000-scale geological map and Central Queensland GIS (Withnall & others, 2007).

Type locality

The type locality is at MGA 234265 7232045, on the eastern side of a station track. The unit forms low, bouldery outcrops at this locality, and is relatively well exposed.

Lithology

The unit is texturally and compositionally heterogeneous. Outcrops at the type locality consist of grey, fine to medium-grained (average grainsize ~1mm), somewhat uneven-grained clinopyroxene-biotite-hornblende quartz monzodiorite (Figure 87d). The quartz monzodiorite contains abundant calcic plagioclase (~65%), as well as subordinate quartz (~15%) and minor K-feldspar (~10%), pale green hornblende, and biotite (~10% total mafics). Traces of clinopyroxene (as relict cores in some hornblende grains) and titanite are also present. Opaque oxide and zircon (as relatively coarse grains) are the most common accessory minerals. The rocks are moderately altered; sericite (after plagioclase), actinolite (after hornblende), chlorite (mainly after biotite), and epidote (mainly after biotite) are the most common secondary minerals.

The quartz monzodiorite also contains sparse, rounded, mafic inclusions up to ~3cm across.

Clinopyroxene was not detected in the two samples examined from the western part of the pluton (at MGA 231270 7232060 and MGA 232395 7232930), and K-feldspar is rare or absent. Hornblende is also more abundant in the former sample (~15%) than at the type locality, and is mainly unaltered. This sample is moderately porphyritic with numerous phenocrysts, up to ~3mm in length, of calcic plagioclase and brownish green hornblende. The rocks at this locality (boulders excavated from a small stock-water dam) are much finer grained (average size of groundmass grains ~0.3mm) than the samples examined from the type locality, and are quartz diorites rather than quartz monzodiorites.

The other sample, from adjacent to the contact with the Torsdale Volcanics, has a finer grained groundmass, contains only traces of quartz, and is distinguished by the presence of sparse microphenocrysts of titanite. It has the modal composition of a hornblende diorite. The rocks in this area are extensively altered, and are locally brecciated and silicified. Tourmaline is common in these zones, which appear to be pipe-like in character.

Geophysical response

The unit has low potassium and thorium and very low uranium radiometric responses resulting in dark brown hues (Figure 82), which distinguish it from adjacent units.

It shows moderate to high responses on total magnetic intensity images (Figure 83). Magnetic susceptibility readings (total of 10) made at two sites near the north-eastern margin of the unit range from 1557 to 3624 x 10^{-5} SI units.

Relationships and age

The Okangal Quartz Monzodiorite intrudes the Torsdale Volcanics, and is inferred to pre-date unnamed units **CPg_b**, **CPg_g**, and **CPbx**.

The unit is inferred to have been emplaced during the late Carboniferous – early Permian, but it has not been isotopically dated.

PARRAWEENA GABBRO

Introduction

The Parraweena Gabbro forms a small ovoid pluton of ~2km^2 on eastern Parraweena Station in eastern THEODORE (Figure 81). Much of the area, which is well defined by the low response on the composite radiometric image, is covered by black soil derived from the gabbro and outcrop is very poor.

Type locality

The type locality is along a station track ~3km east of Parraweena homestead at MGA 234000 7264000. Dark grey to black, medium to coarse grained hornblende gabbro crops out (Figure 87e). The rock comprises andesine to labradorite (~70%), pale amphibole (~17%), commonly with pyroxene cores (~5%), orthopyroxene (~3%) and opaques (~5%). This exposure is one of the few outcrops actually seen in the unit.

Lithology

The unit comprises poorly exposed, medium to coarse-grained hornblende gabbro. Apart from the type locality, dark grey to grey, medium-grained gabbro comprising bytownite to labradorite (~70%), hornblende (~30%) and minor opaque oxides was observed along Shaw Road.

Geophysical response

The radiometric response is very low in all channels, resulting in very dark greenish blue to black hues on composite images (Figure 82).

Magnetic susceptibilities range from 2300–4750 x 10^{-5}SI units, consistent with a strong response on total magnetic intensity images, although the contrast with the surrounding volcanic and plutonic units is not great.

Relationships and age

The Parraweena Gabbro appears to intrude the Torsdale Volcanics, Glenhalvern Granite, and Lonesome Creek Quartz Monzodiorite, based mainly on the mapped distribution of the units. It therefore appears to be intruded late in the magmatic evolution in the area, and a Permian age is assigned. It could be early Permian and related to basalts in the Camboon Volcanics or part of the late Permian to Early Triassic suite of gabbros.

PINEDALE GRANITE

Introduction

The Pinedale Granite crops out over ~52km^2, principally on Pinedale and Hainault stations and straddling the boundary between THEODORE and SCORIA (Figure 81). It forms two separate plutons, being intruded and separated by a body of Montour Gabbro, but it may originally have been continuous.

Type locality

The type locality is beside a station track ~1.5km north-west of Pinedale homestead at MGA 255300 7240500. Grey and pink, medium grained biotite granite with pink K-feldspar phenocrysts to ~3cm crops out, and comprises quartz (~30%), K-feldspar (~40%), plagioclase (~25%), biotite (~3%), opaques (~2%) and epidote. Quartz grain boundaries are sutured with some subgrain development suggestive of recrystallisation.

Lithology

Rock types similar to those at the type locality occur throughout the pluton, with the principal variation being the percentage of the distinctive, large pink K-feldspar phenocrysts. The distribution of phenocrysts is irregular and the abundance ranges from sparse to common. Even within a single outcrop, the distribution is uneven.

In the north-west of the pluton, similar biotite granite to the type locality comprises strained quartz (~25%), K-feldspar (~40%), plagioclase (~30%) and biotite (~5%), with traces of epidote and muscovite. Closer to Pinedale homestead, granite comprises strained and partly recrystallised quartz (~30%), K-feldspar (~35%, larger grains are perthitic), plagioclase (~30%), biotite (~3%), opaque oxides and accessory epidote. This sample, along with all other samples described from the Pinedale Granite, shows evidence of recrystallisation and subgrain development suggesting that this pluton has undergone deformation and metamorphism. To the west of Pinedale homestead, the granite shows more intense recrystallisation textures. In the south-east of the pluton along Marvel Creek, the granite has a moderate to well developed foliation, probably related to faulting along the southern margin of the pluton.

The western part of the pluton on Hainault Station comprises quartz (~25%), K-feldspar (~40%), plagioclase (~30%), and biotite (~5%), with minor epidote and muscovite. This sample is strained but does not appear to be as recrystallised as samples from closer to Pinedale homestead.

Geophysical response

The unit has a distinctive dark red response on composite radiometric images due to a moderate potassium response but low uranium and thorium (Figure 82). The adjacent Keen Creek Granite has a higher response in all channels and has paler pink hues on composite images.

Measured magnetic susceptibilities are mostly less than 800 x10^{-5}SI units and have a skewed distribution with a mode represented by values <200). In spite of this the unit shows a moderate response on total magnetic intensity images (Figure 83).

Relationships and age

The Pinedale Granite appears to be intruded by the Keen Creek Granite, based on the shape of the contact as inferred from radiometric data. However, the relationship to the Jonah Vale Granite to the north and west is not known. It is intruded by bodies of the Montour Gabbro within a poorly-defined west-north-west striking shear zone which has resulted in the moderate to well developed foliation in the south-east cusp of the pluton along Marvel Creek. In the west, the Pinedale Granite terminates against a north-south fault zone, mapped mainly from geophysics, and which may be a southern extension of the Dry Creek Fault Zone in the Prospect Creek area.

A late Carboniferous to early Permian age is tentatively assigned but the foliation suggests that it could be older like the Mount Clairvoyant Granite to the east.

ROCKDALE GRANITE

Introduction

The Rockdale Granite (~17km^2) crops out as a northerly aligned, elongate pluton bordering the Defence Road, ~10–12km north-east of Cracow (Figure 81). The unit forms mainly undulating country with low rounded hills. Exposures are generally poor and the unit is commonly deeply weathered. The granite is capped by duricrust in the east, along the western flank of the Auburn Range. The unit is named after Rockdale pastoral holding, on which most of the unit crops out.

Type locality

The designated type locality is beside the Defence Road at MGA 241610 7210800. The granite is exposed in a bridge abutment at this locality and as scattered boulders for at least 100m to the south.

Lithology

The Rockdale Granite consists of very pale pink to very pale brown, fine to medium-grained, slightly porphyritic hornblende-biotite monzogranite at the type locality (Figure 87f). It contains phenocrysts of K-feldspar (up to ~3cm long), plagioclase (up to ~2cm long), and hornblende (up to ~3cm long). Biotite (~3–4%) is more abundant than hornblende (~1–2%). K-feldspar and plagioclase are present in roughly equal amounts. The groundmass is somewhat uneven grained, the average size of the groundmass grains being ~1.5–2mm. Accessory and secondary minerals recorded are opaques, allanite, zircon, sericite, chlorite, epidote and secondary? titanite (associated with chloritised biotite).

The monzogranite also contains sparse, rounded mafic inclusions up to ~3cm in diameter.

Rocks examined from the unit elsewhere are broadly similar to those in the type locality, with some local variations. Their colour ranges from pale pink to white. Hornblende (~4%) appears to be more abundant than biotite (~2–3%) in several samples (*e.g.* those from MGA 240230 7207400, MGA 239780 7206690 and MGA 239490 7204965). Plagioclase is more abundant than K-feldspar, which tends to form relatively small, interstitial grains, and the rocks may be granodiorite. Minor amounts of primary titanite are also present.

These rocks are more mafic than those in the type locality and are probably granodiorite rather than monzogranite.

Relatively felsic monzogranite is well exposed at MGA 243825 7209090, where it forms scattered pavements, boulders, and bouldery outcrops (some quite large). Some K-feldspar phenocrysts at this locality have rims of sodic plagioclase (rapakivi texture). A sample collected from MGA 242235 7207345 is characterised by granophyric intergrowths between quartz and K-feldspar; and outcrops examined at MGA 244220 7208875 contain sparse pegmatitic patches up to ~15cm in diameter.

The unit is locally cut by thin aplite dykes up to ~20cm wide.

Geophysical response

The unit is characterised by high potassium, moderate thorium and low uranium radiometric responses that result in pink to red hues on composite images. These hues tend to be slightly darker than those shown by adjacent units but the distinction is not clear cut. Similarly, the moderate responses shown by the unit on total magnetic intensity images are not distinct from those shown by adjoining units.

Average magnetic susceptibilities are mainly in the range 300 x 10^{-5} SI units to 1300 x 10^{-5} SI units, and show a normal distribution with a mode at ~800 x 10^{-5} SI units.

Relationships and age

The Rockdale Granite intrudes the Torsdale Volcanics. It is also interpreted to post-date the J P Granite and Glen View Quartz Monzodiorite, and to pre-date the Mungunal and Nine Mile Granites, Ravenscraig Gabbro, and unnamed units CRg_b and CPg_{gd}. However, exposures of contacts between the Rockdale Granite and the adjacent units were not found during the fieldwork, so most of the relationships postulated above are tentative.

The Rockdale Granite has yielded a K–Ar (hornblende) age of 300±6Ma (Webb & McDougall, 1968; adjusted for IUGS constants) and is therefore late Carboniferous.

ROCKYBAR GRANODIORITE

Introduction

The Rockybar Granodiorite (~1km^2) crops out in south-eastern CRACOW (Figure 81), around Rockybar homestead, from which the unit is named. The unit forms gently undulating country with scattered boulders and pavements and rare whalebacks.

Type locality

The designated type locality is south of the road into Rockybar homestead, at MGA 245455 7182245.

Lithology

Pale grey, fine to medium-grained, slightly porphyritic biotite-hornblende granodiorite crops out at the type locality. Phenocrysts consist mainly of plagioclase up to ~1.5cm long, but slender hornblende laths up to ~1cm long are also present. Hornblende (brownish green) is more abundant than biotite (total mafics content ~8%). The groundmass is characterised by granophyric intergrowths between quartz and K-feldspar. The granodiorite is moderately altered. Plagioclase phenocrysts and groundmass K-feldspar grains are generally turbid, and biotite has been extensively replaced. The main accessory and secondary minerals are opaques, titanite, epidote (mainly in interstices and after plagioclase, and also as a minor replacement of biotite and hornblende), sericite (after plagioclase), and chlorite (mainly after biotite, but also a minor replacement of hornblende).

The granodiorite also contains sparse rounded to elongate mafic inclusions up to ~3cm in diameter, as well as biotite-rich clots up to ~1cm across.

Elsewhere, the granodiorite is pale pink, with hornblende laths up to ~2cm long locally. Outcrops in the bed of the Auburn River near Rockybar homestead are cut by dykes, up to ~50cm wide, of aplite and fine-grained, slightly porphyritic biotite diorite.

Geophysical response

The granodiorite has high potassium and low to moderate thorium and uranium radiometric responses resulting in pink to red hues on a composite radiometric image.

On total magnetic intensity images, the unit is characterised by low to moderate intensities, which appear to be continuous with those shown by the rocks underlying the enclosing Cainozoic deposits. Magnetic susceptibility readings obtained from rocks at the type locality range from 395 to 1215 x 10^{-5} SI units (average of 21 readings = 759 x 10^{-5} SI units). Elsewhere, the average magnetic susceptibilities recorded at four sites (> 20 readings taken at each site) range from 360 to 1200 x 10^{-5} SI units.

Relationships and age

The Rockybar Granodiorite is presumed to intrude the Torsdale Volcanics beneath the cover of overlying Cainozoic deposits. A deep weathering profile has developed on the granodiorite in places.

The age of the granodiorite is poorly constrained, but it post-dates the late Carboniferous Torsdale Volcanics. It could be late Carboniferous to early Permian like other granitoids to the north or late Permian to Early Triassic like the nearby Flat Range Granodiorite.

ROSS GRANITE

Introduction

The Ross Granite (~2km^2) forms scattered outcrops in south-eastern CRACOW, 8km north-west of Rockybar homestead (Figure 81). The unit is very poorly exposed and forms undulating country with scattered pavements and a low rounded hill. It is extensively weathered and supports stands of cypress pine in places. The unit is named after Ross Creek, the upper reaches of which drain parts of the intrusion.

Type locality

The designated type locality is at MGA 236060 7184580, south-east of Fairyland homestead, where the granite forms a low rounded hill with extensive weathered rock pavements.

Rock types

No fresh, unweathered outcrops of the granite were found. The unit consists of very extensively weathered, pink to brown or white (bleached), medium to coarse-grained, uneven-grained to slightly porphyritic biotite granite. The granite at the type locality contains ~3–4% biotite (commonly extensively altered/weathered), and abundant pink K-feldspar grains.

Elsewhere, the granite examined in proximity to a prominent aeromagnetic lineament is sheared and foliated.

Geophysical response

The granite has high potassium and low to moderate thorium and uranium radiometric responses resulting in pink hues on composite images.

It is characterised by non-distinctive relatively low responses on airborne total magnetic intensity images. No magnetic susceptibility measurements were made.

Relationships and age

The Ross Granite intrudes the Torsdale Volcanics and is overlain by unconsolidated Cainozoic deposits. A deep weathering profile, locally with a prominent pallid zone, is extensively developed on the granite.

The age range for emplacement of the granite is poorly constrained, but it is tentatively interpreted to have been emplaced in the late Carboniferous – early Permian.

SHAWLANDS GRANITE COMPLEX

Introduction

The Shawlands Granite Complex is a small pluton that crops out over ~20km^2 in the eastern part of the Auburn Arch in THEODORE. It occurs along Shawlands Road between the Biloela–Camboon road and Parraweena Station. Shawlands homestead is at MGA 240900 7260700. Outcrop is poor and mostly very weathered.

Type locality

The type locality is at MGA 239200 7261400 along a station track ~2km north-west of Shawlands homestead. Good outcrop of light grey to pinkish grey, medium-grained quartz monzonite to granite comprises quartz (~20%), K-feldspar (30-35%), andesine (35–40%), chloritised biotite (~5%), pale green hornblende (~5%), titanite and opaques. This rock type appears to be dominant throughout the unit.

A reference locality is defined in a tributary of Oaky Creek beside Shawlands road at MGA 241500 7260300, where complex net-veining between two magma types attests to the complexity of the magmatic system. Grey, medium grained biotite-hornblende tonalite (?) is mingled with grey, fine grained porphyritic hornblende quartz diorite (?). Both of the above rock types are intruded by microdiorite dykes.

Lithology

The Shawlands Granite Complex comprises a range of granitoid types including light grey to pinkish-grey medium-grained granite to monzonite and grey to white, medium-grained hornblende-biotite granodiorite to diorite or possibly monzonite. A zone of magma mingling on eastern Shawlands Station appears to be part of the unit based on interpretation of the composite radiometric images. In this zone, white to green, medium-grained granodiorite-diorite-monzonite contains irregular enclaves of light grey, fine-grained diorite and is intruded by microdiorite or dacitic dykes.

Locally intense potassic alteration may explain some of the variation within the unit. Potassically altered syenite and micro-syenite occur along the road west of Shawlands homestead.

Very poor, weathered and altered outcrop through the remainder of the unit precludes useful descriptions.

Geophysical response

On radiometric images, the complex shows a relatively low response in all channels producing dark brownish green hues on composite images similar to that of the mafic marginal phase of the Glandore Granodiorite farther south.

Magnetic susceptibilities are variable in the few outcrops examined. At the type locality, susceptibilities measured ranged from 750–1250 x 10^{-5}SI units. At the reference locality, they ranged from 1900–2900 x 10^{-5} SI units. These values are consistent with the strong response on total magnetic intensity images.

Relationships and age

The relationships with surrounding units are masked by poor outcrop. The shape of contacts mapped from the radiometric data suggests that the Shawlands Granite Complex intrudes the Tindarra Granite to the south. An alternative is that the Tindarra Granite intrudes the Shawlands Granite Complex separating it from the mafic phase of the Glandore Granodiorite with which it may originally been continuous.

The relationship with the Glenhalvern Granite to the north is unclear. Camboon Volcanics occur to the east. At least part of this contact is faulted along the Dry Creek Fault, and the rest may be unconformable.

The age of the Complex is uncertain, but was tentatively assigned to the late Carboniferous to early Permian on the THEODORE map. If it is related to the Glandore Granodiorite, it could be mid-Carboniferous.

SUJEEWONG GABBRO

Introduction

The Sujeewong Gabbro crops out over ~3km^2 around Sujeewong homestead, but the geophysical data suggests that it may be part of a larger pluton of ~10km^2 under cover to the north-west. Whitaker & others (1974) included the rocks within their Kilbeggan Adamellite.

Type locality

A type locality is designated on the eastern side of the Auburn–Sujeewong road at MGA 259650 7152550. It consists of dark grey to black, medium to coarse-grained clinopyroxene-biotite-hornblende diorite or gabbro. In thin section the rock contains plagioclase (~70%, as laths and subequant crystals to 2.5mm of weakly oscillatory zoned andesine with some labradorite cores), greenish brown hornblende (~20%, 1–4mm, commonly ophitic), clinopyroxene (<5%, mostly <1mm, as discrete grains and also rare cores in hornblende), partly chloritised reddish brown biotite (~5%, to 2mm), opaques (1–2%), interstitial quartz (1–2%) and accessory apatite. The dating locality (see below) is ~50m to the east.

Lithology

The few outcrops of the unit that were examined are similar to that at the type locality, although biotite is not present in some samples, and others contain cores of orthopyroxene as well as clinopyroxene in the hornblende crystals. Hornblende crystals are locally up to 1cm across and ophitically enclose plagioclase laths. In places the clinopyroxene is replaced by acicular amphibole. The rocks appear to be marginal between diorite and gabbro, the plagioclase being close to the boundary between andesine and labradorite. Interstitial quartz (up to 5%) is locally present. The unit might better be renamed Sujeewong Diorite, although the name given on the map is retained for this report.

Geophysical response

The Sujeewong Gabbro has the typical low response in all channels of a gabbroic rock and is represented on composite radiometric images by dark green hues.

The eastern part of the unit as mapped corresponds to a very strong peak in the airborne magnetic data that is part of a generally strong anomaly that suggests that gabbro underlies the Tertiary deposits mapped to the west of the unit. Magnetic susceptibility readings from three outcrops were in the range 1600–4600 x 10^{-5} SI units.

Relationships and age

The Sujeewong Gabbro probably intrudes the Ah Fat Granodiorite Complex and Glisson Granodiorite. Although petrographically similar to the late Permian Delubra Quartz Gabbro, K–Ar dating of hornblende gave a (recalculated) late Carboniferous age of 310±9Ma (Green, 1975; Green & Webb, 1974; Whitaker & others, 1974; age adjusted for IUGS constants).

TEN MILE GRANITE

Introduction

The Ten Mile Granite crops out in two discrete areas totalling ~6km^2, 18–22km north-east of Cracow (Figure 81). The unit mainly forms low ridges and hills with relatively abundant bouldery rubble. These landforms contrast with the comparatively flat undulating country developed on the adjacent Glen View Quartz Monzodiorite, which shows extensive development of dark red-brown soils and has been preferentially selected by pastoralists for pasture improvement.

The unit was not examined during the recent survey. The brief description below was summarised from observations made by a member of the GSQ mapping party of the early 1970s. The unit was delineated using these and interpretation of airborne geophysical images and colour aerial photographs.

The unit is named after Ten Mile Creek, tributaries of which drain part of the unit.

Type locality

The type locality is designated at MGA 2369056 7219055.

Lithology

The unit consists of pale grey, leucocratic hornblende-biotite monzogranite at the type locality.

Geophysical response

The Ten Mile Granite is characterised by high potassium and thorium and low to moderate uranium radiometric responses, which result in pale yellow to whitish hues on composite images. These contrast markedly with the brownish pink to dark brown hues shown by the adjacent Glen View Quartz Monzodiorite.

The unit shows low to moderate magnetic intensities on total magnetic intensity images, in contrast to notably higher intensities for the Glen View Quartz Monzodiorite.

Relationships and age

The Ten Mile Granite is tentatively interpreted to post-date the Glen View Quartz Monzodiorite and Wind Mill Diorite, based mainly on the ovoid shapes of the two intrusions of Ten Mile Granite.

The unit has not been isotopically dated and its age is uncertain. It has been tentatively assigned to the late Carboniferous – early Permian.

TINDARRA GRANITE

Introduction

The Tindarra Granite crops out over ~46km^2 between Castle Creek and Shawlands Road in eastern THEODORE (Figure 81). The name is derived from Tindarra Station on which much of the granite crops out. In the southern part of the pluton, outcrop is sparse and commonly deeply weathered despite the hilly terrain that is characteristic of the unit. Many of the hills are capped by duricrust.

Type locality

The type locality is in a tributary of Oaky Creek near the boundary between Shawlands and Twenty Mile stations at MGA 242100 7259100, where pale red, medium to coarse grained, biotite syenogranite is intruded by rhyolite and microdiorite dykes.

Lithology

The unit comprises pink to red, medium-grained biotite granite. However, although there is better outcrop around the northern part of the pluton, much of it is potassically altered and fractured, making identification of original rock types difficult.

Geophysical response

In the radiometric data, the granite has a moderate to high potassium response, moderate thorium and moderate to high uranium producing pale pink hues on composite images that contrast with adjoining units (Figure 82). The altered northern part of the unit does not have any significantly different radiometric response. On the composite radiometric image, the Tindarra Granite and the adjacent Torsdale Volcanics have similar responses.

Magnetic susceptibility was measured at only one outcrop which had values in the range 250–450 x 10^{-5} SI units. Nevertheless the granite has a moderate response on total magnetic intensity images (Figure 83) suggesting that these values are not representative of the unit.

Relationships and age

The Tindarra Granite appears to intrude the Torsdale Volcanics to the west, although no hornfelsing was noted. The shape of the contacts mapped from the radiometric data suggests that the Tindarra Granite is intruded by the Glandore Granodiorite. However, an alternative is that the Shawlands Granodiorite Complex and a marginal mafic phase of the Glandore Granodiorite may originally been continuous and the Tindarra Granite intruded and separated them.

The age is uncertain. A late Carboniferous to early Permian age was assigned on the published map because of its relationship with the Torsdale Volcanics. If it is intruded by the Glandore Granodiorite, it would be mid-Carboniferous

WIND MILL DIORITE

Introduction

The Wind Mill Diorite forms an irregular, north-trending stock (~49km^2) in north-eastern CRACOW and south-eastern THEODORE (Figure 81). It is very poorly exposed, and forms mainly gently undulating country characterised by extensive development of dark red-brown soils. The unit is named after Wind Mill pastoral holding, which extends over part of the formation in the south.

Type locality

The type locality is on the crest of a low rounded hill at MGA 244200 7221830, in the north-eastern part of CRACOW. The unit is relatively well exposed in this area and forms scattered boulders and pavements.

Lithology

Rock types range from dark grey gabbro to pale grey quartz diorite. The rocks are mainly medium-grained and show a range of textures from even grained to moderately porphyritic. Hornblende and clinopyroxene are the main mafic minerals in most samples. Minor amounts of magnetite are also generally present. Clinopyroxene generally forms relict cores in hornblende grains, or anhedral grains commonly rimmed by hornblende. Accessory and secondary minerals (not necessarily all present in every sample) include apatite (locally as relatively coarse, euhedral grains), biotite, titanite, quartz, opaques, chlorite, sericite, epidote, and prehnite. Biotite and quartz are relatively common in the dioritic rocks, some of which also contain traces of K-feldspar.

The unit locally forms net-veined complexes with granite (*e.g.* at MGA 244140 7221355). Elsewhere (*e.g*. at MGA 244100 7221830), diorite forms net-veined complexes with quartz diorite. A well-developed igneous foliation is present in places.

The unit is cut by narrow (up to ~3cm wide), dyke-like alteration zones, containing epidote, secondary iron oxide (pink) and, locally, traces of pyrite.

Geophysical response

The unit is characterised by low counts in the potassium, thorium and uranium channels, reflected by dark brown hues on composite radiometric images (Figure 82).

It has a moderate to high magnetic response (Figure 83), but it is indistinguishable from that of the surrounding rocks. Magnetic susceptibilities measured at the type locality are in the range 1790–3925 x 10^{-5} SI units (average = 2850 x 10^{-5} SI units). The highest susceptibility measurements (average = 3535 x 10^{-5} SI units) were obtained from hornblende gabbro exposed as scattered boulders on the southern side of Moocoorooba Road (at MGA 242145 7223140). Drainage channels in this area are characterised by the presence of abundant detrital magnetite. Hornblende gabbro, which crops out at the base of a knoll on the eastern side of the Defence Road, at MGA 244115 7221220, has much lower magnetic susceptibilities (average = 203 x 10^{-5} SI units), in marked contrast to the other sites examined.

Relationships and age

The Wind Mill Diorite intrudes the Torsdale Volcanics near Camboon homestead. The unit is cut by unit $\mathbf{CPg_g}$ which contains inclusions of gabbro/diorite up to ~1m across adjacent to the contact. Granodiorite of unit $\mathbf{CPg_{gd}}$, exposed at MGA 243525 7222585, contains numerous mafic (dioritic) inclusions up to ~15cm across, which may have been derived from the Wind Mill Diorite. Relationships with the other juxtaposed units are uncertain; contacts between these units and the Wind Mill Diorite have not been observed.

The age of the unit is uncertain. It has been tentatively assigned a late Carboniferous – early Permian age.

WOOLTON GRANITE COMPLEX

Introduction

The Woolton Granite Complex forms a roughly ovoid body that crops out over 17km^2 on the northern side of Castle Creek, ~30km north-east of Theodore (Figure 81). The name is derived from the Parish of Woolton.

Type and reference localities

Although at least three rock associations occur in the Woolton Granite Complex, the dominant rock type appears to be granite, based on the composite radiometric images. Therefore, the type locality is designated at MGA 231700 7256700 along the road to Castle Creek homestead from Belmont homestead. Light grey to pinkish grey, medium grained, biotite-hornblende quartz monzonite to monzogranite with common mafic xenoliths crops out. It consists of quartz (~15%), anhedral K-feldspar (some with graphic intergrowths with quartz, ~30%), oligoclase (~44%), pale green amphibole (~5%), biotite (~3%) and opaques (~3%).

Reference localities are also given for the other associations. One is at MGA 232600 7254100 on a low ridge ~3km south-south-east of the type locality. Good outcrop of greenish-grey, medium grained hornblende-biotite quartz diorite to granodiorite is mingled with greenish grey, fine grained, altered biotite granodiorite. The quartz diorite comprises oligoclase to andesine (~70%), pale amphibole (~8%), with pyroxene cores (~5%), biotite (~5%), quartz (~5%), and opaques (~5%). This rock is petrologically similar to rocks in the Lyndale Diorite ~5km farther south.

The second reference locality is at MGA 230450 7255850 beside a station track ~2km south-west of the type locality. Outcrop comprises mainly pink, fine to medium grained, biotite leucogranite. This phase has been mapped as a separate subunit (**$CPgwo_a$**) within the complex.

Lithology

The Woolton Granite Complex includes greenish-grey, medium-grained hornblende-biotite granodiorite to diorite, pinkish-grey medium-grained hornblende-biotite granite and pinkish-orange fractionated leucogranite as described for the type and reference localities.

Geophysical response

The radiometric data have allowed the leucogranite to be mapped out in spite of the poor outcrop. The main part of the pluton has moderate to high potassium, moderate thorium and low uranium having mottled pink and yellowish green hues on composite images (Figure 82). The fractionated leucogranite that crops out mainly in the west has moderate to high potassium, high thorium and low to moderate uranium, resulting in pale greenish yellow hues. Similar hues suggest that this phase could extend south of Castle Creek as far as the contact with the Glenleigh Granite, but the area was not examined and is currently mapped as Torsdale Volcanics.

The eastern half of the complex has a high magnetic response (Figure 83), and the eastern contact with the Torsdale Volcanics is reasonably well-delineated. The western half where the leucogranite has been mapped has only a moderate response and cannot be distinguished from the volcanic rocks. Magnetic susceptibility of the granite at the type locality ranges from 1280–2010 x 10^{-5} SI units (average 1598). Susceptibilities of granodiorite at the first reference locality range from 2700–4100 x 10^{-5} SI units (average 3218). These are consistent with the airborne magnetic response. However, the pink fractionated leucogranite at the second reference locality is non-magnetic (0 x 10^{-5} SI units), suggesting that more magnetic rocks also crop out within the area mapped as leucogranite.

Relationships and age

The Woolton Granite Complex appears to intrude the Torsdale Volcanics although there is only minor hornfelsing. The relationships of the three phases to each other have not been determined because of the poor outcrop. A late Carboniferous to early Permian age is tentatively assigned.

UNNAMED INTRUSIONS

Several small plutons of unnamed Carboniferous to Permian granitoid occur in THEODORE, SCORIA, CRACOW and RAWBELLE. These plutons are poorly known due to poor outcrop, resulting in few observations. They are assigned to an unnamed unit (**CPg_g**). These unnamed granitoids mostly appear to be pink and grey, medium-grained, hornblende-biotite and biotite granite and granodiorite. In southern SCORIA, such granite bodies are commonly deformed (locally strongly). In this area, the granite bodies occur with unnamed metamorphics which are interpreted, at least in part, as older metamorphic basement.

In the southern part of SCORIA, a large area of poor outcrop is included in this category. The response on composite radiometric images is consistent with the area being granitic. This area includes altered medium-grained biotite granodiorite along the road to Pinedale Station. At one outcrop east of Pinedale homestead a mixture of three granitoids, ranging from porphyritic diorite to pink biotite granite, was observed. A biotite-hornblende tonalite from this locality comprises quartz (~25%), K-feldspar (~5%), plagioclase (~50%), hornblende (~10%), biotite (~5%), titanite, opaques and minor epidote. The whole area may comprise various proportions of these three granitoid types. South of Pinedale homestead at MGA 257200 7237200, a foliated medium-grained biotite-rich granodiorite yielded a K–Ar age of 256Ma (Webb & McDougall, 1968).

Several small plutons in eastern CRACOW have been mapped as **CPg_{gd}**. They consist of grey, brown or pink, medium to coarse-grained, equigranular to slightly porphyritic hornblende-biotite and biotite-hornblende granodiorite to quartz monzodiorite; some hornblende-biotite and biotite monzogranite and minor diorite is also present. Several irregular plutons north of Mount Mungungal have been assigned to **CPg_{lg}**. They consist of grey, medium-grained granite. At Mount Table, the granite is brecciated. This breccia and several other small bodies or pipes in northern Cracow are mapped as **CPbx**. The breccia is pale grey or pale brown to dark reddish brown, mainly in rhyolite or granite, and is generally extensively altered. Pyrite and vuggy quartz veins are locally common.

Numerous diorite/gabbro bodies occur, particularly in THEODORE and CRACOW. While some of these have been named, many of the smaller bodies have not and are mapped as “unnamed diorite” (units **Cg_d** and **CPg_d**). Most of these bodies comprise medium to fine-grained, dark grey to black, hornblende and biotite-hornblende diorite and granodiorite. On southern Pinedale Station, hornblende gabbro comprises 2–3cm thick, hornblende-rich layers in a more plagioclase-rich rock. The gabbro comprises labradorite (~65%), hornblende (commonly cored by pyroxene; ~20%), augite (7–8%) and opaques (7–8%).

Unnamed diorite occurs along the Glandore/Rawbelle road on Valencia Station. This rock comprises andesine to labradorite (~60%), quartz (~10%), pyroxene (~10%), and biotite/chlorite/epidote (~ 20%) with minor opaques.

GEOCHEMISTRY OF THE CARBONIFEROUS TO EARLY PERMIAN GRANITOIDS OF THE AUBURN ARCH

Data for early Carboniferous to early Permian plutonic rocks of the Auburn Arch are plotted in Figures 88 to 91. Only the early Carboniferous Donore Granite Gneiss and the Horse Granite Gneiss, Carinya Granite and Mount Clairvoyant Granite (which may be of a similar age) have been plotted with separate symbols. The remaining 94 samples have not been differentiated, because they are from about 30 different units, with in most cases only 1–3 samples per unit. In the Harker variation diagrams in Figures 88 and 89, TiO_2, FeO_{total} and CaO show relatively narrow linear trends for the Auburn rocks. The rocks mostly plot in the high-K field of Peccerillo & Taylor (1976).

Only the Donore Granite Gneiss can be distinguished as a separate suite. It shows generally higher FeO_{total} and TiO_2 and Zn and generally lower CaO and Na_2O than the rest of the Auburn rocks and is distinctly peraluminous with three samples having an Alumina Saturation Index (ASI) >1.1 suggesting that they are S-type granites (Chappell & White, 1974). The samples plot in a similar field to the early Permian Coonambula Suite, and may have been derived by a similar process. The Horse Granite Gneiss, although strongly foliated and tentatively regarded as early Carboniferous cannot be easily distinguished from the other Auburn rocks, except that it has similar low Na_2O to the Donore Granite Gneiss. The two samples are peraluminous, but not to the extent of the Donore Granite Gneiss. The other two units that are possibly of this age, the Carinya and Mount Clairvoyant Granites, cannot generally be distinguished as easily from the other Auburn rocks, although the two samples of Mount Clairvoyant Granite have higher CaO and lower K_2O, Rb and Th. However, it is clearly unlike the Donore Granite Gneiss.

The remainder of the Auburn rocks are metaluminous to mildly peraluminous and are I-types, consistent with the fact that most are hornblende-bearing. The plots of selected trace elements and major element ratios against the Ga/Al ratio (Figure 90) indicate that none are A-types, although some of the more felsic samples do extend outside the field of orogenic granites. All rocks plot in the field of “volcanic arc granites” on the Rb vs Y+Nb plot (Figure 114, using the criteria of Pearce & others, 1984).

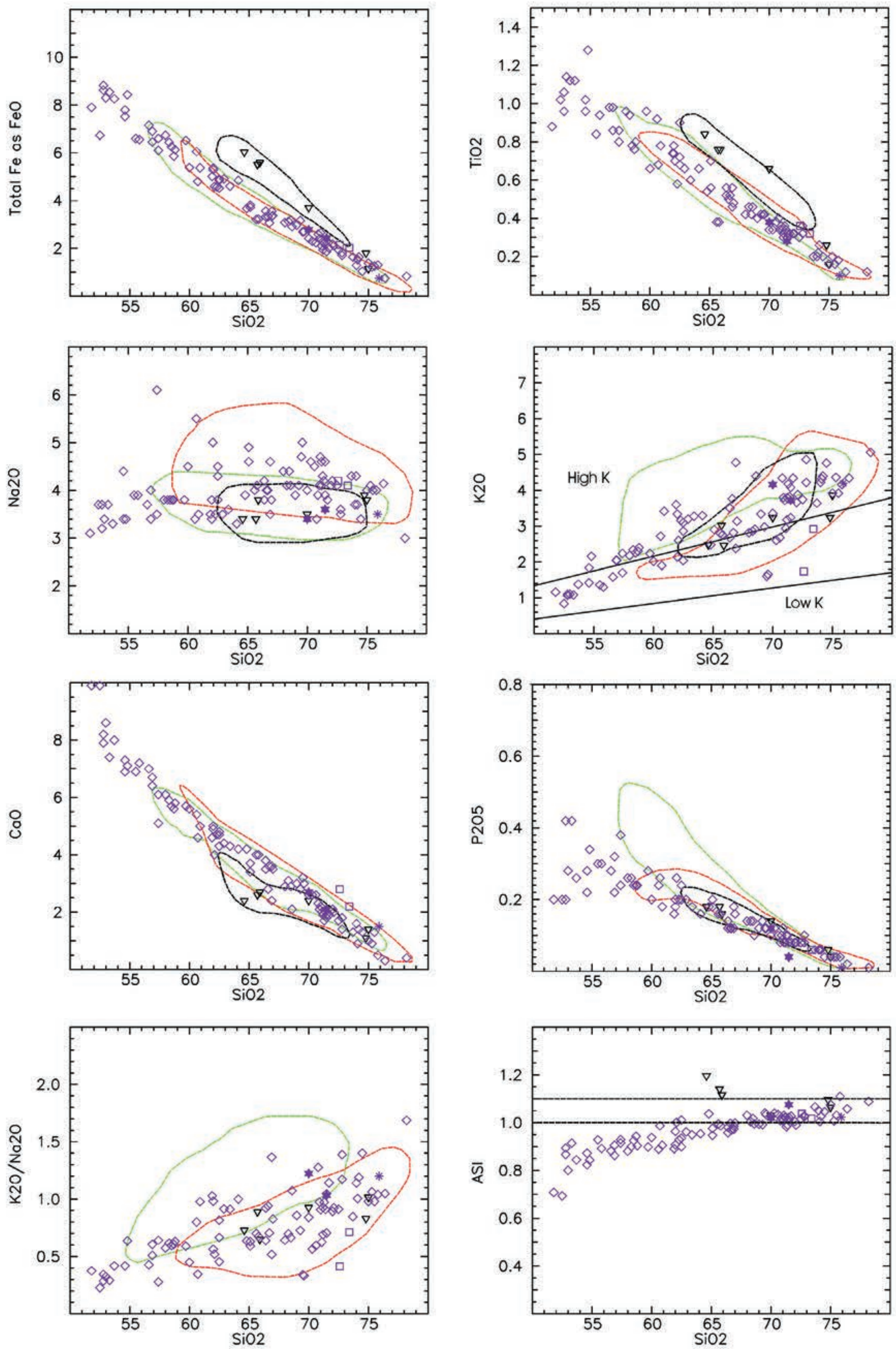

Figure 88. Variation diagrams for Carboniferous to early Permian plutonic rocks from the Auburn Arch showing selected major elements in weight percent and the Alumina Saturation Index (ASI) vs SiO_2 in weight percent. Symbols are Donore Granite Gneiss (triangles), Horse Granite Gneiss (stars), Carinya Granite (asterisk), Mount Clairvoyant Granite (squares) and other plutons of the Auburn Arch (diamonds). Coloured fields are for the Coonambula (black), Tandora (red) and Winfield (green) Suites from the Rawbelle Batholith.

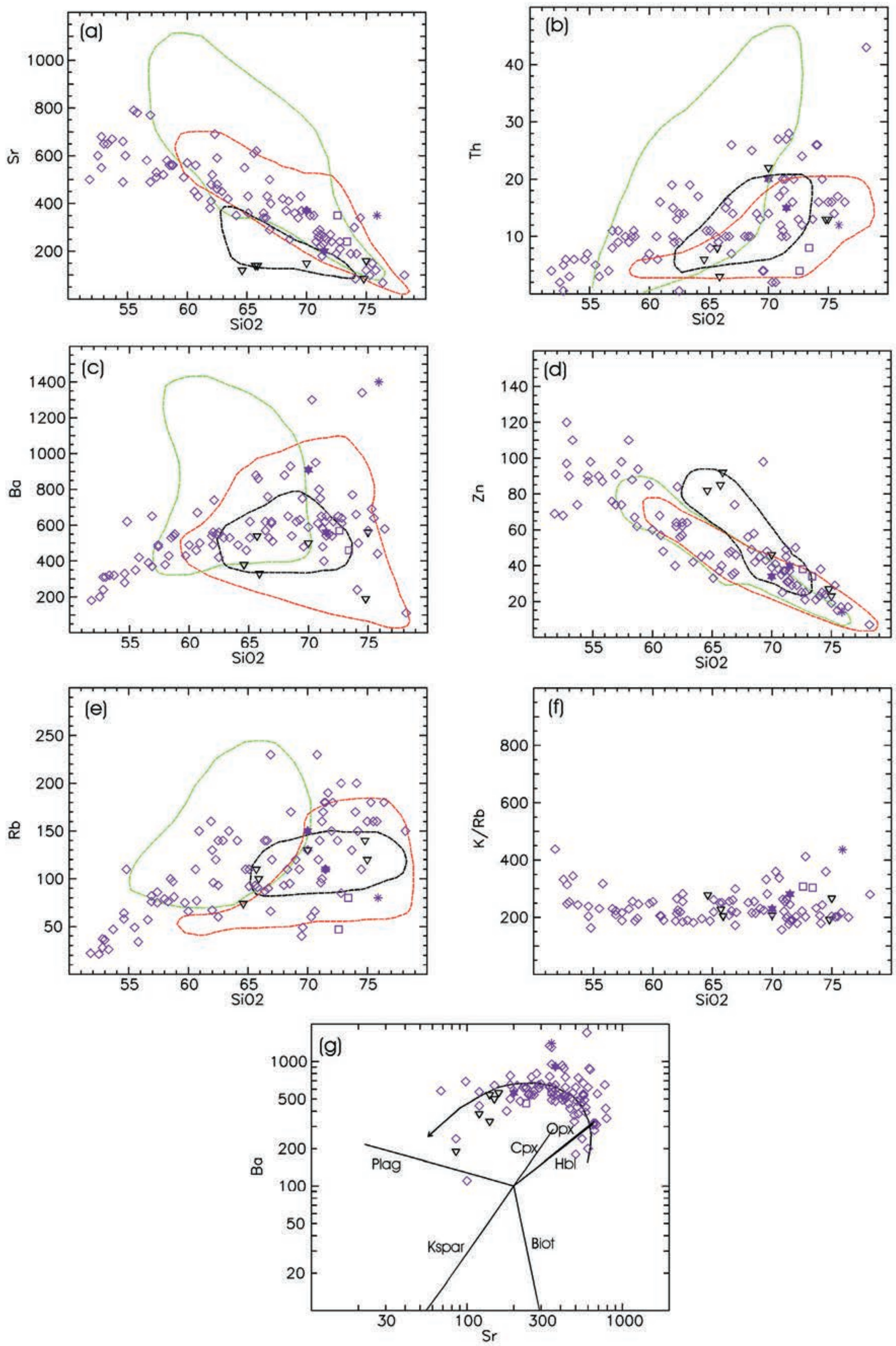

Figure 89. Variation diagrams for Carboniferous to early Permian plutonic rocks from the Auburn Arch showing selected trace elements in parts per million and K/Rb vs SiO_2 in weight percent. Mineral vectors in (g) are from Rollinson (1993, page161) and show fractional crystallisation trends for Ba and Sr for the various minerals shown. The arrowed line shows an approximate overall fractionation trend for the samples plotted. Symbols are as shown in Figure 88. Coloured fields are for the Coonambula (black), Tandora (red) and Winfield (green) Suites from the Rawbelle Batholith.

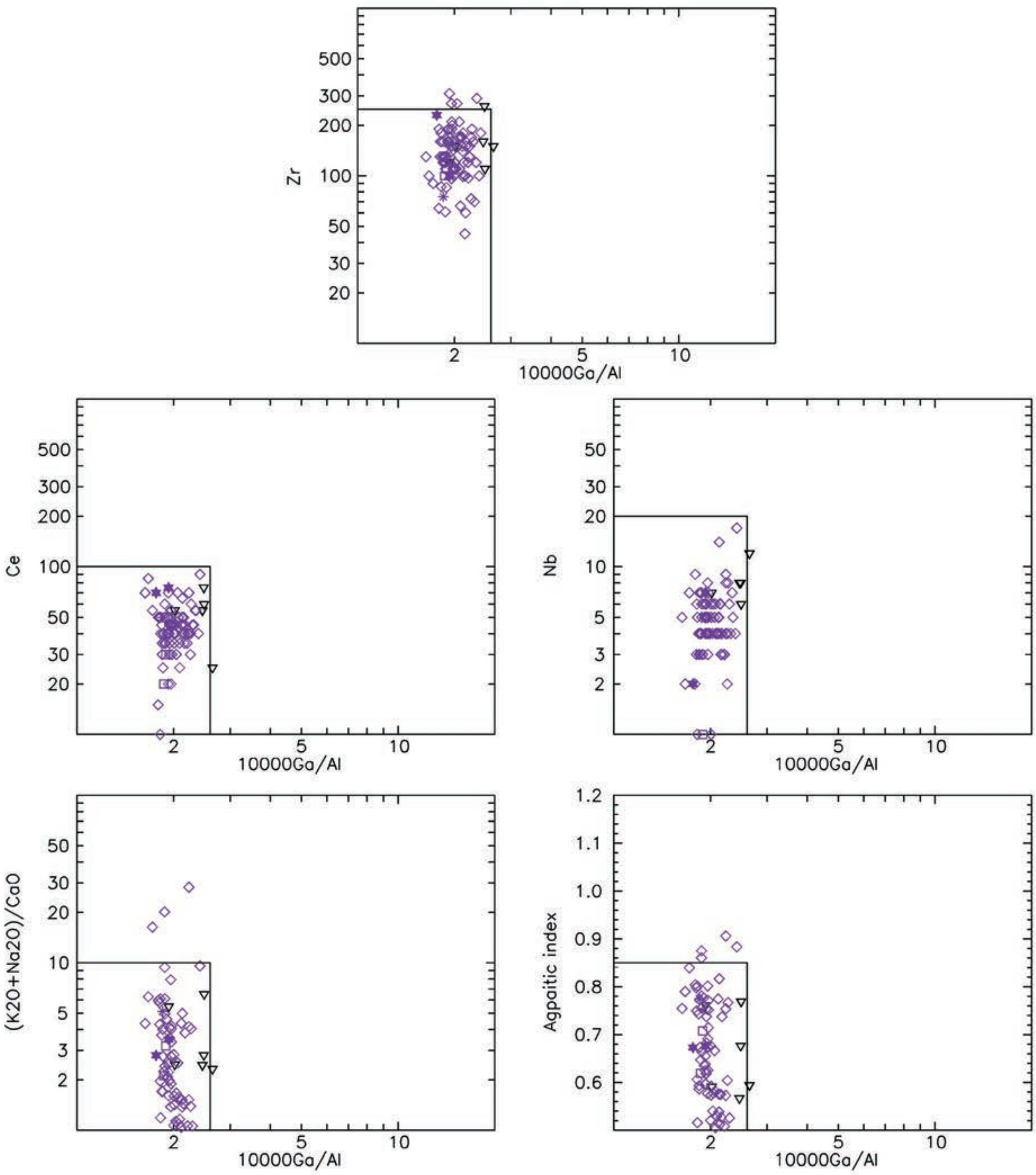

Figure 90. Plots of selected trace elements in parts per million and major element ratios vs 1000Ga/Al for Carboniferous to early Permian plutonic rocks from the Auburn Arch. Agpaitic Index is molar (Na_2O+K_2O)/Al_2O_3). Fields for orogenic granites in the bottom left corners are from Whalen & others (1987). Symbols are as shown in Figure 88.

Another significant difference between the Donore Granite Gneiss and the main group of Auburn rocks is illustrated by the plots of average analyses in the multi-element plots (spider diagrams) in Figure 91. The Auburn rocks are undepleted in Sr and mildly depleted in Y, whereas both the Donore Granite Gneiss and Horse Granite Gneiss are depleted in Sr. The Horse Granite Gneiss shows distinct Y enrichment. Although plots are not shown, the Mount Clairvoyant and Carinya Granites are undepleted suggesting that they are more like the rest of the Auburn rocks and may not be early Carboniferous.

Tarney & others (1987) and Wyborn & others (1988, 1992) suggested that granitoids with <70% SiO_2, that are depleted in Sr and undepleted in Y, probably had a plagioclase-bearing source (gabbroic). Those undepleted in Sr and depleted in Y had a deeper garnet-bearing source (eclogitic). The boundary between these two rock types, the eclogite transition zone, is at 35–40km depth. This suggests that the Donore Granite Gneiss and Horse Granite Gneiss were derived from a shallower crustal level, consistent with them possibly being

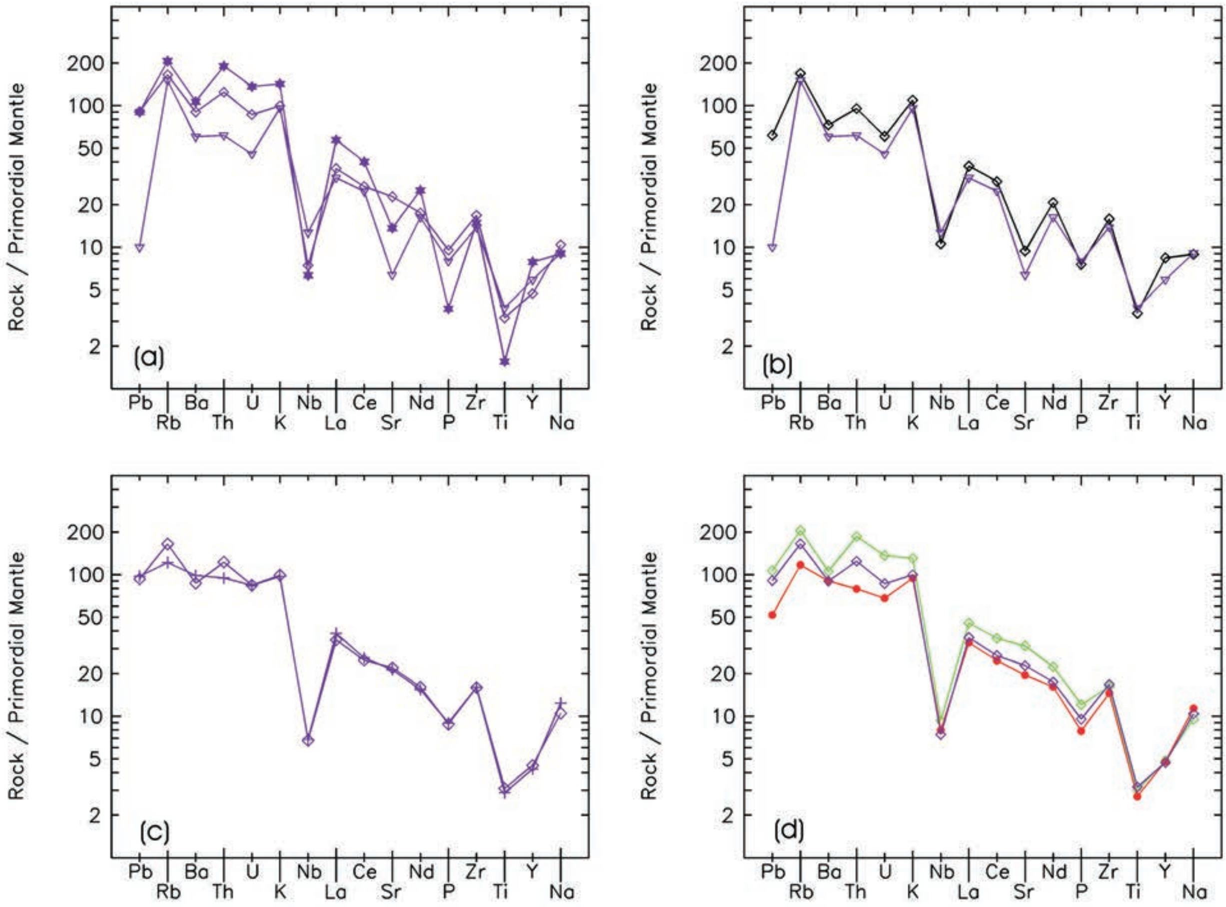

Figure 91. Spider diagrams normalised against the primordial mantle values of McDonough (1987) for average analyses of samples in the range 55–70% SiO_2 for granitoid groups from the Auburn–Rawbelle area:
(a) Auburn Arch granitoids (diamond), Horse Granite Gneiss (star) and Donore Granite Gneiss (triangle);
(b) Comparison of Donore Orthogneiss (purple triangle) and Coonambula Suite (black diamond);
(c) Auburn Arch granitoids (diamond) and Torsdale Volcanics (cross);
(d) Comparison of Tandora Suite (red), Wingfield Suite (green) and Auburn Arch granitoids (purple).

derived from rocks with a metasedimentary component. Alternatively, they may have had a similar source, but have assimilated large amounts of supracrustal material.

The multi-element plot in Figure 91c shows a very good match between the average analyses of the Auburn granitoids and the Torsdale Volcanics, consistent with the volcanic rocks being comagmatic with and derived from the granitoids. SHRIMP dating shows that the rocks overlap in age (see Appendix).

Compared with the younger Permian to Triassic rocks of the adjacent Rawbelle Batholith, the Auburn rocks show most similarities to the Tandora Suite, although in many of the plots, the samples fall in the area of overlap between the Tandora and Wingfield Suites. P_2O_5 and Sr in the Auburn samples do not show the elevated values that characterise the Wingfield Suite between 55–65% SiO_2 although Th shows a broader range than the Tandora Suite and overlaps with the Wingfield Suite.

According to Wyborn & others (1992) restite-dominated plutons can be distinguished from melt-dominated ones by near-constant K/Rb ratios over the range of SiO_2. Therefore the relatively constant values of 200–300 for K/Rb for most of the Auburn rocks suggest that they are restite-dominated (Figure 89), although a few samples show an increase towards the high-SiO_2 end. Fractionation trends shown by the plot of Ba vs Sr (Figure 89) suggest the variations in the suite come from hornblende/pyroxene and plagioclase fractionation with little K-feldspar fractionation.

EARLY PERMIAN PLUTONS

COONAMBULA GRANODIORITE

Introduction

The Coonambula Granodiorite was named and defined by Whitaker & others (1974) in the north-eastern part of AUBURN extending into RAWBELLE (Figure 81). The unit forms a roughly equant-shaped pluton ~200km^2 in area, centred ~25km south-west of Eidsvold. It is probably not as extensive as mapped by Whitaker & others in the south-east, where hornfelsed Nogo beds have been recognised instead. In addition, a small, another unit, the Widbury Granite, has been recognised and mapped separately from the Coonambula Granodiorite.

Type locality

The type locality is an area of abundant boulders and whaleback outcrops around Target Creek at MGA 284600 7177350 ~9km west of Coonambula homestead. The rock type is medium grey, strongly contorted, foliated, equigranular, fine to medium-grained saccharoidal biotite granodiorite. The typical mineral assemblage consists of plagioclase (~50%), quartz (25%), biotite (~20%), minor K-feldspar (2–5%), chlorite and hornblende (~5%) with accessory apatite and zircon. Dark grey to black biotite-rich xenoliths, probably of microdiorite composition, are common.

Lithology

The Coonambula Granodiorite as now defined incorporates a range of different rock types. These include equigranular, fine-grained biotite granodiorite or granite, irregularly foliated fine to medium-grained biotite gneiss, and grey hornblende-biotite granodiorite. Pegmatite and aplite dykes are common.

The dominant rock type within the Coonambula Granodiorite is medium grey, equigranular, fine to medium-grained, saccharoidal biotite granodiorite, which crops out well in the hills around St John Creek, between Mount Target and Widbury homestead (Figure 92a). As reported by Whitaker & others (1974), it typically consists of plagioclase (andesine), quartz, biotite, minor K-feldspar, chlorite and actinolite and accessory apatite. Mafic xenoliths from 3–8cm are common. Very commonly the granodiorite shows a moderate to strong foliation (Figure 92b) and passes into strongly contorted biotite granodioritic gneiss.

Rocks around the Banshee antimony mine appear to be richer in mafic minerals, particularly biotite, and commonly show weak to moderate foliation. Hornblende aggregates are also common. The rock is somewhat darker than the other rock types with slightly pink (hematite altered?) feldspar.

Moderately to strongly foliated biotite gneiss crops out extensively around the upper reaches of Target Creek and along the road south from Coonambula homestead,. The gneiss contains fine leucocratic and melanocratic bands, which are irregularly folded and highly contorted (Figure 92c and d). The foliation in the gneiss appears to lack a lineation, does not have a consistent orientation, and potentially wraps around to define a regional concentric pattern. In places the gneiss strongly resembles migmatite.

Geophysical response

The radiometric response for this unit is moderate in uranium and potassium and moderate to high for thorium, resulting in pale pinkish grey to pale greenish on the composite images (Figure 99).

The magnetic susceptibilities measured in the field are generally very low (0–200 x 10^{-5} SI units) for the dominant saccharoidal granodiorite. However, moderately strong values (400–1400 x 10^{-5} SI units) were recorded for the more mafic biotite granodiorite and values of 100–600 x 10^{-5} SI units for gneissic rocks. Although not dominant rock types, nevertheless these rocks may account for the response of this unit on magnetic images. The unit has a generally low background response with north-north-west-trending linear features that elevate the overall response (Figure 100). These linear features are absent from the Morrow Granite and Boolgal Granophyre.

Relationships and age

During map compilation, the Coonambula Granodiorite was tentatively regarded as Carboniferous because of its locally strong foliation. However, it was mapped in contact with the Permian Nogo beds which are strongly hornfelsed. Therefore, a potentially younger unit adjacent to the Nogo beds, the Widbury Granite, was

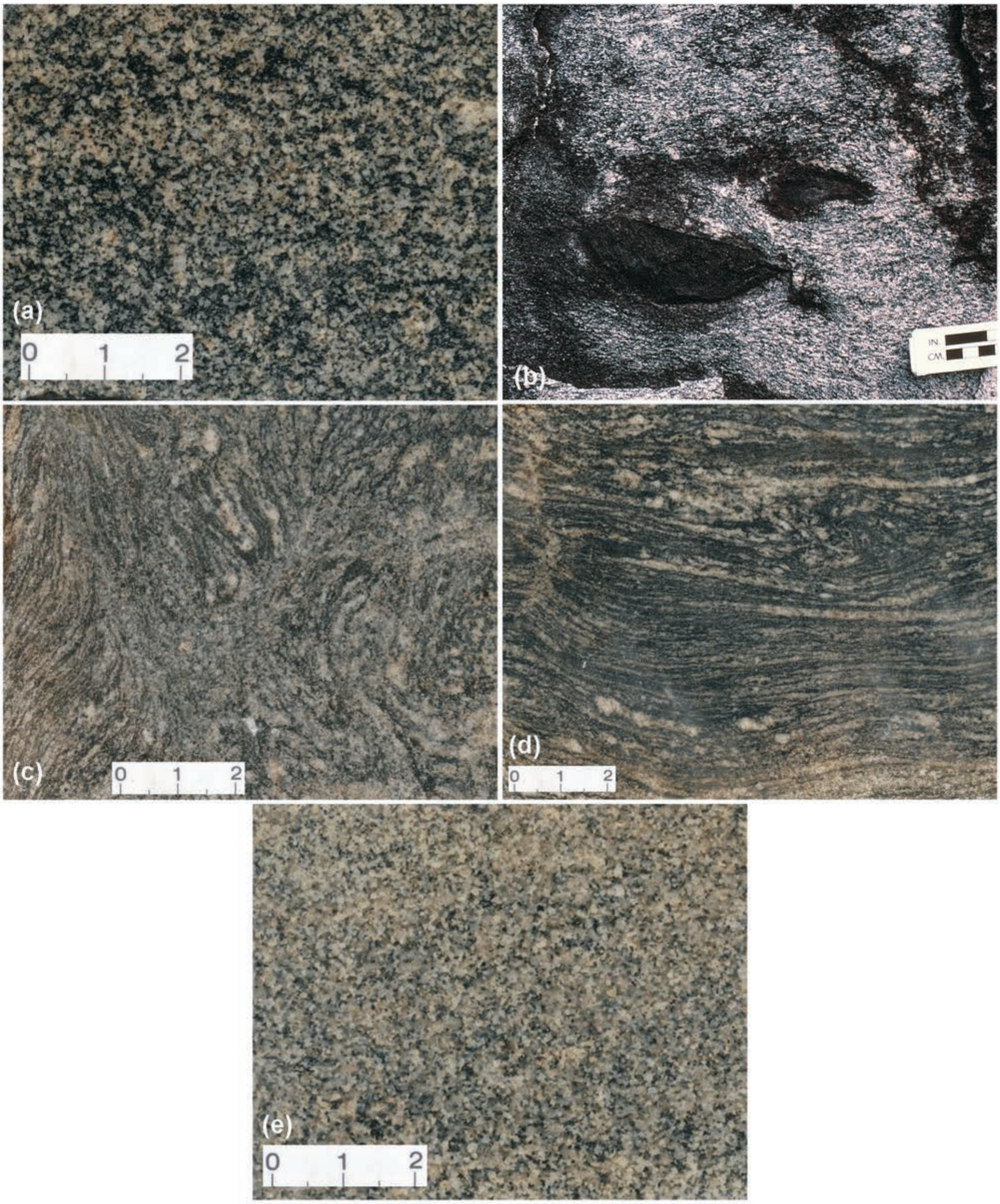

Figure 92. Early Permian granitoids. (Scale is shown in centimetres)
(a) Even-grained biotite granite showing the distinctive saccharoidal texture of parts of the Coonambula Granite. 3km north-north-west of Coonambula homestead at MGA 293172 7180970 (QFG2699)
(b) Strongly foliated biotite granite showing foliation wrapping around mafic xenoliths, Coonambula Granodiorite. Pollard Creek ~5.5km south-south-east of Wathonga homestead at MGA 280405 7177831 (QFG3211)
(c) Gneissic biotite granite, Coonambula Granodiorite;.Target Creek 7km west-south-west of Mount Target at MGA 284574 7177327 (QFG2722)
(d) Intensely foliated biotite orthogneiss. Same locality as (c)
(e) Equigranular, fine to medium-grained, saccharoidal biotite granite or granodiorite of the Widbury Granite (compare the texture with that of the Coonambula Granite in (a). Near the Cracow–Eidsvold Road, 500m west of Widbury homestead at MGA 292441 7185166 homestead (RSC166)

delineated from subtle radiometric differences and considered to be responsible for the strong hornfelsing of the Nogo beds. SHRIMP dating confirmed its early Permian age (see below and the Appendix).

A sample of the gneissic part of the Coonambula Granodiorite was also submitted for U-Pb zircon dating by SHRIMP to determine whether it represented an older part of the Rawbelle Batholith, perhaps related to the Donore Granite Gneiss, which is mapped in contact with the Coonambula Granodiorite to the north-west. As outlined in the Appendix, the analysed zircons represented a complex population that is difficult to resolve, with some inheritance back to ~460Ma, and two younger populations with mean ages of ~320Ma and 295Ma. The population of 295Ma zircons in the Coonambula Granodiorite could indicate it too is early Permian like the Widbury Granite, with a large inherited component from the entrained metamorphic material. The intensely foliated character is a problem with an early Permian age. Further research should re-examine this to determine whether it is magmatic rather than tectonic and to resolve whether the unit is composite as suggested above.

On the Harker variation diagrams (Figures 93 and 94) most samples from this unit plot with the Widbury Granite as a distinct suite, here named the Coonambula Suite, which is clearly different to the surrounding late Permian to Early Triassic rocks that have been divided into the Tandora and Wingfield Suites. The Coonambula Suite is lower in Sr and higher in TiO_2, FeO_{total} and Zn than either the Tandora or the Wingfield Suites. It tends to be lower in Na_2O than the Tandora Suite and lower in K_2O and Th than the Wingfield Suite (Figure 93). P_2O_5 is at the lower side of the range of the other suites. Higher Al_2O_3 than the other suites is reflected by its consistently peraluminous nature of the suite, with many samples having an alumina saturation index (ASI) >1.1 at relatively moderate SiO_2 values, suggesting that they are S-type granites.

However, five samples of the Coonambula Granodiorite plot separately and most closely match the Wingfield Suite. These samples were all collected in the northern part of the unit along or near the Eidsvold–Cracow road. Whitaker & others (1974) mapped this area as undifferentiated Permo-Triassic granitoids rather than Coonambula Granodiorite. The geochemical differences suggest that this may have been a correct interpretation, even though the rocks cannot be distinguished from the Coonambula Granodiorite in the geophysical images.

K–Ar dating of the Coonambula Granodiorite gave an Early Triassic biotite age (recalculated) of 247Ma (Webb & McDougall, 1968; Whitaker & others, 1974). However, this age may be the result of resetting during intrusion of the rest of the Rawbelle Batholith.

The Coonambula Granodiorite is intruded by the Late Triassic Boolgal Granophyre.

WIDBURY GRANITE

Introduction

This is a new name for a group of irregularly shaped plutons in the south-eastern part of RAWBELLE extending into AUBURN, ~20km south-west of Eidsvold (Figure 81). These bodies were previously incorporated in the Coonambula Granodiorite by Whitaker & others (1974). The subdivision was made because the locally gneissic Coonambula Granodiorite was initially thought to be Carboniferous and therefore basement to the Nogo beds, which nevertheless have been strongly hornfelsed. Less obviously foliated granite in the eastern part of the area was thought to be potentially younger and was tentatively mapped as a separate unit herein referred to as the Widbury Granite. Delineation of the unit was based mainly on subtle variations in radiometric response. Because this was done in the office after fieldwork was completed, follow-up fieldwork would be needed to substantiate and properly delineate the unit. However, as discussed below, isotopic and geochemical evidence suggests that the distinction between Widbury Granite and Coonambula Granodiorite may not be valid.

Type locality

Large tor-like boulders south of Widbury homestead at MGA 294010 7183480 comprising medium grey, equigranular, fine to medium-grained, saccharoidal biotite granite have been selected to represent the type locality. The rock has very common dark specks (clots of biotite), and fine-grained rounded to lensoidal black xenoliths of dioritic composition, 3–8cm across are also common. Its mineralogy consists of quartz (~35%), plagioclase (andesine, ~30%), K-feldspar (~22%), biotite (~12%), very minor muscovite (under 1%), chlorite, sericite and actinolite as alteration products and accessory apatite and titanite.

Lithology

The unit incorporates a range of different rock types. The most common comprises equigranular, saccharoidal fine-grained biotite granodiorite or granite (Figure 92e). Also some grey hornblende-biotite granodiorite was observed. Pegmatite and aplite dykes are common.

Near Widbury homestead to the north, medium to coarse-grained, equigranular to slightly porphyritic biotite granite is widespread. It also has a saccharoidal texture, but owes its different appearance to more abundant K-feldspar. Clots of biotite and other mafic minerals from 0.2–1cm are common. Mafic xenoliths of a fine-grained biotite-rich rock, locally diffusely banded, are common, in some cases being aligned as schlieren and defining a foliation.

Geophysical response

The radiometric response for this unit is similar to the Coonambula Granodiorite, but is slightly higher in potassium giving a more pinkish hue on composite images, and this was used to delineate the boundary.

The unit cannot be distinguished from the Coonambula Granodiorite on the magnetic images. As for the Coonambula Granodiorite magnetic susceptibilities measured in the field are generally very low (0-200 x 10^{-5} SI units) but with a tail of values extending to 1400.

Relationships and age

The Widbury Granite is interpreted to have strongly hornfelsed the Nogo beds to the east and is intruded by the Late Triassic Boolgal Granophyre.

A sample of biotite granite from the type locality was dated by the SHRIMP U-Pb zircon method. Analyses of nine grains formed a more dominant age grouping giving an age of 290±5Ma (MSWD = 2.0). Five older grains at ~310Ma and near 330Ma were also analysed. The early Permian age is consistent with an intrusive relationship with the Nogo beds, provided it was intruded soon after the volcanic rocks were emplaced. However, the dominant age grouping is not dissimilar to the younger population in the Coonambula Granodiorite sample, and the older grains from the Widbury Granite sample fall within the range of the older population in the Coonambula Granodiorite.

Geochemically, the Widbury Granite is similar to the Coonambula Granite having lower Sr and higher TiO_2, FeO_{total} and Zn than either the Tandora or Wingfield Suites (Figures 94 and 95). It is also peraluminous, some samples having an ASI>1.1.

Therefore the evidence for the rocks being of different ages and separate units is not compelling. Granites with the distinctive saccharoidal texture of the Widbury Granite are also common within the Coonambula Granodiorite.

EIDSVOLD COMPLEX

Introduction

The Eidsvold Complex crops out as a belt ~15km long and up 3km wide on the eastern side of the Burnett River, trending north from Eidsvold township (Figure 81). However, the airborne magnetic data indicates that it is more extensive at depth underlying the Jurassic sedimentary rocks of the Mulgildie Basin. An area of granitic rocks on the eastern margin of the basin 15km south-east of Eidsvold may represent the eastern margin of the complex. The full extent of the complex may be an elliptical pluton ~30km long and up to 13km wide.

Various reports have described rocks from the area (Rands, 1887, 1895, 1901; Webb, 1960; Whitaker & others, 1974; Leadbeatter, 1992). The name was first used by Webb (1960). It is spatially separate from the Rawbelle Batholith, and is much more strongly magnetic.

The outcrop is typically associated with hilly terrain and consists of closely spaced northerly trending ridges with sparse vegetation, locally referred to as the Eidsvold Range. Boulder outcrop is common.

The rocks in the Eidsvold Complex are quite fresh outside the mineralised area around the Stockmans, Spencer and Lady Augusta mines of the old Eidsvold Gold Field.

Constituent units

Detailed mapping with the help of the airborne geophysics and recent geological mapping by company geologists, Leadbeatter (1992) and QUT third-year students (Clark & others, 2000, unpublished) have been used to subdivide the complex into three distinct intrusive units, which are described separately. Most of the detailed observations have been made around the southern part of the complex. The major rock types of the complex are leucogranite, granite, granodiorite, gabbro and diorite, with diorite and gabbro being more dominant in the western part. The eastern part of the complex is dominated by granite and leucogranite. The granodiorite, which in most places incorporates diorite and gabbroic enclaves, has mainly been observed in the southern part of the complex as highly irregular bodies in contact with both other units. In general the contacts between granite and diorite are characteristically sharp, whereas gradational contacts between granite and granodiorite have more commonly been observed.

The diorite and gabbro of the Eidsvold Complex have been named Mount Rose Gabbro. The leucocratic granites have been named Ceratodus Granite. The third unit comprising hornblende granodiorite that forms a net-vein complex with the diorite and gabbro is named Harkness Granodiorite.

Relationships and age

The Eidsvold Complex intrudes and has strongly hornfelsed the early Permian Nogo beds. The airborne magnetic images show a sharply defined western margin which may represent a fault or shear. Outcrop evidence indicates a shear zone containing mylonite which has been hornfelsed. The mylonite affects both the country rocks and the Eidsvold Complex, and suggests that the movement occurred during or soon after emplacement of the complex, while the rocks were still hot and ductile.

Numerous rhyolite and aplite dykes (1cm to 5m thick) occur as laterally restricted, thin bodies that cut all the major rocks of the complex but are most common in the western part of the complex.

Internal relationships within the complex are discussed below with the separate units.

The complex is unconformably overlain by the Evergreen Formation, which in this area is the basal unit of the Mulgildie Basin.

The magnetic images suggest that the Eidsvold Complex dips shallowly eastward under the Mulgildie Basin. They also show that the Anyarro Fault as shown on the existing Mundubbera 1:250 000 geology sheet, and which supposedly defines the western edge of the Abercorn Trough, does not sharply truncate the Eidsvold Complex at depth. A simple downwarp rather than a fault is suggested. On the basis of the less detailed BMR regional aeromagnetic data, Murray (1994) suggested that the Abercorn Trough may not be a major structural feature in this area.

The Eidsvold Complex is host to gold mineralisation that occurs in quartz reefs and quartz veins in altered and sheared granite and in quartz stockworks and granite-quartz breccias. Hydrothermal alteration has resulted in the kaolinisation of feldspars up to a few metres from the margins of the reefs. The veins and reefs consist of quartz that contains minor pyrite, chalcopyrite and sphalerite (Maid of Erin mine), stibnite and cassiterite (Stockman mine), galena (All Nations mine) molybdenite (Moonlight mine) and arsenopyrite. Most shafts appeared to follow contacts between light grey granite and diorite.

K–Ar ages were reported by Webb & McDougall (1968) and Whitaker & others (1974) from two localities in the complex. They were a hornblende age of 250Ma (recalculated to conform with IUGS constants), from a fine-grained diorite in the Mount Rose Gabbro and a biotite age of 241Ma (probably from the Ceratodus Granite). However, Leadbeatter (1992) suggested that these ages result may be reset. He carried out K–Ar dating on two samples of sericite derived from alteration of feldspars, hornblende and possibly biotite in rocks adjacent to the Lady Augusta reef and obtained an average age of 269±5Ma (mid-Permian using the ICS Timescale of Gradstein & others, 2004). This is 19Ma older than the hornblende age reported by Webb & McDougall (1968). The indicates that if the date of 269Ma is a minimum age for the mineralisation, the host Eidsvold Complex must be close to this or somewhat older. The Nogo beds which are intruded by the Eidsvold Complex are probably early Permian, and being partly marine, may correlate with the Narayen beds and Buffel Formation which are Artinskian (275–284Ma on the ISC timescale). Combined with the K–Ar date, this would place the Eidsvold Complex in the early Permian.

MOUNT ROSE GABBRO

Introduction

The Mount Rose Gabbro is a new unit within the Eidsvold Complex, and incorporates the highly magnetic, more mafic components. It is named after one of the most active historical mines on the Eidsvold Gold Field, the Mount Rose mine and battery near Spring Gully to the west of Eidsvold township. It is the most widespread unit within the exposed Eidsvold Complex. In the southern part of the complex, the Mount Rose Gabbro mainly occupies the western side. It is exposed as large well-rounded boulders that weather to a black surface.

Type locality

The type locality is at the site of the Mount Rose mine at MGA 309600 7192500, where boulders of fresh, dark grey, fine-grained equigranular hornblende-quartz gabbro cut by medium to coarse-grained equigranular light grey granite were observed.

Lithology

The Mount Rose Gabbro consists generally of dark grey to black, fine to coarse-grained rocks that range from gabbro or diorite to quartz diorite (Figure 93a) with equigranular to locally porphyritic textures. The quartz diorite may be more common in the northern part of the complex but there have been fewer observations there. Rare pegmatitic patches are defined by large hornblende and plagioclase crystals. Vague layered fabrics were observed in some locations.

The gabbro or diorite typically consists of plagioclase, hornblende, clinopyroxene and opaque oxides, and locally has minor orthopyroxene, biotite, quartz and K-feldspar. Webb (1960) and Whitaker & others (1974) described the rocks as quartz gabbro and cited an assemblage consisting of labradorite (50%), clinopyroxene and orthopyroxene (15%), hornblende (25%) , quartz (5%), accessories (5%) and traces of biotite. Plagioclase forms subhedral to euhedral, rectangular laths, usually 0.5–2mm, but locally up to 5mm, with normal and oscillatory zoning ranging from oligoclase to labradorite. Subhedral to anhedral, pale green to brown hornblende is the major mafic mineral. It is usually <1mm, but it locally forms larger ophitic crystals that enclose plagioclase. In some of the rocks examined it is the only mafic mineral present and the rocks may be described as either diorite or hornblende gabbro depending on the plagioclase composition. Clinopyroxene (usually anhedral to subhedral augite) occurs in most samples, usually as cores rimmed by hornblende. Minor orthopyroxene is locally present as subhedral crystals adjacent to hornblende. Interstitial quartz occurs in some rocks and K-feldspar may also be an interstitial phase or in some cases form large grains up to 5mm across poikilitically enclosing the other minerals. Biotite also occurs as a minor phase in some of the quartz-bearing rocks as subhedral to anhedral flakes commonly associated with hornblende. Ilmenite and magnetite and sulphide minerals (pyrite and chalcopyrite) are accessory components.

Geophysical response

The rocks are represented on composite radiometric images by images by dark brownish hues, due to the low response in all channels.

Magnetic susceptibility readings for the Mount Rose Gabbro mostly fall in the range 100–3200 x 10^5 SI units, with some values extending to about 6000. The overall distribution is strongly skewed with a strong mode at about 500. In detail the data can be divided into fine-grained gabbros and diorites that have readings of 1600–3200 and the medium to coarse-grained quartz diorites with readings up to 600.

Relationships

The Mount Rose Gabbro is in contact with the Harkness Granodiorite, and the two units appear to be intimately mixed with abundant enclaves of the gabbro in the granodiorite (Figure 93b–d). Extensive areas of unaffected diorite occur near the Eidsvold–Cracow road on the south side of the locally named Eidsvold Range and along Spring Gully Road near Currong homestead.

Although the gabbro superficially appears to be older than the granodiorite, because it forms xenoliths in and is intruded by the latter, the crenulate margins and finer (chilled) rims are features observed in net-vein complexes elsewhere, and suggest that the two magmas may have been intruded contemporaneously and became mingled. However, the finer rims in some cases appear to be due to alteration of the diorite to fine-grained amphibole, and may not in fact be due to chilling.

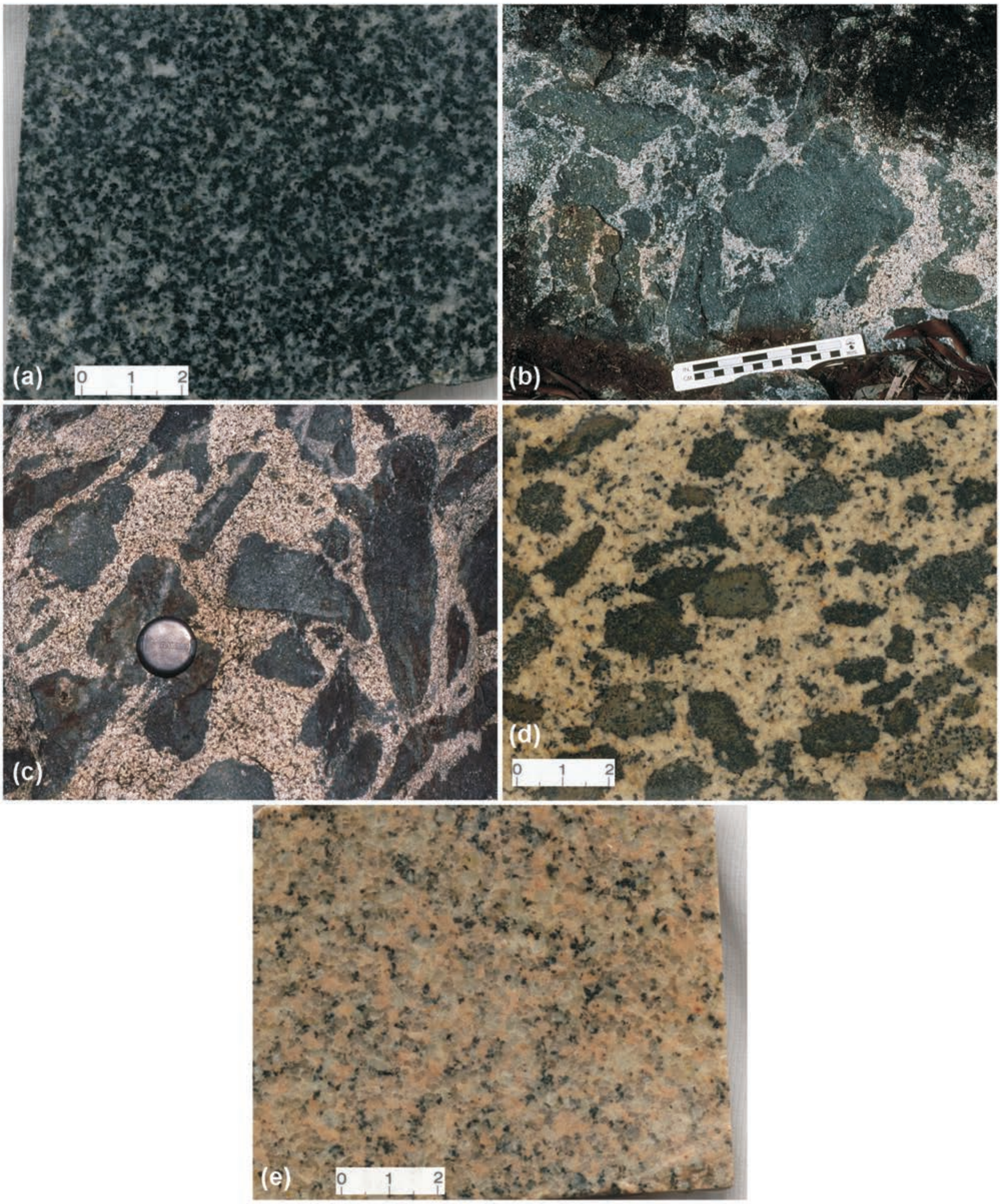

Figure 93. Eidsvold Complex
(a) Scanned slab of Mount Rose Gabbro. About 1.6km west of Eidsvold at MGA 309524 7192410 (QFG3219); scale is shown in centimetres in (a), (d) and (e)
(b) Enclaves of Mount Rose Gabbro in Harkness Granodiorite; note the complex crenulate margins of the enclaves, suggestive of magma mingling; ~1.8km south-west of Eidsvold at MGA 310143 7191160 QFG2259
(c) Enclaves of Mount Rose Gabbro in Harkness Granodiorite; again note the complex, locally chilled, crenulate margins of the enclaves, suggestive of magma mingling; Eidsvold–Cracow road 2.5km south-south-west of Eidsvold at MGA 310424 7190141 (RSC174)
(d) Scanned slab of Harkness Granodiorite containing small enclaves of diorite or gabbro; Tolderodden Conservation Park ~3km west of Eidsvold at MGA 308031 7192668 (QFG3949)
(e) Scanned slab of Ceratodus Granite; Spring Gully Road, ~2km west-north-west of Eidsvold at MGA 309191 7193040

The Mount Rose Gabbro intrudes the early Permian Nogo beds to the west, although the contact locally appears to be a mylonite zone suggesting forceful emplacement.

HARKNESS GRANODIORITE

Introduction

The Harkness Granodiorite is a new unit within the Eidsvold Complex, and incorporates a moderate to highly magnetic, mostly felsic unit with characteristic large enclaves of the diorite and gabbro of the Mount Rose Gabbro. It is mainly restricted to the southern part of the complex in the vicinity of the Eidsvold goldfield. It is commonly in contact with both the Ceratodus Granite and the Mount Rose Gabbro.

This unit is named after Harkness Boundary Creek, which drains out of the Eidsvold Range in a southerly direction, south of Eidsvold.

Type locality

An easily accessed platform-outcrop of the Harkness Granodiorite can be found at MGA 310420 7189830 along the track to the old Craven town site, south of the Eidsvold–Cracow road, near the Eidsvold cemetery. It comprises a light grey medium to coarse-grained biotite-hornblende granodiorite that illustrates a typical erratic array of diorite and gabbro clasts generally from 10–80cm, but locally even larger. They constitute 60–70% of the rock here. Some show intricately embayed margins, whereas others are more regular.

Lithology

The Harkness Granodiorite ranges from tonalite or quartz diorite to granodiorite. The rocks are fine to medium-grained and equigranular. They form an extensive net-vein complex with angular to rounded diorite or gabbro xenoliths/enclaves commonly having darker, apparently finer-grained, crenulated or embayed margins (Figure 93b–d). The xenoliths mostly range from 1–70cm, but in places are up to 5 metres across. The size and abundance tends to increase away from the Ceratodus Granite towards the Mount Rose Gabbro, and locally the enclaves constitute 60–80% of the rock.

The granodiorite consists of plagioclase, K-feldspar, quartz, biotite and hornblende. Plagioclase is subhedral, 1–2mm and rimmed by K-feldspar. Quartz and K-feldspar embay the plagioclase, which is twinned and zoned in places. Hornblende is euhedral and 0.5–1mm. Hornblende commonly occurs as clumped masses with interlocking crystals but also rims opaque minerals. Rare overgrowths of hornblende on earlier hornblende were observed. Iron-rich, dark brown biotite is up to 10% of the rock, and mostly forms euhedral flakes 0.5–2mm in diameter. It generally has poikilitic texture with small plagioclase and quartz inclusions. Quartz in the granodiorite has a variety of textures being interstitial to or as inclusions in other minerals such as plagioclase, biotite and hornblende, as rims around K-feldspar or poikilitically enclosing plagioclase, biotite and hornblende.

The enclaves have two types of margins — embayed and smooth. The enclaves or xenoliths with embayed margins are commonly porphyritic with plagioclase and/or hornblende phenocrysts that are commonly ophitically intergrown. Small intrusions or veins of the granodiorite into the embayed diorite enclaves are also present. The enclaves vary in grain size and composition. The finer-grained enclaves are dioritic whereas the the coarser-grained enclaves tend to look like ‘ghosts’ of fine-grained granodiorite and show similar textural and mineralogical characteristics to their coarser-grained host.

The enclaves or xenoliths with the smooth margins consist mainly of diorite and are commonly small and angular resembling a pull-apart breccia. Small (0.5–1mm) hornblende crystals form along the contact between the xenolith and the granitic material.

Rims of magnetite (in some cases as euhedral crystals) occur around some of the enclaves. Small patches of pegmatitic material are also found in the granodiorite unit.

Geophysical response

Although the Harkness Granodiorite might be expected to have different radiometric response from the Mount Rose Gabbro, they may be too intimately mixed to be distinguishable at the resolution of the data. The rocks are represented on composite radiometric images by dark brownish hues, due to a low response in all channels.

The rocks also cannot be distinguished from the Mount Rose Gabbro in the airborne magnetic data. The magnetic susceptibilities measured in the field for the granodiorite are similar to the Mount Rose Gabbro and were around 200–3200 x 10^{-5} SI units, showing a skewed bimodal distribution with a major mode at about 900 and a smaller mode at about 2000 whereas the gabbro–diorite clasts showed similar values in the range from 400–2800 x 10^{-5} SI units with a mode at 1600.

Relationships

The Harkness Granodiorite and the Mount Rose Gabbro are intimately mixed in the field. As already noted, the gabbro forms xenoliths in and is intruded by the granodiorite, but the crenulate margins and finer rims are features common in net-vein complexes elsewhere, and could suggest that the two magmas were intruded contemporaneously and became mingled.

CERATODUS GRANITE

Introduction

The Ceratodus Granite is a new unit within the Eidsvold Complex, and incorporates leucocratic granites that mainly crop out along the eastern side of the complex. It is named after a railway siding north of Eidsvold. Outcrops are usually large well-rounded boulders, but also some whaleback-type outcrops forming hills.

Type locality

A quarry at MGA 310300 7205100, west of the Ceratodus siding, is designated as the type locality. It exposes medium to coarse-grained pink equigranular granite comprising quartz (35–40%), plagioclase (~30%), K-feldspar (~40%), biotite (~3%), minor hornblende (>1%) and accessory titanite, apatite, zircon and opaque oxides. Minor stains from oxidised sulphides are present. Dark greenish grey very fine-grained xenoliths, mostly of diorite, are common and are mostly 1–2cm, but in places are up to 10cm.

Lithology

The Ceratodus Granite is generally pink to light grey, fine to medium-grained, and contains quartz, oligoclase, perthitic microcline, biotite, hornblende, titanite and opaque oxides. Most of the rocks have roughly equal proportions of K-feldspar and plagioclase and are classified as granite, but some granodiorite also occurs. The rocks are mostly equigranular or seriate, but there are porphyritic variants.

The Ceratodus Granite can be divided into four types:

1. Fine-grained porphyritic granite contains medium-grained phenocrysts of normally zoned plagioclase (An_{10}). Euhedral crystals of hornblende and biotite form inclusions within the plagioclase phenocrysts. The fine-grained groundmass is composed of quartz, perthitic K-feldspar and anhedral to subhedral hornblende and biotite.

2. Medium-grained granite with sparse euhedral to subhedral plagioclase (An_{15}) phenocrysts that display normal zoning. Subhedral, normally zoned plagioclase also occurs in the groundmass along with anhedral granophyric quartz, perthitic K-feldspar and subhedral biotite and minor anhedral hornblende.

3. Medium-grained equigranular granite ((Figure 93e), which displays a similar composition to the above mentioned medium-grained porphyritic granite. It contains euhedral normally zoned plagioclase (An_{30}) and subhedral hornblende.

4. Very fine-grained porphyritic granite containing fine-grained phenocrysts of anhedral quartz and K-feldspar and euhedral plagioclase (An_{15}) that shows normal zoning and sericitised cores. The very fine-grained groundmass is composed of granophyric quartz and euhedral K-feldspar (perthite), subordinate plagioclase and very minor biotite.

The medium-grained varieties of granite (both porphyritic and equigranular) contain mafic enclaves with diffuse boundaries. The enclaves contain euhedral, fine-grained, normally zoned plagioclase (An_{30}) with sericitised cores, anhedral to euhedral hornblende and biotite, and abundant opaque oxides.

Geophysical response

The Ceratodus Granite can be recognised on the composite radiometric images by dull pinkish hues that contrast with the dark brownish hues of the other two units. This is due to a moderate potassium response, whereas the other two channels have low responses similar to those of the rest of the complex

The Ceratodus Granite cannot be distinguished in the airborne magnetic data and this is borne out in the magnetic susceptibility data. Magnetic susceptibility readings for this unit show a relatively normal distribution in the range 0–1400 x 10^{-5} SI units with a mode at about 600.

Relationships

The relationship of the granite to the other two units is uncertain. It contains dioritic xenoliths but it is not certain whether these are related to the Mount Rose Gabbro. Numerous very fine-grained felsic dykes cut across all the rocks in the area. They range from 30cm to a few metres in thickness and are beige to light grey when fresh and weather to a cream colour. These dykes are similar to the finer-grained varieties of the Ceratodus Granite.

LOOKERBIE IGNEOUS COMPLEX

Introduction

The Lookerbie Igneous Complex is an intrusive complex centred 25km south of Biloela in northern SCORIA (Figure 98). Placer Exploration first reported the occurrence of small granitic and granodioritic intrusions in the area and coined the name “Lookerbie Igneous Complex” while exploring for Carlin-style gold mineralisation (Taylor, 1988). This unit occurs to the north-east of Mount Lookerbie as a north-west trending belt ~6km wide by 15km long. The unit takes its name from Mount Lookerbie at MGA 257200 7274900 on SCORIA. The unit forms undulating hilly topography and generally crops out poorly. A noticeable exception is the more deeply incised topography and correspondingly better outcrop in the type area as defined below.

Type area

Numerous small tors on the eastern bank of Grevillea Creek just downstream from the junction with Saddle Gully at MGA 263200 7275900 are designated as the type area.

Lithology

Rock types include biotite-hornblende tonalite, granodiorite, quartz diorite, diorite and microdiorite dykes. The plutonic rocks are commonly quite strongly altered, manifested by sericitisation of plagioclase and chloritisation of mafic minerals.

Geophysical response

Radiometric response for the Lookerbie Igneous Complex is low in all channels and is represented by dark hues on the composite images. They are mostly indistinguishable from those of the Yaparaba Volcanics.

Unlike the Kariboe Layered Gabbro or Eidsvold Complex, the Lookerbie Igneous Complex produces a low response on a total magnetic intensity (total magnetic intensity) image in spite of the dioritic compositions. Thin north-west-trending linear features through the area are probably due to later dykes. The low response is consistent with measured magnetic susceptibilities which have a strongly skewed distribution with a strong mode for values <100 x 10^{-5} SI units, with most other values <1000.

Relationships and age

The generally poor outcrop in the area rendered observation of contacts difficult. Rocks of the adjacent Yaparaba Volcanics are hornfelsed near the margins of the complex indicating a Permian or younger age for the intrusion. The complex is intruded by numerous dykes of andesitic to rhyolitic composition.

The unit is shown as being late Permian or Early Triassic on the SCORIA map, but is here considered to be early Permian like the Eidsvold Complex. Geochemical data for the two complexes are shown in Figures 96 and 97 and indicate that the two complexes are chemically similar. They also occupy a similar structural setting, intruding early Permian volcanic rocks of the Nogo Suprovince.

GEOCHEMISTRY OF EARLY PERMIAN GRANITOIDS

Coonambula Suite

SHRIMP dating has shown that the Coonambula Granodiorite and Widbury Granite in the central part of the Rawbelle Batholith west of Eidsvold are probably early Permian (~295Ma), although the former shows a strong inherited component with zircons at ~320Ma. Both granitoids are foliated, particularly the Coonambula Granodiorite, which also commonly has abundant metasedimentary xenoliths. On the Harker variation diagrams (Figures 94 and 95) most samples from these units plot as a distinct suite, here named the Coonambula Suite, that is clearly different to the surrounding late Permian to Early Triassic rocks that have been divided into the Tandora and Wingfield Suites (see Figures 110 and 111). However, five samples of the Coonambula Granodiorite and one from the Widbury Granite plot separately and most closely match the Wingfield Suite. These samples were all collected in the northern part of the unit along or near the Eidsvold–Cracow road. Whitaker & others (1974) mapped this area as undifferentiated Permo-Triassic granitoids rather than Coonambula Granodiorite. The geochemical differences suggest that this may have been a correct interpretation, even though the rocks cannot be distinguished from the Coonambula Granodiorite in the geophysical images.

Ignoring these samples, the Coonambula Suite is lower in Sr and higher in TiO_2, FeO_{total} and Zn than either the Tandora or Wingfield Suites. It tends to be lower in Na_2O than the Tandora Suite and lower in K_2O and Th than Wingfield Suite (Figures 93 and 94). P_2O_5 is at the lower side of the range of the other suites. Higher Al_2O_3 than the other suites is reflected in the consistently peraluminous nature of the suite, with many samples having an ASI >1.1 at relatively moderate SiO_2 values, suggesting that the rocks are S-type granites.

Plotting with the Coonambula Suite are samples from two other units that hitherto were thought to be late Permian or Early Triassic. These are the Tecoma Granite (three samples) and Greystone Granite (six samples). Neither has been dated isotopically, but the geochemical affinities suggest that they may be older or at least have older components.

The six samples of Greystone Granodiorite are from the eastern half of the unit, and include gneissic rocks and biotite granite. Like the Coonambula Granodiorite, these samples are peraluminous with three samples having an ASI >1.1. However, the geochemistry also suggests that the unit as mapped may be composite, because three other samples from farther west, including the type locality, plot with the Tandora Suite. These are only mildly peraluminous and the samples contain modal hornblende. Further work is needed to resolve the distribution of these different suites within the Greystone Granodiorite as currently mapped.

The three samples of Tecoma Granodiorite are strongly peraluminous with three samples having an ASI ~1.1, in spite of the samples containing hornblende. However, the geochemistry also suggests that the unit as mapped may be composite, because two other samples plot with the Tandora and Wingfield Suites. Two samples from outcrops within the Colodon Granodiorite also plot with the Coonambula Suite suggesting that they may be from an unmapped area of Tecoma Granodiorite.

In Figure 91b, the average analysis for the Coonambula Suite is Sr depleted and shows a distinct enrichment in Y, a characteristic of crustal melts generated above the eclogite transition (Wyborn & others, 1992). While these data point to these as being S-type granites, they may also have undergone extensive assimilation of crustal rocks during emplacement as evident from the abundant xenoliths in the Coonambula Granodiorite. The suite shows decreasing P_2O_5 with increasing SiO_2, a trend which supports an I-type source as S-type granites should show an increase (Chappell & White, 1992).

The relatively flat pattern in the K/Rb vs SiO_2 plot suggests restite unmixing could be the main controller on composition in the suite, although plagioclase fractionation is suggested by the Ba vs Sr plot.

Tectonically, the early Permian corresponds to the initiation of the Bowen Basin, and is interpreted as a time of crustal extension. During extension, crustal geotherms are higher and can be accompanied by melting of mid crustal rocks and such a process may have generated the Coonambula Suite.

Eidsvold Complex and Lookerbie Igneous Complex

These two complexes occur to the east of the Rawbelle Batholith where they intrude rocks of the Nogo Subprovince. K–Ar dating suggests that the Eidsvold Complex is early Permian. The Lookerbie Igneous Complex has not been dated, and although it is shown on the SCORIA map as Permian to Triassic, it may be similar in age to the Eidsvold Complex.

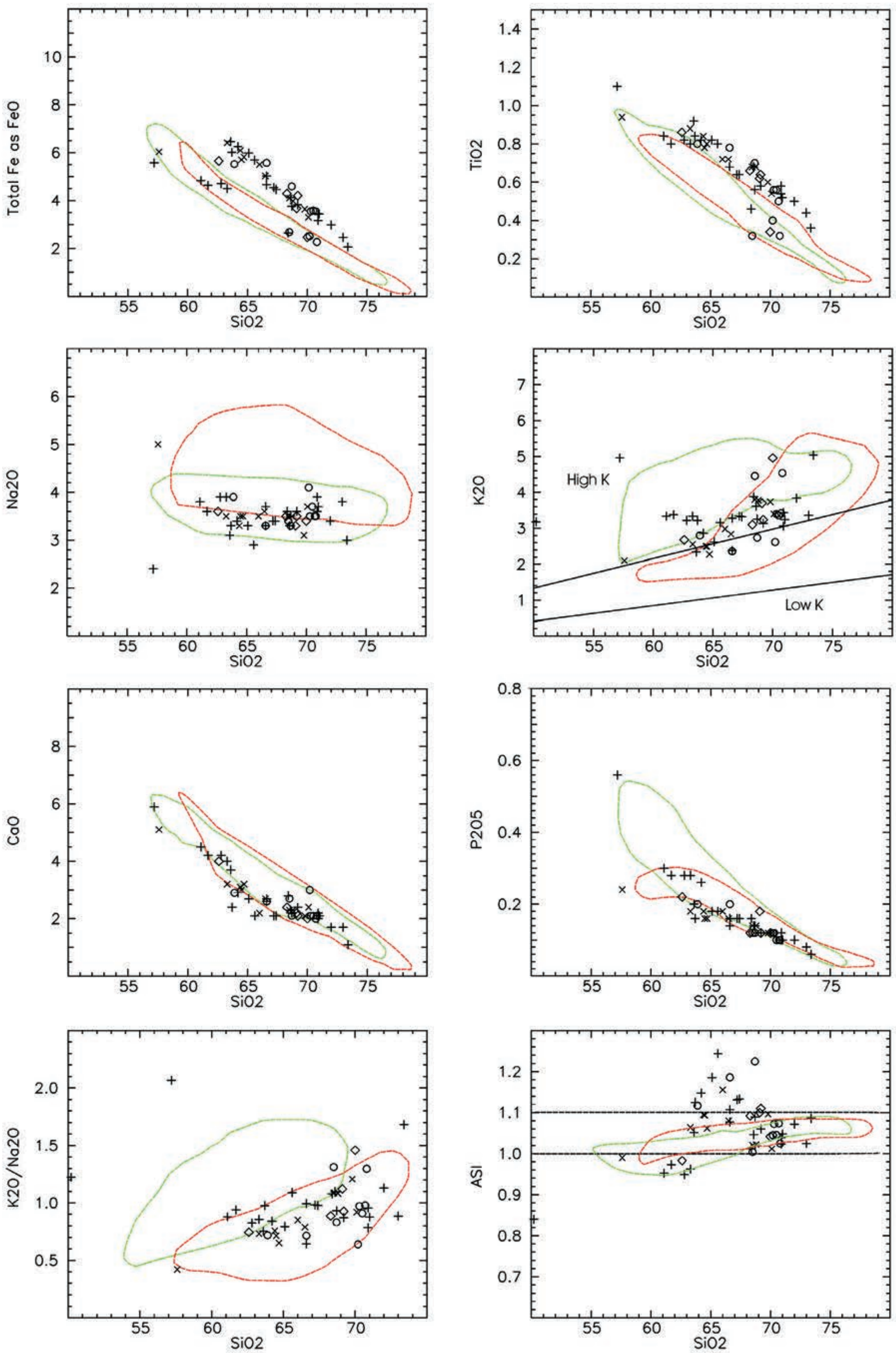

Figure 94. Variation diagrams for the early Permian Coonambula Granodiorite (+) Widbury Granite (x), Greystone Granite (circles) and Tecoma Granite (diamonds) showing selected major elements in weight percent and the Alumina Saturation Index (ASI) vs SiO_2 in weight percent. Coloured fields are for the Tandora (red) and Wingfield (green) Suites from the Rawbelle Batholith.

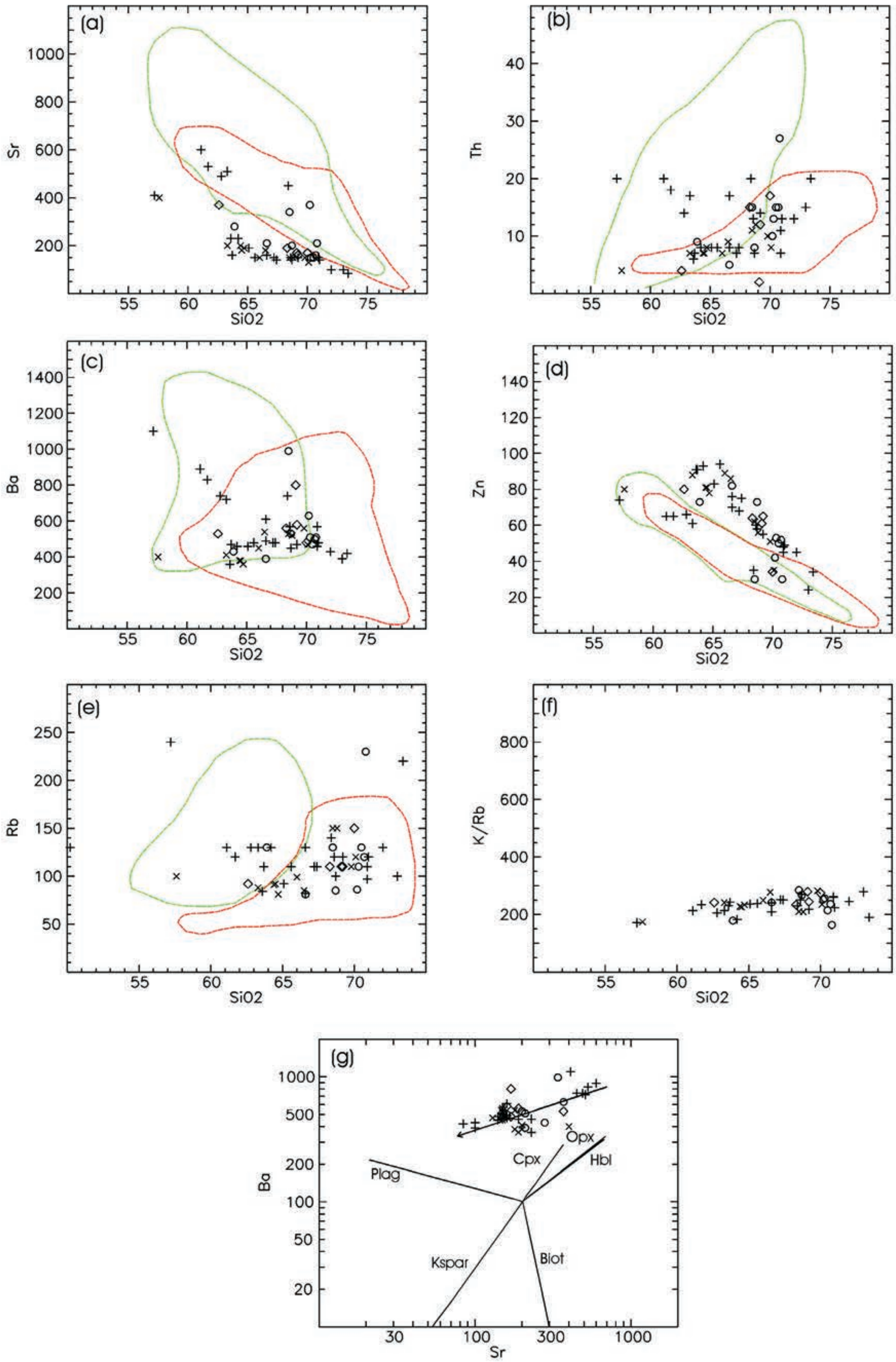

Figure 95. Variation diagrams for the early Permian Coonambula Granodiorite (crosses) Widbury Granite (x), Greystone Granite (circles) and Tecoma Granite (diamonds) showing selected trace elements in parts per million and K/Rb vs SiO_2 in weight percent. Mineral vectors in (g) are from Rollinson (1993, page 161) and show fractional crystallisation trends for Ba and Sr for the various minerals shown. The arrowed line shows an approximate overall fractionation trend for the samples plotted. Coloured fields are for the Tandora (red) and Wingfield (green) Suites from the Rawbelle Batholith.

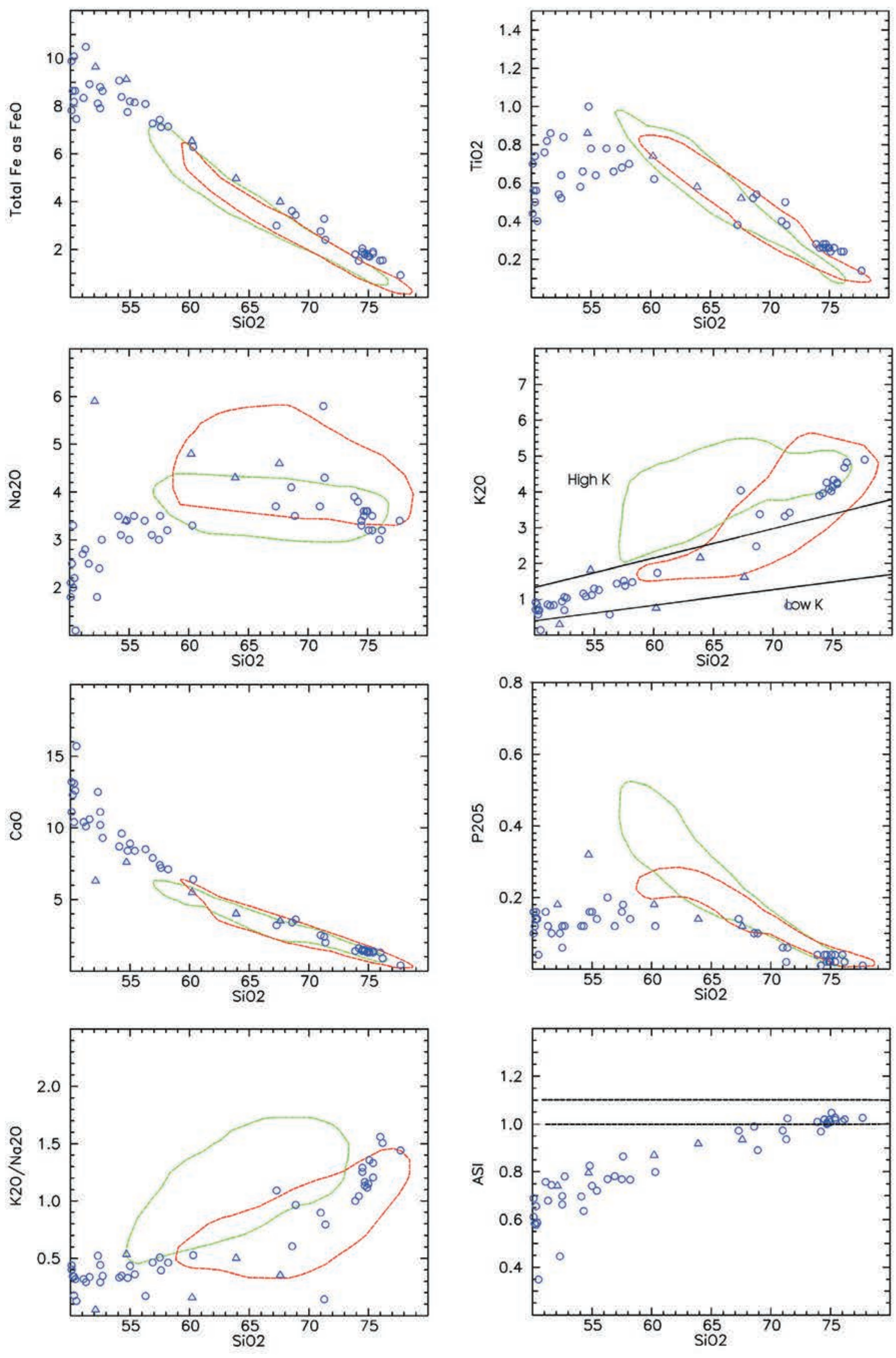

Figure 96. Variation diagrams for the early Permian Eidsvold Complex (circles) and Lookerbie Igneous Complex (triangles) showing selected major elements in weight percent and the Alumina Saturation Index (ASI) vs SiO_2 in weight percent. Coloured fields are for the Tandora (red) and Wingfield (green) Suites from the Rawbelle Batholith.

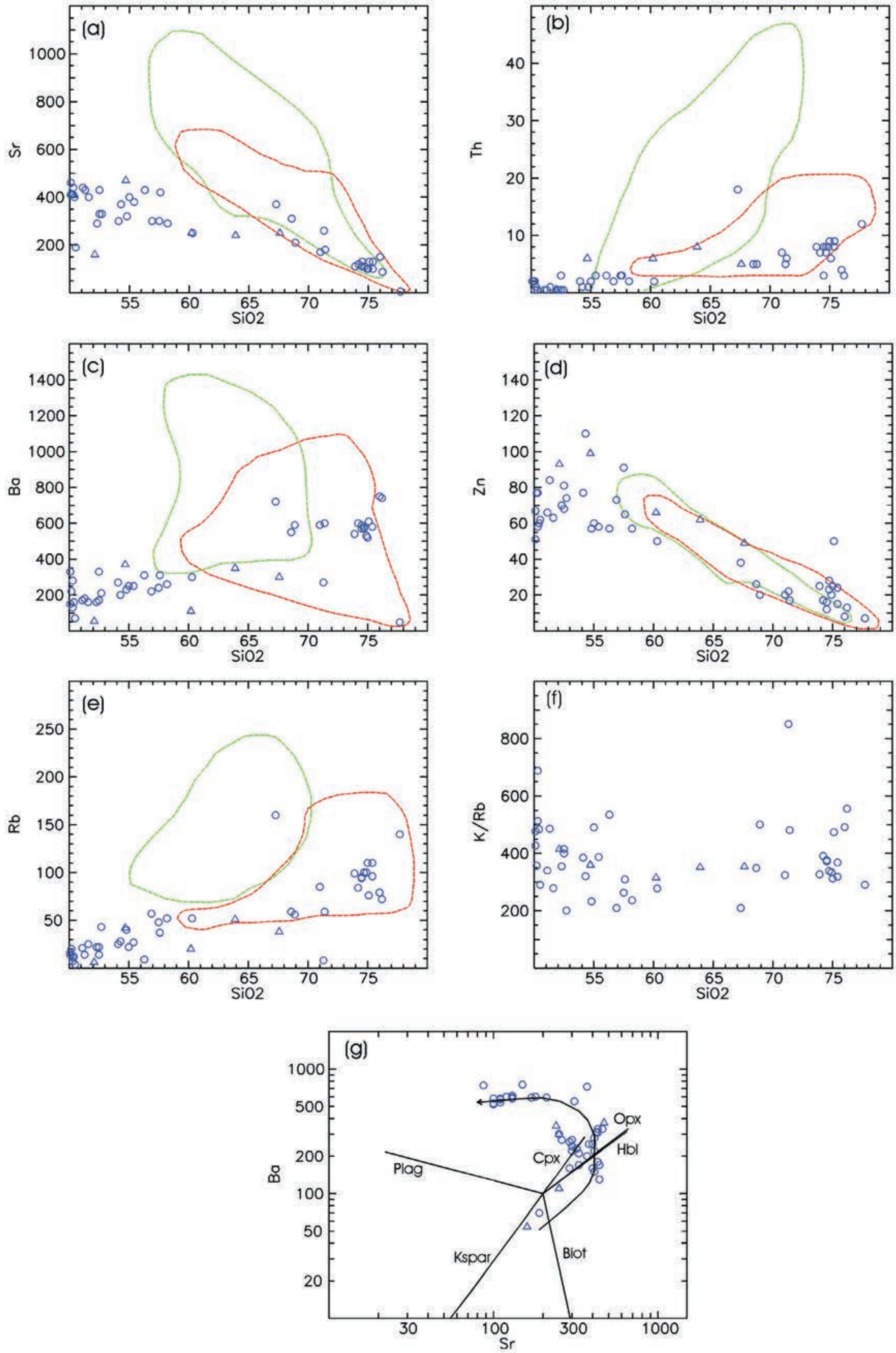

Figure 97. Variation diagrams for the early Permian Eidsvold Complex (circles) and Lookerbie Igneous Complex (triangles) showing selected trace elements in parts per million and K/Rb vs SiO_2 in weight percent. Mineral vectors in (f) are from Rollinson (1993, page 161) and show fractional crystallisation trends for Ba and Sr for the various minerals shown. The arrowed line shows an approximate overall fractionation trend for the samples plotted. Coloured fields

Data for the two complexes are shown in Figures 96 and 97 and indicate that the two complexes are chemically similar. Compared with the late Permian to Early Triassic rocks, the complexes are most similar to the Tandora Suite, although they have higher FeO_{total} and lower P_2O_5. The multi-element plot of average analyses in Figure 112b indicates that the two units are depleted in most elements, although this is probably partly due to the greater proportion of gabbro and diorite samples compared with samples defining the Tandora and Wingfield Suites. The Eidsvold Complex shows a compositional gap between the more SiO_2-rich Ceratodus Granite and a low SiO_2 group, corresponding with the Mount Rose Gabbro and Harkness Granodiorite that form a net-veined complex. The low SiO_2 group falls in the intermediate-K field of Peccerillo & Taylor (1976), whereas the more SiO_2-rich rocks are in the high-K field, but this may simply be a fractionation trend. The rocks are mainly metaluminous, but some of the more siliceous granites extend into the peraluminous field. K/Rb shows greater variation than some of the other suites, although there is no obvious trend with increasing SiO_2. Nevertheless, fractional crystallisation may account for some of the variation. The plot of Ba vs Sr suggests that fractionation of pyroxenes or hornblende and plagioclase could account for the compositional variation in these rocks.

LATE PERMIAN TO EARLY TRIASSIC PLUTONS

AISBETTS GRANODIORITE

Introduction

The Aisbetts Granodiorite is a small ovoid pluton of ~20km^2, centred ~12km north-east of Auburn homestead in southern AUBURN (Figure 98). The granite forms low hills and mostly crops out poorly, and has been delineated by its geophysical response. An unnamed pluton mapped from geophysics immediately to the east may also be part of the Aisbetts Granodiorite, the two being separated by a south-east-trending fault that partly displaces the Greencoat Monzonite to the north. The granite was previously mapped within the undifferentiated part of the Rawbelle batholith by Whitaker & others (1974).

Type locality

A type locality is designated along the Hawkwood–Auburn road at MGA 269300 7134400. Outcrop consists of grey, medium-grained, equigranular to seriate clinopyroxene-hornblende-biotite granodiorite that consists of quartz (10–15%, *ca* 1mm), plagioclase (60–70%, mostly 1–2mm, but up to 6mm, and normally zoned from Ca-andesine to oligoclase), K-feldspar (5–10%), slightly chloritised dark brown biotite (10%, to 2mm), green hornblende (5% to 1mm) that rims colourless, partly uralitised clinopyroxene (5%). Accessory titanite, zircon and opaques are present.

Lithology

The Aisbetts Granodiorite consists mainly of grey, equigranular to slightly porphyritic, medium-grained hornblende-biotite granodiorite similar to the type locality. It is not known if clinopyroxene is widespread in occurrence. At a rocky hill at MGA 271000 7137600, outcrop consists of pinkish grey, medium-grained hornblende-biotite granodiorite. It is slightly porphyritic with sparse hornblende and pink feldspar phenocrysts to 5mm. In thin section it consists of quartz (15–20%) and K-feldspar (~20%, commonly intergrown with quartz), plagioclase (~60%, as partly sericitised laths to 3mm) green hornblende (~5%) and reddish brown chloritised biotite (<5%). Some of the hornblende is acicular and may have resulted from alteration of clinopyroxene although none is now present. The granodiorite is cut by numerous aplite and dolerite dykes.

The rocks are not foliated, which distinguishes them from rocks elsewhere along the Hawkwood–Auburn road that have been assigned to the Horse Granite Gneiss. The only outcrop observed in the unnamed pluton to the east was decomposed biotite granite or granodiorite.

Geophysical response

The radiometric response of the unit is moderate to high potassium, low to moderate thorium and moderate uranium, giving overall bright pink hues on composite images. The surrounding Evandale Tonalite has a lower potassium response.

The unit has a moderate magnetic response. Magnetic susceptibility readings on two outcrops were in the range 850–1425 x 10^{-5} SI units. The unnamed pluton to the east has the same radiometric and magnetic response suggesting that it is probably part of the same unit.

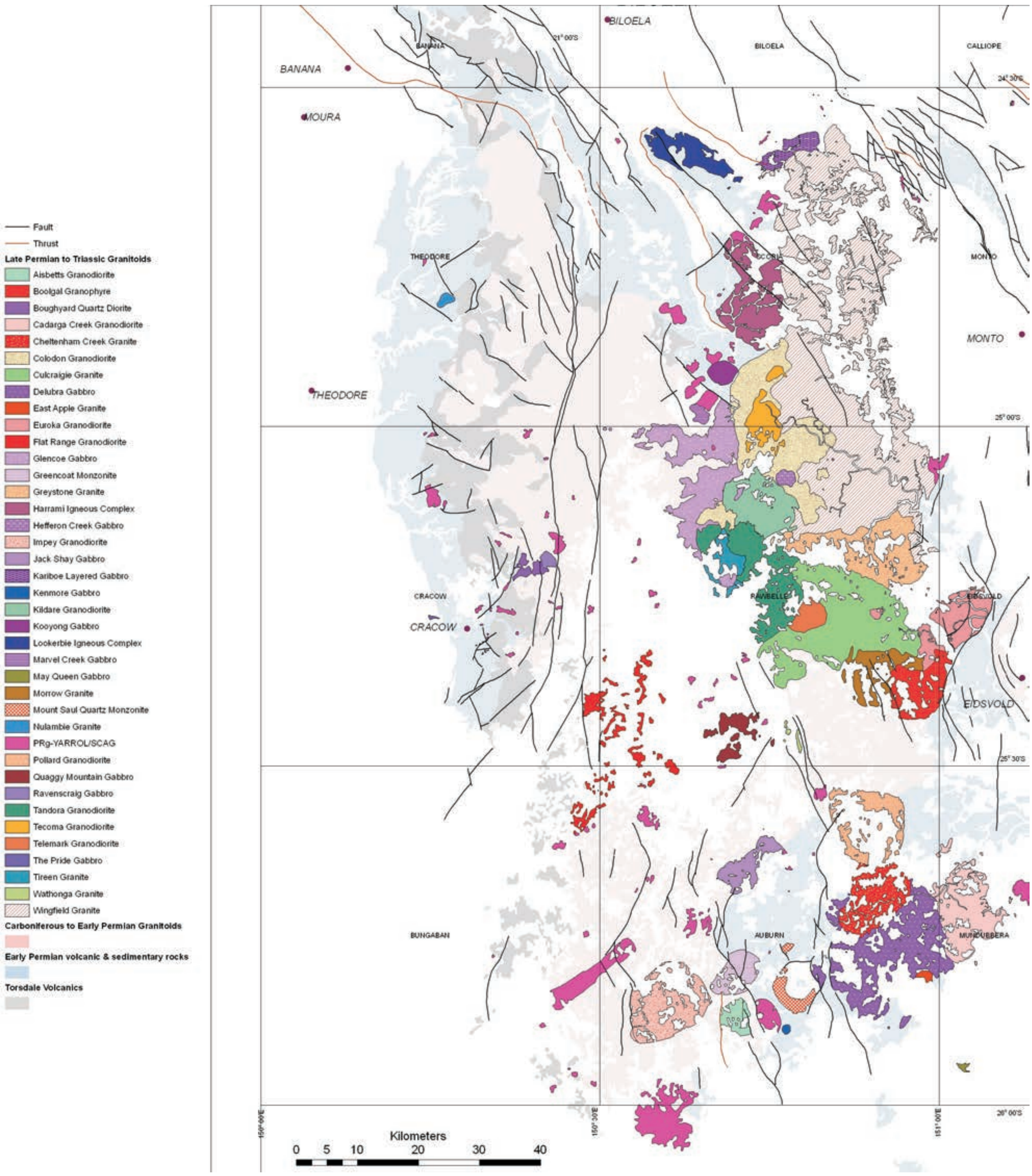

Figure 98. Distribution of late Permian to Triassic plutonic rocks of the Rawbelle Batholith

Relationships and age

The Aisbetts Granodiorite is unfoliated and probably younger than the locally foliated Evandale Tonalite, and intrudes and may have partly recrystallised the more strongly foliated rocks assigned to the Horse Granite Gneiss. The elliptical to ovoid outline in the magnetic images suggests that it probably belongs to the late Permian or Early Triassic group of units.

CADARGA CREEK GRANODIORITE

Introduction

The Cadarga Creek Granodiorite was first mapped and named by Whitaker & others (1974). The pluton has an area of ~90km^2 and is centred ~30km south-west of Mundubbera. It is the easternmost exposed part of the Rawbelle Batholith in this area (Figure 98).

The pluton is generally well exposed, even in weathered areas along the Hawkwood–Auburn River Road. It is also very well exposed at the Auburn Falls National Park (Figure 103a), and good exposure can also be found in more rugged and inaccessible parts to the south near Cadarga Creek.

Type locality

The Cadarga Creek Granodiorite is well exposed in the Auburn Falls National Park (*i.e.* MGA 304100 7154600), which is here designated as the type area (Figure 103a–b). Greenish-pink medium-grained biotite-hornblende granodiorite crops out.

Lithology

The Cadarga Creek Granodiorite consists of greenish-pink medium-grained biotite-hornblende granodiorite that could possibly grade into quartz monzodiorite. The rock consists of abundant white or pale green plagioclase to 1cm (mainly 2–5mm); ferromagnesian mineral aggregates to 1cm; and a groundmass of pale pink alkali feldspar and interstitial quartz to 2mm. Whitaker & others (1974) described a typical specimen as consisting of zoned plagioclase (oligoclase to andesine — 60%), K-feldspar (15%), quartz (15%), biotite (5%), hornblende (5%) and traces of titanite, apatite and magnetite. Mafic and intermediate microgranular enclaves are commonly abundant.

Geophysical response

The rocks are recognised on the composite radiometric images by strong potassium and low thorium and uranium responses resulting in strong pink hues on composite images that contrast sharply with the low responses in all channels and dark brownish composite hues of the Nogo beds to the north and the Delubra Gabbro to the west (Figure 102).

The magnetic susceptibilities measured in the field were mostly normally distributed in the range 600–1200 x 10^{-5} SI units with a mode at 900. This is not entirely reflected in the moderate to strong positive response in the aeromagnetic data which cannot be distinguished from that of the adjacent Delubra Gabbro (Figure 101).

Relationships and age

The Cadarga Creek Granodiorite is in contact with the Delubra Gabbro along its entire western margin. Net-veining in the east of the Delubra Gabbro near the contact with the Cadarga Granodiorite suggests the two units could have been emplaced at much the same time. The Cadarga Creek Granodiorite, the Delubra Gabbro and the Hawkwood Gabbro appear to form a complex that are scarcely distinguishable on aeromagnetic images and are possibly related.

The eastern margin of the pluton is obscured by overlying Jurassic Evergreen Formation, but the aeromagnetic data suggests that the unit does not extend much farther east beneath this cover.

K–Ar dating of the Cadarga Creek Granodiorite from a sample collected at MGA 30000 7155800 gave late Permian to Early Triassic ages (recalculated) of 242±2Ma (on biotite) and 258±8Ma (on hornblende) (Whitaker & others, 1974; Green, 1975). The older of these suggests that the granodiorite is late Permian.

CHELTENHAM CREEK GRANITE

Introduction

The Cheltenham Creek Granite was named and described by Whitaker & others (1974) as the Cheltenham Creek Adamellite. The name is changed here in accordance with modern igneous nomenclature. As now mapped the unit forms a roughly elliptical pluton ~30km^2 in area centred ~40km west-south-west of Mundubbera (Figure 98). The distribution of the unit is somewhat different from that shown by Whitaker & others (1974). The northern half of the unit as previously mapped is a separate pluton herein named Pollard

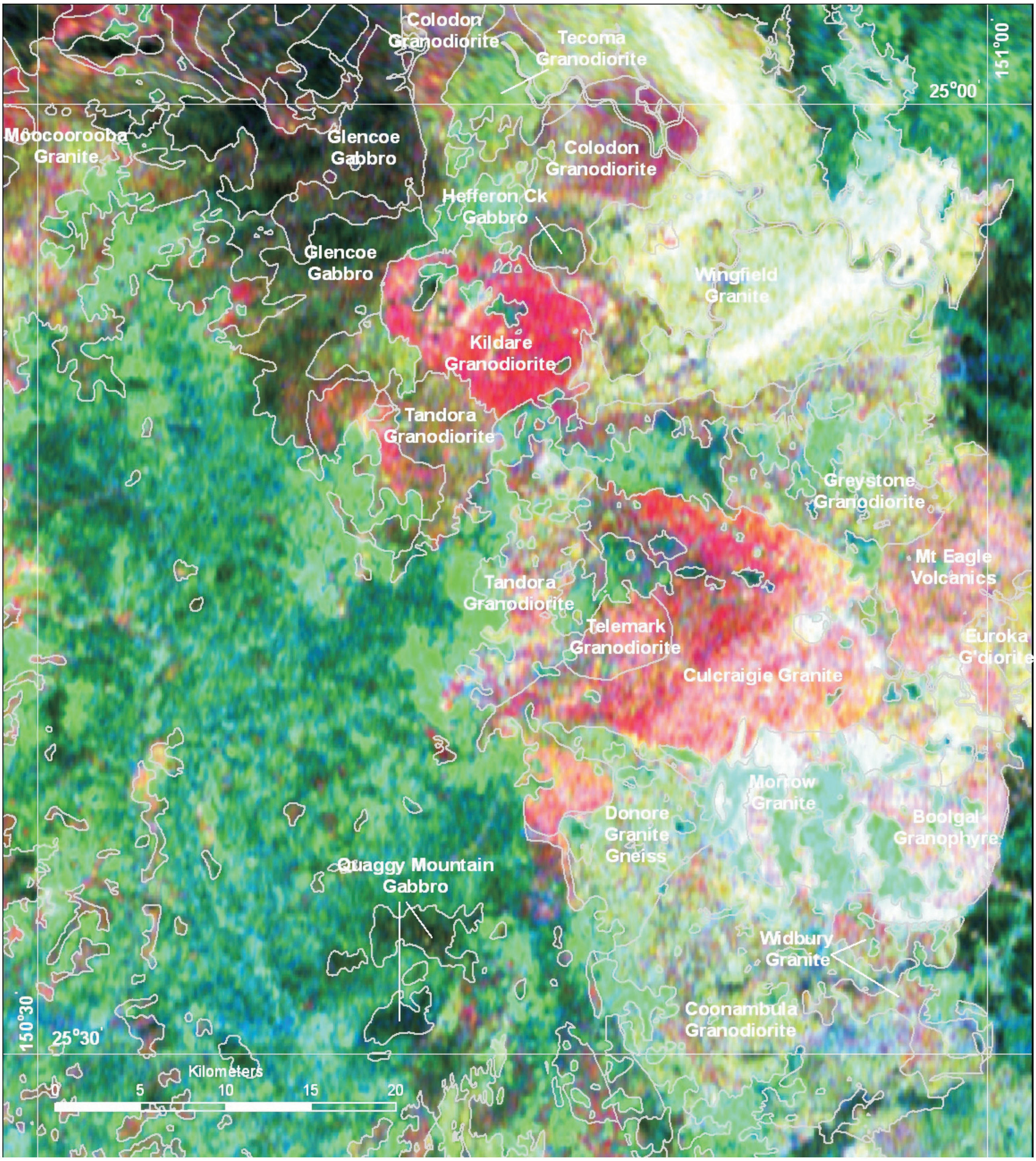

Figure 99. Radiometric image of the central part of the Rawbelle Batholith showing selected units

Granodiorite. The western boundary approximately coincides with segments of aeromagnetic lineaments and may be faulted.

Outcrop is generally poor except along the Auburn River and Cheltenham Creek. The soil is characteristically coarse textured with weathered-out feldspar megacrysts.

Type locality

The best exposures seen were adjacent to the southerly Narayen access road in the Auburn River downstream of the crossing (MGA 288300 7153600) and this is designated as the type locality (Figure 104a–d). Other excellent exposures occur elsewhere along this route. Pink to grey, coarse-grained, porphyritic hornblende-biotite monzogranite, with common to abundant alkali feldspar megacrysts to 4cm is exposed in the area. The somewhat heterogeneous nature of the monzogranite is conspicuous, and variation in the

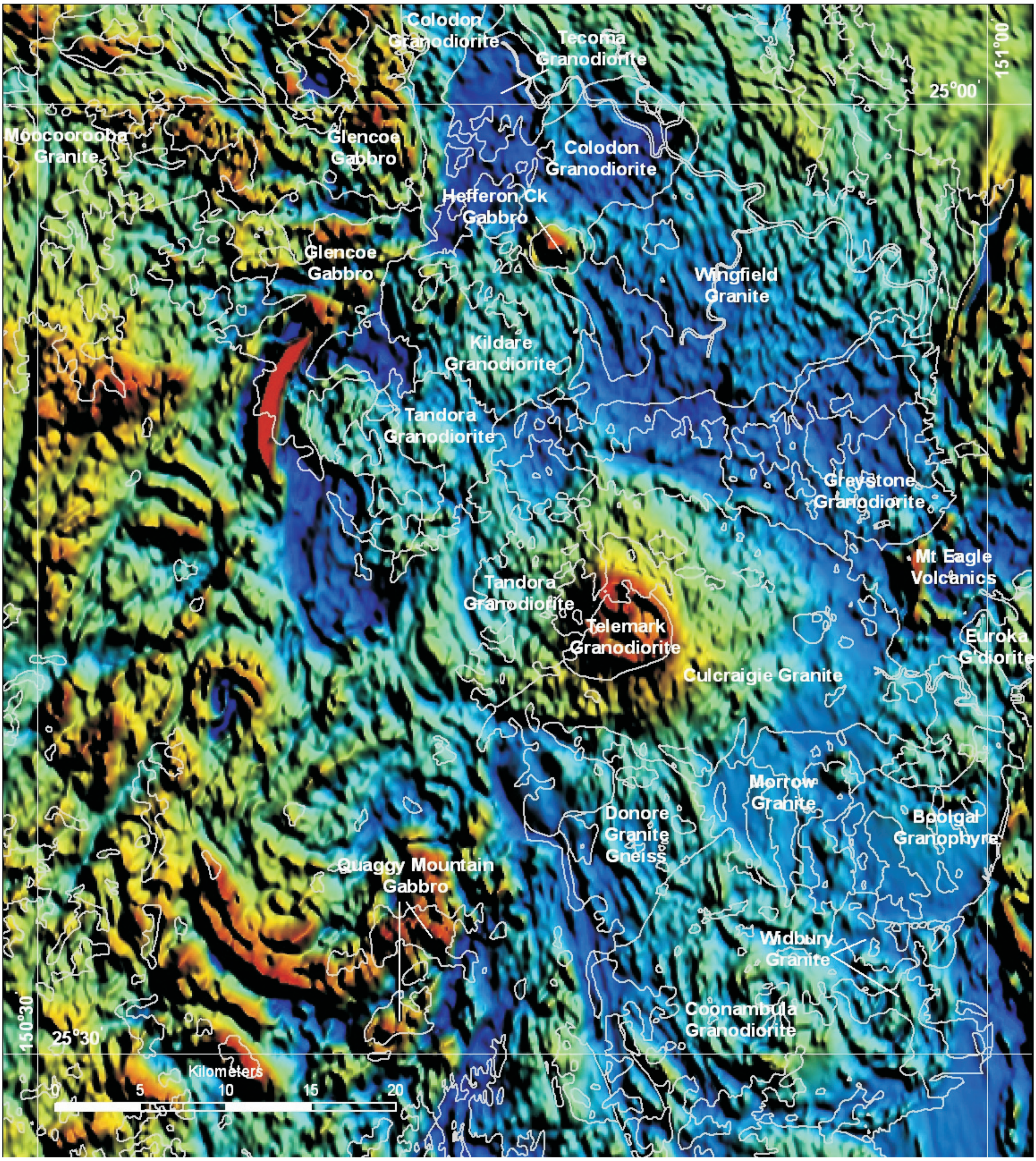

Figure 100. Magnetic image of the central part of the Rawbelle Batholith showing selected units

proportion of alkali feldspar megacrysts, mafic and felsic schlieren, and microgranular enclaves that also contain alkali feldspar megacrysts are all well displayed. In places concentrations of megacrysts form up to 80% of the rock.

Lithology

As at the type locality, the Cheltenham Creek Granite consists of pink to grey coarse-grained porphyritic hornblende-biotite monzogranite, characterised by mainly common to abundant alkali feldspar phenocrysts to 4cm (Figure 104a–d). Very abundant brownish titanite up to 1.5mm and some common allanite were observed in hand specimen. A typical specimen consists of K-feldspar (35%), zoned plagioclase (An_{30}, 40%), quartz (20%), biotite (5%), green hornblende (5%) and accessory titanite, zircon, apatite and allanite. The alkali feldspar phenocrysts appear to be anomalous, as the bulk composition does not seem sufficiently potassic for alkali feldspar to be early-crystallising.

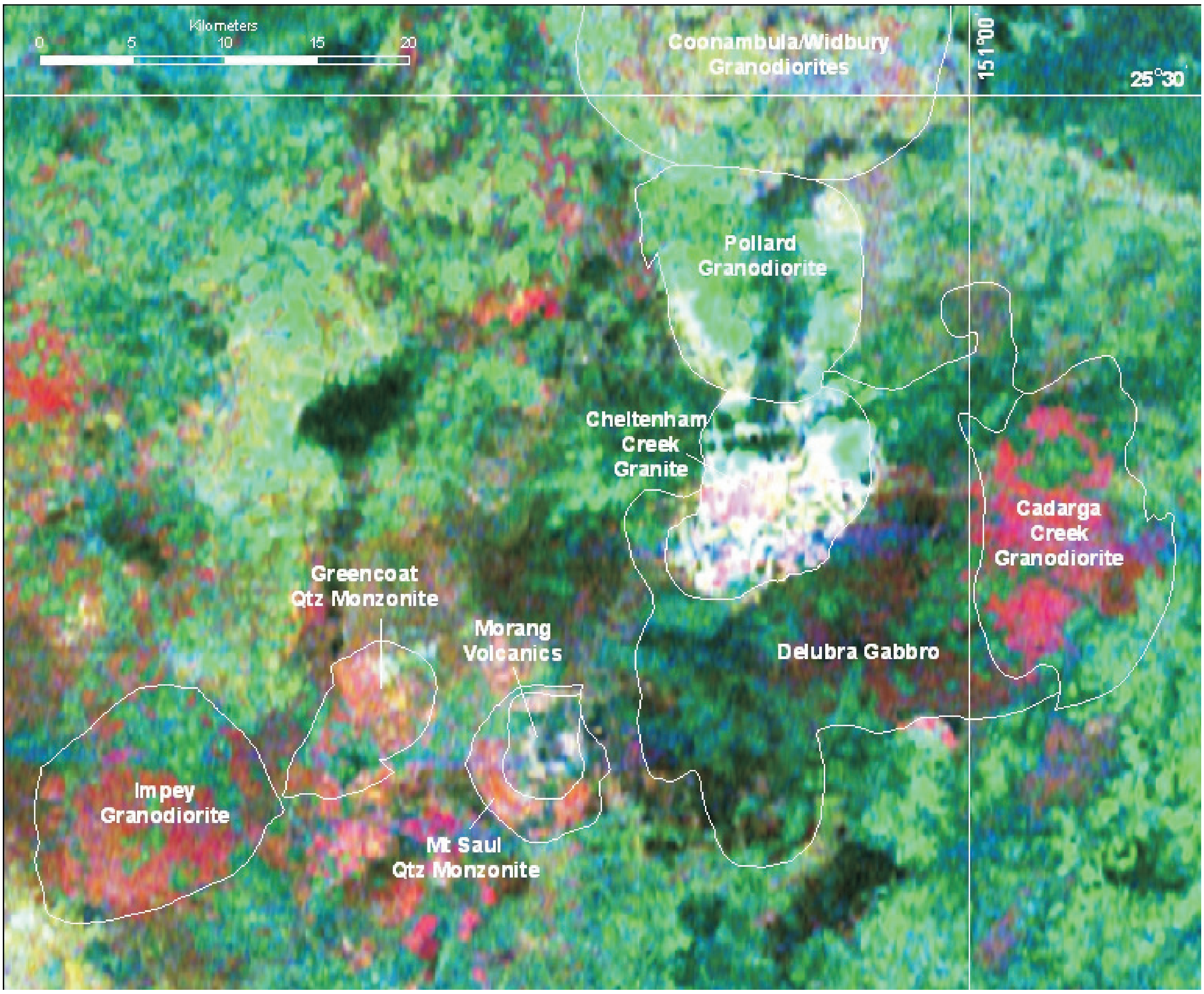

Figure 101. Radiometric image of the southern part of the Rawbelle Batholith showing selected units and their outlines based on the magnetic data

Xenoliths of variable composition and pegmatitic veins are common.

A variant of the unit observed as forming an arcuate rim around the south-western end of the pluton consists of grey, fine to medium-grained sub-leucocratic foliated biotite granodiorite. Its relationship to the main unit is uncertain.

Geophysical response

The unit has a strong radiometric response in all three channels and appears on composite images in yellowish to whitish hues (Figure 101). It has been used by airborne geophysical companies to calibrate their instruments.

The magnetic susceptibility is moderate with most values irregularly distributed between 100 and 1600 x 10^{-5} SI units with a peak at about 500. This range is similar to that for the Cadarga Creek Granodiorite. However, in contrast with the positive response of the latter on aeromagnetic images, the intensity of the Cheltenham Creek Granite is low, suggesting considerable remanence (Figure 102).

Relationships and age

The Cheltenham Creek Granite intrudes the Narayen beds and appears to be intruded in the north by the Pollard Granodiorite (based on the shape of the contact visible on aeromagnetic images). On the east, it is in contact with the Delubra Gabbro, but the poor outcrop precludes determining the exact relationship. However, the smoothly arcuate shape of the contact on aeromagnetic images suggests that the Cheltenham Creek Granite is younger. This is confirmed by the K–Ar dating.

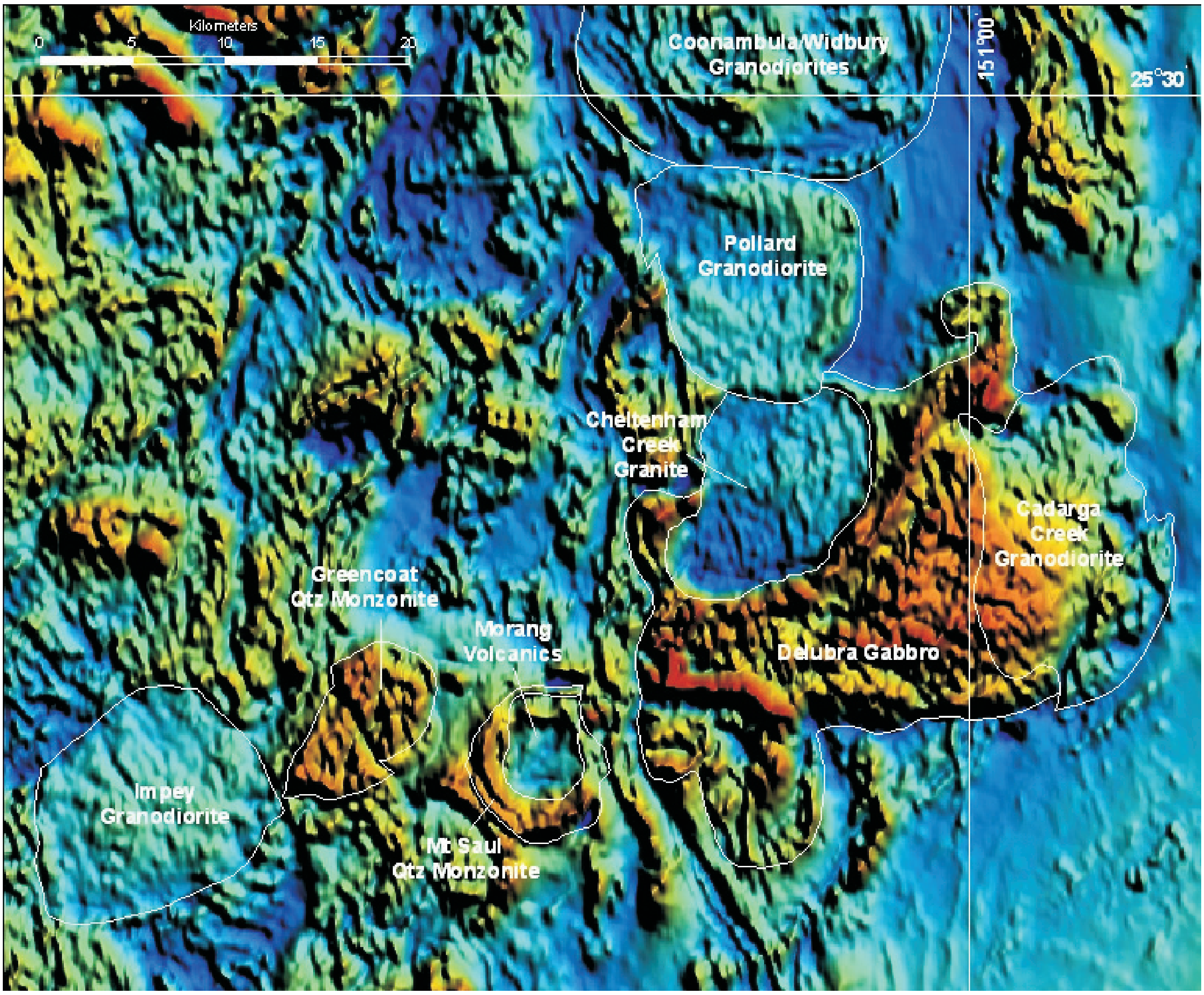

Figure 102. Magnetic image of the southern part of the Rawbelle Batholith showing selected units

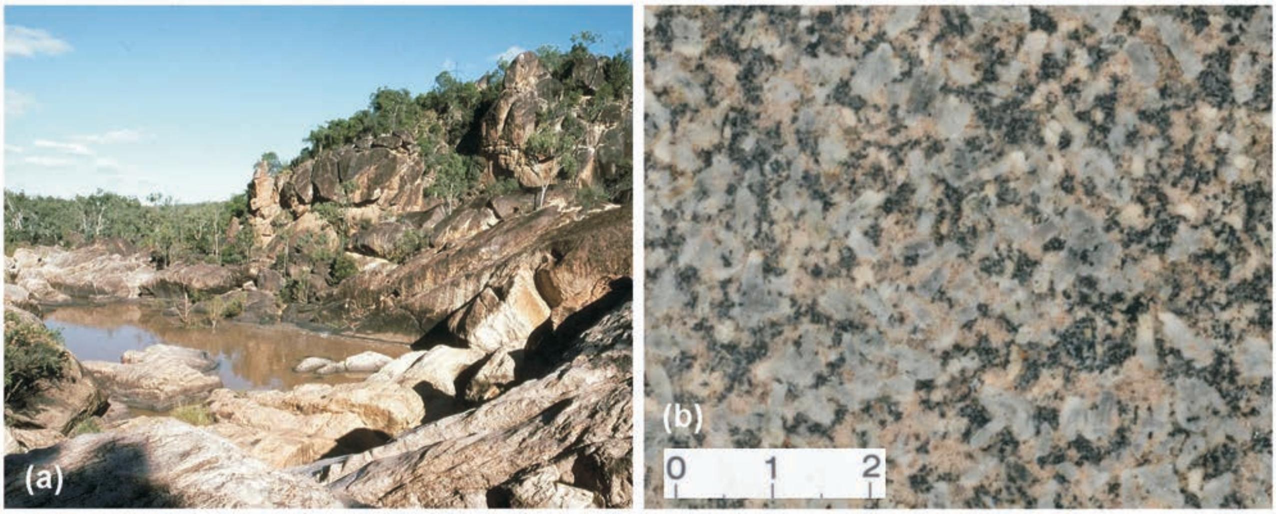

Figure 103. Cadarga Creek Granodiorite
(a) Outcrops of Cadarga Creek Granodiorite at the type locality in Auburn Falls National Park on the Auburn River at MGA 304100 7154600
(b) Scanned slab of Cadarga Creek Granodiorite; access road to Auburn Falls National Park at MGA 305226 7159411 (RSC191); scale is 2cm.

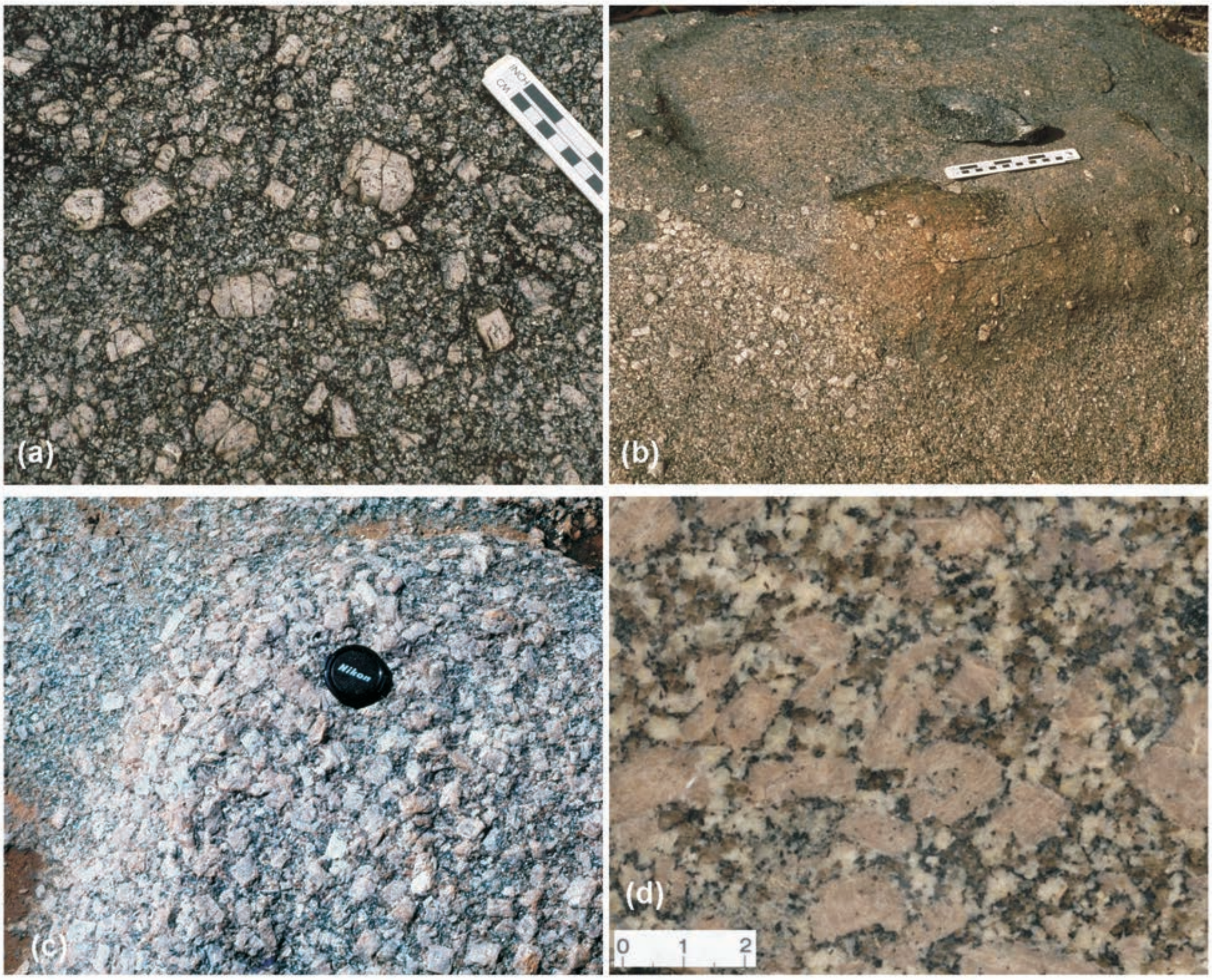

Figure 104. Cheltenham Creek Granite
(a) Porphyritic biotite granite showing characteristic large K-feldspar megacrysts, access road to former Narayen CSIRO Research Station at the crossing of the Auburn River at MGA 288304 7153612 (RSC204)
(b) Porphyritic biotite granite containing a large mafic xenolith. Note the patchy distribution of the megacrysts in the granite and the presence of similar megacrysts that have grown within the xenolith. Same locality as (a)
(c) Concentration of K-feldspar megacrysts in porphyritic biotite granite. Same locality as (a)
(d) Scanned slab of porphyritic biotite granite from locality in (a); scale is 2cm.

Thin cappings of Evergreen Formation overlie the granite in places.

K–Ar dating of the Cheltenham Creek Granite gave Early Triassic ages (recalculated) of 244±8Ma and 245±7Ma from hornblende and biotite respectively (Green, 1975; Green & Webb, 1974; Whitaker & others, 1974).

COLODON GRANODIORITE

Introduction

The Colodon Granodiorite was previously included in the Wingfield Adamellite by Dear & others (1971) and Whitaker & others (1974). It crops out along the western edge of the Rawbelle Batholith in SCORIA and northern RAWBELLE (Figure 98) as an irregularly shaped pluton of ~200km^2. Most of the outcrop is very poor and decomposed. Boulders and small tors are typical surface expressions. A smaller body to the south-west of the Kildare Granodiorite has also been tentatively assigned to the Colodon Granite, mainly based on its similar radiometric and magnetic response. It is shown on SCORIA and RAWBELLE maps as Colodon Granite, but the name is herein changed to more accurately reflect its composition.

Type locality

The type locality for the Colodon Granodiorite is designated as an outcrop west of Old Rawbelle homestead at MGA 277800 7229980. Pale grey, medium-grained, slightly porphyritic (or seriate) biotite-hornblende granodiorite was observed here. In thin section the rock contains quartz (~20%), plagioclase (~40%), K-feldspar (~15%), biotite (~10%), hornblende (~15%) and accessory titanite, apatite and zircon.

Lithology

The Colodon Granodiorite shows considerable variation and ranges from quartz monzodiorite to granodiorite (Figure 105a). The most common rock type as described at the type locality is a slightly porphyritic (seriate) biotite-hornblende granodiorite with common dioritic xenoliths mostly around 8cm but with some elongated bodies up to 25cm long. Some of these xenoliths contain feldspar and/or hornblende phenocrysts up to 5mm.

East of the Rawbelle copper mine at MGA 272600 7245300, pale grey to pink, medium grained biotite-hornblende granodiorite is characterised by the presence of numerous mafic (dioritic) xenoliths. It has a strongly developed foliation, probably of igneous origin and defined by alignment of both xenoliths and larger hornblende prisms. Titanite is a common accessory.

Such foliated granodiorite is common along the western margin and porphyritic granite, although present locally, is uncommon. Porphyritic granite in Montour Creek is similar to porphyritic granite of the Wingfield Granite apart from being foliated. It is mapped as a small subunit ($\mathbf{PRgcl_g}$). A small gabbro body adjacent to it is mapped as $\mathbf{PRgcl_{ga}}$ but is probably a separate unit like the nearby Marvel Creek and Hefferon Gabbros. Along the western margin of the pluton, pods of gneissic country rocks locally contain strongly developed vertical lineations, possibly related to the forceful intrusion of the granite.

Geophysical response

Radiometric responses indicate lower responses in all channels with respect to the Wingfield Granite, although the contrast is less marked in the potassium channel. This results in dark pinkish hues (Figure 99). The Tecoma Granodiorite has lower potassium but higher thorium.

Magnetic susceptibilities range up to 1500 x 10^{-5} SI units, but show a strongly skewed distribution with a mode at about 100, consistent with the low magnetic intensity in the airborne magnetic data compared with adjacent units (Figure 100).

Relationships and age

The Colodon Granodiorite intrudes the Mount Bulgi Conglomerate Member of the Camboon Volcanics in the north-west. However, most of its contacts are with other plutonic units. The Colodon Granodiorite is in contact with the Wingfield Granite along the latter’s western margin. It also encloses the Tecoma Granodiorite (which may be older rafts) and Hefferon Creek Gabbro (which may be intrusive into it) and is in contact with the Kooyong Gabbro and Glencoe Gabbro to the west. However, contact relationships with these units are all masked by soil cover.

Geochemically, the Colodon Granodiorite is part of the Wingfield Suite, although two samples are similar to the Tecoma Granodiorite and plot with the Coonambula Suite, suggesting that additional unmapped areas of Tecoma Granodiorite may be present.

In various places porphyritic rhyolite dykes, microgranite dykes pegmatite and aplite dykes intrude the Colodon Granodiorite.

The Colodon Granodiorite has not been dated isotopically, but is likely to be late Permian to Early Triassic as for most of the other units in the Rawbelle Batholith.

CULCRAIGIE GRANITE

Introduction

The Culcraigie Granite was named and defined by Whitaker & others (1974) as forming a large circular pluton centred on Culcraigie homestead in southern RAWBELLE and a smaller pluton near Kildare homestead to the north-west (Figure 98). The western half of this larger body is now mapped as Tandora Granodiorite and the smaller body to the north-west has been mapped as Kildare Granodiorite. The remainder of the unit

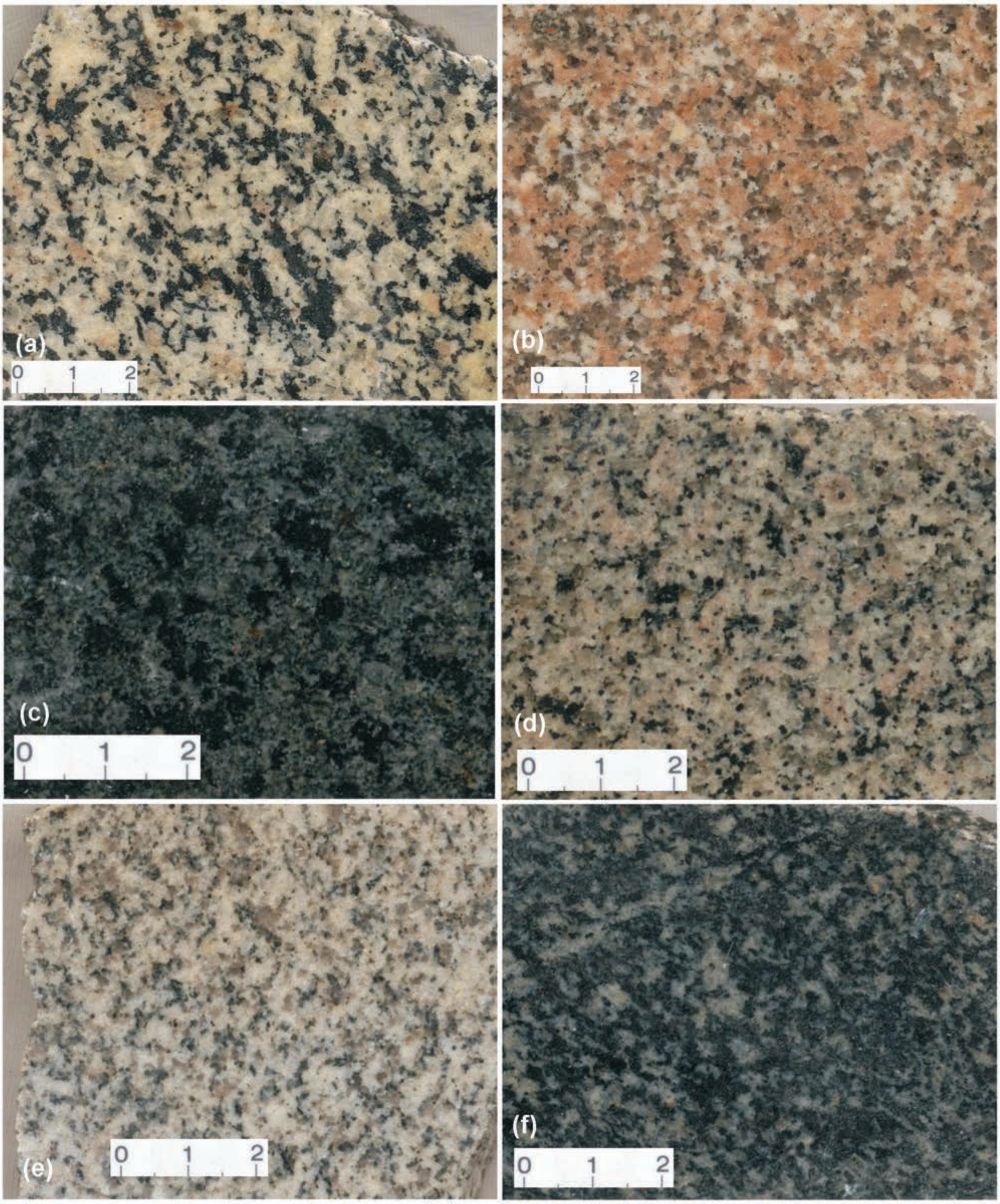

Figure 105. Late Permian to Triassic granitoids; scale is 2cm
(a) Scanned slab of titanite-bearing biotite-hornblende granodiorite of the Colodon Granodiorite; 5.3km west-north-west of Rawbelle homestead at MGA 275916 7232211 (QFG2602)
(b) Scanned slab of leucocratic biotite granite from the Culcraigie Granite; road between Tireen and Tandora homesteads at MGA 272201 7204787 (QFG2881)
(c) Scanned slab of fine-grained Delubra Gabbro showing larger poikilitic hornblende crystals; Hawkwood–Auburn River road at MGA 296761 7156669 (RSC197)
(d) Scanned slab of hornblende-biotite granite from the Euroka Granite; ~14km west-north-west of Eidsvold along the road to Culcraigie homestead near Smalls Creek at MGA 298343 7197875 (RSC178)
(e) Scanned slab of (muscovite)-biotite granodiorite from the type locality of the Flat Range Granodiorite; Auburn River crossing on Rockybar–Redbank road at MGA 254200 7177800 (RSC162)
(f) Scanned slab of hornblende-clinopyroxene gabbro from the Glencoe Gabbro; road from Glencoe to Mount Clairvoyant at MGA 263244 7222825 (RSC185)

retained as Culcraigie Granite has been subdivided into two informal units (shown as unit **PRgcc** and **PRgcc$_2$** on the map) that are lithologically similar, although having distinct radiometric responses. The unit as now mapped has an area of 200km^2.

The topography is hilly and an extensive north-east-trending dyke swarm forms closely-spaced, sharp ridges in the eastern part of the unit. The granite is deeply weathered and outcrop is typically very poor. Where present, outcrops consist of low ridges or whaleback-type exposures such as near the junction of Pelican and Smalls Creeks. No genuinely fresh rock has been observed in the entire unit. Large (1cm) quartz grains form a characteristic, very coarse, sandy soil.

Type locality

The type locality is on a ridge east of the Culcraigie–Dareen Road, ~2.3km north of Culcraigie homestead at MGA 284600 7206500. Pale pink, coarse-grained, equigranular, leucocratic alkali granite consists dominantly of mostly pink perthitic K-feldspar (~55%), quartz (~25–30%), white oligoclase (~15%) and very minor bleached biotite (~2%) and accessory opaque oxides, zircon and apatite. Sparse, small, altered mafic xenoliths are up to 4cm across.

Lithology

Rocks mapped as Culcraigie Granite in the main body are pink, coarse-grained, equigranular, leucocratic alkali granite (Figure 105b) with dominant mostly pink perthitic K-feldspar (up to 70%), quartz (~20%), white oligoclase (10–15%) and very minor bleached biotite (under 2%). Some fresher outcrops show fresh biotite flakes under 1mm, locally in clots, and also rare muscovite <0.5mm. The granite is generally very weathered and was possibly affected by hematitic alteration.

Dykes very commonly intrude the granite, particularly in the eastern portion of the southern mass. They are mostly felsite and locally have pink phenocrysts of alkali feldspar and subordinate clear quartz. Some show strong flow-banding. Near Springfield homestead, the granite is intruded by various porphyritic dykes, some of which are more intermediate, with high magnetic responses, and which may be related to the Telemark Granodiorite.

Geophysical response

The unit can be recognised on the composite radiometric images by a very strong potassium response (pink-red on composite images) whereas surrounding units have weaker responses producing paler pink to green and yellow hues (Figure 99). A subdivision of the Culcraigie Granite into the **PRgcc** and **PRgcc$_2$** units is also evident. The former is higher in all channels, particularly potassium and thorium, and has a paler pinkish hue on composite images to a deeper pink for the latter unit. However field-checking has shown the very similar rock types with possibly only a change in the degree of alteration.

The distinction between **PRgcc$_2$** and the Telemark Granodiorite on radiometric images is slight, but the magnetic response shows a marked contrast (Figure 100). The Culcraigie Granite has a moderate to low response whereas the Telemark Granodiorite forms an intense circular anomaly. Magnetic susceptibilities measured in the field for the Culcraigie Granodiorite were generally low (mostly <200 x 10^{-5} SI units and commonly 0, with an average of 134).

Relationships and age

Most of the contact relationships of the Culcraigie Granite to other units are masked by Cainozoic cover. The Triassic Mount Eagle Volcanics overlie the Culcraigie Granite in the north-east and the Triassic Boolgal Granophyre intrudes it in the east. The geophysical data suggests that the newly recognised Telemark Granodiorite also intrudes it. The dykes that intrude the Culcraigie Granite, and which may be related to the Telemark Granodiorite, have not been observed to intrude the latter. Also near the contact, the Culcraigie Granite appears to be strongly altered to kaolin and sericite(?), whereas the Telemark Granodiorite is relatively fresh.

The unit has not been dated. Whitaker & others (1974) noted that the deeply weathered nature and low and commonly altered biotite content made it unsuitable for K–Ar dating. It is probably late Permian or Early Triassic like the other units in the area.

DELUBRA GABBRO

Introduction

Whitaker & others (1974) gave the name Delubra Quartz Gabbro to all of the mafic intrusions that cropped out within the Rawbelle Batholith, although they noted that there were seven main areas. We restrict the name, which we modify to Delubra Gabbro, to the largest of these bodies, which is in the Delubra area in central AUBURN (Figure 98) and has a total area of ~140km^2. Many of the other bodies have been named separately, although some smaller ones have been included in unnamed units of diorite and gabbro (designated **PRg$_d$** and **PRg$_b$** respectively). The gabbro in the Delubra area forms undulating topography of low rounded ridges and low relief. Outcrop is poor and most of the unit appears to have been deeply weathered and locally capped by laterite.

Whitaker & others (1974) mapped and named a separate layered gabbro unit, the Hawkwood Gabbro, which adjoined the main body of Delubra Gabbro. The poor outcrop and lack of obvious geophysical contrasts made delineating a separate pluton difficult, and because layering is also developed in places within the Delubra Gabbro, the decision was made at the time of mapping to include the Hawkwood Gabbro within the former unit. Although the Hawkwood Gabbro may indeed be a separate intrusion, it is possible that the Delubra Gabbro as originally mapped may consist of multiple bodies.

Relevant university honours theses on the Delubra Gabbro (including the Hawkwood Gabbro) are by Graham (1966), Nitkiewicz (1972), McInnes (1974) and Moore (1999).

Type locality

Whitaker & others gave no specific type area for the unit. Some of the best exposures are on a ridge in the vicinity of MGA 296860 7154730 near the Hawkwood–Auburn River road, ~1.5km south-west of the Auburn River crossing. This is therefore designated as the type locality. An attempt was made to quarry the site for dimension stone in the late 1990s resulting in fresh exposures. Outcrop consists of dark grey, fine to medium-grained, rhythmically layered hornblende-clinopyroxene gabbro. The layering is mostly on the scale of several metres, but ranges down to tens of centimetres, and dips moderately to gently to the south-east, in keeping with the strike of aeromagnetic features in the area. In thin section, labradorite (30–40% to 5mm) poikilitically encloses subequant, pale green or colourless clinopyroxene (50% mostly 0.5–1.5mm). Green hornblende (~15%) partly replaces some clinopyroxene grains and also forms subhedral to euhedral, subequant crystals to 5mm across that also enclose clinopyroxene. The poikilitic plagioclase-clinopyroxene aggregates produce a characteristic ‘knobbly’ texture on weathered surfaces. This locality occurs within the area studied in detail by Nitkiewicz (1972).

Lithology

The Delubra Gabbro is a medium to coarse-grained gabbro characterised by abundant equant hornblende crystals (Figure 105c) reaching several centimetres across, poikilitically enclosing clinopyroxene and plagioclase. Smaller grains of hornblende are also present in the groundmass. Clinopyroxene (up to 40%) is present in most samples examined in thin section, and is mostly colourless or very pale green and partly replaced by hornblende. Orthopyroxene is not common and is usually rimmed by clinopyroxene and may be replaced by colourless amphibole. Plagioclase (up to 60%) is labradorite, at least in the cores, and it is commonly zoned to rims of andesine. Although it generally occurs mostly in the matrix, in some outcrops, such as at the type locality, it forms large anhedral crystals to 5mm, poikilitically enclosing the clinopyroxene. As the original name for the unit suggests, the gabbros locally contain interstitial quartz (up to 5%) and also interstitial K-feldspar. Opaque grains, probably mainly magnetite, are usually abundant, and accessory titanite and apatite are usually present.

Layering is not obvious within most outcrops, but a coating of lichen and black algae is commonly present and obscures the layering even where it is known to be present, such as at the type locality. However, it is well developed in the northern part of the unit around the type area, where it was described in detail by Nitkiewicz (1973). He identified five macro-rhythmic units on the scale of tens of metres, each consisting of plagioclase orthocumulates, plagioclase-magnetite-(olivine) mesocumulates and augite hetradcumulates, using the nomenclature of Wager & others (1960). Within them Nitkiewicz also identified rhythmic layering on a metre-scale and finer igneous layering on a centimetre-scale.

Parts of the Delubra Gabbro, particularly the eastern margin, are commonly net veined. The best net-veined exposures observed were in the south-east of the unit along Jaru Road, near the southern boundary fence of Delubra Station. Mafic inclusions are almost everywhere rounded, and larger ones showed coarser grainsize and in places chilled rinds, whereas smaller ones tend to be of a more uniform fine grainsize, with or without a rind. The granitoid veins tend to become coarser-grained in their thinner parts. They range from leucocratic biotite monzogranite to hornblende-biotite granodiorite. Small, leucocratic granitoid plugs reaching ~20m across also occur throughout some parts of the Delubra Gabbro. Net-veined outcrops also occur adjacent to the northern contact with the Cadarga Granodiorite near the Hawkwood road, just east of the Auburn River, where hornblende quartz diorite forms veins between pillow-like masses of dolerite or gabbro. These were also described by Nitkiewicz (1973).

The fact that the net-veining is interposed between the Delubra Gabbro and the Cadarga Creek Granodiorite led Whitaker & others (1974) to interpret the granodiorite as later. However, it has not been established with confidence that the granodiorite from the net-veined area is the same as, or for that matter related to, the Cadarga Creek pluton. If the granodiorite net-veins are related to the Cadarga Creek pluton, the field relationships suggest that the latter must be a similar age to the Delubra pluton. Mineral K–Ar ages for the Cadarga Creek Granodiorite and Delubra Gabbro overlap.

The southern part of the Delubra Gabbro as currently mapped was demonstrated to be a composite layered intrusion during 1950–1960s company mapping and Mines Department drilling (Brooks, 1968) and was named the *Hawkwood Gabbro.* These studies investigated the area as a source of magnetite. Company exploration of the gabbro for magnetite and more recently for platinoids was summarised by O'Brien (2001) and Child (2005), along with the results of the most recent exploration by Pan Australian Exploration Pty Ltd. To date, none of the exploration has been successful. The magnetite is titaniferous and unsuitable for coal washing. However, the complex is anomalous in platinoids and has not been fully tested.

The predominant rock type in this southern area is layered gabbro, which may be subdivided into leucogabbro (plagioclase and clinopyroxene with varying amounts of orthopyroxene, olivine and brown hornblende and magnetite), pyroxenite (mainly coarsely crystalline clinopyroxene) and ferrigabbro (magnetite, clinopyroxene, plagioclase, olivine and minor hornblende). The gabbro is cut by dyke-like masses of anorthosite (plagioclase with minor pyroxene), diorite (plagioclase, hornblende and biotite) and syenogranite. Planar structures can be observed in the gabbro as orientated tabular minerals, mainly plagioclase and hornblende. This is probably a flow foliation that formed in partly crystallised gabbro magma. However, the orientation of the flow foliation, compositional layering and overall attitude of the intrusion were not established. From the work by exploration companies (Child, 2005), there is little agreement on the direction of dip of the layering in the "Hawkwood Gabbro", although it is generally agreed that dips are shallow (10–30°). At least forty layers were identified and are typically 2–20m wide.

Irregular masses of diorite and locally abundant rafts of metasediments (fine-grained hornfels and biotite schist) derived from the Narayen beds are also present locally such as near Mount Saul homestead. One hornfels derived from the Narayen beds consists of relict plagioclase phenocrysts in a granuloblastic mosaic of plagioclase, clinopyroxene and hornblende and was probably a porphyritic andesite. The pelitic rafts appear to have been partially melted, as they contain thin ptygmatic granite veins. Amphibolite grade calc-silicate and gneiss occur near MGA 282200 7146800. Some of the "calc-silicate" rocks appear to be recrystallised granodiorite. They consist of granuloblastic quartz, plagioclase, K-feldspar, clinopyroxene and titanite, with poikiloblastic hornblende and laths of plagioclase to 5mm.

Geophysical response

The Delubra Gabbro shows the expected low response in all three radiometric channels of a gabbro (Figure 101). However, potassium is slightly elevated in the eastern half of the pluton, producing a dark pinkish mottling in composite images and possibly reflecting the presence of net-veining or magma mingling with the Cadarga Granodiorite

The Delubra Gabbro shows a wide range of magnetic susceptibility measurements from <100–5000 x 10^{-5} SI units, but there tend not to be obvious field differences between weakly and strongly magnetic rocks. The distribution of the data shows a very strong mode for values <100, but the overall mean is ~2000. Sporadic vales up to 40 000 x 10^{-5} SI units were obtained from samples of magnetite cumulate from the "Hawkwood Gabbro". All of these data are consistent with the very strongly magnetic response of the Delubra Gabbro in the airborne data, although the southern part where the "Hawkwood Gabbro" was originally mapped appears to have a somewhat lower response (Figure 102). This suggests that it could be delineated as a separate unit with further work. The hardcopy images available at the time of the fieldwork were not as clear as those available at the time of writing of this report.

Relationships and age

The Delubra Gabbro intrudes the Narayen beds and has been intruded by the Cheltenham Creek Granite. It may be intruded by the Cadarga Creek Granodiorite, but as noted elsewhere net-veining in the east of the Delubra Gabbro near the contact suggests the two plutons could have been emplaced at the same time. The unit is unconformably overlain by the Jurassic Evergreen Formation in the south-east and by Tertiary basalt near Mount Redhead. Tertiary sediments and laterite as well as younger Tertiary–Quaternary colluvial deposits also overlie it in places.

Ar^{39}/Ar^{40} dating gave late Permian ages (recalculated) of 256±14 from hornblende from a sample designated AA36 that plots in the area previously mapped as Hawkwood Gabbro (Green, 1975). As noted elsewhere in this report, samples designated AA33-35 that plot in the Pollard Granodiorite, using Green's coordinates, were probably from the Delubra Gabbro. They were included in the thesis by Nitkiewicz (1973) although locations were not given by him. They also gave late Permian Ar^{39}/Ar^{40} ages (recalculated) of 257±10Ma and 253±10Ma from hornblende and biotite respectively (Green, 1975).

An Ar^{39}/Ar^{40} age determined on hornblende at Latrobe University, as part of this project, gave an age of 261±6Ma for the Delubra Gabbro. A slightly younger K–Ar age (recalculated) of 247±7Ma from hornblende was reported by Whitaker & others (1974) may be partly reset. However, all of these ages are in error of each other and indicate that the gabbro is late Permian.

EAST APPLE GRANITE

Introduction

The East Apple Granite is a small pluton that crops out ~17km east-south-east of Hawkwood homestead in eastern AUBURN (Figure 98). The name is derived from East Apple Creek. As mapped, the granite is ~3km^2 in area, but it may extend further to the south under the cover of the Evergreen Formation. It crops out poorly in relatively subdued topography.

Type locality

A type locality is designated at MGA 297230 7143590, where boulders of pink to brown, fine to medium-grained, porphyritic hornblende-biotite granite crop out along a station track. The phenocrysts include quartz, K-feldspar and plagioclase. Plagioclase phenocrysts are up to 1cm long. The groundmass consists of subequal amounts of quartz, K-feldspar and plagioclase mainly 0.25–1mm. Biotite (1–2%) forms partly chloritised dark brown flakes up to 3mm across. The sparse hornblende prisms are up to 2mm long and occur in clusters ~5mm across.

Lithology

No other outcrops were examined in the outcrop area, other than MGA 298100 7143800 where weathered, mottled, medium to coarse-grained, porphyritic granite underlies Cainozoic sandy claystone.

Geophysical response

The granite has high potassium, low to moderate thorium and moderate to high uranium radiometric responses, resulting in pale pink hues on the composite images that contrast with the low response in all channels of the Delubra Gabbro to the north, and the low potassium, high thorium and low to moderate uranium of the Evergreen Formation.

The unit has a low magnetic response, which contrasts with that of the Delubra Gabbro, but cannot be easily distinguished from that of the Narayen beds, making mapping it under cover to the south difficult.

Relationships and age

The East Apple Granite intrudes the early Permian Narayen beds and is overlain by the Jurassic Evergreen Formation. Its relationship to the Delubra Gabbro is not known. Its age is uncertain, but is probably late Permian or Early Triassic.

EUROKA GRANODIORITE

Introduction

The Euroka Granodiorite is a new name for a granite pluton that is centred ~15km north-west of Eidsvold in eastern RAWBELLE (Figure 98). The name is derived from Euroka homestead. The unit was previously mapped as undifferentiated "Rawbelle Batholith" by Whitaker & others (1974). As now exposed it crops out as two discrete areas separated by a narrow belt of younger Triassic Mount Eagle Volcanics. However, these areas are probably continuous under this cover. Total exposed area is ~60km^2. Outcrop is mainly scattered boulders and local whalebacks. The name Euroka Granite is shown on the RAWBELLE and EIDSVOLD maps, but is changed herein to more accurately reflect the dominant rock type.

Type locality

The type locality is situated near Euroka homestead at MGA 296900 7198900 in the westernmost outcrop area. Fine to medium-grained, light grey, equigranular biotite-hornblende granodiorite forms boulder and whaleback outcrops. The granite contains quartz (~29%), plagioclase (~45%), K-feldspar (~15%), biotite (~3%) and hornblende (~7%) and conspicuous titanite (~1%).The granodiorite is fairly homogenous and shows rare small (2–8cm) elongated black microdioritic xenoliths.

Lithology

The dominant rock type is similar to that at the type locality, and consists of fine to medium-grained, equigranular biotite-hornblende granodiorite (Figure 105d). It contains quartz (~30%), plagioclase (~30–45%), K-feldspar (~15–30%), biotite (~3–5%), hornblende (~4–9%), titanite (1–3%) and opaque oxides. Local, slightly elongated and rounded, mafic xenoliths are up to 45cm long, but are generally 2–10cm. Close to the contact with the Boolgal Granophyre the granite is strongly altered to kaolinite.

Northwest of the Burnett and Nogo Rivers junction at MGA 304100 7205600, medium to coarse-grained porphyritic biotite-hornblende granodiorite with numerous large dioritic xenoliths was observed. This rock type appears to be more common in the northern part of the Euroka Granodiorite. The feldspar megacrysts are K-feldspar. Overall the granite consists of K-feldspar (~40–50%), plagioclase (oligoclase, ~35%), green hornblende (5–10%), biotite (5–10%) and quartz (~12%). Accessories include titanite, apatite and opaque oxides (probably magnetite). Similar rocks were observed along the Nogo River north of the Burnett River junction at MGA 303300 7207100. Some leucocratic biotite granite was observed west of Euroka homestead.

Geophysical response

The unit is represented on composite radiometric images by pale yellowish to whitish hues due to strong responses in all channels (Figure 99). These contrast with the pinkish hues of the Mount Eagle Volcanics, which are relatively low in uranium and thorium, and the dark hues of the Nogo beds that have low radiometric responses in all channels.

The unit shows some variation in magnetic intensity in the airborne data. The western half is only low to moderately magnetic, whereas the eastern half is moderately to strongly magnetic. This may correspond to the change from equigranular to porphyritic granodiorite. Magnetic susceptibility values measured in the field show a similar variation. A bimodal distribution is evident with modes at 300 and ~1100 x 10^{-5} SI units. Most readings were <1500 x 10^{-5} SI units. This suggests that two units may be present, but the outcrops are not significantly different to separate them, and the radiometric data is uniform over the mapped extent of the unit.

Relationships and age

No isotopic dating has been attempted for the Euroka Granodiorite. It is intruded by the Late Triassic Boolgal Granophyre and overlain by the Triassic Mount Eagle Volcanics. The eastern contact with the Nogo beds may be intrusive or structural but the early Permian Nogo beds are interpreted to be older. These relationships and the similarity to other units in the Rawbelle Batholith suggest a late Permian to Middle Triassic age. The granodiorite has been intruded by various porphyritic dacitic to rhyolitic dykes, probably related to the Mount Eagle Volcanics.

FLAT RANGE GRANODIORITE

Introduction

The name Flat Range Granodiorite is given to a series of scattered outcrops or ‘windows’ separated by Cainozoic cover deposits, including duricrust, in the southern part of the Auburn Plateau in south-western RAWBELLE, and north-western AUBURN (Figure 98). The name is derived from Flat Range homestead. Total area of the unit is ~300km^2, but only ~50km^2 is exposed. Most outcrops are weathered and commonly leached and mottled.

Type locality

The type locality of the Flat Range Granodiorite is at the Auburn River crossing on Rockybar–Redbank road at MGA 254200 7177800. Here good outcrop of medium-grey, medium-grained equigranular muscovite-biotite granodiorite was observed (Figure 105e). The rock at the type locality comprises quartz (45%), plagioclase (40%), biotite (7%), muscovite (~1%) and opaques (2%). K-feldspar is only minor. Accessory zircon and apatite are present. Mafic xenoliths are sparsely distributed.

Lithology

Most outcrops are similar to the type locality, but some porphyritic variants were noted. For example, on Rockybar Road, near the Lone Pine turnoff at MGA 253500 7193000, pink, medium-grained, porphyritic biotite granodiorite contains K-feldspar megacrysts to 1cm. Some accessory titanite, smoky quartz and another tabular black mineral, possibly tourmaline (?) were also observed.

Within the area of the Flat Range Granodiorite, several outcrops of gabbro and diorite were also observed. For example, on the southern side of the Eidsvold–Theodore road, west of Calrossie Station, at MGA 249000 7196300, dark grey, medium grained gabbro containing hornblende, orthopyroxene and clinopyroxene crops out.

Geophysical response

The radiometric response for the Flat Range Granodiorite is moderate to high in the potassium channel, but low to moderate in thorium and uranium. This results in pale pinkish hues on composite images, which contrast with the dark greens denoting the Tertiary–Quaternary cover.

Magnetic susceptibilities measured in the field range up to 2500 x 10^{-5} SI units with a bimodal distribution showing modes at about 400 and 1600 (average 925). On images, the Flat Range Granodiorite shows a moderate magnetic response consistent with these values. Smaller peaks of higher magnetic anomalies within the area of the Flat Range Granodiorite are interpreted to be small gabbro intrusive bodies such as that described above. They may be related to the Quaggy Mountain Gabbro that crops out to the east.

Relationships and age

Contact relationships with other units are obscured by the Cainozoic cover. The Flat Range Granodiorite is probably late Permian or Early Triassic. Green (1975) and Whitaker & others (1974) reported a K–Ar biotite age of 245Ma (adjusted for IUGS constants) from a granodiorite north of Lone Pine homestead at MGA 253500 7192500 and another biotite age of 240Ma (adjusted) from a granodiorite south-west of Calrossie homestead at MGA 255200 7194700.

GLENCOE GABBRO

Introduction

The Glencoe Gabbro is a new unit in northern RAWBELLE extending into SCORIA. The name is derived from Glencoe homestead in north-eastern RAWBELLE (Figure 98). The gabbro has an exposed area of ~130km^2, but it may extend under the Cainozoic cover of the Auburn Plateau, which is mostly underlain by rocks with a similar strong magnetic response. Whitaker & others (1974) assigned the unit to the Delubra Quartz Gabbro, although parts of the outcrop area were included in the Glandore Granodiorite. Relief over the unit is slight and the topography typically consists of low undulating hills. Outcrop is generally poor and usually occurs as scattered, rounded, residual boulders, surrounded by deeply weathered material.

Type locality

A type locality is designated along the Tireen–Glencoe Road at MGA 262200 7214400, where boulders of dark greenish, grey medium-grained equigranular pyroxene-hornblende gabbro crop out. The rock comprises plagioclase (45%), hornblende (35%), secondary chlorite (15%), some pyroxene (mostly uralitised), minor altered biotite, opaque oxides (probably magnetite, <1%) and traces of titanite.

Lithology

The Glencoe Gabbro consists dominantly of medium to coarse-grained, equigranular, melanocratic clinopyroxene-hornblende gabbro (Figure 105f). The pyroxene is commonly uralitised. Coarse-grained mesocratic hornblende gabbro with some quartz-feldspar-hornblende pegmatoid veins also crops out.

At MGA 260200 7227900 and MGA 260000 7228100, west of Mount Runsome, medium to coarse-grained, melanocratic hornblende–clinopyroxene gabbro comprising clinopyroxene (~60%, mostly altered to secondary hornblende), brown hornblende (~30%, also altered) and plagioclase (~ 10%, andesine, interstitial and slightly poikilitic) and minor magnetite was observed.

Another rock observed south of Mount Clairvoyant at MGA 261100 7230400 is a coarse-grained, mesocratic hornblende gabbro with some quartz-feldspar-hornblende veining. This rock comprises plagioclase (~55%, labradorite) and green hornblende (~40%). Magnetite (~2%) is closely associated with hornblende, and minor interstitial K-feldspar and quartz is present.

Geophysical response

The Glencoe Gabbro can be recognised on the composite radiometric images by a low response in all channels resulting in dark brown hues (Figure 99).

Magnetic susceptibilities measured in the field are highly variable and range up to ~10000 x 10^{-5} SI units although most values are <2000, and the data have a strongly skewed distribution with a mode corresponding to values <100. These low values may be due to depletion of magnetite accompanying the widespread uralitisation. In spite of these low values, the unit shows an overall moderately strong response in the airborne magnetic data. One area with a particularly strong response is south of Glencoe homestead, where a north-trending, slightly arcuate anomaly 9km long and 1.5km wide is present.

Relationships and age

The Kildare Granodiorite, Crystal Vale Monzogranite and Tandora Granodiorite (all probably late Permian to Early Triassic) and the Crystal Vale Monzogranite, Mount Clairvoyant Granite and the Moocoorooba Granite (Carboniferous) are in contact with the Glencoe Gabbro although no contact relationships have been observed. The Mount Clairvoyant Granite and Crystal Vale Monzogranite are recrystallised with sugary textures and may be intruded by the Glencoe Gabbro. At Mount Runsome, a Cretaceous basalt plug clearly intrudes the Glencoe Gabbro.

The age is uncertain, but is inferred to be late Permian to Early Triassic like the Delubra Gabbro, another extensive gabbro unit farther south.

GREYSTONE GRANODIORITE

Introduction

The Greystone Granodiorite is a new name for an area of granitoids that is centred ~30km north-west of Eidsvold in eastern RAWBELLE (Figure 98). The name is derived from Greystone Station. The rocks were previously mapped as undifferentiated “Rawbelle Batholith” by Whitaker & others (1974). It has an area of ~200km^2, but part of this is covered by thin Tertiary deposits. Outcrop is very poor and mainly restricted to isolated boulders. Some whaleback exposures are present but the rocks are generally very weathered. Ridge-forming felsic dykes are the most common outcrop. The name Greystone Granite is used on the RAWBELLE map, but is herein changed to more accurately reflect the dominant rock type.

Type locality

The type locality nominated for the Greystone Granodiorite is south-east of Dareen homestead at MGA 284800 7215300. Boulders of relatively fresh fine-grained, pale grey equigranular hornblende-biotite granodiorite (Figure 106a) occur within abundant decomposed material. The granite contains quartz (~30%), plagioclase (~40%), K-feldspar (~15%), biotite (~10%), hornblende (~3%), conspicuous titanite (~1%) and opaque oxides. Chlorite replacing mafic minerals is also present. The granite contains rare small pink K-feldspar phenocrysts and sparse elongated dioritic enclaves 3–6cm long.

Lithology

The Greystone Granodiorite consists of fine to medium-grained, mostly equigranular hornblende-biotite granite to granodiorite with common titanite as at the type locality. Sparse microdiorite enclaves are usually present. Some outcrops are slightly porphyritic with rare small pink K-feldspar phenocrysts. Sparse microdiorite enclaves are usually present.

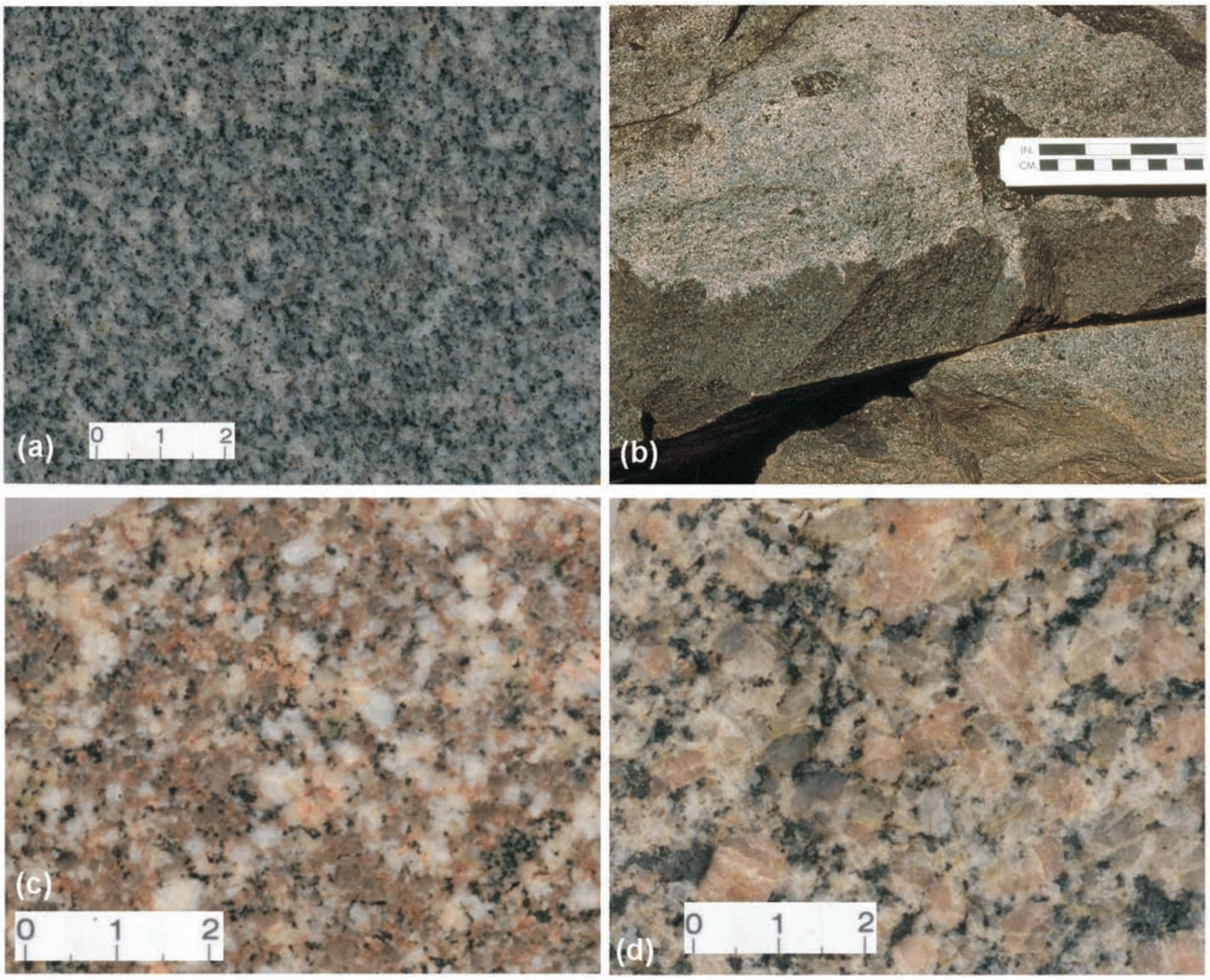

Figure 106. Late Permian to Triassic granitoids (continued); scale is 2cm in (a), (c) and (d)
(a) Scanned slab of fine-grained hornblende-biotite granodiorite from the type locality of the Greystone Granite. South-east of Dareen homestead at MGA 284800 7215300 (QFG2539)
(b) Complex crenulated contact suggestive of magma mingling between fine-grained granodiorite and gabbro or diorite in the Harrami Igneous Complex. Beside Bunns Road ~5km west-south-west of Mount Hindmarsh at MGA 267283 7253065 (LHT453)
(c) Scanned slab of fine-grained (hornblende)-biotite granodiorite from the type locality of the Impey Granodiorite. Auburn-Sujeewong road south of Mount Auburn Outstation at MGA 257098 7142977 (RSC214)
(d) Scanned slab of coarse-grained hornblende-biotite monzogranite or granodiorite of the Kildare Granite. Glencoe–Dareen road about 3km east-south-east of Kildare homestead at MGA 273641 7216292 (RSC189)

Biotite granite or granodiorite is more common in the eastern half of the unit. For example, along a track near Sandy Creek, west of the Nogo River at MGA 293400 7216500, outcrops consist of purplish-cream, moderately weathered, porphyritic biotite granite containing brown K-feldspar megacrysts to 3cm.

At Yard Creek, along a track on the western side of Waruma Lake at MGA 293500 7211500, near the eastern margin of the unit, outcrops of strongly foliated compositional banded biotite orthogneiss similar to that in the Coonambula Granodiorite were observed. It consists of quartz (~35%), feldspar (~55%, mostly plagioclase) and strongly aligned biotite (~7%). Its relationships to the granite are uncertain.

The unit has been extended farther west than shown on an earlier version of the RAWBELLE geology map and in the Central Queensland GIS. It now includes rocks that had been mapped as Tandora Granodiorite. This was based on recognition of a similar radiometric signature of these rocks to the main area of Greystone Granodiorite. This area also includes biotite-hornblende diorite to gabbro, biotite diorite and hornblende tonalite. These are similar to components of the Glencoe Gabbro, suggesting that the units may be complexly intermixed, possibly because of magma mingling.

Geophysical response

On radiometric images, the Greystone Granodiorite has only moderate responses in the three channels resulting in greyish brown hues on composite images that contrast markedly with the whites and pinks of the surrounding units (Figure 100). The response is similar to the Coonambula Granodiorite and Widbury Granite, to which at least part of the unit is related geochemically (see page 295 and below).

The overall magnetic response for the Greystone Granodiorite is low (Figure 100) with some positive linear features (possibly later dykes). Although magnetic susceptibilities range up to 800 x 10^{-5} SI units, they show a strongly skewed distribution with a strong mode <10 and a long tail with a weak mode at ~500 x 10^{-5} SI units.

Relationships and age

The Greystone Granodiorite is bounded by the Culcraigie Granite to the south and south-west and the Wingfield Granite to the north, but the intrusive relationships are not known. The western part of the unit that was formerly mapped as Tandora Granite is bounded by the Kildare Granodiorite, Tireen Granite and the Tandora Granodiorite. Rhyolite dyke swarms within the Greystone Granodiorite, similar to the ones found in the Culcraigie Granite, may be related to the Middle Triassic volcanic units of the area such as the Mount Eagle Volcanics. The Mount Eagle Volcanics unconformably overlie the Greystone Granodiorite to the south-east.

The exact age is not known, because the unit has not been isotopically dated. On the RAWBELLE map, it is shown as late Permian to Early Triassic, but geochemical affinities suggest that part of it is likely to be related to the Coonambula Granodiorite and Widbury Granite, which are dated as early Permian.

The geochemistry suggests that the unit as mapped may be composite. Six samples from the Greystone Granodiorite plot with the Coonambula Suite and have lower Sr and higher TiO_2, FeO_{total} and Zn than either the Tandora or Wingfield Suites (Figures 94 and 95). These are from the eastern half of the unit, and include the gneissic rocks and biotite granite described above. Like the Coonambula Granodiorite, these samples are peraluminous with three samples having an ASI >1.1, suggesting that they may be S-type granites. Three other samples from farther west, including the type locality, plot with the Tandora Suite. These are only mildly peraluminous and the samples contain modal hornblende. Further work is needed to resolve the distribution of these different suites within the Greystone Granodiorite as currently mapped.

HARRAMI IGNEOUS COMPLEX

Introduction

The Harrami Igneous Complex crops out over ~80km^2 in the central part of SCORIA (Figure 98) from near the Rawbelle copper mine in the south to the Coominglah Road in the north. The name is derived from the parish of Harrami. In general, outcrop is very poor.

Type and reference localities

The type locality of the Harrami Igneous Complex is designated on a hill west of Wollowra homestead at MGA 265900 7253400. Light grey to greyish black, medium-grained monzodiorite comprises quartz (~5%), oligoclase to andesine (60–65%), microcline (10–15%), hornblende, some with pyroxene cores, (~15%), biotite (3–4%), opaque oxides, titanite, apatite and epidote. Chlorite is also present as an alteration product.

A reference locality is defined along Bunns Road at MGA 267300 7253100, where magma mingling and net veining between the three magma types is evident (Figure 106b). Pale grey to black, medium-grained gabbro is mingled with medium grey, fine-grained diorite and pale grey, fine to medium-grained, biotite granodiorite.

Lithology

Monzodiorite and hornblende gabbro are probably the most abundant rocks in the complex, but granite and granodiorite are locally mingled with the more mafic rocks.

West of Mount Hindmarsh on The Ponds Station, diorite to quartz monzodiorite comprises quartz (~5%), K-feldspar (~10%), plagioclase (~60%), hornblende (cored by pyroxene) (~7%), clinopyroxene (~10%), biotite (~4%) with minor apatite, zircon and opaque oxides. In Harrami Creek south-west of Mount Hindmarsh, light grey, fine to medium-grained biotite granite or granodiorite is mingled with dark grey, medium grained hornblende gabbro. Granite is also found in a creek in eastern Glenhalvern Holding, south of Mount Hindmarsh.

Light grey to black, medium-grained diorite on Coorardoo Holding south of the Coominglah Road, comprises quartz (3–5%), andesine to labradorite (40–45%), biotite (10–15%), hornblende (15–20%), pyroxene (~10%), apatite and opaque oxides. This rock type contains clumps of biotite up to 2cm across. Such clumps are common in granodiorite/diorite in the Harrami Igneous Complex, and also occur in the Hildura Quartz Monzodiorite.

At the northern end of the Harrami Igneous Complex on Yagoondy Station, biotite-pyroxene diorite comprises quartz (2–5%), andesine (45–50%), clinopyroxene (25–30%), biotite (5–10%), K-feldspar (~5%), with traces of opaque oxides and apatite. Also in the north, biotite-hornblende diorite comprises andesine (50–55%), hornblende (15–20%), biotite (15–20%), quartz (5–7%), opaque oxides (1–2%), with traces of calcite and apatite. The hornblende has cores of pyroxene, suggesting that much of the hornblende may be formed by alteration of pyroxene.

Geophysical response

Low responses in all three radiometric channels over most of the complex and resultant dark greenish to purple hues on composite images (Figure 82) are consistent with gabbro and diorite or monzodiorite being the most common rocks. However, slightly higher responses in the three components, resulting in mottled pinkish hues in the northern part of the complex, suggest that granite or granodiorite may be more abundant there.

The Harrami Igneous Complex corresponds to a large aeromagnetic high, which contrasts with the more moderately magnetic Wingfield Granite to the east (Figure 83). The magnetic high extends beyond the mapped boundary of the unit in the west, suggesting that the contact may be shallowly dipping there, but it appears to be steep in the east and corresponds well with the mapped contact with the Wingfield Granite.

Magnetic susceptibilities for the more mafic components of the complex show a normal distribution with most values lying between 500–3500 x 10^{-5} SI units and a mean of 2100. Sporadic values up to 8700 were recorded. Measurements on the granite show a skewed distribution with a mode at about 200 and values extending to 2000.

Relationships and age

The Harrami Igneous Complex intrudes and has hornfelsed dacitic to basaltic rocks of the Camboon Volcanics north and west of Wollowra homestead. To the east, it appears to be intruded by the Permian to Triassic Wingfield Granite, but this contact is poorly exposed and mostly overlain by Tertiary basalt. The magnetic data indicates that it is relatively straight and steep and may be faulted.

The age is not known precisely. A Permian age is assigned as it intrudes the early Permian Camboon Volcanics and appears intruded by the late Permian to Early Triassic Wingfield Granite.

In various plots in Figure 110 and 111, analyses of the more SiO_2-rich samples from the Harrami Igneous Complex plot with both the Tandora and Wingfield Suites, but TiO_2 is lower than either of these suites, and the complex may represent a separate suite of its own. Relationships in the unit are very complex, with common examples of magma mingling, and a more extensive controlled sampling program than attempted herein would be needed to study it effectively. Most samples, even the gabbros, lie in the high-K field, which distinguish them from the other gabbro units in the Rawbelle Batholith.

HEFFERON CREEK GABBRO

Introduction

The Hefferon Creek Gabbro is a previously unmapped unit in northern RAWBELLE, north of Hefferon Creek from which the unit is named (Figure 98). It forms a small circular pluton ~2.5km in diameter. Outcrop is very poor and the unit is represented on the surface by a reddish heavy clay soil. A few fresh boulders were located and more resistant pegmatites and quartz blows crop out.

Type locality

The type locality is one of the few outcrops located, and is at MGA 275200 7224600 along a track near Two Mile Creek, ~7km north-west of Dareen homestead. Dark green, medium to coarse-grained, hornblende-clinopyroxene gabbro comprises white plagioclase (~50%), clinopyroxene (~35%), hornblende (~10%), opaque oxides (~ 7%) and accessory titanite and apatite.

Lithology

The dominant rock type is dark green, medium to coarse-grained, equigranular hornblende-clinopyroxene gabbro as at the type locality. Aplite, microgranite and coarse mica pegmatite have been observed within the area of the Hefferon Creek Gabbro.

Geophysical response

The rocks are recognised in the airborne radiometric data by their low response in all channels, resulting in dark blue to greenish hues on composite images (Figure 99).

Magnetic susceptibilities measured in the field were in the range 250–14000 x 10^{-5} SI units with a mean of about 5200. This is consistent with the strong positive anomaly recorded in the airborne magnetic data (Figure 100).

Relationships and age

From the shape of the contact, it is likely that the Hefferon Creek Gabbro intrudes the surrounding Colodon Granodiorite, although contact relationships are masked by soil cover. It is likely that the gabbro is late Permian or Early Triassic like the most of the Rawbelle Batholith.

IMPEY GRANODIORITE

Introduction

The Impey Granodiorite forms a large ovoid pluton ~100km^2 in area, centred ~12km north of Auburn homestead (Figure 98). The name is derived from Impey Creek. The central and northern parts of the pluton are moderately hilly, but the outer margins are more subdued and gently undulating. Outcrop is reasonably good in the hillier parts of the unit. The unit was previously mapped partly as Kilbeggan Granite by Whitaker & others (1974).

Type locality

A type locality is designated at MGA 257100 7143000 along the Auburn–Sujeewong Road, where there is excellent exposure of pink, medium-grained, equigranular, leucocratic (hornblende)-biotite granodiorite (Figure 106c) that locally contains microdiorite xenoliths up to 5cm across. The granodiorite consists of quartz (25–30% to 5mm), K-feldspar (~20%, perthitic, locally intergrown with quartz and 1–2mm), plagioclase (40–50%, zoned albite-oligoclase laths to 4mm), biotite (~1% to 2mm), rare green hornblende (to 2mm) and minor opaque oxides. The biotite is dark brown where fresh, but is mostly altered to chlorite and epidote. Accessory titanite, apatite and zircon are present.

Lithology

The Impey Granodiorite consists dominantly of pink, medium to coarse-grained, equigranular biotite granodiorite to monzogranite as at the type locality. K-feldspar is generally slightly perthitic and some grains are intergrown with quartz, and in places it appears to rim the plagioclase. The plagioclase is relatively sodic and zoned from oligoclase to albite. K-feldspar grains are commonly turbid due to exolved hematite, and some plagioclase is slightly sericitised. The rocks are generally leucocratic with only 1–2% biotite, which is generally mostly altered to chlorite, minor epidote and, in some rocks, secondary muscovite. Hornblende is locally present, but is usually rare.

The granite has local thin pegmatite veins and local microgranodiorite dykes that may be related to the granodiorite. One at MGA 258850 7132800 forms a composite dyke with later andesite. It consists of plagioclase (*ca* 50%) as laths to 1mm and also phenocrysts to 3mm in a groundmass of graphically intergrown K-feldspar and quartz. It also contains minor green hornblende as poikilitic prisms to 1mm and subordinate chlorite after biotite to 0.3mm.

Geophysical response

The Impey Granodiorite is well delineated by its radiometric response, which is moderate for potassium and low for thorium and uranium, resulting in reddish pink hues in composite images (Figure 101).

The pluton is also well-delineated by its magnetic response, which is low to moderate and increasing towards the centre of the pluton suggesting some zonation (Figure 102). The response is slightly higher than the surrounding granitoids of the Auburn Batholith, but they are characterised by a pattern of north-north-west-trending moderately magnetic linear features (dykes?) that are truncated by and absent from the Impey Granodiorite. This is consistent with it being younger. Magnetic susceptibility readings are in the range 100–950 x 10^{-5} SI units with a mode at 350, consistent with its regional response.

Relationships and age

The ovoid shape of the Impey Granodiorite delineated from the airborne geophysics clearly suggests that it is a younger pluton than the surrounding Ah Fat Granodiorite Complex and Evandale Tonalite. This is supported by its truncation of the linear magnetic features evident in these units.

Its clean ovoid outline is similar to that of plutons such as the Cheltenham Creek Granite, Pollard Granodiorite and Mount Saul Granite that are late Permian to Early Triassic. However, K–Ar dating of the Impey Granodiorite gave a mid-Permian biotite age (recalculated) of 266±5Ma (Green, 1975; Whitaker & others, 1974). None of the other granites that have been dated in the area have a similar age.

JACK SHAY GABBRO

Introduction

This unit forms an elongate gabbro body in central AUBURN (Figure 98). It crops out over ~30km^2, south-west of Rocky Springs homestead near Jack Shay Mountain, from which it is named. It was previously mapped as part of the Delubra Quartz Gabbro by Whitaker & others (1974), although much of the area mapped as gabbro by Whitaker & others has been shown to consist mainly of Yerilla Metamorphics. The gabbro forms undulating topography of low relief and mostly poor outcrop.

Type locality

A type locality is designated at MGA 269000 7158450 on the flank of a low hill along a station track, 2.5km south-south-west of Jack Shay Mountain, where the rocks consist of dark greenish grey, medium to coarse-grained olivine gabbro. In thin section the rocks consist of randomly orientated laths of labradorite up to 3mm (~60%), clinopyroxene (~20%), orthopyroxene (~5%), olivine (~10%), reddish brown biotite (~5%) and 1–2% magnetite (1–2%). The olivine grains are mostly unaltered and are either discrete or form cores in clinopyroxene.

Lithology

Texture, grainsize, composition and magnetic susceptibility of this unit are variable, suggesting the presence of mesoscopic layering, and this interpretation is supported by trends in aeromagnetic images. Like the Delubra Gabbro, the unit also appears to be a composite body based on both geophysics and field observations. The southern part appears to be olivine gabbro (perhaps comparable to the former 'Hawkwood Gabbro' in the southern part of the Delubra Gabbro), whereas the rocks around Rocky Springs homestead appear to be more like the northern part of the Delubra Gabbro. They contain large crystals of poikilitic hornblende up to 1cm in a groundmass of plagioclase, hornblende and clinopyroxene. In addition there appear to be some outcrops of less mafic rocks (biotite-hornblende granodiorite to quartz diorite), but the relationships are not clear. No net-veining was recorded. Chlorite and local epidote veins are common, and pervasive epidote alteration was seen in places. The gabbro is commonly pyritic, with conspicuous disseminated blebs.

Geophysical response

The southern two-thirds of the unit has low responses in all radiometric channels giving very dark green hues in composite images. However, in the northern part of the area around Rocky Springs, the responses are slightly elevated, resulting in some dark pink mottling in the composite images. This probably reflects the more complex assemblage of rock types there including some granodiorite.

The magnetic data indicate that the unit is composite. The southern part of the unit is represented by a distinct circular magnetic low (possibly due to reversed remanence) ~4km in diameter. Magnetic susceptibility measurements at the type locality, which lies within the magnetic low, were in the range 750–2600 x 10^{-5} SI units. The remainder of the unit has a moderate to high magnetic response with prominent magnetic linear features that are parallel to the margins. Most of the magnetic susceptibility values measured were low, but an outcrop near Rocky Springs homestead had values in the range 200–1050 x 10^{-5} SI units, which may be more representative of the unit.

Relationships and age

The Jack Shay Gabbro intrudes the mid-Palaeozoic Yerilla Metamorphics, early Permian Narayen beds and rocks mapped as the Carboniferous Glissons Granodiorite or Evandale Tonalite to the west. K–Ar dating of hornblende from a gabbro near Rocky Springs gave an age (recalculated) of 251±7Ma (Whitaker & others, 1974; Green, 1975). This is similar to ages obtained from the Delubra Gabbro and indicates that the rocks are late Permian.

KARIBOE LAYERED GABBRO

Introduction

Gabbroic and dioritic rocks were first reported in the Spring Creek region, south-east of Biloela by Bellamy (1976). Mapping outlined an area of layered gabbro cropping out over ~1km^2. The gabbro was interpreted to be bordered by a body of diorite with a mapped extent of ~3km^2. Mapping, combined with petrographic and geochemical studies enabled the recognition of four dominant rock types within the layered gabbro sequence, which Bellamy named the Kariboe Layered Gabbro Intrusion. Mapping by the Yarrol Project Team (Yarrol Project Team, in preparation) extended the known limits of mafic intrusive rocks further west and south-west over a total area of 20km^2 and applied the name Kariboe Layered Gabbro to all of them (Figure 98).

Most of the country occupied by the Kariboe Layered Gabbro is undulating with low relief, but in the east it locally forms low rounded hills.

Type locality

The Yarrol Project Team (in preparation) have designated a type locality in the vicinity of MGA 276500 7279000 (SCORIA) adjacent to a farm track. Grey, medium to coarse-grained, equigranular diorite crops out just east of the track and grey, fine to medium, strongly layered hornblende gabbro crops out as a low hill ~500m west.

Lithology

Within the layered gabbro sequence, Bellamy (1976) recognised macro-layering on two scales; a layering greater than a few centimetres thick, and a second, larger scale layering which allowed subdivision into four zones of dominant rock types. These are ferrigabbro, olivine gabbro, hypersthene gabbro, and porphyritic augite gabbro. The layered gabbro body was interpreted to dip ~5° north-west.

As now mapped, the pluton also includes hornblende gabbro to diorite and tonalite, quartz monzogabbro to diorite and rare hornblendite. Locally the rocks contain xenoliths of metasiltstone and schist. At MGA 276200 7279000, a small hill of hornblende gabbro has some spectacular small-scale layering features. An outcrop on the north-eastern side of this hill exhibits alternating light (plagioclase) and dark (hornblende) bands ~1cm thick. On the western side of the hill an outcrop shows similar layering, which in places is ‘cross-bedded’.

As mentioned above, Bellamy (1976) also recognised diorite on the southern and western margins of the layered gabbro. This diorite essentially comprises plagioclase and hornblende with minor biotite and quartz (both up to 2%). Bellamy (1976) proposed that the diorite and the layered gabbro were geochemically related, and that the diorite probably intruded the gabbro when the latter was still hot, implying that they are of virtually the same age. The Eulogie Park Gabbro in the south of MOUNT MORGAN displays a similar relationship, having been intruded by a large diorite body (Wilson & Mathison, 1968).

Geophysical response

The gabbro and diorite can be easily distinguished from the Wingfield Granite on radiometric images due to their very low signature in all three channels in contrast to the granite being high in all channels. However, there is no contrast with the Lochenbar Formation, which consists mostly of mafic volcanic rocks and related sedimentary rocks.

The Kariboe Layered Gabbro is readily recognised on magnetic images due to its very high response in contrast to adjacent units, although the magnetic anomaly extends beyond the mapped extent suggesting that the contacts may dip shallowly north. Little internal variation within the unit is evident. Magnetic susceptibility values are consistent with the magnetic response. Values have a skewed distribution with a mode at 1200 x 10^{-5} SI units and a mean of 3500 and a tail extending to about 15000.

Relationships and age

The Kariboe Layered Gabbro has metamorphosed rocks of the Late Devonian Lochenbar Formation to hornblende hornfels facies. It is mapped in contact with the late Permian Wingfield Granite. Bellamy (1976) suggested that the Wingfield Granite was older. Observations by the Yarrol Project Team recorded fine grained pink aplite/pegmatite dykes intruding the diorite and suggested a genetic link between these and the Wingfield Granite. Accordingly the diorite would be older, although it is possible that the two could be of similar age and have undergone magma mingling as for the contact between the Delubra Gabbro and Cadarga Creek Granodiorite. In the absence of definitive dates or intrusive relationships, the Yarrol Project Team assigned a tentative late Permian-Early Triassic age to the gabbro.

It is noteworthy that the Kariboe Layered Gabbro appears to be one of a chain of gabbroic intrusions forming a north-west trending belt extending from north-west of Brisbane to south-west of Rockhampton. From south to north these intrusions are the Somerset Dam Igneous Complex, Wateranga Gabbro, 'Hawkwood Gabbro', Goondicum Gabbro, Kariboe Gabbro, Eulogie Park Gabbro and Bucknalla Gabbro. They are Permian or Triassic except for the Goondicum Gabbro, which may be Cretaceous. Several of these intrusions have been explored for platinoids and/or magnetite with varying success. The Kariboe Layered Gabbro hosts copper mineralisation that was worked in 1869 to 1874 at the Great Blackall Mine and Flanagans workings in the early 1870s.

KENMORE GABBRO

Introduction

The Kenmore Gabbro is a small, roughly circular pluton, ~1.5km in diameter in southern AUBURN (Figure 98). It is centred 13km south-south-west of Hawkwood homestead on Kenmore Station, from which the name is derived. It crops out poorly in gently undulating topography.

Type locality

A type locality is designated at MGA 276650 7134600, where dark bluish grey, medium-grained gabbro crops out. Poikilitic biotite flakes up to 2cm are conspicuous in the gabbro. In thin section the rock contains plagioclase (~40%, as labradorite laths, 1-2mm), pale green clinopyroxene (~30%, 0.5-1.5mm), olivine (~20%, 0.5-1mm), biotite (~10%, reddish brown and poikilitically enclosing all other minerals) and opaque oxides (<5%, to 0.5mm and commonly as small inclusions in olivine).

Lithology

Only one other outcrop was recorded in the outcrop area. It was dark greenish grey, fine to medium-grained gabbro cut by a rhyolite dyke. It was not examined in thin section.

Geophysical response

The Kenmore Gabbro has the typical low response in all channels of a gabbroic rock and is represented on composite radiometric images by a dark brownish green hue.

The pluton, as mapped, lies on a strongly magnetic ridge that extends southwards from the Mount Saul Granite. However, field observations between the two plutons suggest that the magnetic body is probably mostly not exposed. Magnetic susceptibility readings from the type locality were in the range 1500–4000 x 10^{-5} SI units.

Relationships and age

The Kenmore Gabbro intrudes the early Permian Narayen beds. Outcrops of Jurassic Evergreen Formation were recorded overlying the gabbro, but they were too small to map out. Its age is uncertain, but is probably late Permian or Early Triassic.

KILDARE GRANODIORITE

Introduction

The Kildare Granodiorite is a new unit, which forms a roughly circular pluton cropping out over ~75km^2 in north-western RAWBELLE (Figure 98). The name is derived from Kildare homestead. Whitaker & others

(1974) partly mapped the pluton but assigned the rocks to the Culcraigie Granite. Most common outcrops of this unit are strongly decomposed whalebacks and boulders.

Type locality

The type locality is designated ~1km east of Kildare homestead at MGA 272100 7217100. A large whaleback exposure consists of pale pink, coarse-grained, porphyritic titanite-hornblende-biotite monzogranite or granodiorite with some mafic enclaves. This rock is cut by even-grained aplitic microgranite dykes with traces of biotite.

Lithology

The Kildare Granodiorite is mostly coarse-grained, porphyritic titanite-bearing hornblende-biotite monzogranite to granodiorite as at the type locality (Figure 106d). The K-feldspar megacrysts commonly show rapakavi textures. Microdiorite enclaves from 5–20cm and pink aplite and pegmatite dykes are common.

Another rock type commonly found is medium to coarse-grained, equigranular to slightly porphyritic, titanite-bearing biotite granodiorite. An example of this granodiorite can be found east of Kildare homestead at MGA 276100 7217200. The granodiorite comprises plagioclase (~45%), quartz (~15%), K-feldspar (~20%), biotite (~12%) and titanite (~3%). Common accessories are apatite, opaque oxides and some zircon.

Minor variants include coarse-grained titanite-bearing, hornblende quartz monzonite and syenogranite. East of Kildare homestead at MGA 274600 7216600 pink, coarse-grained, equigranular to strongly porphyritic, leucocratic syenogranite crops out. The granite shows mostly pink perthitic K-feldspar (50–70%), quartz (~25%) and white oligoclase (10–15%) and very minor bleached biotite (to 2%). Some fresher outcrops show fresh biotite flakes to 1mm, locally in clots, and also rare muscovite to 0.5mm. The granite is generally very weathered and was possibly overprinted by hematitic alteration.

Geophysical response

In the airborne radiometric data the Kildare Granodiorite has a strong potassium response, with low thorium and moderate uranium responses, resulting in strong pinkish-red hues on composite images (Figure 99). These contrast markedly with the surrounding units that mostly have low potassium responses.

Magnetic susceptibilities measured in the field show an extensive range from 0 to ~2900 x 10^{-5} SI units. Rocks identified as monzogranite and quartz monzonite have a bimodal distribution with modes at about 400 and 1000 with most values <1300. Granodiorite values have a mode at about 1000 with a tail showing a weak mode at 2100. Syenogranite values were much lower, being <400, with a mode at about 250. In the airborne magnetic data the Kildare Granodiorite shows moderate magnetic intensity similar to that of the Tandora Granodiorite and contrasting with the lower response of the adjacent Colodon Granodiorite (Figure 100).

Relationships and age

The Kildare Granodiorite is in contact with the Colodon Granodiorite, Wingfield Granite, Tandora Granodiorite and Glencoe Gabbro. Contact relationships are masked by soil cover, but the outcrop pattern suggests that it may have intruded the Colodon Granodiorite, isolating the smaller south-western outcrop area of the latter from the main mass. The shape of the contact also suggests that it may have intruded the Glencoe Gabbro. No isotopic dating has been done on the Kildare Granodiorite, but it is inferred to be late Permian to Early Triassic like most of the other units in the Rawbelle Batholith.

KOOYONG GABBRO

Introduction

The Kooyong Gabbro forms a circular pluton ~4km in diameter, between Rawbelle and Kooyong stations (from which the name is derived) in southern SCORIA (Figure 98). Outcrop is very poor, but the unit can be delineated by its reddish soils, which are obvious on coloured aerial photographs.

Type locality

The type locality is along the Rawbelle–Kooyong road at MGA 265100 7242300. Dark green to grey, fine to medium-grained, hornblende gabbro comprises andesine and labradorite (50–55%), dark green hornblende (40–45%) and opaque oxides.

Lithology

Only three outcrops were located in the unit. All are hornblende gabbro or possibly diorite. Near Kooyong homestead, dark grey to black, medium-grained gabbro contains irregular enclaves of black hornblendite. The enclaves of hornblendite resemble schlieren and possibly define an igneous foliation. Minor coarse-grained gabbro enclaves also occur in a felsic granitoid that may represent back veining by melted country rock at the margin of the Kooyong Gabbro.

Geophysical response

The unit has a low response in all radiometric channels resulting in dark green to purplish hues on composite radiometric images (Figure 82). Because most adjoining units have a similar response, the unit is best delineated on aerial photographs.

Magnetic susceptibilities on the three outcrops are in the range 700–5400 x 10^{-5} SI units. The pluton occurs in an area of generally high response on total magnetic intensity images and cannot be delineated in these data (Figure 83), although the Wingfield Granite to the east has a lower intensity.

Relationships and age

The Kooyong Gabbro intrudes the Torsdale Volcanics and probably an unnamed granitoid near Kooyong homestead. Its relationship to the Wingfield Granite is unclear, but as with many gabbro/diorite bodies in the region, it may have been intruded late in the magmatic history. A late Permian to Early Triassic age is therefore assigned.

MARVEL CREEK GABBRO

Introduction

The Marvel Creek Gabbro forms a roughly ovoid mass ~3km long, between Marvel and Montour Creeks along the boundary between Kooyong and Rossmore stations in southern SCORIA (Figure 98).

Type locality

The type locality is defined along the boundary fence between Kooyong and Rossmore stations at MGA 262500 7235000. Grey, medium to coarse-grained gabbro comprises bytownite/labradorite (~85%), olivine (8–10%), orthopyroxene (3–5%), and minor opaques.

Lithology

The unit comprises mainly dark grey, medium-grained olivine gabbro, altered leucogabbro, and fine to medium-grained hornblende-plagioclase diorite. The presence of olivine in some places distinguishes this gabbro from those such as the Kooyong Gabbro and the Parraweena Gabbro, which are essentially plagioclase-hornblende gabbros with minor clinopyroxene.

Geophysical response

The radiometric response is very low in all channels, resulting in very dark greenish blue to black hues on composite images (Figure 82).

At the type locality, magnetic susceptibilities are in the range 24–193 x 10^{-5} SI units. Elsewhere, values are in the range 200–2000 x 10^{-5} SI units. The unit coincides with a negative aeromagnetic anomaly, indicating reverse polarisation (Figure 83). This contrasts with the Glencoe Gabbro, a larger pluton to the south, and indicates that the two are not directly related.

Relationships and age

The Marvel Creek Gabbro intrudes low-grade metamorphic rocks of uncertain affinities. The reverse polarisation may suggest that is early Permian rather than part of the late Permian to Early Triassic suite of gabbros as shown on the SCORIA map.

MAY QUEEN GABBRO

Introduction

The May Queen Gabbro is a small body mapped in a window in the Jurassic Evergreen Sandstone along Fishy Creek, 10km west of Brovinia in south-western MUNDUBBERA (Figure 98). It is interpreted to crop out over an area of ~1km^2, but may be smaller.

Type locality

The type locality is at the May Queen gold mine (from which the unit is named) at MGA 303450 7128450. Dark greenish-grey, medium-grained equigranular to slightly hornblende-phyric gabbro or diorite is exposed near the mine and also occurs as abundant rubble on the mullock dump. Poorly preserved layering can be observed in some blocks on the dump.

Lithology

The dominant rock-type (as at the type locality) is a dark greenish-grey mostly medium-grained equigranular to slightly hornblende-phyric gabbro or diorite. It comprises plagioclase (~55%), hornblende (~40%), clinopyroxene (~5%) and opaques (~4%). Apatite, epidote and possibly titanite were identified in thin section. Chlorite (after hornblende and clinopyroxene) and sericite (after plagioclase) are common.

At MGA 303550 7128630 at the May Queen workings, a dyke of dark greenish-grey porphyritic andesite intrudes moderately decomposed gabbro. The phenocrysts are white plagioclase laths and the groundmass is a strongly altered.

Some contacts with limestone and argillitic rocks of the Rockhampton Group were also observed. At MGA 303590 7128710, very fine-grained, slightly banded skarn was observed in a small prospecting pit in contact with decomposed gabbro.

Geophysical response

The May Queen Gabbro is too small to show a distinct radiometric response and colluvial wash from the overlying Evergreen Sandstone may also mask it. The gabbro has a moderate magnetic response, appearing as a small peak anomaly ~0.75km in diameter, suggesting that the body is much smaller than shown on the map. No magnetic susceptibility data is available.

Relationships and age

The May Queen Gabbro intrudes rocks assigned to the early Carboniferous Rockhampton Group and is overlain by the Jurassic Evergreen Formation. It has not been isotopically dated, but is probably late Permian like the Delubra Gabbro.

MORROW GRANITE

Introduction

The Morrow Granite is a new unit in southern RAWBELLE (Figure 98). It has been mapped over ~70km^2, mainly based on geophysical response, since its outcrop is extraordinarily poor. Only strongly decomposed rocks have been found, other than common ridge-forming rhyolite dykes. Mostly the unit appears to form recessive topography contrasting with the rugged topography of the Boolgal Granophyre and the hilly terrain of the Culcraigie Granite and the Coonambula Granodiorite. The soils are light brown to cream-coloured, sandy and have some mica. Over much of the area Tertiary deposits with various degrees of induration are evident.

Type locality

In Morrow Creek (from which the unit is named) at MGA 290400 7190930, pale pink, medium-grained equigranular biotite granite (Figure 107a) crops out and this is designated as the type locality.

Lithology

Rock types such as at the type locality also occur near the power line south of Culcraigie road at MGA 294200 7195000. Cream, strongly decomposed, fine-grained equigranular granite containing strongly

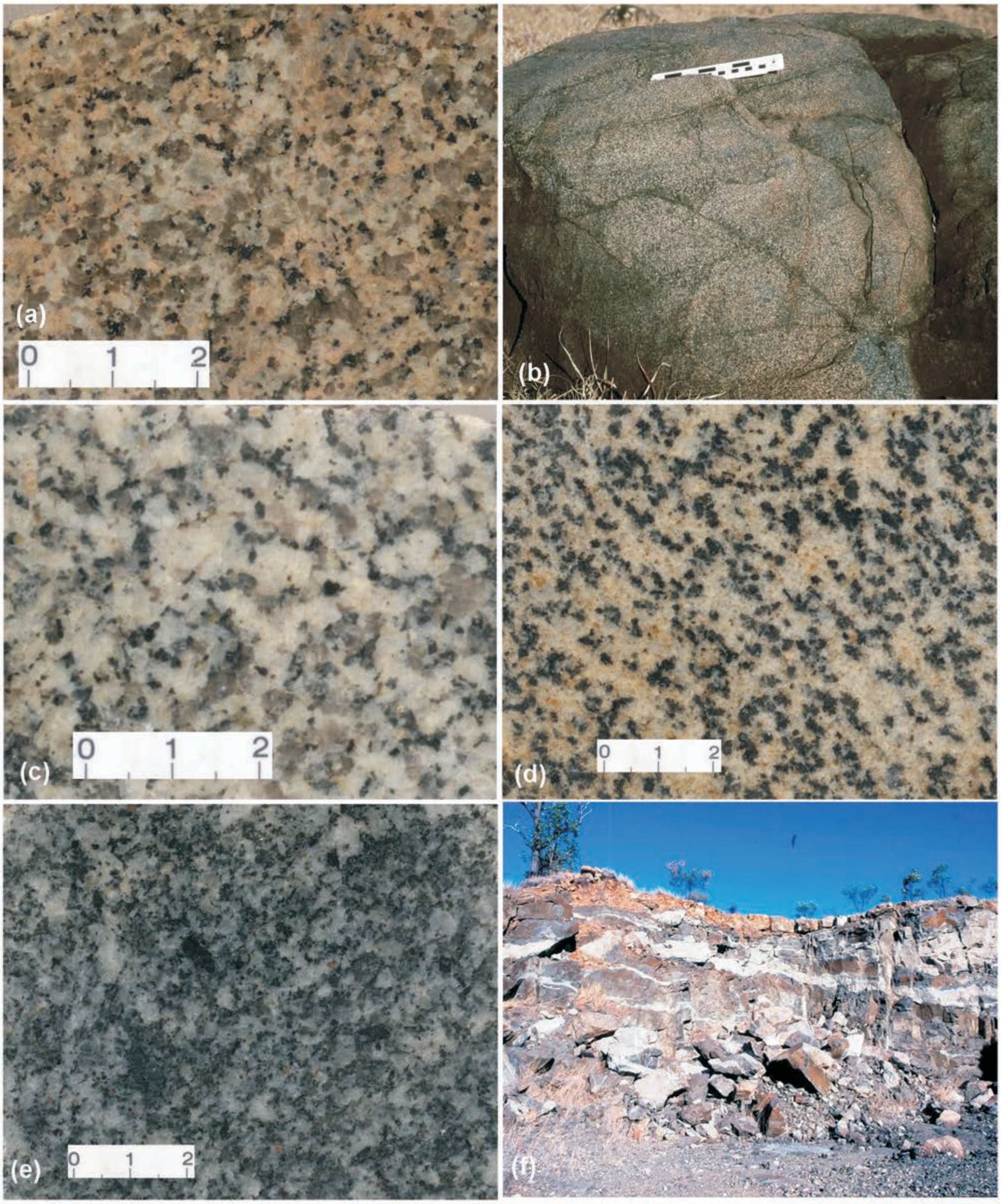

Figure 107. Late Permian to Triassic granitoids (continued); scale is 2cm in (a), (c), (d) and (e)
(a) Scanned slab of medium-grained biotite granite from the type locality of the Morrow Granite. Morrow Creek 6.5km north-west of Widbury homestead at MGA 290415 7190930 (QFG2966)
(b) Outcrop of Quaggy Mountain Gabbro showing diffuse shallowly dipping layering and crosscutting chlorite veins. Near cattle yards, 1km north-west of Quaggy Mountain at MGA 268305 7185177 (IRAU095)
(c) Scanned slab of equigranular titanite-bearing biotite-hornblende granodiorite from the type locality of the Tandora Granodiorite. Culgraigie–Tireen road near the Tandora turnoff at MGA 275111 7203665 (RSC182)
(d) Scanned slab of biotite-hornblende granodiorite of the Tecoma Granodiorite. Near the Nogo River north-west of Redmount homestead at MGA 273854 7233232 (QFG2605)
(e) Scanned slab of biotite-hornblende granodiorite of the Telemark Granodiorite from the locality dated by Whitaker & others (1974). About 1km east-south-east of Telemark homestead at MGA 278066 7199727 (QFG2871)
(f) Gabbro cut by dykes and lenses more leucocratic diorite at the type locality of The Pride Gabbro. Abandoned quarry on the eastern side of the Cracow–Theodore road, at MGA 223390 7201176 (BB2611).

leached biotite crops out. Porphyritic biotite granite was observed south of Smalls Creek and Euroka Road at MGA 291700 7196000.

Geophysical response

On radiometric images, the Morrow Granite has a high response in all three channels, similar to the Boolgal Granophyre, resulting in whitish hues on composite images (Figure 99).

The Morrow Granite can be partly outlined on the airborne magnetic images by having low magnetic intensity compared with the surrounding Culcraigie and Coonambula Granodiorite and Euroka Granodiorite (Figure 100). Magnetic susceptibility values were recorded at only a few outcrops, but they are consistent with the low airborne response and mostly were in the range 0–10 x 10^{-5} SI units. A few values up to 300 x 10^{-5} SI units were recorded.

Relationships and age

The age is not known precisely, but a late Permian or Triassic age is likely. Abundant rhyolite dykes that cut the Morrow Granite may be related to the Mount Eagle Volcanics or Boolgal Granophyre. The Late Triassic Boolgal Granite appears to intrude the Morrow Granite in the east.

NULAMBIE GRANITE

Introduction

The Nulambie Granite crops out over ~3km^2 near Nulambie homestead (from which the name is derived) between Castle and Lonesome Creeks ~25km north-east of Theodore (Figure 98). The unit forms undulating topography.

Type locality

The type locality is beside a station track at MGA 224500 7252800. Light grey, medium grained, quartz monzonite or granodiorite comprises quartz (10–15%), K-feldspar (15–20%), andesine (45–50%), pale green hornblende (~5%), chloritised biotite (~5%), with minor titanite, opaques and possibly topaz as an alteration mineral. Another sample from nearby comprises quartz (~15%), K-feldspar (~45%, mostly in intergrowth with quartz), oligoclase (~35%), pale amphibole (~2%), clinopyroxene (~1%), biotite (~1%) and opaques (~3%). A minor phase at the type locality is a pink to grey medium to coarse-grained granite suggesting a complex magmatic system.

Lithology

The unit mainly comprises light grey, medium grained to slightly porphyritic biotite-hornblende quartz monzonite and granite to granodiorite as described above. West of the type locality, a more leucocratic phase comprises very light grey, fine to medium grained biotite granite indicating the complex nature of this pluton. Many outcrops are altered and fractured making identification of original rock types difficult.

Geophysical response

The Nulambie Granite has a moderate to high potassium response, moderate thorium and low to moderate uranium producing pale pinkish hues in composite images. The margins of the pluton are not well-defined in the radiometric data (Figure 82). Similar hues extending to the south-west in the Camboon Volcanics are probably related to felsic dyke swarms.

The pluton lies at the south-western end of a strong magnetic anomaly that forms a ridge extending for ~9km to the north-east (Figure 83), suggesting that the pluton may be part of a more extensive pluton at shallow depth. Magnetic susceptibility readings on three outcrops were in the range 1250–4800 x 10^{-5} SI units with a mean of 2560.

Relationships and age

The Nulambie Granite intrudes a sequence of andesitic or basaltic volcanic rocks, massive conglomerate and minor siltstone and sandstone causing extensive hornfelsing, particularly in the conglomerate to the east. These rocks are assigned to the Camboon Volcanics on lithological grounds, but may be Torsdale Volcanics. Similar rocks to the south are intruded by granodiorite dykes that may be co-magmatic with the main pluton.

The age of the Nulambie Granite is uncertain. If the country rocks are Camboon Volcanics, the pluton is probably late Permian to Early Triassic. If, however, they belong to the Torsdale Volcanics, it could be older.

POLLARD GRANODIORITE

Introduction

The Pollard Granodiorite forms a large, roughly equant pluton of ~100km^2, centred ~30km south-west of Eidsvold in north-eastern AUBURN (Figure 98). However, much of this is concealed by thin Mesozoic and Tertiary cover that forms dissected plateaux that are covered in *Acacia* scrub. The granodiorite forms relatively recessive, undulating topography and has been cleared for pastoral purposes. Outcrop is relatively poor and outcrops are commonly weathered and decomposed. However, clusters of large boulders and platform outcrops are locally present. The name is derived from Pollard Creek.

Type locality

The type locality is designated at MGA 292600 7170950 where prominent boulders and tors occur just east of the road between Coonambula and Narayen. The rock is cream to grey, medium to coarse-grained, porphyritic, titanite-bearing, hornblende-biotite granodiorite. It has common K-feldspar phenocrysts to 2cm, clusters of hornblende to 1.5cm across and microdiorite xenoliths to 10cm. In thin section it consists of quartz (25%, 1–2mm), K-feldspar (15–20%, 1–2mm), plagioclase (35–40%, Na-andesine, up to 3mm), dark brown biotite (5–10%, to 2mm), green hornblende (~5%, prismatic, to 2.5mm), common euhedral titanite (to 2mm) and minor opaques. Myrmekite commonly occurs along the contacts between K-feldspar and plagioclase grains.

Lithology

The rocks exposed in the eastern part of the pluton along the Coonambula–Narayen road are mostly similar to that at the type locality, the main variation being the proportion of feldspars, so that the unit ranges from granodiorite to monzogranite. The rocks are usually porphyritic with mainly K-feldspar phenocrysts to 2cm poikilitically enclosing hornblende, biotite and plagioclase. As at the type locality, myrmekite is common. Hornblende locally forms conspicuous prismatic grains, locally up to 1cm. Euhedral titanite is characteristic, and accessory allanite is also present. The rocks are characteristically unaltered, the biotite usually being fresh.

Locally the granite is cut by fine-grained, equigranular biotite leucogranite and aplite dykes and veins.

Granite in the north-western part of the pluton is mostly deeply weathered, but at MGA 283500 7170700 outcrop consists of grey, seriate to porphyritic, fine to coarse-grained biotite monzogranite.

Geophysical response

The pluton is well delineated in both radiometric and magnetic airborne data. Like the Cheltenham Creek Granite, the Pollard Granodiorite has a high response in all three radiometric channels so that exposed parts of the pluton are depicted as pale yellowish to white in composite images (Figure 100).

The magnetic response is low to moderate, contrasting with the low to very low response of the country rocks and also standing out from the apparently less magnetic Cheltenham Creek Granite (Figure 101). Magnetic susceptibility readings show a normal distribution from 100–800 x 10^{-5} SI units with a mean of 420.

Relationships and age

The Pollard Granodiorite intrudes the Nogo beds and Yerilla Metamorphics and appears to intrude the Cheltenham Creek Granite in the south (based on the shape of the contact visible on aeromagnetic images). Its relationship to the Coonambula Granodiorite to the north cannot be determined by geophysical or field relationships, but the Pollard Granodiorite is probably younger. Thin cappings of Evergreen Formation and Tertiary sediments overlie much of the pluton.

The Pollard Granodiorite is regarded as late Permian or Early Triassic like the Cheltenham Creek Granite. It probably has not been dated isotopically, although a set of samples reported by Green (1975) do plot within the unit. The rock type is given as gabbro, and it is likely that the location, which is very imprecise and based on the old thousand yard grid, is in error. Ar^{39}/Ar^{40} dating gave late Permian ages (recalculated) of 257±10Ma and 253±10Ma from hornblende and biotite respectively (from samples designated AA33-35 with field numbers M7-M9). The dates were reported by Nitkiewicz (1973) as part of his study of the Delubra Gabbro, although his thesis does not include locations for these samples. The ages are similar to one obtained from sample AA36 that plots in the Delubra Quartz Gabbro and is ascribed to the same collector (B. Nitkiewicz).

QUAGGY MOUNTAIN GABBRO

Introduction

The Quaggy Mountain Gabbro crops out over an exposed area of ~25km^2 in southern RAWBELLE, at the eastern edge of the Auburn Plateau (Figure 98). However, its extent under the Cainozoic cover deposits of the plateau is likely to be much greater as evidenced by the airborne magnetic data. It forms low hills of which Quaggy Mountain is the most prominent, but outcrop is commonly poor or strongly decomposed with deep reddish-brown soils.

Type locality

Outcrop at MGA 268300 7185200 on the flanks of Quaggy Mountain (from which the unit is named) is designated as the type locality. It consists of dark greenish grey gabbro that is locally layered (Figure 107b). Pegmatitic veins and pods occur within the gabbro.

Lithology

Around Quaggy Mountain, the rocks range from olivine gabbro to hornblende-pyroxene gabbro. The former consists of subequant labradorite (70%), olivine (10–15%) that forms fresh unaltered cores rimmed by clinopyroxene (5%) and in turn by pale green hornblende (10%). Magnetite and minor green spinel are common within the mafic grains. The hornblende-pyroxene consists of labradorite (~45% as randomly orientated subhedral laths), orthopyroxene (~30%), rimmed by brownish hornblende (~20%). The rocks are locally layered (Figure 107b) with alternating mafic and felsic layers or layers of different grainsize. In places the rocks contain large ophitic hornblende crystals to 3cm across.

Other rocks within the outcrop area include hornblende diorite to quartz diorite and possibly tonalite.

A smaller body to the east has been assigned to the Quaggy Mountain Gabbro, but may be one of the numerous unassigned dioritic bodies that occur throughout the region. It is dark green porphyritic microdiorite containing phenocrysts of plagioclase to 5mm and green hornblende to 2mm in a very fine-grained groundmass of plagioclase and hornblende. Some hornblende phenocrysts contain cores of randomly orientated hornblende prisms that possible replaced pyroxene.

Geophysical response

On radiometric images, the Quaggy Mountain Gabbro has very low response in all channels resulting in very dark to black hues (Figure 99).

At the type locality, magnetic susceptibilities range from 2500–6200 x 10^{-5} SI units (average 4200) consistent with the strong positive response in the airborne magnetic data (Figure 100). The data suggest that the gabbro forms an arcuate intrusion ~13km across and open to the north, intruding other moderately to strongly magnetic rocks. The exposed areas lie on the eastern end of the intrusion.

Relationships and age

The Quaggy Mountain Gabbro intrudes the Yerilla Metamorphics on its eastern margin, but elsewhere is overlain by Tertiary to Quaternary sediments. Under this cover, it is probably in contact with other granitoids. The age is not known precisely, but a late Permian age is inferred because of similarities to the Delubra Gabbro, which has K–Ar ages in this range.

RAVENSCRAIG GABBRO

Introduction

The Ravenscraig Gabbro forms an ovoid pluton of ~4km^2, in central-eastern CRACOW (Figure 98). It is named after Ravenscraig pastoral holding, which encompasses part of the unit.

The Ravenscraig Gabbro forms a broad, low, rounded hill or dome with gentle slopes. The gabbro is deeply weathered with extensive development of dark red-brown to black (locally) soils, as well as some calcrete.

The unit has been virtually completed cleared of native trees and shrubs to improve the stock carrying capacity by promoting the growth of grasses on the fertile soils.

Type area

The type area extends from around MGA 240660 7210710 east to the top of the hill or dome.

Lithology

The unit consists mainly of fine to coarse-grained, porphyritic hornblende gabbro. Phenocrysts consist of plagioclase (up to 2cm long) and hornblende (as slender laths up to ~2cm long). The Ravenscraig Gabbro has not been studied in detail, but the presence of well-developed primary igneous layering is noteworthy. The layering is defined mainly by variations in grainsize and the relative abundances of plagioclase and mafic minerals.

Geophysical response

The gabbro shows black to dark brownish green hues on a composite radiometric image, reflecting very low concentrations of potassium, thorium, and uranium.

It is characterised by a strong positive response on total magnetic intensity images. Magnetic susceptibility readings are variable (presumably reflecting the presence of mineralogical layering). They range from 1090–8835 x 10^{-5} SI units at the two sites where observations were made.

Relationships and age

The Ravenscraig Gabbro is characterised by arcuate (convex-outwards) contacts with all, but one of the adjacent units. It is, therefore, interpreted to intrude the Glen View Quartz Monzodiorite and Rockdale Granite. It is also interpreted to post-date the Mungunal Granite, which has yielded a late Carboniferous K–Ar age (Webb & McDougall, 1968).

The age of the unit is uncertain. The regular, ovoid outline of the pluton implies it is probably a relatively young intrusion. The gabbro has, therefore been assigned a late Permian–Early Triassic age.

TANDORA GRANODIORITE

Introduction

This is a new name for an extensive irregularly-shaped intrusive body in central RAWBELLE (Figure 98). The northern part of the body was previously mapped by Whitaker & others (1974) as Wingfield Adamellite and the south-eastern part as Culcraigie Granite. The name is derived from Tandora homestead.

The unit is dominantly granodiorite, but also incorporates a variety of different rock types including, syenogranite, leucogranite, monzogranite, diorite, quartz diorite and gabbro, suggesting that it may not be a single unit and may eventually need subdivision. This unit has been separated from the Culcraigie Granite mainly on the basis of radiometric interpretation and a more diverse range of rock types.

The total area calculated for this unit as mapped is ~50km^2. This area is somewhat reduced from that shown on an earlier version of the RAWBELLE geology map and the Central Queensland GIS. The north-western part of the unit as shown on those maps has been included in the Greystone Granodiorite, based on its radiometric response.

Type locality

Boulders and tors near the Tandora turnoff from the Culcraigie–Tireen road at MGA 275100 7203700 represent the type locality. Medium-grained, light grey, equigranular titanite-bearing biotite-hornblende granodiorite (Figure 107c) crops out and comprises quartz (~30%), albite–plagioclase (~40–45%), K-feldspar (~12%), biotite (~8–10%), hornblende (~2–4%), titanite (~2–3%) and opaque oxides (to 2%). Pink coarse-grained syenogranite also crops out nearby, but no contact relationships were observed.

Lithology

The dominant rock type, such as that exposed along the Culcraigie–Tireen road at MGA 272800 7204800, is medium to coarse-grained, mostly equigranular, light to medium-grey, titanite-bearing hornblende-biotite granodiorite. This rock comprises quartz (~25%), plagioclase (~40%), K-feldspar (~15%), biotite (~10%), hornblende (~2–4%), titanite (to 2%) and opaque oxides (to 2%). In most hand specimens, transparent, brownish yellow titanite is conspicuous. Some of the granodiorite is porphyritic with hornblende and plagioclase phenocrysts.

Near the Tireen to Springfield road at MGA 274200 7203900, light grey, medium-grained, equigranular biotite granite with sulphides (mainly chalcopyrite) was observed. It comprises quartz (~45%), plagioclase (~25%), K-feldspar (~20%), biotite (~10%) and accessory opaque oxides. Sericite and epidote are present as alteration minerals.

Another rock type, which is similar to parts of the Culcraigie Granite, is medium to very coarse grained, light grey to pink, mostly equigranular biotite syenogranite. This is more common in the south-eastern part of the Tandora Granodiorite. Syenogranite west of Tandora homestead at MGA 273400 7206000 comprises quartz (~30%), plagioclase (~10%, albite/oligoclase %), micro-perthitic K-feldspar (~50%) and biotite (~3%). Some rocks have been observed to contain titanite (~1%). Most outcrops are moderately to strongly weathered.

Geophysical response

The airborne radiometric data show some variation across the unit. The south-eastern half of the unit has pale pinkish to whitish hues on the composite images, due to moderate to high potassium and thorium and moderate uranium responses (Figure 99). The potassium is similar to that in the adjoining part of the Culcraigie Granite, but thorium is significantly higher.

The magnetic susceptibilities measured in the field ranged up to ~1500 x 10^{-5} SI units, but show a strongly skewed distribution with the main mode representing values <100. Values recorded for diorite are 150–1000 x 10^{-5} SI units. In the airborne magnetic data, the Tandora Granite, shows a low to moderate response, similar to the Kildare Granodiorite and Culcraigie Granite (Figure 100). It is higher than the Colodon Granodiorite, but significantly lower than the Glencoe Gabbro and Telemark Granodiorite or the unexposed intrusive rocks beneath the Auburn plateau to the west.

Relationships and age

Contact relationships of the Tandora Granodiorite to other units are masked by Cainozoic cover. It is mapped in contact with the Culcraigie Granite and Telemark Granodiorite. No samples from this unit have been isotopically dated, but it is inferred to be late Permian or Early Triassic.

TECOMA GRANODIORITE

Introduction

The Tecoma Granodiorite crops out over ~22km^2 in southern SCORIA extending south into RAWBELLE (Figure 98). In SCORIA, it occurs as two separate bodies, a northern body covering ~4km^2 and the larger mass to the south. Both are enclosed by the Colodon Granodiorite. Boulders and small tors are typical surface expressions. The name Tecoma Granite is used on SCORIA and RAWBELLE maps, but the name is herein changed to more accurately reflect the dominant rock type.

Type locality

The type locality is north-west of Redmount homestead near the Nogo River at MGA 273850 7233230. Light grey, fine-grained granite to granodiorite (Figure 107d) comprises quartz (~15%), K-feldspar (<10%), plagioclase (~50%), fresh biotite (~15%), pale green hornblende (~10%), opaques, apatite and epidote. Mafic xenoliths up to 60cm occur sporadically in the outcrop.

Lithology

Rock types such as at the type locality occur throughout the Tecoma Granodiorite with only minor variation. The generally fine-grainsize contrasts with that in the surrounding medium grained, locally porphyritic Colodon Granodiorite. In the western part of the Tecoma Granodiorite, particularly on Colodon Station, numerous dykes of leucogranite, some containing tourmaline, intrude it.

Geophysical response

In the radiometric data the Tecoma Granodiorite has a relatively low potassium response, a strong thorium response and a moderate uranium response resulting in pale green hues on composite images that contrast with the pinks and reds of the surrounding Colodon Granodiorite (Figure 99).

Magnetic susceptibility values show a strongly skewed distribution with a very strong mode represented by values up to 100 and a tail extending to ~1000 x 10^{-5} SI units (average 220). This is consistent with the total magnetic intensity data, in which the Tecoma Granodiorite is clearly delineated by a low response compared with the moderate response of the Colodon Granodiorite and Wingfield Granite (Figure 100).

Relationships and age

The Tecoma Granodiorite forms irregular bodies enclosed in the Colodon Granodiorite, but the relationships are uncertain. They may intrude the Colodon Granodiorite or be large rafts of an older pluton within it.

The age is not known. A late Permian or Early Triassic age is shown on the maps, but geochemical similarities to the Coonambula Suite suggest that it may be older (early Permian).

Three samples from the Tecoma Granodiorite plot with the Coonambula Suite and have lower Sr and higher TiO_2, FeO_{total} and Zn than either the Tandora or Wingfield Suites (Figures 94 and 95). Like the Coonambula Granodiorite, these samples are strongly peraluminous with three samples having an ASI ~1.1, in spite of the samples having hornblende. However, the geochemistry also suggests that the unit as mapped may be composite, because two other samples plot with the Tandora and Wingfield Suites. Two samples from outcrops within the Colodon Granodiorite also plot with the Coonambula Suite suggesting that they may be from an unmapped area of Tecoma Granodiorite.

TELEMARK GRANODIORITE

Introduction

This is a new name for a granodiorite pluton that was previously mapped by Whitaker & others (1974) as a part of a tongue of undifferentiated granite intruding into the centre of the Culcraigie Granite in central RAWBELLE (Figure 98). Outcrop is generally poor, mostly scattered boulders, but the unit is clearly outlined by the airborne magnetic data as an oval-shaped body, ~20km^2 in area. The name is derived from Telemark homestead and also the Parish of Telemark.

Type locality

The type locality is a fairly fresh outcrop along the Euroka–Tireen road, 1.3km north-north-west of Springfield homestead at MGA 281500 7203800. Coarse-grained, light grey, slightly porphyritic biotite granodiorite comprises white to pinkish plagioclase (around 40%), K-feldspar (15%), quartz (25%), fresh, black biotite (8%) and dark green hornblende (10%). Accessory minerals include common euhedral honey-coloured titanite up to 1mm, along with opaque oxides, zircon and apatite. Elongate, aligned, biotite-rich mafic xenoliths up to 20cm long are common.

Lithology

The dominant rock type comprises grey, medium to coarse-grained granodiorite (Figure 107e) similar to that at the type locality. Another rock type observed to the north along the Culcraigie–Tireen road near the Taroon homestead turnoff at MGA 278400 7204520, is greenish-grey, coarse-grained, equigranular hornblende-pyroxene diorite. The pyroxene is mostly altered to pale green amphibole.

Some of the porphyritic dykes that intrude the Culcraigie Granite are possibly related to the Telemark Granodiorite.

Geophysical response

On composite radiometric images, the Telemark Granodiorite is represented by pinkish hues due to a moderate to strong potassium response. Thorium and uranium are low to moderate. There is no significant radiometric contrast against the surrounding Culcraigie Granite and Tandora Granodiorite (Figure 99).

The airborne magnetic images show a strong, annular magnetic anomaly near Telemark homestead, ~4.5km in diameter, with a slightly less magnetic core (Figure 100). Magnetic susceptibilities measured in the field for the diorite were in the range 4000–6000 x 10^{-5} SI units whereas the granodiorite showed a bimodal distribution with modes at ~100 and 700 x 10^{-5} SI units. Because of the poor outcrop it is difficult to determine the rock types contributing to the core and rim. However, the diorite may be responsible for the strongly magnetic anomaly, because the magnetic susceptibility values for the granodiorite seem to be too low to produce such an anomaly. If so the diorite may be still largely subsurface, because there is no obvious annular pattern in the radiometric data and the strong potassium response is inconsistent with diorite.

Relationships and age

The Telemark Granodiorite is interpreted as intruding the Tandora Granodiorite and the Culcraigie Granite.

Hornblende from a granodiorite sample from east of Telemark homestead yielded a K–Ar age of 226Ma (Green, 1975; Whitaker & others, 1974; adjusted to the decay constants of Steiger & Jäger, 1977). Although the sample locality plots just outside the magnetic anomaly that defines the Telemark Granodiorite, the rock is very similar to the typical rocks of this unit. Therefore the pluton is probably Triassic.

THE PRIDE GABBRO

Introduction

The Pride Gabbro crops out as a small (~1km^2), poorly exposed, elongate pluton, 5km west-north-west of Cracow (Figure 98). The unit forms a low, easterly trending ridge, which straddles the main Cracow–Theodore road. The gabbro is named after a nearby small pastoral holding.

Type locality

The designated type locality is at an abandoned quarry located on the eastern side of the Cracow–Theodore road, at MGA 223390 7201176. The gabbro is well exposed in the walls of the quarry.

Lithology

The main rock type exposed in the walls of the quarry is dark grey, medium-grained, slightly to moderately porphyritic gabbro, containing phenocrysts of clinopyroxene (fresh), olivine (completely replaced by iddingsite and bowlingite?), plagioclase, and minor opaque oxide (commonly with embayed margins). Sparse opaque oxide granules are also scattered throughout the groundmass. The gabbro shows mineralogical layering in places, and is slightly to moderately altered. Chlorite, iddingsite, and sericite are the main secondary minerals.

The gabbro is cut by highly irregular dykes and lenses, up to ~4m wide, of coarser grained, more leucocratic diorite (Figure 107f). The diorite has not been examined in detail, because only one poor-quality thin section was available for examination. It is mainly medium-grained, and characterised by the presence of slender amphibole (cummingtonite?) laths up to ~10cm long (most <5cm). The amphibole laths show an irregular distribution, but are generally most abundant in marginal zones. Some plagioclase grains are rimmed by narrow selvedge of pale pink K-feldspar. Traces of K-feldspar are also present in interstices between plagioclase grains. Pegmatoidal zones, locally showing well-developed unidirectional growth textures, are common adjacent to contacts with the olivine gabbro. The diorite also contains scattered miarolitic cavities up to ~10cm across. Many of these are filled or partly filled with calcite ± prehnite (?). The diorite commonly contains inclusions of porphyritic olivine gabbro up to several metres across.

Geophysical response

The gabbro shows dark brownish green hues on composite radiometric images, reflecting low to very low concentrations of potassium, thorium and uranium; it is not readily distinguishable from adjacent units.

The gabbro is characterised by a high response on total magnetic intensity images. Magnetic susceptibilities measured at the type locality range from 1420–2770 x 10^{-5} SI units for the porphyritic olivine gabbro (average of 19 readings = 1870 x 10^{-5} SI units); and from 1400–3300 x 10^{-5} SI units for the hornblende diorite (average of 20 readings = 2165 x 10^{-5} SI units).

Relationships and age

The Pride Gabbro intrudes the late Permian Barfield Formation of the Back Creek Group. The sedimentary rocks adjacent to the contact have been indurated and hornfelsed. Therefore the unit has been assigned a late Permian – Early Triassic age.

TIREEN GRANITE

Introduction

The Tireen Granite is a new unit cropping out over an area of ~20km^2 in west-central RAWBELLE (Figure 98). The area was previously mapped by Whitaker & others (1974) as part of the Delubra Gabbro, but granitic rocks are common through the area. However, as discussed below, re-examination of the geophysical data has shed doubt on whether the Tireen Granite as mapped is an appropriate unit. Outcrop is very poor with extensive residual soil cover. Most outcrops are very weathered. The name is derived from Tireen homestead.

Type locality

No type locality has been nominated for this unit at this stage, because of the diverse range of rock types and the possibility that it may be redefined by subsequent mapping.

Lithology

The most common rock type is grey to pink, fine to coarse-grained, equigranular, biotite monzogranite with sparse black, rounded to lensoidal, fine-grained mafic enclaves to 5cm. Slight variations in grain size and texture are common with some outcrops being porphyritic, with scattered pale pink K-feldspar phenocrysts up to 2cm long. Some leucogranite containing only sparse biotite and syenogranite were also recorded within the unit. An outcrop near Tireen homestead at MGA 267500 7205800 is very leucocratic and is medium-coarse grained, moderately porphyritic, leucocratic biotite granite. It comprises quartz (~30%), plagioclase (~25%), perthitic microcline (~45%), biotite (<1%) and rare muscovite. Some observations made during the mapping in the 1970s record a slight foliation in the unit.

In some places, more melanocratic rocks have been observed such as at MGA 266700 7212300, where dark grey, medium-grained, equigranular, titanite-bearing biotite-hornblende tonalite with sparse pyrite was observed. It comprises quartz (~20%), plagioclase (~45%), K-feldspar (<5%), hornblende (~20–25%), biotite (~5–10%), conspicuous titanite (to 3%) and accessory apatite, zircon and opaques (magnetite). Chlorite, epidote, sericite and calcite alteration products are common. At another site north-north-east of Tireen homestead a strongly sheared and altered hornblende-biotite diorite was observed in contact with coarse-grained, slightly foliated, biotite granite. Such mafic rocks may be related to the Glencoe Gabbro but were too small to map out.

Geophysical response

On the composite radiometric images, the Tireen Granite locally has very strong pink-red hues due to elevated potassium. However, much of the unit has a weaker potassium response, and overall the radiometric response is similar to parts of the Greystone Granodiorite and Tandora Granodiorite. Therefore the Tireen Granite as mapped may not be an appropriate unit.

Magnetic susceptibility readings were recorded at only one outcrop within this unit where the values were in the range 7–80 x 10^{-5} SI units. It has a similar response in the airborne magnetic data to that of the Tandora Granodiorite.

Relationships and age

The Tireen Granite is mapped as an irregular body, cutting across and dividing the outcrop area of the Tandora Granodiorite into two. The unit is inferred to be late Permian to Early Triassic.

WATHONGA GRANITE

Introduction

The name Wathonga Granite is here applied to a small area of granite forming several small windows totalling ~2.5km^2 in Tertiary sedimentary deposits in southern RAWBELLE (Figure 98). In spite of the deep weathering profile, relatively fresh boulders and small tors are exposed locally.

Type locality

Tors at MGA 278300 7180600 near Wathonga homestead (from which the unit is named) are designated as the type locality. They consist of pale grey to white, fine to medium-grained biotite leucogranite. The major minerals comprise quartz (~40%), plagioclase (~23%), K-feldspar (~35%) and minor biotite (~2%). Some opaque oxides (~1%). together with accessory apatite, possible titanite and zircon.

Lithology

The Wathonga Granite is mainly very light grey, fine to medium-grained, equigranular biotite granite or leucogranite as at the type locality. Alteration minerals sericite, chlorite and epidote were also observed.

Geophysical response

On radiometric images, the Wathonga Granite shows a moderately strong potassium response and low thorium and uranium values resulting in pinkish hues on composite images.

Magnetic susceptibilities mostly range up to 500 x 10^{-5} SI units and are commonly <100, although at one site a biotite granite showed higher values from 1200 to 2500 x 10^{-5} SI units. The unit lies within an area of low magnetic intensity in the airborne magnetic data, but as the surrounding units (for example, Yerilla Metamorphics) are also low, the unit is difficult to delineate under the extensive cover.

Relationships and age

The Wathonga Granite probably intrudes the Palaeozoic Yerilla Metamorphics under cover, but its relationship to the granites of inferred Carboniferous age in the area is not known. Tertiary deposits conceal all contacts. The age is uncertain, but the lack of a foliation suggests that it is younger than the nearby Carboniferous granites, and may be late Permian or Early Triassic.

WINGFIELD GRANITE

Introduction

The Wingfield Granite was originally named the Wingfield Adamellite by Dear & others (1971) in the Monto 1:250 000 Sheet area, and was extended into the Mundubbera 1:250 000 Sheet area by Whitaker & others (1974). The Wingfield Adamellite is renamed the Wingfield Granite in line with modern nomenclature (Le Maitre, 1989), although the unit remains substantially the same as mapped by Dear & others (1971) and Whitaker & others (1974). It forms a major component of the Rawbelle Batholith and crops out over ~1415km^2 in SCORIA and northern RAWBELLE (Figure 98). Topography is generally gently undulating, with scattered small tors (Figure 108a).

Type locality

The type locality is on the west bank of Cattle Creek, ~2.5km south-west of Wingfield homestead (from which the unit is named) along the track to Coominglah Holding at MGA 277900 7246300. Pale grey and pink, medium grained, porphyritic hornblende-biotite granite to granodiorite is characterised by large pink K-feldspar megacrysts up to 4cm. The distribution of megacrysts is irregular. The rock at the type locality comprises quartz (20–25%), andesine (35–40%), K-feldspar (25–30%), biotite (~5%), hornblende (5–8%), titanite (~1%), with a trace of opaques. Mafic xenoliths are also irregularly distributed.

Lithology

The Wingfield Granite covers a very large area and not surprisingly includes several variants, although the porphyritic granite or granodiorite as at the type locality is the most common rock type (Figure 108c–d). Similar porphyritic granite occurs along the Burnett Highway west of the Coominglah Range and around Bonnie Doon homestead on Spring Creek. Deeply weathered porphyritic granite or granodiorite underlies large tracts of country north of Wingfield Station.

Some samples contain 15–20% quartz and are strictly quartz monzonite to quartz monzodiorite, but the general name Wingfield Granite is retained for the unit.

South of Bonnie Doon homestead and near the road to Oaky Creek homestead, outcrops on a knoll are pale grey, medium-grained, even grained hornblende-biotite granodiorite. This variant of the Wingfield Granite does not contain pink K-feldspar and megacrysts to be and appears more mafic-rich than the porphyritic varieties. Mafic xenoliths are again common.

Near Oaky Creek homestead, biotite-hornblende granodiorite comprising quartz (20–25%), oligoclase (35–40%), K-feldspar (20–25%), biotite (5–8%), hornblende (5–8%), titanite (~1%) with a trace of opaques.

Figure 108. Wingfield Granite
(a) Typical exposure and topographic expression of the Wingfield Granite. About 1.5km north of Dareen homestead at MGA 282118 7220213 (QFG2537) (QFG2537 Wingfield FGS97-4-35)
(b) Porphyritic hornblende-biotite granite containing aligned xenoliths; note the growth of feldspar megacrysts in one of the xenoliths. Nogo River ~12km east-north-east of Dareen homestead at MGA 292823 7223287 (QFG2523)
(c) Scanned slab of porphyritic hornblende-biotite monzogranite. About 4km south-east of Arthurs Knob at MGA 294096 7225029 (QFG2554)
(d) Porphyritic hornblende-biotite granite containing a large zoned euhedral K-feldspar megacryst. About 15km east-south-east of Rawbelle homestead near Boogalgopal Creek at MGA 295069 7224631

It is juxtaposed against biotite granite comprising quartz (20–25%), K-feldspar (35–40%), plagioclase (30–35%), biotite (5–6%), and titanite (~ 1%) with traces of opaques, zircon, and epidote.

Around Upson Downs, Boogalgopal and Hazledean homesteads, the Wingfield Granite crops out as large boulders and tors of very fresh, slightly porphyritic hornblende-biotite granite. It contains pink, perthitic K-feldspar (30%), slightly zoned white oligoclase (35%), quartz (20%), hornblende and biotite (variable to 15%). Titanite is a characteristic accessory mineral (*ca* 1%). Dark grey to black, subrounded to rounded, biotite rich xenoliths, 2–40cm long are commonly elongated and slightly aligned (Figure 108b), defining a foliation striking north-north-west. Leucocratic microgranite, aplite and pegmatite dykes are common.

Another rock type observed at MGA 291550 7227600 is a slightly porphyritic hornblende-biotite granodiorite, which does not have the pronounced feldspar phenocrysts. The feldspars are mainly 0.5–1cm. Euhedral hornblende prisms up to 1.8cm are the most common phenocrysts. Hornblende and biotite together comprise ~10% of the rock. Some mafic xenoliths are present.

Geophysical response

Radiometric responses indicate relatively high values in all channels, resulting in a whitish colour on the composite images (Figure 99). Somewhat lower responses in all three channels, particularly potassium, are indicated in the western parts of the pluton, where granodiorite is more common. In the east, higher total counts appear to be mainly related to the porphyritic granite.

Magnetic susceptibilities over the whole batholith have a slightly skewed distribution and range from 300–1800 x 10^{-5} SI units (average 892 and standard deviation of 673). This even range of susceptibilities is reflected by the uniform moderate aeromagnetic response over the whole pluton (Figure 100). However, several areas of lower magnetic intensity can be delineated and are probably associated with alteration. They may correspond with a small, but distinct population of magnetic susceptibility values of <200 x 10^{-5} SI units.

Relationships and age

The Wingfield Granite appears to be one of the youngest intrusives in the region. Although outcrop is poor, it is inferred to intrude the Yaparaba Volcanics and Camboon Volcanics. The relationship between the Wingfield Granite and the Harrami Igneous Complex is uncertain. Outcrop is too poor or the margin is covered by Tertiary basalt for the relationship to be determined, although the regular outline of the contact suggests that the Wingfield Granite is younger. The relationships with the Colodon and Tecoma Granodiorites are also uncertain. Magnetic images show a distinct highly magnetic rim around the pluton, particularly in the east under the cover of Mulgildie Basin. This is inferred to be due to hornfelsing of the Yarrol Basin succession. Magnetic highs to the north and west may be partly hornfels-related, but are probably mainly due to highly magnetic plutons such as the Harrami Complex and Kariboe Layered Gabbro.

Most of the samples chemically analysed from the Wingfield Granite define a distinct suite along with some other units such as the Cheltenham Creek Granite, Colodon Granodiorite, Pollard Granodiorite and Euroka Granodiorite (Figures 110 and 111). However, the geochemistry suggests that the Wingfield Granite as mapped may include some other phases. In general, the Wingfield Granite has a restricted range of SiO_2 with most samples lying between 60–70%. However, those samples from Wingfield Granite that have SiO_2 >70% tend to plot with the Tandora Suite. This suggests that the unit as mapped may be composite. However, delineating different units would be extremely difficult.

K–Ar dating on six samples (four from the Monto 1:250 000 Sheet area and two from Mundubbera 1:250 000 Sheet area) by Webb & McDougall (1968) gave Early to Middle Triassic ages ranging from 233 to 247Ma (recalculated to IUGS constants). These may be partly reset because SHRIMP U-Pb zircon dating of a sample of biotite granite from the Nogo River, near Old Rawbelle homestead from MGA 282878 7229103 gave an age 251.1±3.6Ma (based on 18 analyses with a MSWD = 2.7), close to the Permian-Triassic boundary (see Appendix).

UNNAMED INTRUSIONS

Numerous small intrusions, which were not considered significant enough to be named and which are probably late Permian or Early Triassic age, crop out through the southern half of the project area in the Auburn Arch, Rawbelle Batholith and Gogango Overfolded Zone. They are assigned to one of several categories:

PRg	Granite, granodiorite, diorite, gabbro
PRg_b	Dominantly gabbro, some diorite and quartz diorite
PRg_d	Dominantly hornblende diorite, biotite-hornblende quartz diorite, monzodiorite and monzonite
Pg_g and **PRg_g**	Undivided granite and granodiorite

Some of the plutons that were examined in more detail are described below.

(1) The Rookwood Volcanics are intruded by a pluton ~3km in diameter near Rookwood homestead. It is moderately well exposed, forming small boulder-strewn hills. It consists of medium-grained, equigranular hornblende quartz diorite to quartz monzodiorite. It contains mostly hornblende (30–50%) as subhedral prisms ~2mm long, plagioclase (40–50%) as zoned subhedral laths mostly ~2mm long and interstitial quartz (5–10%). K-feldspar (up to 10%) forms large anhedral, poikilitic grains up to 4mm across. Minor clinopyroxene (2%), partly replaced by hornblende, is present locally. Accessory minerals include opaque oxides and titanite. Rounded xenoliths of fine-grained microdiorite up to 10cm across with sharp to diffuse margins are locally abundant.

This pluton was dated by Webb & McDougall (1968), samples GA1068 and GA1069 giving K–Ar biotite and hornblende ages ranging from 241–245Ma (Early Triassic — ages adjusted for decay constants of Steiger & Jäger, 1977).

(2) Farther north, several small irregularly shaped gabbro bodies, each ~1km^2 in area, intrude the Mount Benmore Volcanics and Goodedulla beds. The gabbro consists of ~60% laths of plagioclase to 5mm and 40% subhedral to euhedral clinopyroxene and its alteration products (mostly aggregates of fine-grained

chlorite and uralite). Skeletal grains of ilmenite are partly replaced by leucoxene. The plagioclase crystals are somewhat fractured and broken, suggesting that the emplacement may have pre-dated the thrusting in the area.

(3) Two small elongate gabbro bodies a few hundred metres long intrude the Back Creek Group, just south of the Capricorn Highway near the Telstra microwave tower. The gabbro at MGA 796700 7370200 consisted originally of plagioclase (30–40%), clinopyroxene (50–60%) and ilmenite (5%). The rocks are altered partly to epidote, chlorite and leucoxene.

(4) In the Gogango Range, the Camboon Volcanics are intruded by several gabbro or diorite plutons around Mount Wheal and Mount Spencer. Mount Wheal is relatively inaccessible and was not examined during this study. Floaters of altered diorite or gabbro were observed in creeks draining the area. The mapped extent of this intrusion is based on air-photo interpretation. Gabbro examined on Mount Spencer on its eastern flank and near the UHF repeater station is strongly altered. It is medium to coarse-grained and consists of partly sericitised laths of plagioclase (50–60%), clinopyroxene (35–40%) that is commonly replaced along fractures and margins by fibrous uralite aggregates, and ilmenite (5%) partly altered to titanite or leucoxene. Irregular aggregates of epidote (5%) are disseminated through the rock.

(5) Small bodies of gabbro and dolerite, including dykes, intrude the Nogo beds. The bodies are probably Permian and may be comagmatic with some of the volcanics themselves. The most common type of gabbro is very homogeneous, dark green to black, medium to coarse-grained and equigranular. It contains plagioclase crystals up to 5mm and clinopyroxene (augite) or amphibole pseudomorphs after clinopyroxene. Other minerals present include ilmenite, titanite and calcite. Stages of uralitisation are variable, but the clinopyroxene appears to change directly to a pale green uralitic amphibole, in places reacting with the plagioclase to form a deeper green border. In the final stages of uralitisation, small amphibole needles develop in the feldspars. Xenoliths have not been observed. No banding or compositional layering has been observed.

Margins are commonly chilled and are very dark grey and show doleritic textures with plagioclase laths that are thin and ~1mm long. Pyroxene tends to be completely altered to amphibole. Effects of chilling of the gabbro were observed at a contact over 10m at MGA 306300 7191160 by Webb (1960).

GEOCHEMISTRY OF PERMIAN TO EARLY TRIASSIC GRANITOIDS IN THE RAWBELLE BATHOLITH

Harker plots of the late Permian to Early Triassic plutons of the Rawbelle Batholith are shown in Figures 110 and 111. Plots of FeO_{total}, TiO_2, CaO and P_2O_5 show strong linear trends with little separation suggesting that the rocks are closely related. However, the alkali elements and some trace elements such as Sr and Th suggest that the rocks can be grouped into two suites, herein termed the Tandora and Wingfield Suites.

Although the suites show overlap, the Wingfield Suite tends to have higher K_2O (particularly for lower SiO_2 values), Rb, Sr and Th and lower Na_2O than the Tandora Suite. Although it is not plotted, the suite also has higher U. This is reflected in the radiometric data, and most members of the suite can be identified by being moderate to high in all three channels and generally show white or yellowish hues on composite images, whereas those in the Tandora Suite have dark pink to brown hues. The differences in K_2O and Na_2O are highlighted by the plot of K_2O/Na_2O vs SiO_2, in which the two groups show relatively clear separation. The Cheltenham Creek Granite is particularly high in K_2O. At lower SiO_2 values, P_2O_5 in the Wingfield Suite is also generally higher than in the Tandora Suite.

The Wingfield Suite lies entirely in the high-K field of Peccerillo & Taylor (1976), whereas the Tandora Suite lies partly in the intermediate-K field, particularly for the less siliceous samples. In general, the Wingfield Suite has a more restricted range of SiO_2 with most samples lying between 60 and 70%. The Tandora Suite ranges up to 78% SiO_2. Those samples from Wingfield Suite units that do have SiO_2 >70% tend to plot with the Tandora Suite. This particularly applies to such samples from the Wingfield Granite suggesting that the unit as mapped may contain some other phases. Anomalous samples from the Pollard Granodiorite that plot with the Tandora Suite are aplite. Unassigned granitoids from the Rawbelle area mostly plot with the Wingfield Suite.

Two samples from the Colodon Granodiorite lie in the Coonambula Suite in plots of FeO_{total}, TiO_2, Sr and Zn. Both are associated with abundant xenoliths of metamorphic rocks and it is uncertain whether the geochemical affinities are simply due to assimilation or whether they represent an unmapped area of Tecoma Granodiorite which shares similarities with the Coonambula Suite (see page 295). The majority of samples from the Greystone Granite also plot with the Coonambula Suite, although some are similar to the Tandora Suite indicating that the unit is composite.

Auburn-Rawbelle-Eidsvold plutons

Early Carboniferous?

▽ Donore Granite Gneiss
✸ Horse Granite Gneiss
✳ Carinya Granite
□ Mount Clairvoyant Granite

Carboniferous-Early Permian

◇ Plutons of the Auburn Arch
+ Torsdale Volcanics

Early Permian?

○ Eidsvold Igneous Complex
△ Lookerbie Igneous Complex

Coonambula Suite

+ Coonambula Granodiorite
○ Greystone Granodiorite
◇ Tecoma Granodiorite
× Widbury Granite

Late Permian-Early Triassic

Wingfield Suite

✡ Cheltenham Creek Granite
✳ Colodon Granodiorite
□ Euroka Granodiorite
○ Pollard Granodiorite
◇ Wingfield Granite

Tandora Suite

✡ Cadarga Creek Granodiorite
□ Culcraigie Granite
◇ Flat Range Granodiorite
○ Impey Granodiorite
△ Kildare Granodiorite
● Tandora Granodiorite
× Telemark Granodiorite
▽ Wathonga Granite
+ Other units (Aisbetts Granodiorite, East Apple Granite & Morrow Granite)

▲ Harrami Igneous Complex
□ Unassigned Rawbelle Batholith granitoids
✳ Delubra, Quaggy Mountain & Hefferon Creek Gabbros

Late Triassic

✸ Mount Saul Quartz Monzonite
▼ Greencoat Quartz Monzonite
● Boolgal Granophyre

Connors-Urannah plutons

▲ Tertiary plutons
○ Cretaceous plutons
◇ Late Carboniferous-Early Permian (southern Urannah Batholith)
▲ Late Carboniferous plutons (Connors Arch)
■ Early Carboniferous plutons (Connors Arch)

Figure 109. Symbols used for the plutonic rocks on geochemical plots.

In various plots in Figure 110 and 111, the more SiO_2-rich samples from the Harrami Igneous Complex, which ranges from gabbro to granite lie in both the Tandora and Wingfield Suites, but TiO_2 is lower than either of these suites, and the complex may represent a separate suite of its own. Relationships in the unit are very complex with common examples of magma mingling and a more extensive controlled sampling program than attempted by us would be needed to study it effectively. Most samples, even the gabbros, lie in the high-K field, which distinguish them from the other gabbro units in the batholith. The latter are also plotted in Figures 110 and 111. It has not been possible to group these. Some felsic rocks within these units plot with the Tandora Suite, but it is uncertain whether these represent minor intrusions related to this suite or felsic differentiates from the host gabbros.

As with the late Carboniferous to early Permian granitoids of the Auburn Arch, the Tandora and Wingfield Suites are Sr undepleted and Y depleted (Figure 112), suggesting derivation by partial melting from below the eclogite transition, in either the lower crust or mantle (depending on the thickness of the crust at the time).

The Wingfield Suite and the Tandora Suite units show little variation in K/Rb, and the Ba vs Sr plot suggests that plagioclase fractionation may account for much of the compositional variation. However, the Culcraigie

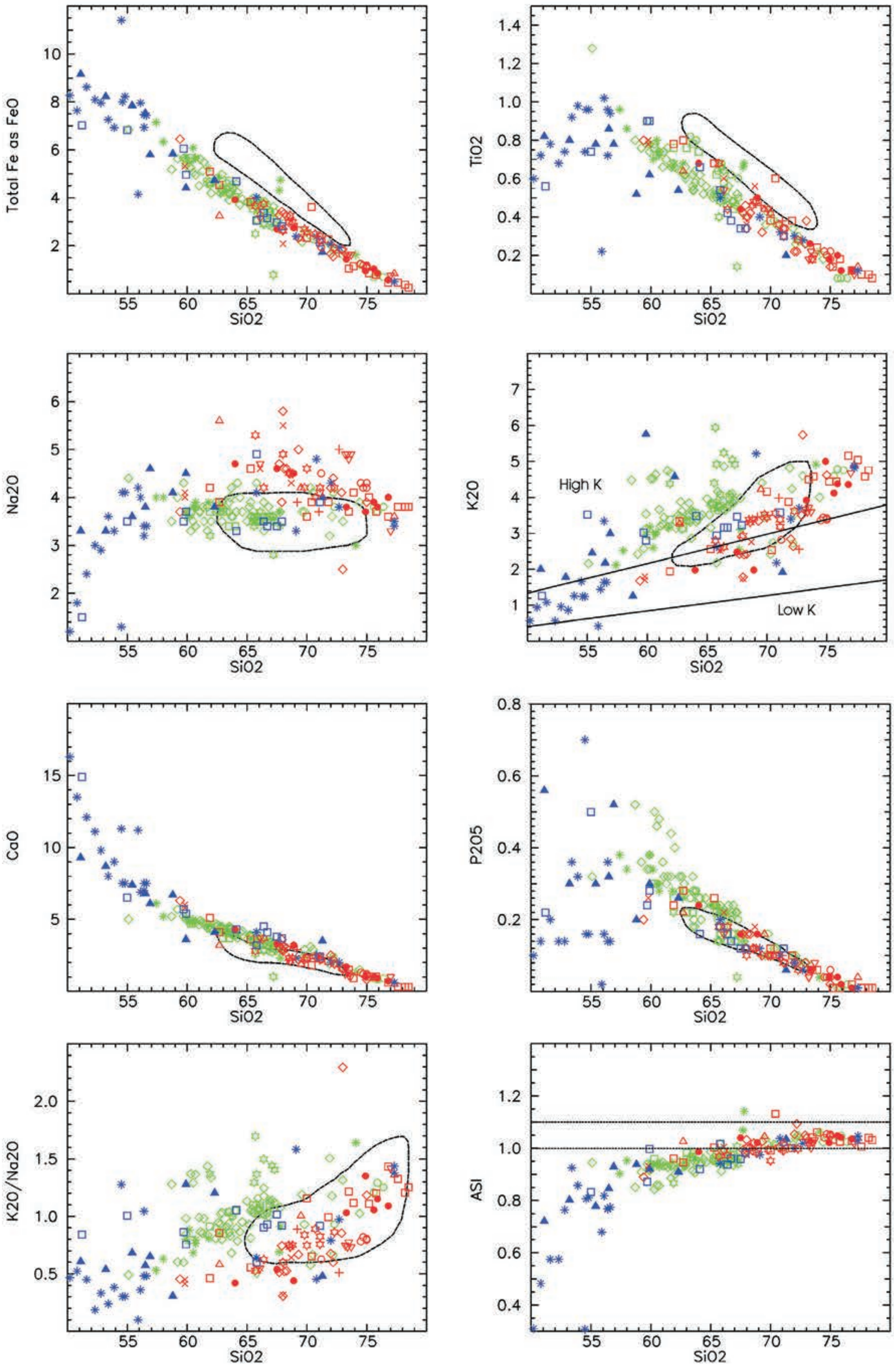

Figure 110. Variation diagrams for Permian to Early Triassic plutonic rocks from the Rawbelle Batholith showing selected major elements in weight percent and the Alumina Saturation Index (ASI) vs SiO_2 in weight percent. The field is for the Coonambula Suite. Symbols are as shown in Figure 109.

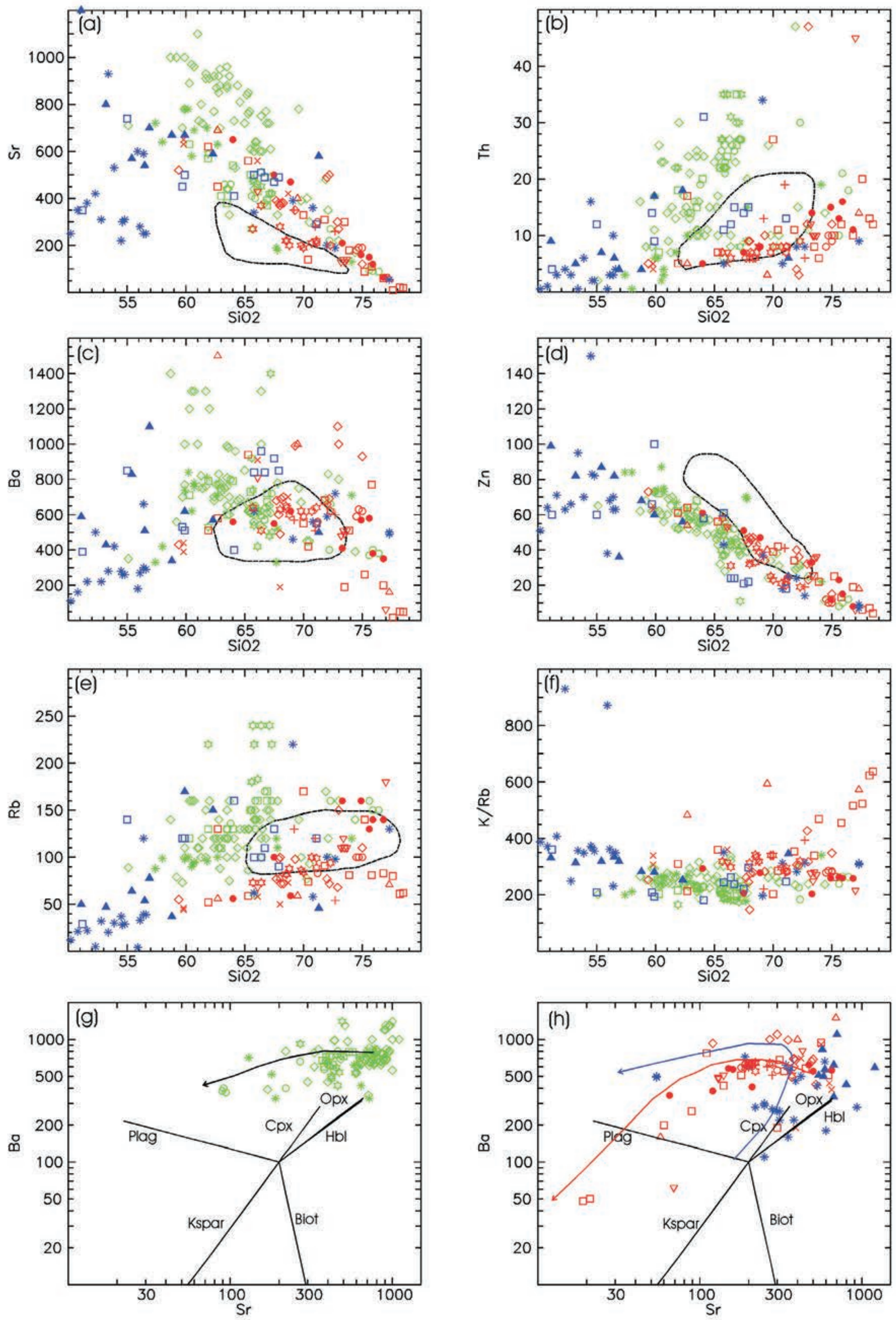

Figure 111. Variation diagrams for Permian to Early Triassic plutonic rocks from the Rawbelle Batholith showing selected trace elements in parts per million and K/Rb vs SiO_2 in weight percent. Mineral vectors in (g) and (h) are from Rollinson (1993, page 161) and show fractional crystallisation trends for Ba and Sr for the various minerals shown. The arrowed lines show approximate overall fractionation trends for the samples plotted. The field is for the Coonambula Suite. Symbols are as shown in Figure 109.

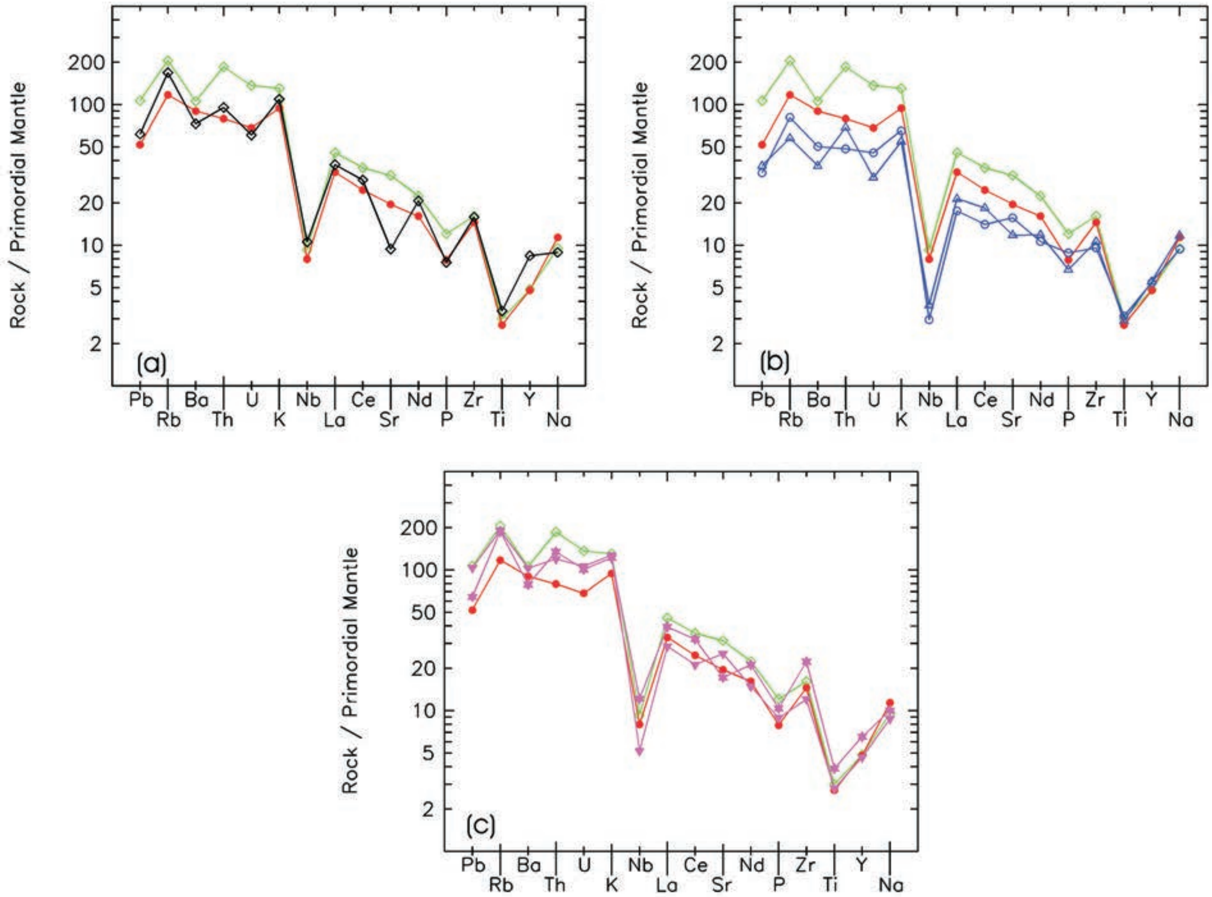

Figure 112. Spider diagrams normalised against the primordial mantle values of McDonough (1987) for average analyses of samples in the range 55–70% SiO_2 for granitoid groups from the Auburn-Rawbelle–Eidsvold area:
(a) Comparison of Tandora Suite (red), Wingfield Suite (green) and Coonambula Suite (black)
(b) Comparison of Tandora Suite (red), Wingfield Suite (green), Eidsvold Complex (blue circles) and Lookerbie Igneous Complex (blue triangles)
(c) Comparison of Tandora Suite (red), Wingfield Suite (green), Mount Saul Quartz Monzonite (magenta stars) and Greencoat Quartz Monzonite (magenta triangles).

Granite, which is a relatively felsic granite, shows a strong increase in K/Rb and the Ba vs Sr plot suggests that K-feldspar fractionation may be an important process.

The rocks of the Rawbelle batholith are metaluminous to mildly peraluminous and are I-types, consistent with the fact that many are hornblende-bearing. In the discrimination diagrams of Whalen & others (1987), the more fractionated samples of Culcraigie Granite extend above the field of orogenic granites because of elevated K_2O, but otherwise the rocks do not show characteristics of A-type granites (Figure 113). In Figure 114, all units plot as “volcanic arc granites” on the Rb vs Y+Nb plot (using the criteria of Pearce & others, 1984).

LATE TRIASSIC PLUTONS

BOOLGAL GRANOPHYRE

Introduction

This unit was named and defined by Whitaker & others (1974) as the Boolgal Granite. The name is changed here to Boolgal Granophyre. The total surface area of the Boolgal Granophyre is ~45km^2 and it is centred ~15km west of Eidsvold (Figure 98).

The unit forms an irregularly shaped intrusion with relatively high relief. The higher areas are generally capped by a thin layer of Cainozoic sediments. The soil on the granite is light coloured, clayey sand. The unit

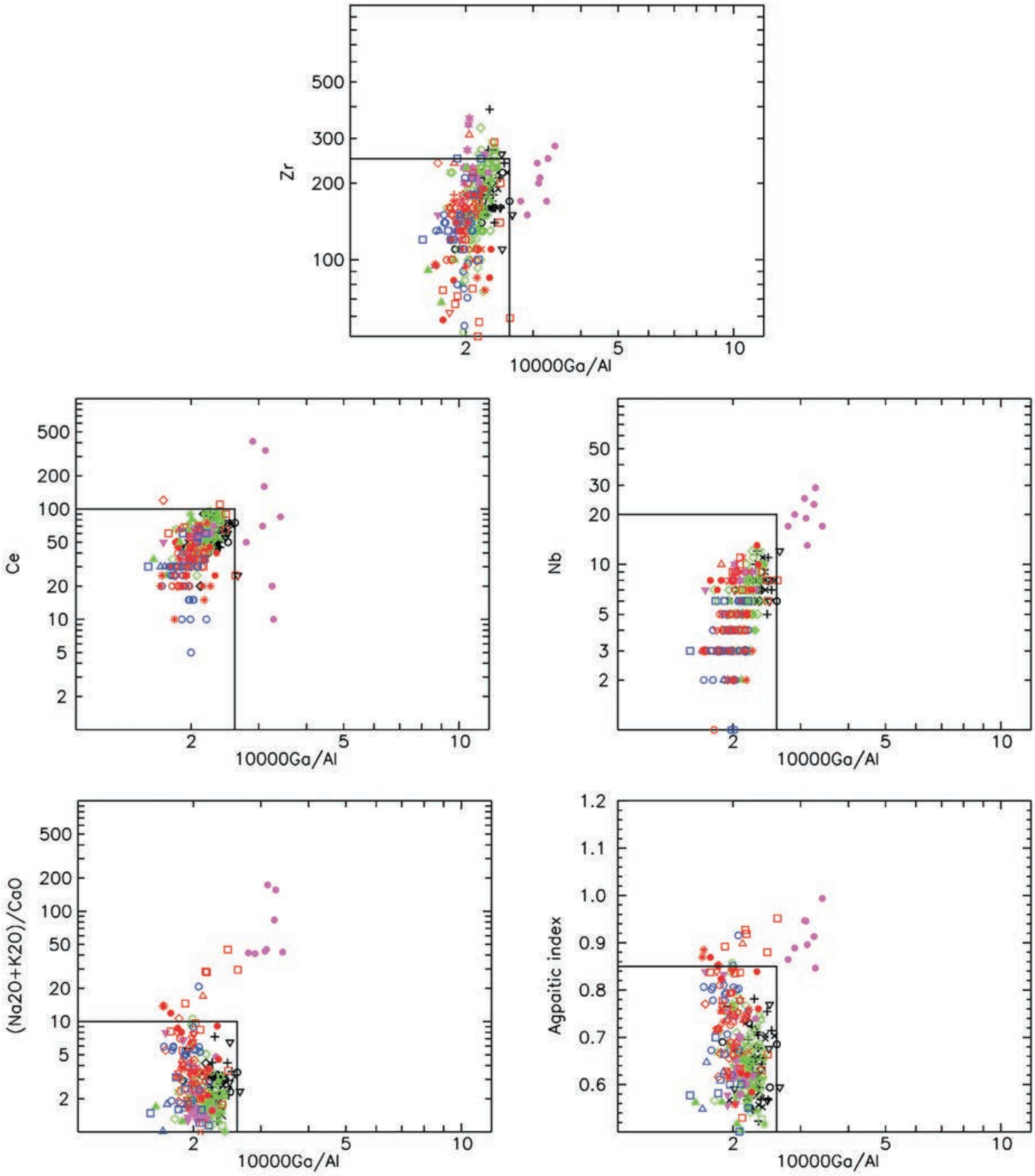

Figure 113. Plots of selected trace elements in parts per million and major element ratios vs 1000Ga/Al for Permian to Triassic plutonic rocks from the Rawbelle Batholith. Agpaitic Index is molar (Na_2O+K_2O)/Al_2O_3). Fields for orogenic granites in the bottom left corners are from Whalen & others (1987). Symbols are as shown in Figure 109.

supports a dense growth of wattles and grass trees, whereas the surrounding granites support open eucalypt forest. A well developed joint system is clearly indicated on aerial photographs by straight, densely vegetated gullies, which make access very difficult. Access was gained along a newly bulldozed power-line through the centre of the unit.

Type locality

The type locality is designated along the power line north-east of Widbury homestead at MGA 296600 7186700. This site shows relatively fresh, pale pink arfvedsonite-bearing miarolitic granophyre containing graphically intergrown quartz and alkali-feldspar (Figure 115a). It consists of alkali-feldspar (78%), quartz (15%) arfvedsonite (up to 5%) and opaques (1–2%).

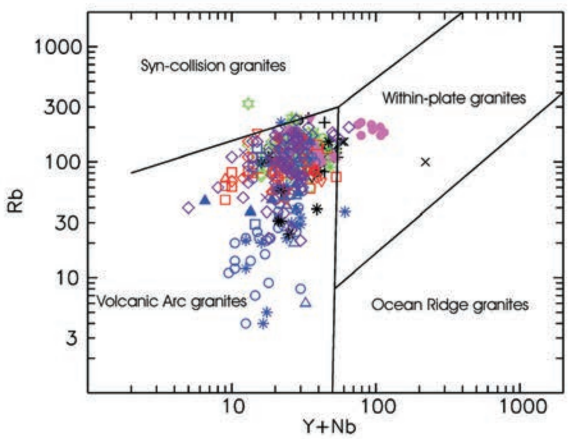

Figure 114. Plots of Rb vs Y+Nb in parts per million for plutonic rocks from the Auburn–Rawbelle–Eidsvold area. Fields are from Pearce & others (1984). Symbols are as shown in Figure 109.

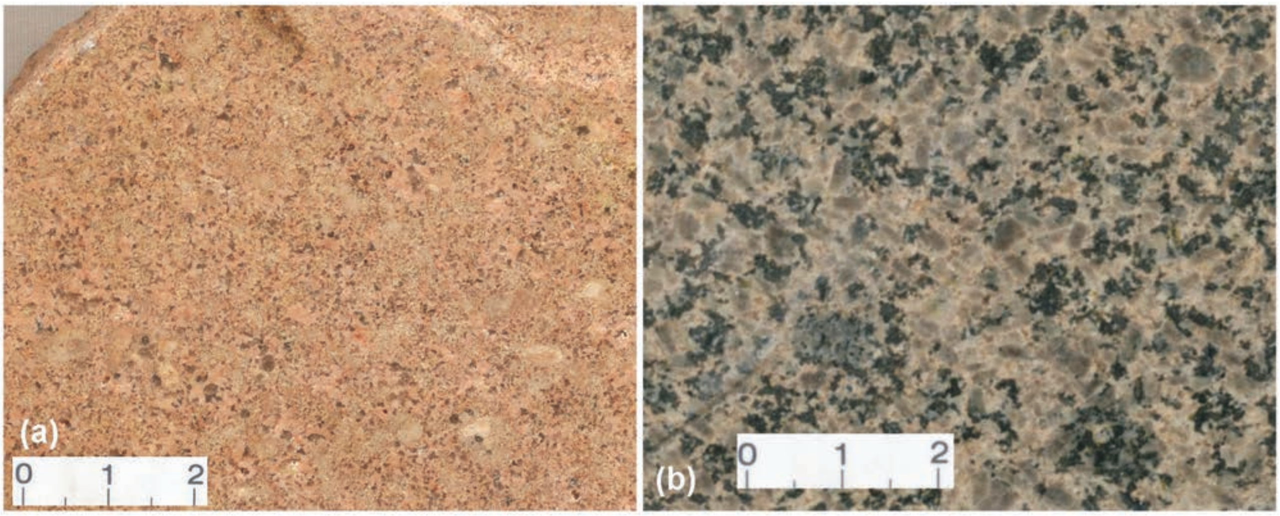

Figure 115. Triassic plutons of the Rawbelle Batholith; scale is 2cm
(a) Scanned slab of miarolitic granophyre from the type locality of the Boolgal Granophyre, showing very strong graphically intergrown quartz and alkali-feldspar. Powerline track north-east of Widbury homestead at MGA 295575 7190697 (QFG2828)
(b) Scanned slab of fine to medium-grained biotite-hornblende quartz monzonite to monzogranite from the type area of the Mount Saul Granite. Hawkwood–Auburn road at MGA 276138 7142545 (RSC210)

Lithology

The dominant rock-type is pale brown, coarse-grained to aplitic, equigranular, arfvedsonite-bearing granophyre. It consists mainly of alkali-feldspar (K-feldspar with some albite), intergrown with subordinate quartz, minor arfvedsonite and traces of opaque oxides. It commonly shows kaolin alteration, particularly near the western contact, but also within the body. Irregular patches of medium-grained quartz and feldspar and miarolitic cavities are common.

The granophyre is commonly intruded by medium grey to pale pink, porphyritic, felsic to intermediate dykes. A narrow dyke of perlite was observed intruding the country rocks adjacent to the contact at MGA 293100 7187800.

Geophysical response

The radiometric response for this unit is moderate in uranium and thorium, but high in potassium, resulting in bright pinkish hues on the composite images, which contrast with the dark green denoting the Cainozoic cover sequences (Figure 99). Some purple hues probably represent subcrop under a very thin veneer of Cainozoic or more strongly altered granophyre.

Magnetic susceptibilities measured in the field mostly showed a nil response (0 x 10^{-5} SI units) consistent with the low response on magnetic images compared with the neighbouring units (Figure 100). The porphyritic (dacite) dykes have a range of 250–900 x 10^{-5} SI units (average 700), but do not show an effective response on the airborne magnetic images possibly because they are too thin.

Relationships and age

The Boolgal Granophyre intrudes the Nogo beds and surrounding granites of the Rawbelle Batholith, including the Coonambula Granodiorite and the Culcraigie Granite, although none of the contacts could be seen in outcrop. Strong kaolinisation in the granitoids around the Boolgal Granophyre also suggests it intruded these units. An alkali-amphibole (arfvedsonite) from a granophyre sample (QA68) from MGA 294400 7186200, in a gorge on Morrow Creek, north of Widbury homestead, gave a recalculated K–Ar age of 218Ma (Whitaker & others, 1974).

MOUNT SAUL QUARTZ MONZONITE

Introduction

Whitaker & others (1974) assigned the name Mount Saul Adamellite to two separate stocks. The name, herein modified to Mount Saul Quartz Monzonite is retained for the south-eastern stock in which Mount Saul is the most prominent topographic feature. Present mapping indicates that the distribution of this stock is largely as shown by Whitaker & others (1974) with the exception of the extreme south-east, where Narayen beds crop out instead. The Mount Saul Quartz Monzonite in its restricted definition is an arcuate body of ~16km^2 that partly encloses an area of Triassic Morang Volcanics (Figure 98). The unit crops out well as boulder outcrop and stands out from the surrounding more recessive terrain. The north-western stock has been renamed Greencoat Quartz Monzonite.

The name has also been applied on the AUBURN map to a small, previously unmapped pluton ~2km across, ~3km north of the main pluton.

Type locality

The type area is designated along the Hawkwood–Auburn River Road from MGA 276650 7143400 to MGA 275050 7141200. Outcrop consists of greyish to greenish pink, medium-grained biotite-hornblende quartz monzonite (Figure 115b), containing mafic clots and small mafic xenoliths. Numerous felsic dykes intrude the unit here as elsewhere.

Lithology

Whitaker & others (1974) described the dominant rock type as consisting of medium to coarse-grained ‘adamellite’ containing andesine (25%), K-feldspar (35%), quartz (10%), green hornblende (15%), minor biotite, minor opaque oxides and accessory zircon and apatite; alteration products including chlorite after biotite, and sericite and saussurite after feldspar, together with epidote, made up the rest of the rock.

Thin sections examined in this study confirm the low quartz content, which suggests that the stock is quartz monzonite rather than monzogranite, and the name is changed here to reflect this, although the AUBURN map still retains the name Mount Saul Granite. Chemical analyses (showing 60–65% SiO_2) and calculated CIPW norms are also consistent with this. In places the rocks may grade into quartz monzodiorite. The quartz is interstitial to the feldspars, and in places intergrown with the K-feldspar.

Although mostly equigranular, the rock locally has conspicuous prismatic hornblende phenocrysts up to 6mm long. In some thin sections, the hornblende is pale green and somewhat acicular, and colourless clinopyroxene is common as discrete crystals or cores to hornblende. Biotite in some specimens is equal in abundance to hornblende.

The southern stock is commonly altered. Epidote is usually associated with ferromagnesian minerals. Chloritic veins are also common. A more felsic mineralised and strongly altered phase crops out in hilly terrain around MGA 276900 7140400. Alteration includes pervasive chloritisation and vein-controlled epidote. Open-space infill quartz is also present. An extensive drilling program has been undertaken in this area, attempting to prove-up a gold resource. The dominant lode trend appears to be south-easterly, changing to east-north-easterly to the east.

Near the northern margin of the unit, finer-grained, more leucocratic hornblende-biotite monzogranite (subunit **$Rgms_m$**) occurs near the intersection of the Doon Doon Station access road and the Mount Narayen Road, near MGA 276400 7147300. Magnetic intensity in the area is low, in contrast with the rest of the unit (see below).

The small pluton to the north is finer grained and contains phenocrysts of plagioclase and hornblende, as well as clots and aggregates of hornblende, in a fine-grained groundmass of plagioclase and K-feldspar that is graphically intergrown with interstitial quartz. Biotite is also present.

Geophysical response

In the radiometric data, the unit has a strong potassic response and moderate uranium and thorium producing overall pinkish hues on composite radiometric images. These stand out from the overall low response of the surrounding Narayen beds and the uniformly moderate response in all channels of the Morang Volcanics (Figure 101).

The magnetic susceptibility measured in the field ranges up to ~2500 x 10^{-5} SI units showing a bimodal distribution with modes at ~300 and 1600. The higher values are consistent with the airborne magnetic data that shows the unit to be characterised by a relatively high intensity magnetic response. The airborne data suggests that the Mount Saul Quartz Monzonite underlies the northern part of the Morang Volcanics and forms a complete ring-like structure at depth (Figure 102).

The small pluton to the north has low magnetic susceptibility and a low response on the total magnetic intensity image, suggesting that its assignment to the Mount Saul Quartz Monzonite may not be appropriate.

Relationships and age

This stock intrudes and is distinctly chilled against Narayen beds. The south-western boundary of the unit is marked by a screen of Narayen beds with an anomalously high aeromagnetic response, suggesting that they were oxidised during contact metamorphism.

The relationship to the Morang Volcanics is unclear. The contact is not exposed. Whitaker &others (1974, page 72) interpreted the relationship as an unconformity, but also (page 46) suggested that it may be intrusive, citing brecciation and quartz veining in the volcanic rocks near the contact as evidence. The arcuate shape of the pluton, partly enclosing the volcanic rocks, suggests that it may represent a small cauldron subsidence structure, and that the volcanic rocks and the monzogranite may be related.

K–Ar dating of the Mount Saul Granite gave Late Triassic ages (adjusted for IUGS constants) of 219±6Ma and 220±6Ma from biotite and hornblende respectively (Green, 1975; Whitaker & others, 1974). An Ar^{39}–Ar^{40} total degassing age of 227±7Ma was also obtained from biotite (Green, 1975).

GREENCOAT QUARTZ MONZONITE

Introduction

This name has been given to the north-western of two stocks assigned by Whitaker & others (1974) to the Mount Saul Adamellite. The latter name, herein modified to Mount Saul Quartz Monzonite is retained for the south-eastern stock. The Greencoat Quartz Monzonite stock is a roughly elliptical body of ~30km^2 in central AUBURN (Figure 98). The name is derived from Greencoat Creek. Like the Mount Saul Quartz Monzonite, the unit crops out well as boulder outcrop and stands out from the surrounding more recessive terrain.

Type locality

The type locality is designated at MGA 296600 7145000 in the headwaters of South Hooper Creek in the north-eastern part of the stock. Grey, medium-grained, equigranular biotite-clinopyroxene-hornblende quartz monzonite crops out.

Lithology

The Greencoat Quartz Monzonite is similar petrographically to the Mount Saul Quartz Monzonite. It is pinkish grey, medium to coarse-grained, equigranular to slightly porphyritic and consists of laths of plagioclase (35–40%, slightly normally zoned andesine), K-feldspar (30–35%), interstitial, partly graphically intergrown quartz (5–10%), reddish brown, partly chloritised biotite (5%), green hornblende (5–10%), abundant opaque oxides and accessory zircon. Plagioclase phenocrysts to 5mm are present in some rocks and the K-feldspar poikilitically encloses the mafic minerals. The hornblende ranges from ragged prismatic grains to fibrous masses, probably after clinopyroxene, and locally forms aggregates up to 7mm across. Clinopyroxene cores are preserved in some grains. Some plagioclase laths are selectively saussuritised.

In the north-eastern part of the stock, a small area of pink, medium-grained leucocratic biotite monzogranite has been outlined. It consists of quartz (25%), perthitic K-feldspar (40%), plagioclase (30%) and dark brown biotite (<5%). The quartz is slightly intergrown with the K-feldspar. The biotite locally encloses minor green hornblende. Accessory titanite and zircon are present. A similar rock was observed in the south-western part of the stock at MGA 258060 7140680, but its extent was not mapped out.

Geophysical response

Like the Mount Saul Quartz Monzonite, in the radiometric data the unit is has a strong potassic response and moderate uranium and thorium producing overall pinkish hues on composite radiometric images that stand out from the overall lower responses of the surrounding units (Figure 101). The monzogranite subunit has higher thorium than the rest of the unit, although the data suggests that it may extend farther north than mapped.

The magnetic susceptibility measurements made in the field ranged from 900–4000 x 10^{-5} SI units (average about 2300) for the main part of the pluton. This is consistent with the strong response that contrasts with that of surrounding units in the airborne magnetic data (Figure 102). The leucocratic monzogranite had lower susceptibility readings, ranging from 230–580 x 10^{-5} SI units (average about 410), but it does not stand out as significantly different in the airborne magnetic data.

Relationships and age

The Greencoat Quartz Monzonite intrudes the early Permian Narayen beds and is also inferred to intrude the Carboniferous Evandale Tonalite. It is overlain by poorly consolidated Tertiary sedimentary deposits.

The age is uncertain because no isotopic dating has been done. K–Ar dating of the similar Mount Saul Quartz Monzonite gave Late Triassic ages (adjusted) of 219Ma and 220Ma (Green, 1975; Whitaker & others, 1974) and a similar age is possible for the Greencoat Quartz Monzonite.

GEOCHEMISTRY OF THE LATE TRIASSIC GRANITOIDS

The Boolgal Granophyre and Mount Saul Quartz Monzonite have both been dated by the K–Ar method as Late Triassic. The Greencoat Quartz Monzonite has not been dated, but was originally mapped as “Mount Saul Adamellite” by Whitaker & others (1974), and may also be Late Triassic.

The Boolgal Granophyre appears to be highly fractionated and SiO_2 is >72%. It has characteristics of A-type granites with high Ga/Al ratios and relatively high values of Zr, Ce, La and Nb (Figure 113). This is consistent with the plot of Rb vs Nb+Y in Figure 114, where the samples plot in the ‘within-plate’ field of Pearce & others (1984). The granophyre commonly contains arfvedsonite indicating it is peralkaline, although only one of the samples analysed has an Agpaitic Index (molar Na_2O+K_2O/Al_2O_3) >1. The Ba vs Sr plot suggests strong fractionation of K-feldspar resulting in depletion of Ba.

Neither the Mount Saul Quartz Monzonite or Greencoat Quartz Monzonite is an A-type granite and they plot in the field of ‘volcanic arc granites’ (Figure 114). The Mount Saul Quartz Monzonite shows much greater variation in composition than the Boolgal Granophyre with SiO_2 in the range 60–70%. It mostly plots in the field of the Wingfield suite although it has higher TiO_2 and lower Sr (Figures 116 and 117). It shows Sr depletion and slightly enriched Y in the multi-element plot in Figure 113, suggesting it was melted above the eclogite zone, unlike the Wingfield and Tandora Suites.

The Greencoat Quartz Monzonite is also similar to the Wingfield Suite although has lower TiO_2 (in contrast to the Mount Saul Quartz Monzonite which has higher TiO_2 than the Wingfield Suite). It shows Sr enrichment and Y depletion (Figure 113). This suggests that it is unrelated to the Mount Saul Quartz Monzonite.

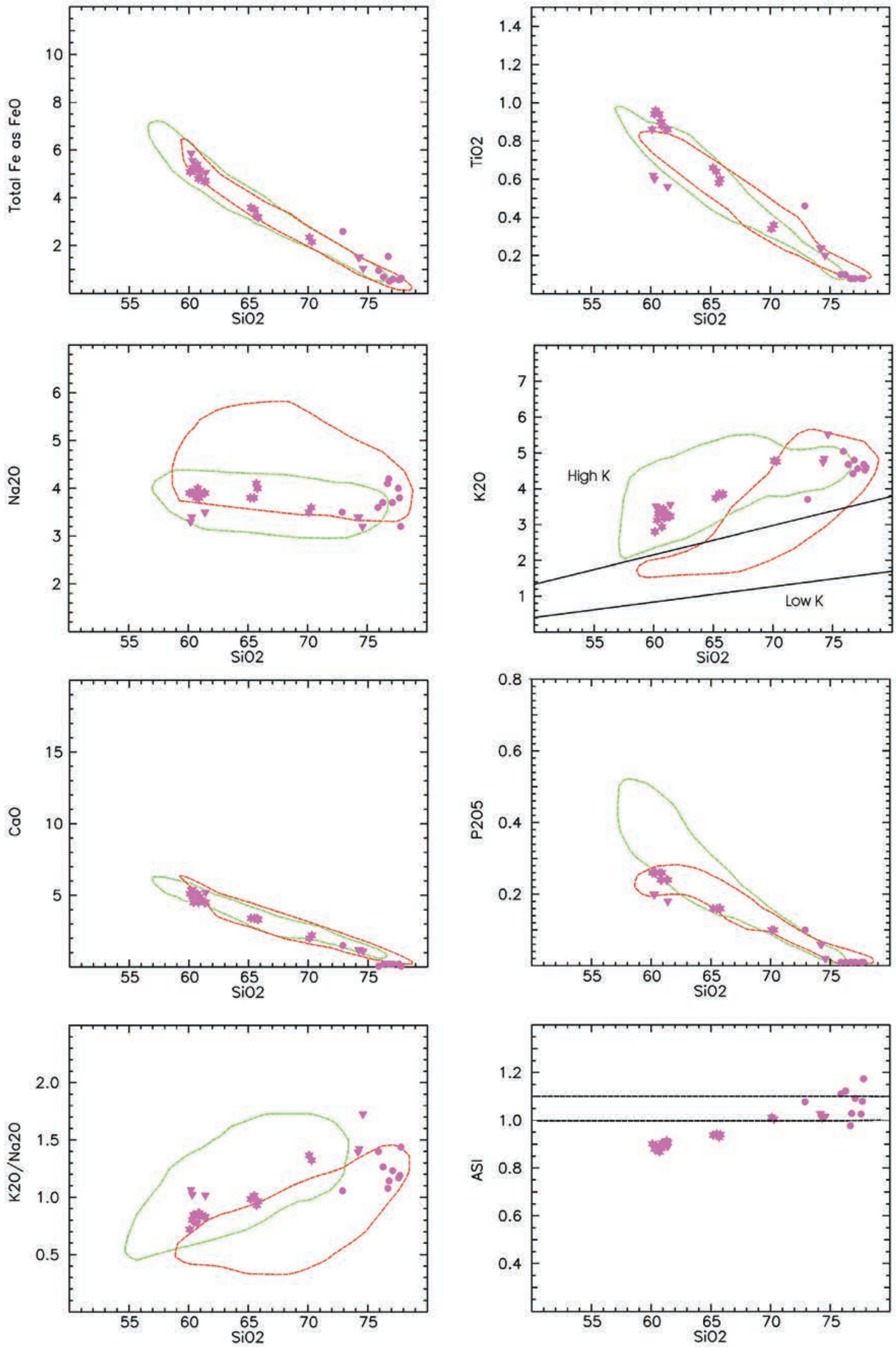

Figure 116. Variation diagrams for Late Triassic plutons showing selected major elements in weight percent and the Alumina Saturation Index (ASI) vs SiO_2 in weight percent. Symbols are stars (Mount Saul Granite), triangles (Greencoat Quartz Monzonite) and circles (Boolgal Granophyre). Coloured fields are for the Tandora (red) and Wingfield (green) Suites from the Rawbelle Batholith.

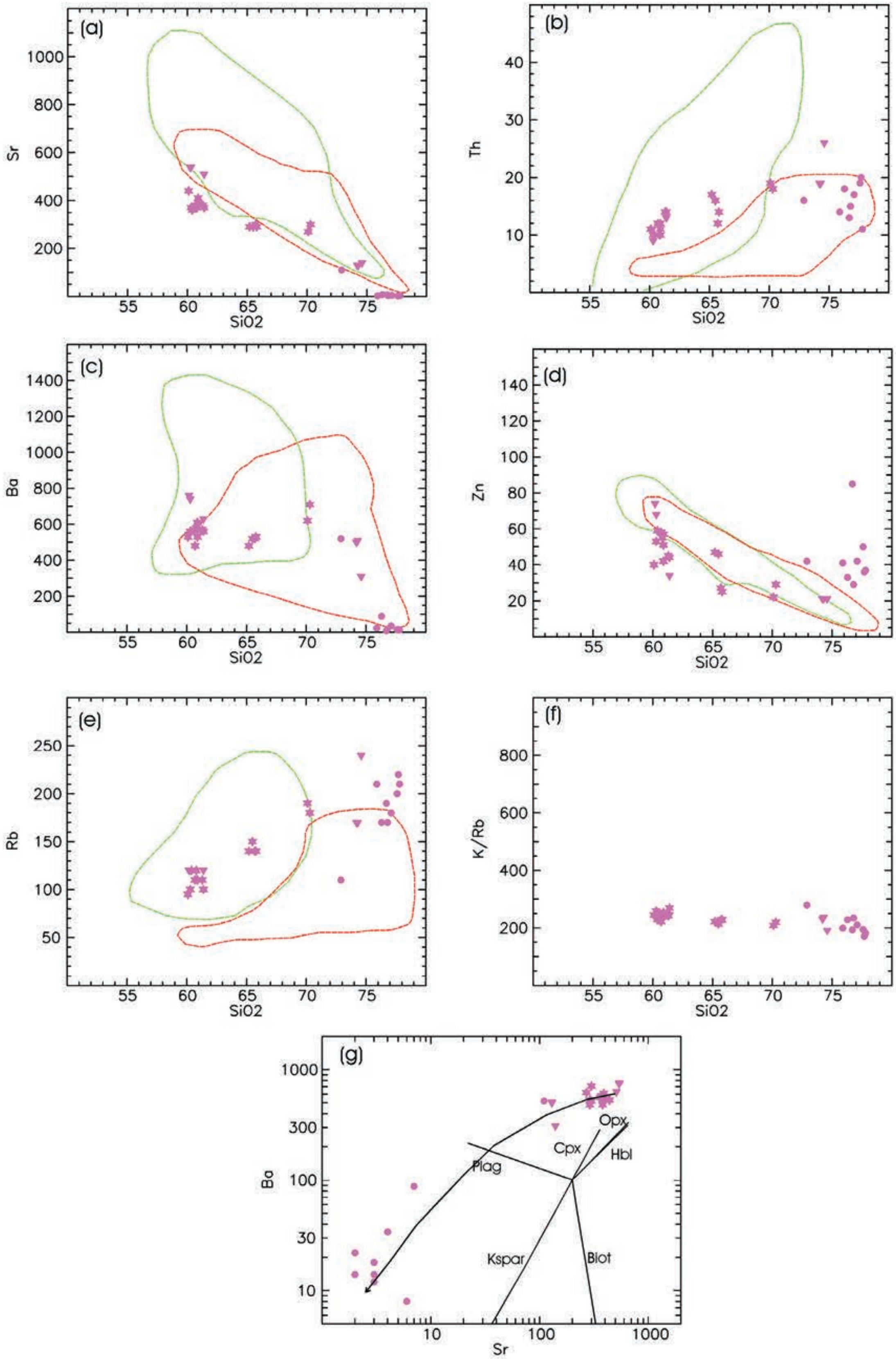

Figure 117. Variation diagrams for Late Triassic plutons showing selected trace elements in parts per million and K/Rb vs SiO_2 in weight percent. Mineral vectors in (g) are from Rollinson (1993, page 161) and show fractional crystallisation trends for Ba and Sr for the various minerals shown. The arrowed line shows an approximate overall fractionation trend for the samples plotted. Symbols are stars (Mount Saul Granite), triangles (Greencoat Quartz Monzonite) and circles (Boolgal Granophyre). Coloured fields are for the Tandora (red) and Wingfield (green) Suites from the Rawbelle Batholith.

PLUTONIC ROCKS OF THE CONNORS PROVINCE

EARLY CARBONIFEROUS PLUTONS

BURWOOD COMPLEX

Introduction

The Burwood Complex forms a somewhat oval-shaped, composite pluton ~12km long and up to 6km wide in the centre of the Broadsound Range (Figure 37). It crops out mainly on Burwood Station (from which the unit is named) and the adjacent Wahroonga Station to the west. The eastern part of the complex around and to the south of Burwood homestead is relatively poorly exposed, forming a plateau on the top of the range that has probably been affected by Tertiary deep weathering. The area of lower topography to the west is somewhat better exposed.

Fieldwork was restricted mainly to the northern part of the complex. Rugged terrain and the country being waterlogged limited access elsewhere. The complex has been subdivided on the basis of the geophysical data and field notes made by J.F. Dear (unpublished notebooks).

Two smaller, elongate, north-trending plutons 3–4km long and up to 2km wide crop out west of the Burwood pluton. They contain similar rocks to the more felsic parts of the Burwood Complex and are assigned to it for convenience. They crop out poorly and are recognised mainly by their recessive, topographic expression.

Type locality

The type locality is along the track to Burwood homestead in the vicinity of the 'jump-up' onto the plateau around MGA 745300 7507650 where pinkish grey, biotite-hornblende monzogranite is exposed.

Lithology

Three unnamed components have been delineated on the basis of the limited field data and radiometric interpretation. They are $\mathbf{Cgbu_{gd}}$, $\mathbf{Cgbu_{mz}}$ and $\mathbf{Cgbu_{gr}}$.

Grey to pinkish grey, medium-grained, equigranular biotite-hornblende granodiorite to quartz monzodiorite crops out along the north-eastern margin of the pluton, corresponding with deep pink hues on the radiometric image. It is assigned to subunit $\mathbf{Cgbu_{gd}}$. The rocks are commonly strongly fractured and have pervasive chloritic alteration. Epidote alteration and reddening of feldspars is prevalent along and adjacent to fractures. In thin section, the rocks contain quartz (10–15%), turbid K-feldspar (15–20%) up to 3mm, and subhedral, subequant grains and laths up to 3mm of plagioclase (50–60%) that shows weak oscillatory zoning and thin, more sodic rims around andesine cores. The mafic minerals mainly comprise subhedral to anhedral, poikilitic, brownish green hornblende (5–15%) and greenish brown, partly chloritised biotite flakes (up to 5%). Traces of clinopyroxene partly rimmed by hornblende are present. Opaque minerals are common and accessories include apatite, monazite and zircon.

Similar rocks are inferred to crop out in the areas in the southern part of the complex, which correspond to the deep pink to bluish hues on composite radiometric images. Dear's descriptions from south of Burwood, although somewhat brief, suggest that granodiorite is probably present there. At the southern margin of the pluton, he noted medium-grained diorite containing chloritised mafic minerals and veined by aplite.

Pink, medium-grained, equigranular, hornblende-biotite quartz monzonite to monzogranite assigned to $\mathbf{Cgbu_{mz}}$ occurs in the western part of the pluton and around Burwood homestead. Dear (unpublished notes) described pink hornblende granite or 'adamellite' to the south-west and south-east of Burwood and also 'adamellite porphyry' that contains prominent feldspar and quartz phenocrysts. Both areas correspond with the 'hotter' radiometric response. Thin sections of the granite from north and west of Burwood contain quartz (20–25%), turbid, anhedral K-feldspar (25–30%) to 5mm and weakly to mildly sericitised, subequant grains and laths of plagioclase to 3mm (30–40%). The plagioclase is sodic andesine and some grains have narrow more sodic rims. Hornblende (1–5%) forms irregular, elongate poikilitic, brownish green grains up to 2mm. In one sample it appears to be restricted mostly to small dioritic enclaves. Biotite (2–5%) flakes to 1.5mm are greenish brown or reddish brown and partly chloritised. Rare clinopyroxene grains are present, and are rimmed by hornblende or biotite. Accessory minerals include titanite and zircon.

On the north-western corner of the pluton, cream to pale pink, medium-grained equigranular leucogranite crops out and is assigned to **Cgbu$_{gr}$**. It forms an elongate north-east-trending cusp 4km long and up to 1km wide. The rocks are generally strongly fractured, brecciated and altered (argillic to sericitic) with yellowish jarosite and rare malachite staining. The breccias are mostly of the ‘crackle’ type, but locally are less coherent and ‘milled’. Minor biotite is present in less altered outcrops, but is usually replaced by sericite. At the northern end of the ‘cusp’ the granite has shallow-dipping, strongly silicified zones up to 2m wide, consisting of very fine-grained pinkish silica cut by a network of laminated quartz veinlets to several centimetres wide.

The smaller plutons to the west that are assigned to the Burwood Complex, are also composite, although they appear to be mainly pink to cream, medium to coarse-grained, biotite leucogranite. Hornblende-biotite granite or quartz monzonite similar to that in the main pluton was also observed in parts of the plutons. The leucogranite consists of quartz (30%), turbid, strongly perthitic K-feldspar (30–40%), mildly sericitised plagioclase (30–40%) and chloritised biotite (1–2%). One sample contains traces of tourmaline. Dykes and veins of microgranite and aplite occur locally. Like the cusp on the main pluton, the rocks are locally sericitised and stained by jarosite. Plagioclase is sericitised and biotite is replaced by muscovite, but the K-feldspar is relatively unaffected.

Many outcrops in the small plutons are strongly fractured and cut by breccia zones ranging from microscopic cataclastic seams to mesoscopic ‘crackle’ and less coherent breccia. The westernmost pluton is strongly fractured and brecciated near the contact with the Lotus Creek Rhyolite. Dykes and pipes of milled breccia, locally containing fragments of the granite, also cut the Lotus Creek Rhyolite and ignimbrite at the base of the Leura Volcanics. Therefore, the brecciation of the granite in the ‘cusp’ and the small plutons may either post-date or be associated with the emplacement of these volcanic rocks.

Geophysical response

The airborne radiometric data suggest a two-fold subdivision. On composite images, mottled yellow, pale pink and whitish hues are evident over most of the complex resulting from moderate to high responses in all three channels. These correspond with the **Cgbu$_{mz}$** and **Cgbu$_{gr}$** subunits. Lower responses in all three channels, resulting in mottled deep pink and bluish composite hues occur along the north-eastern edge and in the south-east to central parts and correspond with subunit **Cgbu$_{gd}$**.

Most of the complex also has a relatively higher magnetic intensity than the surrounding Mountain View Volcanics and Leura Volcanics. This is reflected in the measured magnetic susceptibility values which have a mean of 1200 x 10^{-5} SI units with 3 main populations: a narrow cluster with a mode of 10, a wide cluster with a mode of 1400 and another narrow cluster with a mode of 3200.

Relationships and age

The relationships between the different subunits within the Burwood Complex are not known, but the complex as a whole intrudes and has hornfelsed the Mountain View Volcanics.

Along its eastern margin the complex is unconformably overlain by a sequence of felsic to intermediate volcanic rocks, which are assigned to the Leura Volcanics, but may include outflow equivalents of the Lotus Creek Rhyolite. Conglomerates at the base of the sequence in several places include clasts of granodiorite, for example at MGA 745760 7508830, north of Burwood homestead. Dear also recorded similar relationships in his notes, for example at MGA 747710 7502430, south-east of Burwood homestead.

The smaller plutons also intrude the Mountain View Volcanics, and are in mapped contact with the Lotus Creek Rhyolite. The Lotus Creek Rhyolite is inferred to be younger, because of the abundant granite clasts in ignimbrite in the southern part of the unit.

Dykes of basalt or dolerite commonly cut the smaller plutons, and may be related to the Ametdale Volcanics.

Carboniferous K–Ar ages for the Burwood Complex were reported by Malone & others (1969, table 3) and Webb & McDougall (1968). These dates (adjusted for IUGS constants) were 311±6Ma (on hornblende) and 313±6Ma (on biotite). Another less precise hornblende age of 318±12Ma was also reported.

SHRIMP dating of a sample of granodiorite from the Burwood Complex (subunit **Cgbu$_{gd}$**) has shown that the K–Ar ages are partly reset and that the complex is significantly older than the Bora Creek Quartz Monzodiorite. A weighted mean of 16 zircon analyses for IWSC0733 has no excess scatter (MSWD = 1.3) and gives an age of 328±4Ma (see Appendix). Interestingly, the Bora Creek Quartz Monzodiorite shows a component of older, inherited zircon with a similar age. The age of the Burwood Complex is consistent with the relationships described above between the Burwood Complex and the Lotus Creek Rhyolite and Leura Volcanics.

LATE CARBONIFEROUS PLUTONS

BORA CREEK QUARTZ MONZODIORITE

Introduction

This unit forms a large elongate composite pluton trending south-south-west from near Mount Lorne and the headwaters of Bora Creek (from which the unit is named) in the middle of the Broadsound Range in eastern MOUNT BLUFFKIN (Figure 35). It is ~14km long and up to 5km wide. The unit crops out moderately well, and except for the northern part of the area, where felsic dykes form ridges, the unit forms undulating country within a topographic depression surrounded by the more hilly terrain of the Broadsound Range Rhyolite and Leura Volcanics.

Type locality

The biotite-hornblende quartz monzodiorite is well exposed and relatively unaltered west of Mount Larry on Stockyard Creek Station around MGA 747360 7485855, and this is designated as the type locality.

Lithology and petrography

The Bora Creek Quartz Monzodiorite consists mainly of pinkish grey to grey, medium grained, equigranular biotite-hornblende quartz monzodiorite. Xenoliths of microdiorite up to 15cm are usually present. In thin section the rocks consist of quartz (10–15%), slightly perthitic K-feldspar up to 5mm (10–20%) and subequant grains and laths of plagioclase up to 3mm long (50–60%). The plagioclase is generally weakly to mildly sericitised, and commonly shows weakly oscillatory zoning from calcic andesine cores to oligoclase rims. Hornblende (10–15%) is generally brownish green and forms anhedral to subhedral, elongate grains up to 4mm long. Minor clinopyroxene is common, either as cores to hornblende or discrete grains with thin hornblende rims. Biotite flakes (5–10%) are dark reddish brown, where fresh, but are commonly at least partly altered to chlorite with minor epidote and muscovite along cleavage planes. Accessory minerals include apatite and zircon and very rare titanite and allanite.

Pink, medium to coarse-grained, equigranular to seriate hornblende-biotite granite was observed around MGA 750300 7480900, within the area producing a white radiometric response. It consists of quartz (20%), slightly turbid, perthitic K-feldspar up to 7mm (35%), and subequant plagioclase grains (40%) that are 1–2mm and have weak oscillatory zoning with rims of oligoclase and partly sericitised cores. The quartz and K-feldspar locally show coarse graphic intergrowths. Brownish green hornblende (<5%) occurs as aggregates up to 2mm across, and biotite (<5%) forms reddish brown and partly chloritised flakes up to 1.5mm. Accessory titanite occurs as inclusions in hornblende.

Porphyritic microgranite dykes that intrude the northern part of the pluton contain phenocrysts of quartz, feldspar and biotite in a fine-grained, locally granophyric groundmass. In one dyke at MGA 745800 7486800, however, the phenocrysts (feldspar and embayed quartz) are clearly fragmented, some adjacent grains showing jigsaw fit textures. Apart from its field relationships, the rock resembles a tuff in thin section. It is possibly a tuffisite dyke that was a feeder to crystal-rich ignimbrite in the overlying Leura Volcanics.

Geophysical response

The radiometric data suggest that at least two phases occur within the pluton. The south-western third of the pluton has high responses in all three channels resulting in whitish hues on composite images. The remainder of the pluton has more moderate responses in these channels and has a pinkish grey composite hue. However, although biotite monzogranite was observed only within the ‘whitish’ area, granodiorite and quartz monzodiorite also appears to be widely distributed within both areas.

The Bora Creek Granodiorite is moderately magnetic and contrasts with the surrounding Broadsound Range and Leura Volcanics. The eastern margin of the anomaly corresponds well with the granodiorite as exposed, although the data suggest that the pluton extends farther west at shallow depth. No separate phases can be recognised in the magnetic data. Magnetic susceptibility data for all rock types give a mean of 870 x 10^{-5} SI units and have a bimodal distribution with modes at 20 and 1200 and sporadic values extending to 3500.

Relationships and age

The Bora Creek Granodiorite intrudes the Broadsound Range Rhyolite, but on the eastern margin of the pluton, crystal-rich ignimbrite that forms a conspicuous cuesta known as Mount Larry (Figure 42c) appears to overlie the pluton. It is in close contact with the quartz monzodiorite, but does not appear to be hornfelsed. The ignimbrite is basal to the Leura Volcanics.

Numerous porphyritic microgranite dykes up to 10m wide that form conspicuous linear ridges on the aerial photographs intrude the northern part of the pluton. More mafic dykes are also locally present.

Along the south-western contact of the Bora Creek Quartz Monzodiorite, a body of microgranite, 5km long and up to 1km wide, may be related to the dykes. It is assigned to the unnamed unit $\mathbf{Cg_{mg}}$ and consists mainly of pink to orange, equigranular to porphyritic microgranite. The generally sparse phenocrysts are mainly feldspar and minor biotite. Minor medium-grained equigranular biotite granite containing miarolitic cavities crops out locally within the microgranite.

Another unnamed pluton assigned to $\mathbf{Cg_{g}}$ occurs on the eastern side of the Bora Creek Quartz Monzodiorite. It consists of fine to medium-grained leucocratic biotite granite. Its relationship to the Bora Creek Quartz Monzodiorite is not known.

SHRIMP dating of a sample of the Bora Creek Quartz Monzodiorite gave a mean age of 316.4±2.6Ma on 12 zircon grains (MSWD = 0.54). A second population of five grains gave an age of 329±5Ma (MSWD = 0.94) suggesting an inherited component. The age of the inherited component is similar to the magmatic age of the Burwood Complex. One problem is that the SHRIMP age determined on a sample of the Broadsound Range Rhyolite from just east of the Bora Granodiorite gave a younger age (308.4 ± 3.3Ma from 13 analyses with a MSWD of 1.16). The two dates are just outside error of each other. However, another sample from farther south in the Broadsound Range Rhyolite is within error of the Bora Creek Quartz Monzodiorite age, although still slightly younger. More zircon analyses from the ‘younger’ Broadsound Range Volcanics sample as well as the Bora Creek Quartz Monzodiorite may be needed to resolve the problem.

CAMP CREEK GRANITE

Introduction

The Camp Creek Granite forms a small elongate pluton ~4km long from north to south and up to 1.5km wide. It straddles the old Bruce Highway in the middle of the Broadsound Range (Figure 35) within the catchment of Camp Creek (from which the unit is named). The topography of the unit does not contrast markedly with that of the surrounding Clive Creek Volcanics, Broadsound Range Rhyolite and Leura Volcanics, and the contacts are difficult to interpret from aerial photographs, particularly in the south, where the microgranite phase tends to form hilly terrain. The unit also has a similar magnetic and radiometric response to the volcanic rocks.

Type area

A type area is designated along the old Bruce Highway and adjacent outcrops in Camp Creek between MGA 753810 7470330 and MGA 753410 7470480. Pink, coarse-grained, equigranular biotite granite as described below crops out.

Lithology and petrography

The Camp Creek Granite consists mainly of pink, coarse-grained, equigranular biotite granite. It contains quartz (30%) as single grains up to 7mm across, plagioclase (25–40%) as subhedral, non-zoned laths of oligoclase to andesine up to 3mm, perthitic microcline (30–40%) as anhedral, subequant grains up to 7mm across, and ragged, chloritised biotite flakes (<2%) up to 2mm containing abundant opaque inclusions. Some quartz grains are partly graphically intergrown with K-feldspar. The feldspars are turbid in thin section, and the plagioclase is locally mildly sericitised. Small chloritic shears locally cut the granite, and joint faces are commonly chloritic.

Pink leucocratic microgranite and granophyre crop out along the margins of the granite in places.

Geophysical response

In the radiometric data, the Camp Creek Granite has high potassium and uranium and moderate thorium responses, resulting in pinkish hues on composite images that are not clearly distinguishable from the surrounding Clive Creek Volcanics and Broadsound Range Rhyolite.

The pluton shows little contrast with the surrounding volcanic rocks in the magnetic data. It lies on the eastern flank of a moderate anomaly that may correspond with a ‘blind’ intrusion that extends westward beneath the Mount Mackenzie alteration system. Only 44 magnetic susceptibility readings were taken and they are mostly <200 x 10^{-5} SI units but range up to 600.

Relationships and age

The Camp Creek Granite intrudes the Clive Creek Volcanics and Broadsound Range Rhyolite and is probably overlain by the Leura Volcanics along its southern margin. Clasts of microgranite, similar to that associated with the Camp Creek Granite, occur in conglomerate in the Leura Volcanics east of Mount Mackenzie. Dolerite dykes intrude the granite. The granite has not been dated, but is probably late Carboniferous from the field relationships.

CLEMENT CREEK QUARTZ MONZODIORITE

Introduction

This unit forms a small composite pluton of ~2km^2 between Clive and Clement Creeks (from which the unit is named) on the eastern side of the Broadsound Range (Figure 35). It forms a small topographic depression surrounded by steep ridges of hornfelsed and altered Clive Creek Volcanics. Exposure is poor and outcrop was seen mainly in gullies. However, access in 1998 was hampered by a tangle of unburned, pulled softwood scrub trees and thick regrowth. Several drill access tracks existed, but are likely to become overgrown.

Type locality

The best exposure observed of the biotite-hornblende quartz monzodiorite is along a small stream at MGA 747100 7477000 in the southern part of the pluton, and is therefore designated as the type locality.

Lithology and petrography

The main component of the unit appears to be grey, fine to medium-grained biotite-hornblende quartz monzodiorite. The one thin section examined contains quartz (*ca* 10%) as irregular grains up to 1.5mm, and interstitial to subhedral laths of plagioclase (55% — sodic andesine), which are mostly 0.5–2mm, but rarely up to 4mm. The plagioclase is mildly sericitised and some crystals have slightly more sodic rims and very weak zoning. The mafic minerals are subhedral prisms of brownish green hornblende (15%) to 1mm and irregular flakes of partly chloritised, greenish brown biotite (5%) to 1.5mm. Irregular grains of clear K-feldspar (15%) are up to 2.5mm across. They poikilitically enclose the mafic minerals and small plagioclase laths, but are interstitial to the larger laths. Accessory minerals include apatite and opaque oxides.

Cream to pink, medium-grained, porphyritic biotite granite, containing K-feldspar megacrysts crops out in the central western part of the pluton. It appears to be slightly more resistant, and crops out on a low rise at MGA 746900 7477550. It contains quartz (30%) to 1.5mm, turbid K-feldspar (25%), mostly 0.5–1mm but also as megacrysts to 1cm, subhedral, moderately sericitised plagioclase laths to 3mm (40%), and almost completely chloritised biotite flakes to 1mm (2–5%). The only hornblende is present in what appear to be small dioritic enclaves.

Along the eastern margin of the pluton, the granite is affected by the argillic alteration that is widespread in the adjacent country rocks. This alteration is associated with subeconomic gold mineralisation within the Clive Creek prospect, investigated by Marlborough Gold Mines Ltd (Dear, 1994a,b).

Geophysical response

The radiometric data confirm the composite nature of the pluton. The central western part is characterised by high responses in all three channels producing whitish hues on a composite image. This corresponds with the biotite granite observed in outcrop. The eastern half, probably corresponding to the quartz monzodiorite, has low to moderate responses in all three channels and has dark bluish green hues on the composite image.

The pluton has a moderate magnetic response in the magnetic data standing out slightly from the surrounding volcanic rocks. Twenty readings on the granite had a range of 0–700 x 10^{-5} SI units and nine readings from the monzodiorite were in the range 240–1577 x 10^{-5} SI units.

Relationships and age

The Clement Creek Quartz Monzodiorite intrudes and has hornfelsed volcanic and sedimentary rocks of the Clive Creek Volcanics. It has not been dated, but it is probably late Carboniferous.

DACEY GRANITE

Introduction

The Dacey Granite crops out as an irregularly shaped pluton of ~40km^2 in the valley of Spring Creek, between Dacey homestead (from which the unit is named) and Mountain View homestead in central CONNORS RANGE (Figure 37). It forms relatively recessive topography along the valley of Spring Creek. Outcrop is generally poor, deeply weathered, and/or altered and fractured.

Type locality

The type locality of the Dacey Granite is ~3.5km east of Dacey homestead in the upper reaches of Spring Creek. A series of pavements around MGA 734500 7544800, comprise generally medium-grained white to pink, biotite-hornblende granite or granodiorite. Hornblende crystals range up to 1.5cm. The outcrops are typically fractured and cut by late stage aplite veins. Potassic, chloritic and sericitic alteration is locally intense along fractures. Mafic xenoliths are sparse.

Lithology and petrography

Away from the type area, the Dacey Granite is typically altered and weathered and is commonly intruded by felsic to intermediate dykes. Fresh outcrops are rare. The size and percentage of hornblende is variable, but is almost always present. The best outcrops observed are pinkish-grey, medium-grained, equigranular, hornblende-biotite granite or granodiorite near Mountain View homestead, forming the northernmost extent of the unit. These rocks contain abundant mafic xenoliths, and are extensively fractured with chlorite alteration along the fractures. Aplite veins intrude the granite.

Pink to grey, medium to coarse-grained, biotite-hornblende granite crops out in an isolated body ~2km east of the main body east of the type area. This body is also included in the Dacey Granite.

Geophysical response

In the radiometric data, the Dacey Granite is characterised by high potassium and moderate thorium and uranium response that results in pale pink hues on composite images that are indistinguishable from the surrounding Whelan Creek Volcanics.

Magnetic susceptibility was measured on only three outcrops and the values obtained ranged from 0–2600 x 10^{-5} SI units with a mean of 870 and two main clusters of data (<100 and 700–1400). This is consistent with the variable response in the airborne magnetic data which ranges from low to relatively high. The variation may be due to the alteration. The Dacey Granite is surrounded by a zone of relatively high response that may be due to hornfelsing of the country rocks or a more magnetic phase at shallow depth.

Relationships and age

The Dacey Granite intrudes felsic volcanics assigned to the late Carboniferous Whelan Creek Volcanics. The relationship was observed at the crossing of Eighteen Mile Creek on the Killarney road, south of Dacey homestead. Quartz-phyric rhyolitic volcanics are intruded by altered granite assigned to the Dacey Granite.

East of the type area, the Dacey Granite is apparently ‘overlain’ by a topographically higher sheet-like body of unnamed orange, medium-grained syenogranite that also intrudes the Whelan Creek Volcanics. However the relationship between this granite and the Dacey Granite is not clear.

The Dacey Granite is late Carboniferous. K–Ar (hornblende) minimum ages of 300Ma and 308Ma (recalculated using the constants of Steiger & Jäger, 1977) were reported by Malone & others (1969, table 3) and Webb & McDougall (1968) . SHRIMP dating gave an age of 316.5±4.1Ma (MSWD = 1.9 on 18 grains; see Appendix). An alternative interpretation of the data is two populations at 322±2Ma (10 grains, MSWD = 0.83) and 313±2Ma (10 grains, MSWD = 0.71).

HAZLEWOOD GRANITE

Introduction

The Hazlewood Granite is a new name for a small pluton in north-eastern CONNORS RANGE (Figure 37). It crops out over ~5km^2 in the headwaters of Oaky Creek, on Hazlewood Station (from which the unit is named), west of the Bruce highway between Clairview and Flaggy Rock.

Type locality

The type locality of the Hazlewood Granite is in Oaky Creek at MGA 751000 7560700 in CONNORS RANGE, where pink to red, medium-grained to slightly porphyritic granophyric syenogranite intrudes basalt assigned to the Mountain View Volcanics. The granite comprises quartz (~30%, in extensive granophyric intergrowth with K-feldspar), turbid K-feldspar (~50%), plagioclase (~20%), and minor chlorite and zoisite.

Lithology and petrography

Granite as at the type locality is the only rock type found in the unit.

Geophysical response

The Hazlewood Granite is characterised by high radiometric response in all channels producing a white colour on radiometric images.

The pluton has a relatively low magnetic response compared with the adjacent Mountain View Volcanics, and this is consistent with the magnetic susceptibility readings measured on two outcrops that range from 25–540 x 10^{-5} SI units (average 193).

Relationships and age

The Hazlewood Granite intrudes basalt assigned to the Mountain View Volcanics. SHRIMP zircon dating is somewhat inconclusive due to significant inheritance of zircon ranging from ~330–405Ma. Ignoring these oldest grains and two younger grains that may have Pb loss, a late Carboniferous age of 315±4Ma was obtained (based on five grains; see Appendix). A significant population of six grains that gives an age of 332±3Ma is probably inherited, but is similar to the age of the Burwood Complex. The early Carboniferous age shown on the CONNORS RANGE map was based on earlier SHRIMP data in which the younger age could not be resolved.

OLYMPUS GRANITE

Introduction

The Olympus Granite crops out in north-eastern CONNORS RANGE (Figure 37) as a north-trending elongate pluton, ~13km long and 2.5km wide to the west of Olympus homestead (from which the unit is named, although the homestead is incorrectly labelled “Range View” on the Connors Range 1:100 000 scale topographic map). It crops out poorly on low hills on the edge of the coastal plain, but probably extends farther east under the Quaternary fan deposits derived from the prominent ridges of Carmila beds to the west.

Type locality

The type locality of the Olympus Granite is along a fence line, ~3km south-west of Olympus homestead near MGA 754760 7547850. Pink to grey, medium-grained, sparsely porphyritic biotite quartz monzonite to granite comprises quartz (15–20%, in granophyric intergrowth with K-feldspar), K-feldspar (~25%), plagioclase (~35%), augite (~5%), amphibole (~5%), chlorite (~10%, possibly after biotite) and opaque oxides.

Lithology

Other rocks found in the Olympus Granite are similar to those in the type locality. Outcrop is poor, making identification of lithological diversity difficult.

Geophysical response

The southern part of the Olympus Granite has a moderate to high potassium response and moderate thorium and uranium responses resulting in pale pink hues on composite images. Farther north the quality of the radiometric data is poorer because the granite lies in a deep narrow valley.

The Olympus Granite has a relatively strong magnetic response, and suggests that it extends to the east under the fluvial deposits of the coastal plain. Magnetic susceptibilities at two localities range from 670–3259 x 10^{-5} SI units (average 1745).

Relationships and age

The Olympus Granite intrudes basalts assigned to the Mountain View Volcanics and to the west is faulted against felsic volcanic rocks of the early Permian Carmila beds. It has not been dated isotopically. A late Carboniferous age is tentatively assigned.

SAMBO QUARTZ MONZONITE

Introduction

Sambo Quartz Monzonite is a new name for a pluton that crops out over ~22km^2 in north-eastern CONNORS RANGE (Figure 37). It crops out along Sambo Creek (from which the unit is named) and its major unnamed tributary on northern Spring Valley Station. It extends into the catchment of New Country Creek on eastern Mountain View Station.

Type locality

The type locality is along New Country Creek, a tributary of Palm Creek in north-eastern CONNORS RANGE at MGA 747100 7555600. Pinkish-grey, medium-grained augite-biotite quartz monzonite to quartz monzodiorite comprises quartz (~15%), turbid K-feldspar (~25%), plagioclase (~45%), augite (~5%), biotite (~5%) and chlorite/epidote (~5%), with minor opaque oxides. The rock contains numerous mafic xenoliths.

Lithology

The rocks elsewhere in the pluton are mostly similar to that at the type locality, but the percentage of K-feldspar in the unit is the main variable. Mafic xenoliths are common throughout the unit.

Geophysical response

In the radiometric data, the Sambo Quartz Monzonite has a moderate to high response in potassium and moderate responses in thorium and uranium, resulting in pale pink hues on composite images that contrast with the darker hues of the Mountain View Volcanics, but are similar to the Carmila beds.

The pluton appears to correspond with a moderate airborne magnetic anomaly, although the shape of the latter does not match the mapped pluton, particularly on its western side, suggesting that the contacts may be shallowly-dipping in that area. Only 30 magnetic susceptibility readings were taken on the Sambo Quartz Monzonite, but they are in the range 1000–2570 x 10^{-5} SI units, consistent with the airborne magnetic response.

Relationships and age

The Sambo Quartz Monzonite appears to intrude the Mountain View Volcanics and possibly the Whelan Creek Volcanics, although no contacts were observed in the field. The granite is overlain by the early Permian Carmila beds. These relationships are consistent with the late Carboniferous SHRIMP zircon age of 314.8±3.8Ma (see Appendix).

SOUTH CREEK QUARTZ DIORITE

Introduction

This name is given to a horseshoe shaped east–west-orientated body in south-eastern MOUNT BLUFFKIN (Figure 35). It comprises two subparallel arms ~2km long just south of Mount Mackenzie, mainly on the southern side of South Creek, from which the unit is named. The name was used informally by Dear (1994a,b, 1995).

Type locality

Typical, grey, fine to medium grained biotite-augite quartz microdiorite crops out at MGA 750560 7468830, ~800m south-east of Mount Mackenzie. This and adjacent outcrops in South Creek are designated as the type locality.

Lithology and petrography

The South Creek Quartz Diorite consists mainly of grey, fine to medium-grained quartz diorite, and locally porphyritic microdiorite with prismatic phenocrysts of hornblende to 2mm. Pink aplite veins up to a few centimetres wide also occur in places.

In thin section, the quartz diorite contains ~70% plagioclase as subhedral laths up to 2mm long, showing oscillatory zoning from labradorite cores to oligoclase rims. The plagioclase is slightly sericitised and in one section is also partly saussuritised. A total of ~10% graphically intergrown quartz and turbid K-feldspar is interstitial to the plagioclase. The mafic content is variable. In one section, the mafic minerals comprise chlorite (10%) after biotite as flakes up to 1mm, and pale green prismatic hornblende grains (5%) to 0.5mm with sporadic clinopyroxene cores. In another section (from the type locality), hornblende is rare, and clinopyroxene (10%) forms subequant, subhedral grains up to 1mm across, surrounded by chlorite flakes (10%) that appear to be mainly replacing biotite. The rocks also contain up to 5% opaque oxides as discrete grains to ~0.25mm.

Geophysical response

The South Creek Diorite lies in an area of relatively low potassium and thorium response, and moderate uranium response that is not restricted just to the pluton. This combination of responses results in an overall pale bluish hue on composite images.

The pluton corresponds with a moderate to strong magnetic anomaly consistent with the measured magnetic susceptibility values that were in the range 950–4200 x 10^{-5} SI units.

Relationships and age

The South Creek Quartz Diorite intrudes the Leura Volcanics and Macksford Volcanics. The unit has been partly affected by the argillic alteration of the Mount Mackenzie system, and is unconformably overlain by the unaltered Coppermine Andesite at the base of the Mount Benmore Volcanics.

Burch (1999) dated the South Creek Quartz Diorite using the U-Pb SHRIMP method on zircons. The age was determined to be 304±2.2Ma (late Carboniferous) based on analyses from 13 zircon grains. However, her SHRIMP data have not had the rigorous statistical processing using the SQUID program (Ludwig, 2000) as samples from this study have (see Appendix) and it is not certain whether they can be compared exactly. Reprocessing of some original data using SQUID resulted in ages in this study being up to 8 million years younger than preliminary ages obtained using older processing methods.

TOOBIER GRANITE

Introduction

The Toobier Granite straddles the boundary between CONNORS RANGE and CARMILA, mainly on the eastern part of Collaroy Station (Figure 37). Its full extent is unclear, but as mapped, it crops out over at least 30km^2. It is mostly more recessive topographically than the surrounding volcanic rocks, although the mafic variant in the south-east forms more rugged topography.

Type locality

The type locality is ~2km east-north-east of Mount Toobier (from which the unit is named) near Cattle Creek at MGA 738300 7565500. Pinkish-grey, medium-grained, biotite quartz monzonite to monzogranite forms rounded bouldery outcrops. It comprises quartz (~15–20%, commonly in intergrowth with K-feldspar), K-feldspar (~25%), plagioclase (~40%), augite (~5%), pale, anhedral hornblende (~5%) and minor biotite, chlorite and opaques. Hornblende commonly rims pyroxene and feldspars are commonly altered.

Lithology

Through most of the main part of the pluton, the rocks are similar to that in the type area, although the percentage of biotite is locally up to 10%, and is usually partly chloritised.

The more mafic variants have been mapped as a separate subunit in the south-eastern part of the pluton. About 4.5km south east of Mount Toobier, beside Spring Gully, a tributary of Palm Creek, the rocks comprises quartz (~15%), K-feldspar (~20%), plagioclase (~40%), biotite (~10%), pale amphibole (~5%), clinopyroxene (~3%), orthopyroxene (~2%), and opaques.

The Toobier Granite is intruded extensively by andesitic and dacitic dykes that make up most of the outcrop in some areas. It is also commonly fractured, with potassic, chloritic and sericitic alteration along the fractures.

Geophysical reponse

In the radiometric data, the main phase of the Toobier Granite has a high potassium response and moderate to high thorium and uranium responses that produce pale pink hues on composite images. These contrast with the Mountain View Volcanics to the east, but are identical to the Whelan Creek Volcanics to the west. The more mafic variant in the south-east has low to moderate responses in all three channels resulting in dark pinkish grey composite hues.

The main felsic phase has a low to moderate magnetic response similar to the Whelan Creek Volcanics, and distinctly lower than the basaltic Mountain View Volcanics. The mafic phase is more strongly magnetic and cannot be distinguished magnetically from the Mountain View Volcanics. No quantitative magnetic susceptibility measurements were taken, but the reaction to a pendulum magnet ranged from strongly magnetic to non-magnetic. This variation may be due to alteration.

Relationships and age

The Toobier Granite is interpreted to intrude both the early Carboniferous Mountain View Volcanics and late Carboniferous Whelan Creek Volcanics, although no contact was observed in the field. Along Palm Creek, the Toobier Granite appears to be overlain by conglomerate and rhyolitic to dacitic volcanics tentatively assigned to the Carmila beds.

The age is uncertain, but the relationships described above suggest it is late Carboniferous.

TOOLOOMBAH CREEK GRANITE

Introduction

The Tooloombah Creek Granite is a roughly triangular pluton of ~10km^2 in the headwaters of Tooloombah Creek in the Broadsound Range in south-eastern MOUNT BLUFFKIN (Figure 35). It is generally strongly weathered and poorly exposed, forming undulating topography, generally less closely dissected than the adjacent volcanic rocks.

Type locality

A type area is designated at MGA 752360 7472330, along the access road to the Telstra microwave tower, where pink, medium-grained, equigranular biotite granite is exposed.

Lithology

The Tooloombah Creek Granite consists mainly of light greenish grey to pink, medium-grained, equigranular biotite granite. In contains quartz (30%) as subequant grains 0.5–2mm across, plagioclase (30–40%) as subhedral, non-zoned laths of sodic andesine up to 3mm, perthitic K-feldspar (25–30%) as anhedral, subequant grains up to 2mm across, and ragged, partly chloritised reddish brown biotite flakes (up to 5%) up to 2mm containing abundant opaque inclusions. The plagioclase is mildly sericitised and some grains have saussuritised cores.

The margins of some quartz grains are graphically intergrown with K-feldspar. In one sample from near the eastern margin of the granite at MGA 753200 7473800, the quartz and K-feldspar form grains 1–2mm that are entirely graphically intergrown. The rock also contains laths of oligoclase up to 5mm long and ragged biotite flakes to 2mm. Both the oligoclase and biotite are partly sericitised.

Pegmatite and microgranite dykes and veins were observed in places in the pluton.

Geophysical response

In the radiometric data, the Tooloombah Creek Granite has high potassium, low to moderate thorium and moderate to high uranium responses resulting in a pinkish hue on composite images that is not clearly distinguishable from the surrounding Clive Creek Volcanics and Broadsound Range Rhyolite.

Like the Camp Creek Granite, the pluton shows little contrast with the surrounding volcanic rocks in the magnetic data. Only 57 magnetic susceptibility readings were taken on the granite and they range up to 235 x

10^{-5} SI units with a mean of 53. Microgranite dykes are slightly more magnetic and ten values on one outcrop were in the range 150–644 x 10^{-5} SI units.

Relationships and age

The Tooloombah Creek Granite intrudes the Clive Creek Volcanics and Broadsound Range Rhyolite and is overlain by the Leura Volcanics along its eastern margin. The unconformity is exposed in Tooloombah Creek at MGA 753500 7474050. Abundant clasts of granite from the Tooloombah Creek Granite occur in the basal conglomerate of the Leura Volcanics. Dolerite dykes intrude the granite. The granite has not been dated, but the relationships indicate that it is late Carboniferous like the Bora Creek Quartz Monzodiorite.

LATE CARBONIFEROUS TO EARLY PERMIAN PLUTONS

CARMINYA GRANODIORITE

Introduction

The Carminya Granodiorite forms an elongate pluton of ~43km^2, east-north-east of Waitara railway siding and east of Denison Creek, in eastern NEBO (Figure 118). The granodiorite is deeply weathered and poorly exposed and consequently the extent of the unit is only approximately known. It forms mainly undulating country, with scattered ridges and hills, where the pluton is cut by felsic–intermediate dykes.

The Carminya Granodiorite was depicted as unnamed unit **CPgu$_7$** on the first edition NEBO map and Central Queensland GIS (Withnall & others, 2007). The unit is named after the Parish of Carminya.

Type locality

The designated type locality is at MGA 696491 7596653. The granodiorite is well exposed in a creek bed beside a station track at this locality.

Lithology

The unit consists mainly of grey, pinkish grey, greenish grey, or brown to dark reddish brown (extensively weathered), medium to fine-grained, uneven-grained to slightly porphyritic (titanite-) biotite-hornblende granodiorite. Hornblende laths, up to ~1cm long, are relatively common. The granodiorite also contains rounded to ovoid mafic inclusions up to ~40cm across, and traces of titanite. The rocks are slightly to extensively altered. Chlorite, epidote, prehnite, and sericite are the main secondary minerals. The unit is also deformed and partly recrystallised in places. Quartz grains show highly undulose extinction and local subgrain development in the deformed rocks.

Geophysical response

The unit is characterised by a moderate to high potassium response and moderate thorium and uranium responses resulting in mottled pale to dark blue and purple to pale pink hues on composite radiometric images. These contrast with the more potassic pink hues of the Featherstone Granodiorite to the north and the Whelan Creek Volcanics to the south. The unit is characterised by mostly low magnetic intensity, but has a central east-north-east-trending moderately magnetic ‘ridge’. No magnetic susceptibility measurements are available.

Relationships and age

The Carminya Granodiorite probably intrudes rocks tentatively assigned to the Leura and Whelan Creek Volcanics. It is in contact with the Strathdee Granodiorite, Featherstone Granodiorite and Clondalkin Granite, but the relationships are uncertain. The Clondalkin Granite is overlain by the Leura Volcanics, suggesting it is older. The granodiorite is cut by numerous dacite–rhyolite dykes (to ~10 m thick), and by sparse aplite and aplitic microgranite dykes (to ~1.5 m thick). The unit is unconformably overlain by Tertiary basalt (unit **Tb**) and by felsic to intermediate volcanic rocks of unnamed unit **Tv**.

The unit has been assigned a late Carboniferous–early Permian age but it has not been isotopically dated. The possible intrusive relationship with the Leura Volcanics which have been dated as early Permian in this region suggests that it may also be early Permian.

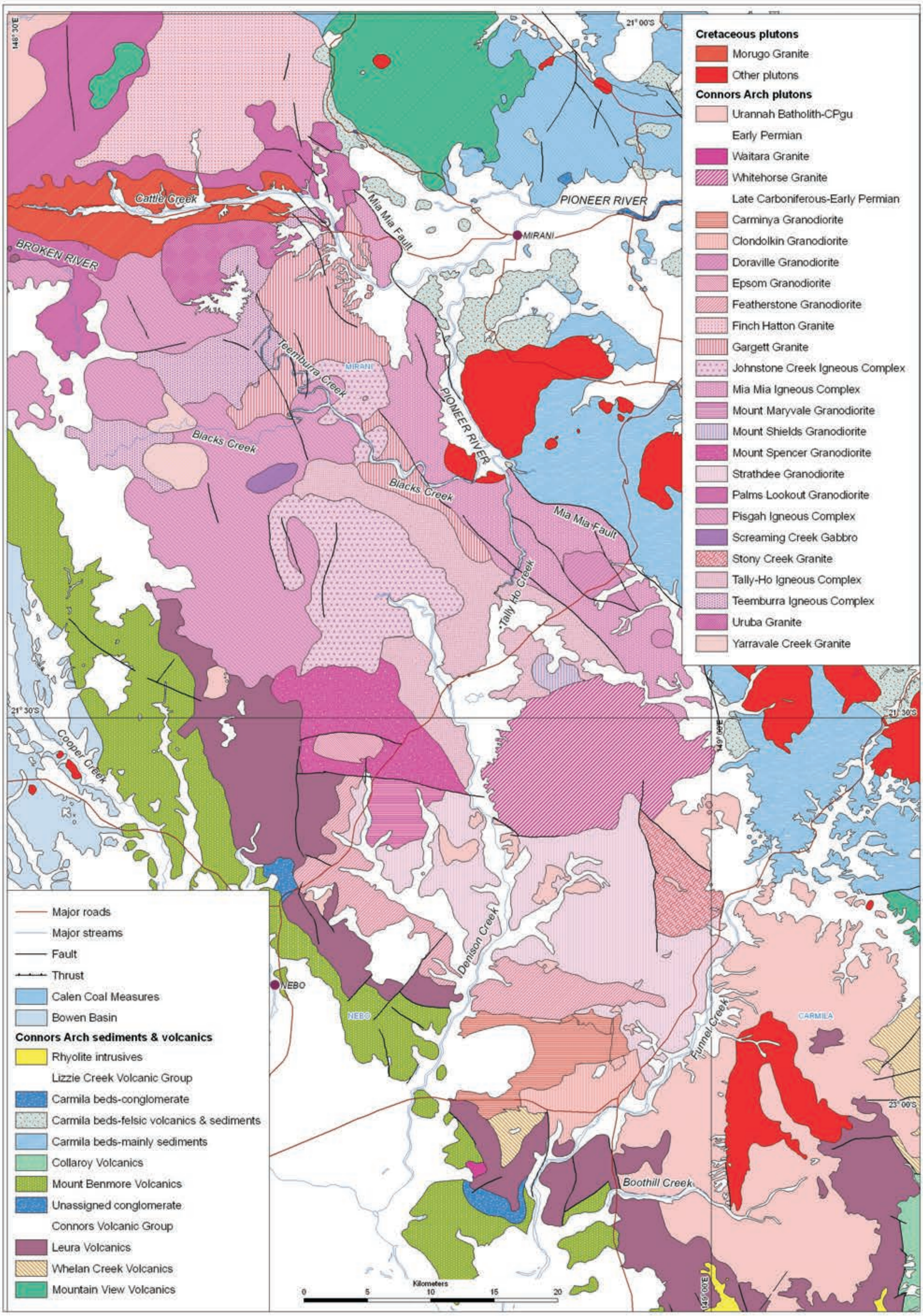

Figure 118. Geology of the southern part of the Urannah Batholith (Nebo–Mirani)

CLONDALKIN GRANITE

Introduction

The Clondalkin Granite crops out as an irregular, elongate pluton of ~30km^2 on the western side of Funnel Creek, in eastern NEBO (Figure 118). The unit forms low undulating country with sparse outcrops in the west and south. In the east (around Mount White) it forms hilly, dissected country due to the presence of numerous relatively resistant felsic–intermediate dykes. The granite is generally deeply weathered and very poorly exposed. Most outcrops examined were in road and railway cuttings.

The unit was shown as unnamed unit **CPgu$_6$** on the first edition NEBO map and Central Queensland GIS (Withnall & others, 2007). It is named after the Parish of Clondalkin.

Type locality

The designated type locality is a railway cutting at MGA 701907 7591818.

Rock types

The unit consists mainly of pink to red, pale green, or brown to reddish brown (deeply weathered) medium to fine-grained, uneven-grained to slightly porphyritic, leucocratic biotite monzogranite. Biotite (generally <5%, and extensively replaced by chlorite) is the main mafic mineral. The granite is moderately deformed and partly recrystallised in places and it is commonly altered. Chlorite, epidote, sericite and calcite are the most common secondary minerals. Pink, dyke-like alteration zones, up to ~5cm thick, are also relatively common. Traces of malachite along joint planes are present locally.

Most outcrops contain sparse mafic inclusions, up to ~10cm across.

Geophysical response

The unit is characterised by a moderate to high potassium response and low thorium and uranium responses resulting in mottled pinkish to slightly purplish hues on composite radiometric images. It has a low response on total magnetic intensity images. No magnetic susceptibility measurements are available.

Relationships and age

The Clondalkin Granite is in contact with the Strathdee and Carminya Granodiorites, but the relationships are uncertain. It is cut by numerous felsic to mafic dykes up to ~20m wide. The mafic (basalt/dolerite) dykes post-date the felsic–intermediate dykes. It is also intruded by Tertiary rhyolite (unit **Tv**) at Mount White.

The granite is unconformably overlain by rhyolite, volcanic sandstone and volcanic breccia of the Leura Volcanics — a thin (up to ~5cm thick) basal lens of granule conglomerate is also present locally. It is also unconformably overlain by coarse, Tertiary–Quaternary alluvial fan (?) deposits.

The unit has been assigned a late Carboniferous–early Permian age, but it has not been isotopically dated. The unconformable relationship with the Leura Volcanics suggests that the granite is late Carboniferous or older.

DORAVILLE GRANODIORITE

Introduction

The Doraville Granodiorite is a roughly triangular pluton with an area of ~14km^2 along the Peak Downs Highway, ~14km north-east of the Retreat Hotel, in south-eastern MIRANI (Figure 118). Its extent is based entirely on its geophysical response since it has no distinctive topographic expression and outcrop is extremely poor. It forms undulating topography behind the main coastal scarp. Only strongly decomposed rocks have mostly been found within the outcrop area. The soils are light brown to cream coloured, fairly sandy with some mica. The name is derived from Doraville homestead.

Type locality

South of the Peak Downs Highway at MGA 698900 7631100, light grey, fine to medium-grained hornblende-biotite granodiorite is designated as the type locality. It consists of quartz (25%), plagioclase (35%), K-feldspar (25%), biotite (10%), hornblende (~2%) and opaques (~3%). Titanite and apatite are accessory minerals. Some of the K-feldspar forms large irregular crystals to 7mm across, poikilitically

Figure 119. Radiometric image of the southern part of the Urannah Batholith showing selected units

enclosing the other minerals. Fine-grained dark grey sub-rounded to rounded equigranular microdiorite xenoliths up to 25cm are common. Green, aphyric andesite dykes intrude the granodiorite.

Lithology

The outcrop at the type locality was the only fresh outcrop located. Exposures in road cuttings along the Peak Downs Highway are very decomposed, fine to medium-grained (biotite) granodiorite that is locally sheared.

Geophysical response

In the radiometric data, the Doraville Granodiorite has moderate to high potassium response, and low to moderate thorium and uranium, resulting in distinctive pink hues that contrast with the mainly darker mottled hues of the surrounding Mia Mia Igneous Complex (Figure 119).

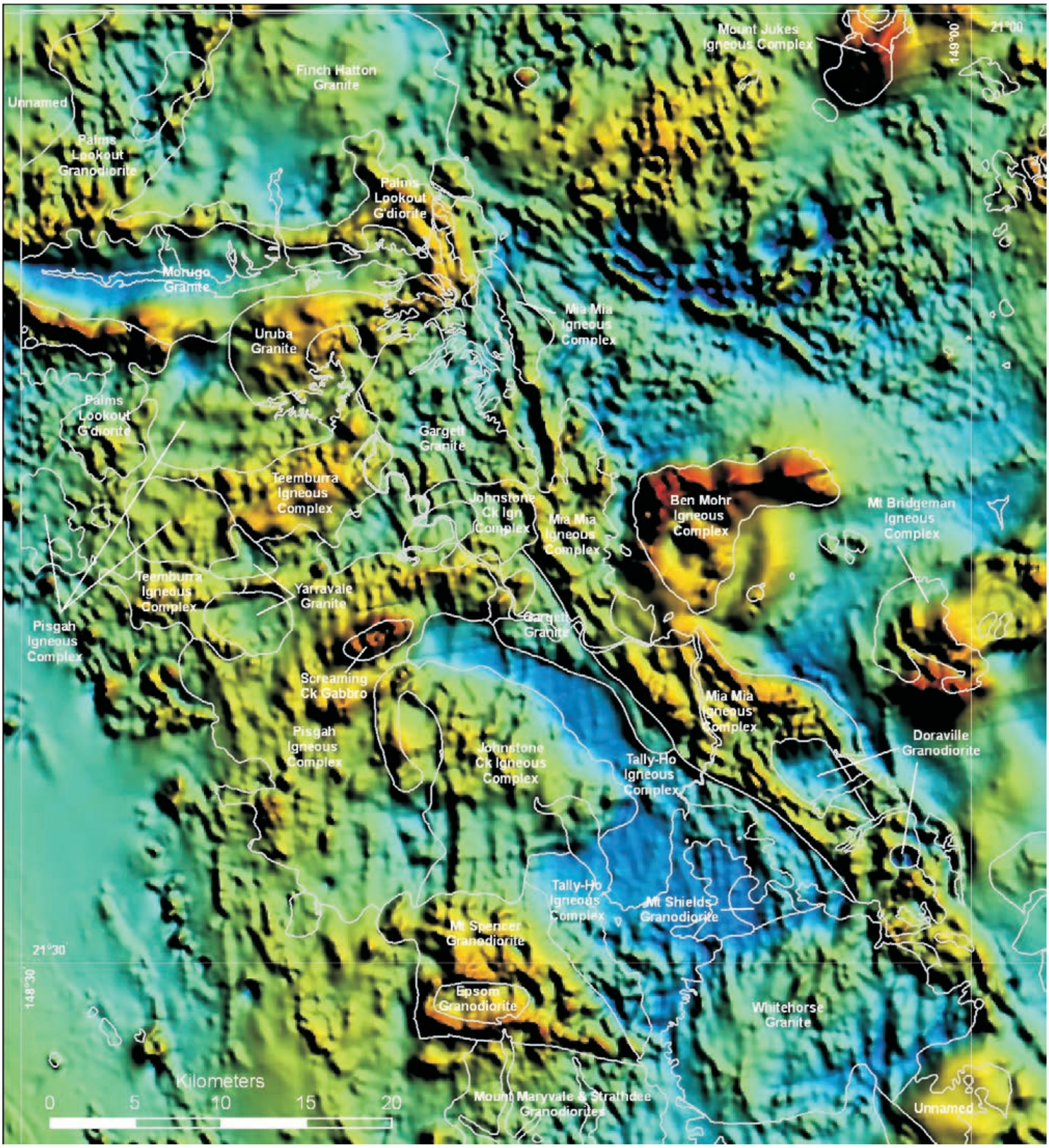

Figure 120. Magnetic image of the southern part of the Urannah Batholith showing selected units

The magnetic response on the airborne geophysical images is uniformly low compared with the strongly magnetic rocks of the Mia Mia Igneous Complex and delineates the unit very well (Figure 120). Magnetic susceptibility was measured only at the type locality, and values are moderate and in the range 290–890 x 10^{-5} SI units, not entirely consistent with the airborne data.

Relationships and age

A late Carboniferous to early Permian age is likely as the Doraville Granodiorite appears to intrude the Mia Mia Igneous Complex.

DOREEN GRANITE

Introduction

Hutton & others (1999a) described the Doreen Granite as cropping out over 8km^2 south-east of Doreen homestead (from which the unit is named) in central west CONNORS RANGE (Figure 37). They also described another unit, the Iron Pot Granite, cropping out over ~5km^2 to the north-west of the Doreen Granite, and separated from it by a ridge of Connors Volcanics. Subsequent mapping demonstrated that they are a single pluton, with the area previously interpreted as Connors Volcanics consisting of granite intruded by a swarm of andesite dykes. The name Doreen Granite is now applied to the whole pluton. As now mapped, it crops out over ~20km^2. Except where intruded by the andesite dyke swarm, the granite forms subdued topography.

Type locality

The type locality of the Doreen Granite is along a tributary of Marble Tree Creek, ~1km east of Iron Pot Mountain at MGA 717500 7546600. Grey, medium-grained biotite-hornblende quartz monzonite comprises slightly strained quartz (~15%), large, anhedral, poikilitic K-feldspar (orthoclase?) with plagioclase chadacrysts (~25%), subhedral to euhedral laths of locally intensely sericitised plagioclase (~40%) hornblende (~10%), biotite (commonly altered to chlorite) (~5%), opaques (~5%), with accessory zircon, epidote and possible apatite.

Lithology

The Doreen Granite comprises equigranular pinkish grey, medium-grained, hornblende biotite granite to quartz monzonite as at the type locality. The granite is intruded by numerous fine-grained felsic and andesitic dykes which are the most commonly outcropping rock type.

A weathered sample from north-west of Iron Pot Mountain comprises quartz (~20%), turbid K-feldspar (~25%), altered plagioclase (~40%), hornblende (commonly altered to chlorite and opaques; ~7%), biotite (also altered to chlorite and opaques but retaining platy structure; ~8%), with accessory titanite and zircon. Another sample from the eastern edge of the pluton comprises quartz (~20%), K-feldspar (~35%), plagioclase (~30%), subhedral hornblende (~10%), biotite (<5%), and opaques.

K-feldspar can be present as either a granular form associated with quartz or as large anhedral poikilitic grains with plagioclase and possibly hornblende chadacrysts. The granular form may be due to later recrystallisation. The presence of strained quartz and interdigitating grain boundaries in some samples suggests that the granite has undergone post crystallisation strain and metamorphism.

Geophysical response

The Doreen Granite has high responses in all three radiometric channels resulting in whitish hues on composite images that contrast with the generally pink hues of the felsic volcanic rocks in the surrounding Leura Volcanics.

The pluton has a low to moderate magnetic response that cannot be distinguished from the surrounding Leura Volcanics. This is consistent with the measured magnetic susceptibility values. Although the values average 560 x 10^{-5} SI units, the data show a bimodal distribution with a strong mode at about 20 and sporadic higher values to 2500 with a less prominent mode at 1400.

Relationships and age

The Doreen Granite is interpreted to have intruded felsic volcanics assigned to the Leura Volcanics. The contact is has been located along a tributary of the Connors River at MGA 717010 7548080 south-east of Doreen homestead. Here hornfelsed rhyolite occurs close to an outcrop of weathered granitoid. Similar hornfelsed rhyolite adjacent to granitoid occurs near the southern margin of the pluton at MGA 719115 7543780. However, Iron Pot Mountain is a younger flow-banded rhyolite plug intruding the granite.

The age of the Doreen Granite is latest Carboniferous or earliest Permian. The granite has given a SHRIMP age of 301±3.4Ma with some inherited zircon at ~314Ma and 318Ma (see Appendix).

However, the hornfelsed rhyolite from the contact described above has also been dated. The zircons dated from the rhyolite show some dispersion about a general mean of 292±4Ma. This age is younger than that determined for the Doreen Granite, although the two ages are only just outside error of each other. The age for the rhyolite is consistent with other ages determined for the Leura Volcanics in the area and also for the

Lotus Creek Rhyolite that underlies them. Assuming that the field relationships have been interpreted correctly, it is possible some of the younger zircons in the granite were also inherited and the magmatic age could be younger.

EPSOM GRANODIORITE

Introduction

The Epsom Granodiorite crops out as an ovoid pluton of ~10km^2, west of the Peak Downs Highway, in the central-north of NEBO (Figure 118). It is generally deeply weathered and poorly exposed. It forms low undulating country, with scattered boulders and pavements east of Boundary Creek, but to the west, it forms hilly country due to the presence of numerous felsic–intermediate dykes, which are relatively resistant to erosion. It was shown as unnamed unit **CPgu$_8$** on the first edition NEBO map and Central Queensland GIS (Withnall & others, 2007). The unit is named after the Parish of Epsom.

Type locality

The designated type locality is west of the Peak Downs Highway, at MGA 681973 7618592, in the headwaters of Boundary Creek. Access is via a station track from the highway.

Lithology

Pale grey to pinkish grey, medium to fine-grained, uneven-grained biotite-hornblende granodiorite is the dominant rock type in the unit. Greenish brown to brown hornblende is the main mafic mineral. The hornblende grains are generally unaltered, in contrast to the biotite flakes, which are commonly partly to completely replaced by chlorite. K-feldspar (pale pink) is present in minor amounts, as interstitial infillings and scattered, relatively large, irregular, poikilitic grains. The granodiorite also contains minor opaques and accessory allanite and titanite (primary). The samples examined are moderately altered; chlorite, epidote, sericite, and titanite are the most common secondary minerals. Ovoid to elongate, mafic inclusions, up to ~5cm across, are present in most outcrops.

Geophysical response

The Epsom Granodiorite has a low to moderate potassium response and low thorium and uranium responses that result in mainly dark pink hues on a composite radiometric image, in contrast to the darker (mainly blue) tones of the enclosing Mount Spencer Granodiorite (Figure 119).

On airborne magnetic images the pluton is characterised by uniform magnetic intensities, somewhat lower than the Mount Spencer Granodiorite (Figure 120). The relatively few magnetic susceptibility readings taken are in the range 200–400 x 10^{-5} SI units. It is surrounded by a narrow, irregular zone characterised by relatively high magnetic intensity that is tentatively interpreted to represent hornfelsing of the Mount Spencer Granodiorite.

Relationships and age

The unit is enclosed by and post-dates the Mount Spencer Granodiorite. It is cut by numerous dykes, which are concentrated in the western part of the pluton. The dykes examined during the survey consisted of porphyritic rhyolite to dacite, and porphyritic microgranite.

The unit has not been isotopically dated. It was most probably emplaced in the late Carboniferous or early Permian. The regular, ‘smooth’ outline of the pluton implies it is one of the youngest units in the southern part of the Urannah Batholith.

FEATHERSTONE GRANODIORITE

Introduction

The Featherstone Granodiorite forms an elliptical pluton of ~78km^2, north of Waitara railway siding and north-east of Nebo, in north-eastern NEBO (Figure 118). It is very deeply weathered and poorly exposed, with only sparse outcrops. The unit forms low undulating country in the west with sparse ridges and low hills reflecting the presence of felsic–intermediate dykes, which are relatively resistant to erosion. In the east the unit forms hilly, dissected country due to the presence of numerous relatively resistant dykes.

The unit is named after Featherstone pastoral holding, which encompasses much of the eastern part of the pluton. It was shown as unnamed unit **$CPgu_5$** on the first edition NEBO map and Central Queensland GIS (Withnall & others, 2007).

Type locality

The designated type locality is at MGA 698875 7599425 on Three Mile Creek, where the granodiorite forms a prominent bar across the creek.

Lithology

The unit consists of pink or brown to dark reddish brown (weathered), medium to fine-grained, uneven-grained to slightly porphyritic muscovite-biotite monzogranite and biotite monzogranite. The monzogranite is leucocratic (~2–3% biotite), and contains traces of opaque minerals, as well as sparse mafic inclusions (up to ~10cm across). Monzogranite at the type locality also contains minor muscovite (~2%). The monzogranite is commonly partly altered. Chlorite, epidote, and sericite are the main secondary minerals. K-feldspar grains are generally turbid.

Decomposed granite, which is well exposed in several cuttings on the Peak Downs Highway between Lonely and Graveyard Creeks, has been assigned to the unit. However, the unit in this area shows mainly mottled white and pink tones on a composite radiometric image, whereas east of Denison Creek it shows pink tones. The radiometric data imply that the unit may be composite or zoned.

Geophysical response

The unit is distinguished from adjoining units (which show mainly darker tones) by predominantly pale pink to whitish hues on a composite radiometric image. These hues reflect a high potassium response and moderate thorium and uranium responses.

It is characterised by non-distinctive, low magnetic intensities on airborne magnetic images. The relatively few magnetic susceptibility readings taken were all low and in the range 0–50 x 10^{-5} SI units.

Relationships and age

The relationship between the Featherstone Granodiorite and volcanic rocks tentatively assigned to the Leura Volcanics is uncertain because no contacts were found. The unit is tentatively interpreted to post-date the Strathdee and Carminya Granodiorites, and unit **$CPgu_{ga}$**, and to pre-date units **$CPgu_{10}$**, **$CPgu_{11}$** of the Urannah Batholith, although no contacts have been observed. Conglomerate at the base of the Mount Benmore Volcanics (**Pvz_{cg}**) contains granite clasts similar to the Featherstone Granite, and is interpreted to unconformably overlie the granite.

The unit is cut by numerous felsic to mafic dykes, as well as by scarce aplite dykes and rare quartz veins (to ~3cm thick).

The unit is tentatively regarded to be late Carboniferous–early Permian, but it has not been isotopically dated.

FINCH HATTON GRANITE

Introduction

The Finch Hatton Granite has been interpreted to crop out over ~150km^2 in northern MIRANI (Figure 118), but it extends an unknown distance farther north into CALEN. The unit extends east from the crest of the Clarke Range to the Mirani–Mount Ossa Road. Most of the area is a high range with thick eucalypt to rainforest vegetation. Typical exposures are house-sized blocks and rock platforms on the crests and flanks of ridges and hilltops. It is also well exposed along Finch Hatton Gorge. Most boulders have a moderately weathered rim with relatively fresh cores. The name is derived from the township of Finch Hatton in northern MIRANI

Type locality

The type locality is designated as large outcrops and rock platforms around MGA 669900 7673600 on the southern slopes of Mount Dalrymple near the headwaters of Finch Hatton Creek, along a bush-walking track within the northern part of Eungella National Park. The outcrops are composed of medium-grained cream to light pink uneven-grained equigranular biotite granite. Xenoliths and quartz or aplite veins are sparse.

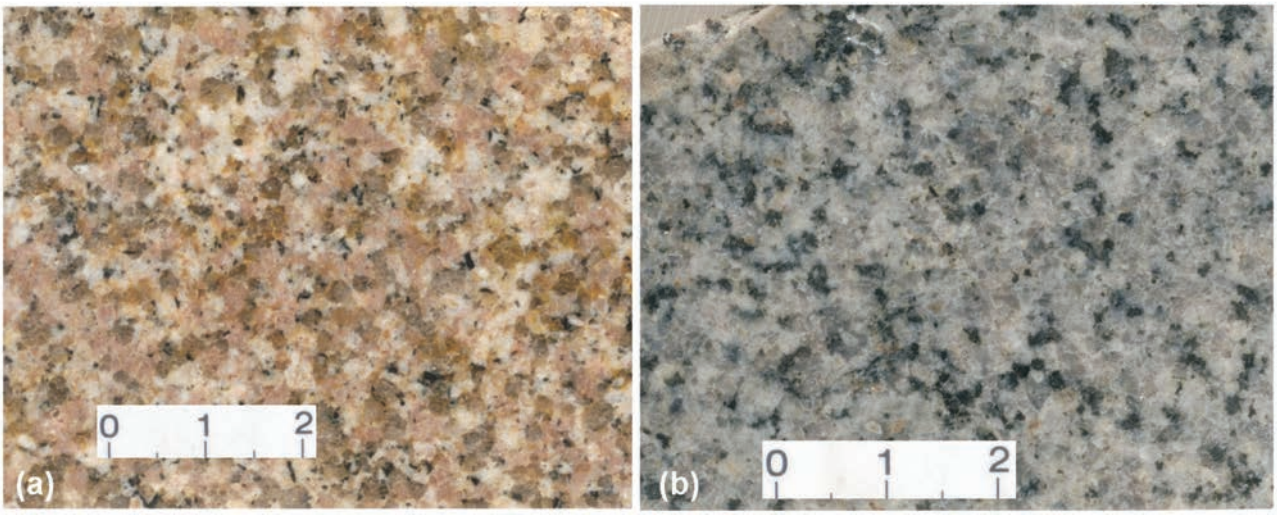

Figure 121. Finch Hatton Granite and Gargett Granite; scale is 2cm
(a) Scanned slab of pink, equigranular biotite granite of the Finch Hatton Granite. Finch Hatton Gorge road at MGA 670082 7668533 (RSC002)
(b) Scanned slab of biotite granite or granodiorite of the Gargett Granite near the type locality. About 2km south of Pinnacle township at MGA 678405 7658356 (QFG3488)

Lithology

The rocks appear to be fairly consistent in composition and texture throughout the unit. They comprise fine to medium-grained, pink or cream to light grey, equigranular to seriate porphyritic biotite granite (Figure 121a). The cream to white feldspar crystals are mostly K-feldspar (40–50%), and mainly 2–5mm. Quartz (30–40%), plagioclase (~10%) and biotite (~2–5%) are the other main constituents. Biotite is commonly altered to chlorite and opaque minerals but represents the dominant mafic mineral. Some thin (<10cm) irregular pegmatite patches consist mainly of pink K-feldspar, quartz and minor chlorite.

Geophysical response

Radiometric data from the Finch Hatton Granite are of variable quality, due to the high relief in the outcrop area, intersected with deep narrow gorges. Low responses along Finch Hatton Gorge and some other areas are more likely due to the extreme topographic relief rather than a real compositional difference. Potassium is moderate to high, but thorium and uranium show varied responses from low to moderate and locally high. Composite images show a mottled pattern with a variety of hues from pale mauve through pink, green and white (Figure 119). Areas mapped as Palms Lookout Granodiorite have generally lower responses.

The unit is best delineated by the airborne magnetic data. It has a conspicuously low response compared with the surrounding more strongly magnetic Palms Lookout Granodiorite and Mountain View Volcanics (Figure 120). This is consistent with the measured magnetic susceptibilities on the granite which show a normal distribution ranging from 15–250 x 10^{-5} SI units about a mode of 140 although there are sporadic higher values up to about 1800.

Relationships and age

On its eastern contact, the granite partly is partly faulted against volcanic and sedimentary rocks of the early Permian Carmila beds, but it is uncertain whether the contact is stratigraphic or intrusive. It is also in contact with rocks tentatively assigned to the early Carboniferous Mountain View Volcanics. The shape of the mapped contact suggests that the Finch Hatton Granite intrudes the Palm Lookout Granodiorite.

Dykes of different compositions and textures were observed in places. Dark green aphyric to slightly porphyritic andesite dykes were most common, but pale pink to brown, porphyritic rhyolite, light grey trachyte or dacite, dark green fine-grained microdiorite and some dark grey basalt were observed. The presence of these dykes is significant as they probably belong to suites of Permian dykes that commonly intrude the Permo-Carboniferous units of the Urannah Batholith. Thus, although the unit has not been isotopically dated, it is inferred to be Carboniferous or early Permian.

GARGETT GRANITE

Introduction

The Gargett Granite has been mapped as two separate outcrop areas in northern MIRANI (Figure 118), one in the Pinnacle Range south of Gargett township (from which the unit is named), and a smaller area farther south along the middle reaches of Blacks Creek and its tributaries. The total outcrop area is ~100km^2. Except in the north near Gargett, the topography is hilly and heavily vegetated. Ridges are formed by prominent rhyolite and dolerite dykes. Main access is along the Teemburra – Mia Mia State Forest track. Outcrop is poor, and the rocks are mostly weathered. Boundaries were derived mostly from radiometric and magnetic interpretation.

Type locality

The type locality is assigned to a small group of large boulders beside a cane field south of Pinnacle township along L'Shews Road at MGA 678360 7658600. The large boulders are fine to medium-grained, light to medium-grey, equigranular biotite granite (Figure 121b), and smaller boulders are coarse-grained, equigranular hornblende granodiorite or tonalite. The granite also contains common dark grey, small, rounded microdiorite xenoliths, commonly 1–3cm.

Lithology

This unit incorporates several different rock types, although biotite granite is characteristic. In addition to the type locality, weathered, light grey, fine to medium-grained, equigranular biotite granite crops out at MGA 678270 7657880, commonly showing chlorite-epidote alteration associated with quartz-calcite veining. The granite comprises quartz (35%), plagioclase (~32%), K-feldspar (25%), biotite (5%) and opaques (~2%). Titanite (~1%) and apatite were also identified.

Nearby at MGA 678370 7658580, boulders of greenish, coarse-grained equigranular uneven-grained hornblende diorite are present. They comprise coarse laths of hornblende (~45%), plagioclase (~30%), quartz (~10%), opaques (~5%) and titanite (~2%). Common accessories are apatite and zircon. Sericite, epidote, calcite and chlorite (total ~5%) are present as alteration minerals. Epidote-chlorite-calcite veins are common. The opaques were identified in hand specimen as chalcopyrite and pyrite. On weathered surfaces some green copper staining was observed.

Another rock type at MGA 678630 7653790 is light grey, medium to coarse-grained, equigranular, hornblende-biotite granodiorite. It comprises quartz (~40%), plagioclase (~30%), K-feldspar (~5%), hornblende (~10–15%), biotite (~5%) and opaques (2–3%). Apatite, titanite and zircon were identified as accessory minerals. Rounded, dark grey to black, fine-grained microdiorite xenoliths 1–3cm are common. This rock appears to be more highly magnetic than the biotite granite, the magnetic susceptibility ranging from ~1100–1800 x 10^{-5} SI units.

Around the Teemburra Creek area, for example at MGA 677090 7648785, coarse-grained porphyritic hornblende tonalite shows net-vein relationships with dark greenish grey, fine-grained equigranular microdiorite or gabbro. A variety of andesite, dolerite and rhyolite dykes cut across these rocks.

Outcrops near gravel scrapes at MGA 683200 7650900 are unusual for this unit. They comprise strongly altered and fractured, porphyritic microgranite. They are commonly decomposed, chloritised and kaolinised and show strong shearing and fracturing.

A range of dykes intrude the Gargett Granite. They are mainly flow-banded rhyolite, altered, porphyritic and aphyric andesite and dacite, and also minor microdiorite and dolerite. The felsic dykes are mostly silicified and commonly form prominent ridges.

Geophysical response

The Gargett Granite is characterised by moderate to high radiometric responses for all three channels resulting in pale bluish white hues on composite images that contrast with most of the adjacent Urannah Batholith units (Figure 119). The Tally Ho Igneous Complex has a similar response, but it is much less magnetic.

The granite shows a moderate response in airborne magnetic images (Figure 120), with stronger north-north-west trending features that may be dykes. Magnetic susceptibilities for the granitoids in the unit show a relatively normal distribution ranging from 0–2200 x 10^{-5} SI units with a mode at about 1100 and a few minor peaks. The sporadic microdiorite and fine-grained gabbro outcrops yielded readings from ~600–6570 x 10^{-5} SI units, but the overall regional response indicates that they are minor components.

The andesite and dolerite dykes show a range of values from <100–6400 x 10^{-5} SI units, with a distinct cluster from 1800 to 3000 consistent with the linear magnetic features being mafic dykes.

Relationships and age

The relationships to the surrounding units are not known. The two outcrop areas are separated by a tongue of the Pisgah Igneous Complex and the Johnston Creek Igneous Complex. This suggests that Gargett Granite may be slightly older and has been cut by these units. Andesite, dolerite and rhyolite dykes intrude the granite in many places.

K–Ar dating of biotite and hornblende from two samples (GA1136 from the Pinnacle Range and GA5267 from Blacks Creek) yielded recalculated early Permian ages of ~280–285Ma from biotite and 295Ma from hornblende (Webb & McDougall, 1968; Jensen, 1972). In view of the discordance between different minerals, these may be minimum ages and a late Carboniferous to early Permian age is assigned to the unit.

JOHNSTONE CREEK IGNEOUS COMPLEX

Introduction

The main outcrop area of the Johnstone Creek Igneous Complex as mapped covers an area of ~110km^2 in the headwaters of Denison and Johnstone Creeks (from which the name is derived) in the Connors Range in south and central MIRANI (Figure 118). Two smaller areas totalling ~25km^2 have mapped farther north along Blacks and Jimmy Jacky Creeks. The area is rugged, strongly dissected and heavily vegetated. Access was limited to a few forestry tracks. The unit was mainly delineated on the basis of its magnetic and radiometric response.

Type locality

The type locality is designated at MGA 683630 7633080 along a track into Connors Range, north of Denison Creek. Boulders of moderately fresh light greenish grey coarse-grained equigranular biotite-hornblende granodiorite are found within red-brown decomposed granodiorite on the flank of the ridge. Nearby various andesite dykes were observed cutting the decomposed granodiorite. The granodiorite comprises quartz (~25%), plagioclase (~40%), K-feldspar (~15%), biotite (~15%), hornblende (~5%) and opaques (~1–2%) and accessory apatite, titanite, zircon and epidote.

Lithology

At MGA 680530 7629020 along a State Forest track on Pisgah Range, light-grey, medium-grained, equigranular biotite-hornblende granodiorite cut by andesite and rhyolite dykes was observed. It is foliated and comprises quartz (~30%), plagioclase (~40%), K-feldspar (~10%), hornblende (~15%), biotite (~5%), and opaques (~1%). Abundant accessory titanite as well as apatite and zircon were observed.

At MGA 683210 7627580 along another State Forest track on the Pisgah Range, white to pale grey, fine-grained equigranular biotite granodiorite was recorded. It comprises quartz (~30%), plagioclase (~40%), K-feldspar (~15%) and biotite (~15%). Accessory zircon and opaque minerals (possibly pyrite) are present. It is cut by a medium greenish-grey, feldspar and pyroxene-phyric andesite or dolerite dyke.

West of Denison Creek, boulders on a ridge at MGA 684360 7627880 consist of highly sheared/foliated and altered, light pinkish-grey, medium-grained, seriate quartz monzonite, which comprises quartz (10%), coarse-grained K-feldspar (~45%), plagioclase (~30%), biotite (<5%), and various secondary minerals (~10%) including muscovite, epidote, chlorite and prehnite. Quartz forms veins and infill textures along fractures. Similar foliated rocks occur ~2km south-south-east of Mount Seaview at MGA 678110 7626330 (Figure 122b).

At Blacks Creek at MGA 679980 7645560, pale grey, fine to medium-grained, equigranular biotite-hornblende tonalite (Figure 122a) comprises quartz (~25%), plagioclase (~50%), hornblende (~15%), biotite (~5%) and opaques (~5%) along with accessory apatite, titanite and zircon.

Along a track west of Denison Creek at MGA 684710 7629000, very fresh, dark greenish grey, coarse-grained, equigranular biotite-hornblende-pyroxene gabbro comprises plagioclase (~50%), hornblende (~25%), clinopyroxene (~10%), orthopyroxene (~5%), biotite (~3%), K-feldspar (~5%), interstitial quartz (~1%), opaques (~2%) and accessory apatite. Similar gabbro crops out nearby at MGA 684250 7627960 (Figure 122c).

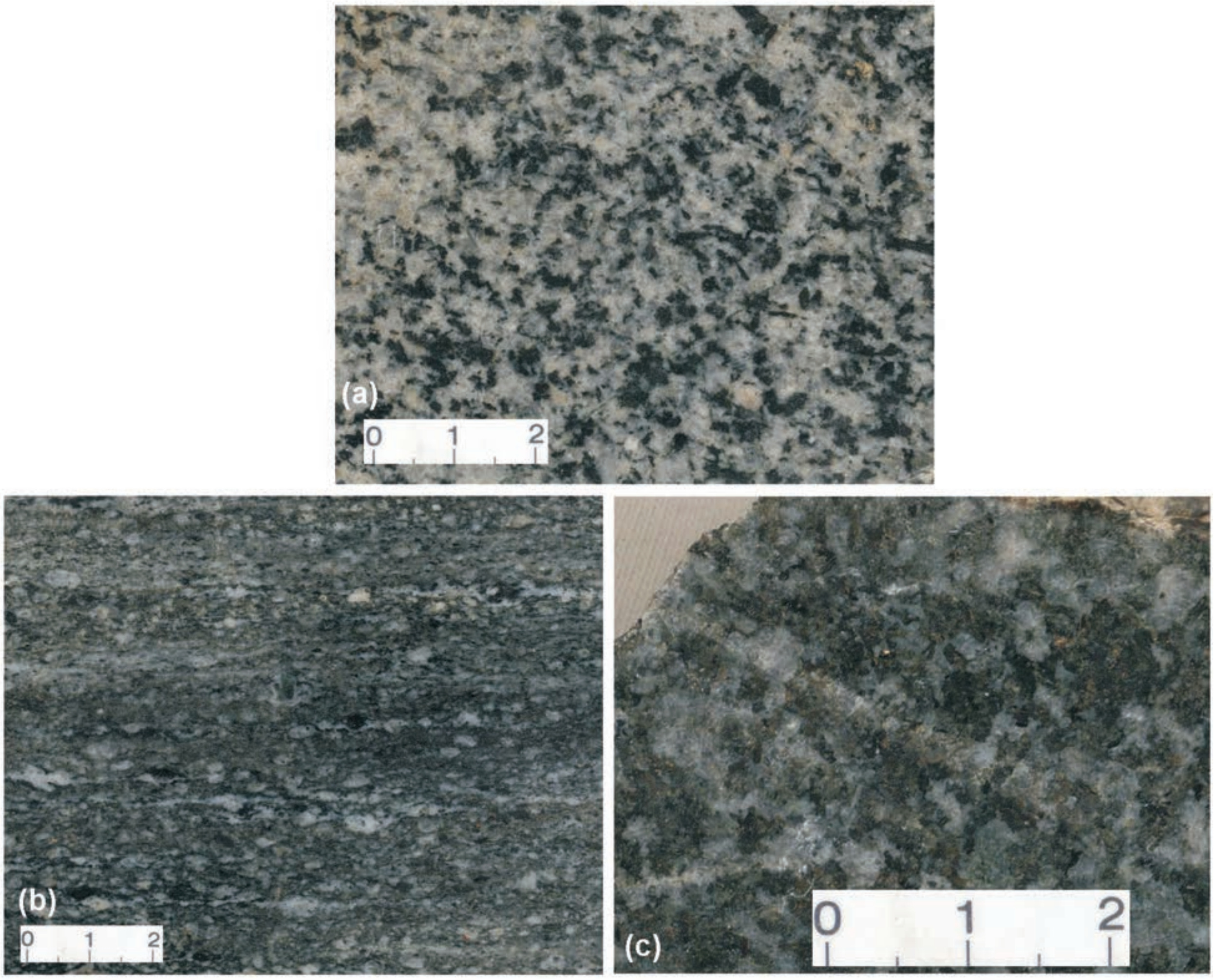

Figure 122. Johnstone Creek Igneous Complex; scale is 2cm
(a) Scanned slab of equigranular biotite-hornblende tonalite; Blacks Creek at MGA 679984 7645557 (QFG3807)
(b) Scanned slab of strongly foliated granitoid; ~2km south-south-east of Mount Seaview at MGA 678114 7626333 (QFG4405)
(c) Scanned slab of biotite-hornblende-pyroxene gabbro; track west of Denison Creek at MGA 684250 7627957 (QFG3563)

Geophysical response

On composite radiometric images, the Johnstone Creek Igneous Complex is mainly characterised by low responses in all three channels resulting in purplish hues on composite images with patches of pale pink, green and white. The dark hues contrast sharply with the generally higher responses of the neighbouring units, the Tally Ho and Pisgah Igneous Complexes (Figure 119). However, the response of the Mount Spencer Granodiorite to the south is similar, suggesting that the two units may be related.

The airborne magnetic response for this unit is variable, justifying its naming as a complex. The northern two-thirds of the main area and the two smaller areas to the north are characterised by a moderate response, but the remainder in the south is characterised by a low response with some stronger, north-trending linear features that are probably dykes (Figure 120). Slightly less than half of the measured magnetic susceptibility values on plutonic rocks in the mapped area are <100 x 10^{-5} SI units with a mode at 20. The remainder of the values show a skewed distribution between 200 and 3000 with a mode at about 900. Andesite dykes show two populations, with about one-third of the values from 0–400 x 10^{-5} SI units and the remainder ranging up to about 2500.

Relationships and age

The relationships of the rocks within the complex to each other and to the surrounding units in the Urannah Batholith are not known. However, the abundance of dyke swarms within the complex indicates that it is early Permian or older. The gabbro observed in this unit may be related to the Screaming Creek Gabbro to the north.

MIA MIA IGNEOUS COMPLEX

Introduction

The extent of the new unit Mia Mia Igneous Complex has been interpreted over ~170km^2 in MIRANI (Figure 118) as an elongated body trending north-north-west from near Blue Mountain homestead to near Gargett. It mainly lies east of the more rugged and heavily vegetated Connors Range. Topography is variable from hilly and dissected in the south to more subdued in the north, where there are locally small ranges of hills such as the Mia Mia Range, from which the name is derived.

Type locality

As the name suggests, the unit shows some variation and it is difficult to specify a single type locality. Therefore two reference localities are given.

To the north of the Peak Downs Highway at MGA 696770 7630580, outcrops consist of medium-grained, equigranular, titanite-bearing clinopyroxene-hornblende-biotite quartz diorite or tonalite (Figure 123a). It comprises quartz (~15%), plagioclase (~50%), biotite (mostly replaced by chlorite, ~12%), hornblende (~10%), clinopyroxene (~5%), opaques (~2%), titanite (~1%) and accessory apatite and zircon. Clinopyroxene commonly has hornblende rims. In places plagioclase is strongly altered to sericite and some epidote and minor calcite. Chlorite is a common alteration product after biotite and hornblende.

The second reference locality is designated on the eastern side of the Mia Mia Range west of the Pioneer River at MGA 6869970 7651610. Boulders of cream to light grey, fine to medium-grained, equigranular biotite granite were observed (Figure 123b). The granite comprises quartz (~25%), K-feldspar (~65%), plagioclase (~5%), biotite (~2%) and opaques (~2%).

Lithology

A variety of rocks, mostly of quartz diorite to granitic composition were observed in this unit, which has been delineated mainly using the airborne magnetic data. Many of the rocks show distinct foliation and are commonly sheared. The unit also incorporates some small gabbro bodies.

On Pinnacle Station, west of the Pioneer River and south-east of Mount Jimmy Jacky at MGA 684440 7643920, boulders of titanite-bearing hornblende tonalite crop out. Common aplite, porphyritic rhyolite, pegmatite and microdiorite dykes cut the tonalite in the area. A similar rock was also observed south of the Peak Downs Highway at MGA 699360 7629010 where it comprises quartz (~25%), plagioclase (~50%), K-feldspar (~5%), hornblende (~15%), clinopyroxene (~5%), biotite (chloritised, ~5%), titanite (1%), opaque minerals (<5%) and accessory apatite and zircon. Chlorite and epidote are common alteration products.

North of Hannaville homestead, coarse-grained, equigranular biotite syenogranite was observed at MGA 696910 7631330. It comprises quartz (~30%), K-feldspar (~50%), plagioclase (~10%), biotite (~5%), hornblende (~5%) and minor opaques. Common alteration minerals are sericite, clay minerals and chlorite and minor epidote. Apatite was observed as an accessory mineral.

South of Mount Mia Mia a series of small conical hills near MGA 686100 7649200 consist of dark green, coarse to very coarse-grained, equigranular hornblende-pyroxene gabbro, which comprises plagioclase (~50–60%), hornblende (~5–15%), clinopyroxene (~10–20%), orthopyroxene (~5–15%) and minor opaques. Secondary chlorite and clinozoisite are common.

At Gargett Quarry at MGA 682150 7660630, hornblende granodiorite (Figure 123c) is cut by various intermediate dykes. The granodiorite comprises quartz (30%), K-feldspar (~15%), plagioclase (~35%), hornblende (~10%), biotite (~5%) and opaque minerals (~5%). In places, the feldspars are strongly altered to sericite and clay. Other common alteration minerals include epidote, chlorite and re-crystallised quartz. Apatite was identified as accessory mineral.

Geophysical response

The Mia Mia Igneous Complex has generally low to moderate responses in all three radiometric channels resulting in dark pinkish grey hues on composite images (Figure 119). Adjacent to the Doraville Granodiorite, the Mia Mia Igneous Complex shows significantly lower responses in the three channels yielding dark purplish grey composite hues. The reason for this halo is not known, but it suggests that the granodiorite may pass out into more mafic rocks.

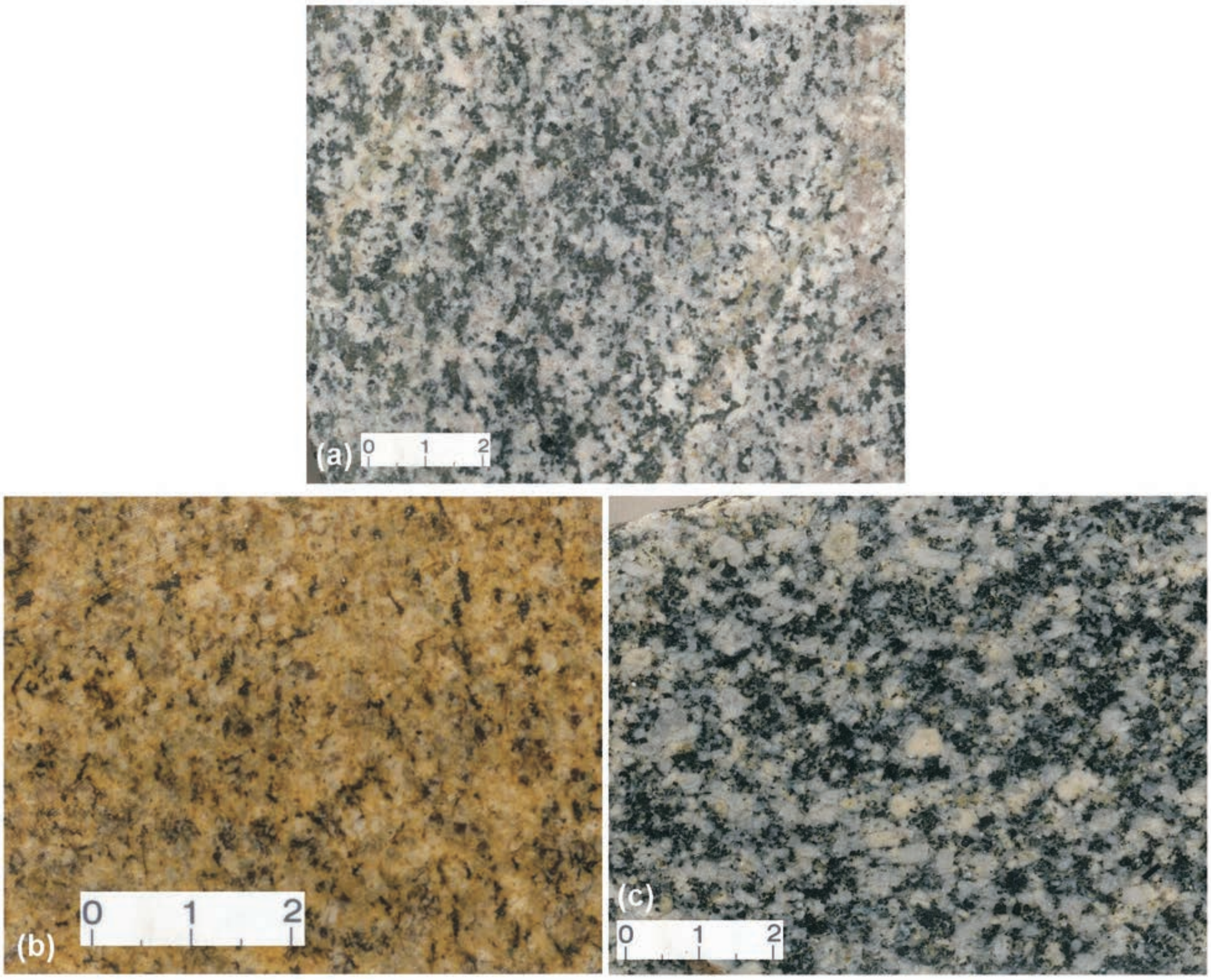

Figure 123. Mia Mia Igneous Complex; scale is 2cm
(a) Scanned slab of equigranular, titanite-bearing clinopyroxene-hornblende-biotite quartz-diorite or tonalite from the reference locality of the Mia Mia Igneous Complex; near Hannaville homestead, 500m north of the Peak Downs Highway at MGA 696770 7630580 (QFG4016)
(b) Scanned slab of equigranular, biotite granite from the second reference locality of the Mia Mia Igneous Complex; east of Mount Mia Mia at MGA 686970 7651613 (QFG4220)
(c) Scanned slab of hornblende granodiorite; Gargett Council Quarry 1.5km north-east of Gargett township at MGA 682153 7660612 (QFG3453)

The unit overall has a moderate to strong magnetic response (Figure 120), but is characterised by a series of linear highs, separated by anastomosing zones of low response that trend parallel to the complex. The presence of a strong foliation through the complex suggests that the linear features may be due to a series of anastomosing shear zones along which magnetite has been destroyed. Magnetic susceptibility measurements show a slightly skewed distribution mainly from 0–1800 x 10^{-5} SI units with a mode at about 700 and sporadic higher values to about 5000. Andesite dykes with values up to 3000 also occur within the unit.

Relationships and age

The age of the Mia Mia Igneous Complex is not known, but is probably late Carboniferous or early Permian as for the other pre-Cretaceous components of the Urannah Batholith.

The Mia Mia Igneous Complex is interpreted to be bounded by fault or shear zones. It is separated from the early Permian Carmila beds by the Mia Mia East Fault Zone and from other units in the Urannah Batholith by the Mia Mia West Fault Zone. The Doraville Granodiorite lies wholly within the Mia Mia Igneous Complex and may intrude it, but it too is interpreted to be partly fault-bounded. Together the two faults and sheared granitoids are regarded as a broader zone up to 5km wide, the Mia Mia Fault Zone, which has been mapped for ~50km along the edge of the Urannah Batholith in MIRANI. The available measurements on the foliation indicate that it is steeply dipping, but few other details are known and it is not possible to draw any conclusions about the kinematics or timing of the fault zone. However, the wide zone of distributed shear in the Mia Mia Igneous Complex suggests that it is more than a simple normal fault, along which the Urannah

Batholith has been uplifted, although that may have been the latest phase of movement on it. Strike-slip movement may be more likely.

MOUNT MARYVALE GRANODIORITE

Introduction

The Mount Maryvale Granodiorite forms an irregular pluton of ~21km^2, between Boundary Creek and Cut Creek in north-eastern NEBO (Figure 118). Although the granodiorite is generally deeply weathered, the unit forms mainly hilly, dissected country due to the presence of numerous felsic–intermediate dykes which are relatively resistant to erosion.

The Mount Maryvale Granodiorite is a somewhat heterogeneous unit, which is generally deeply weathered (extensively decomposed) and poorly exposed. It was shown as unnamed unit $\mathbf{CPgu_2}$ on the first edition NEBO map. The unit is named after Mount Maryvale in the eastern part of the outcrop area.

Type area

The type area is east of Boundary Creek, around MGA 682195 7614058. The unit forms large boulders and bouldery outcrops in this area, which is accessed via a track along the high-voltage power transmission line.

Lithology

The unit consists mainly of pale brownish grey, buff, or brown to dark reddish brown, medium to fine-grained, uneven-grained to porphyritic hornblende-biotite granodiorite and titanite-biotite-hornblende granodiorite.

Titanite-magnetite-hornblende-clinopyroxene quartz monzodiorite(?) crops out at MGA 685022 7614448, where it forms bouldery outcrops on the crest of a prominent ridge. Clinopyroxene is the most abundant mafic mineral (total mafics content ~6–7%), and titanite is relatively abundant. The quartz monzodiorite(?) is deformed and extensively recrystallised.

Geophysical response

The unit is characterised by pale pink to white tones on composite radiometric images, in contrast to the significantly darker tones shown by adjoining Mount Spencer Granodiorite (Figure 119).

It is characterised by mainly low magnetic intensities on airborne magnetic images (Figure 120).

Relationships and age

Contacts with adjoining units have not been found. The granodiorite is tentatively interpreted to be intruded by the Strathdee Granodiorite. The contact with the Mount Spencer Granodiorite, as indicated by magnetic images, is relatively straight and may be a fault. The unit is cut by numerous felsic–mafic dykes, as well as by scarce aplite and granite dykes.

The Mount Maryvale Granodiorite has not been isotopically dated. It is thought to have been emplaced in the late Carboniferous–early Permian.

MOUNT SHIELDS GRANODIORITE

Introduction

The Mount Shields Granodiorite is a small pluton with an area of ~30km^2 in the Connors Range, along and north of the Peak Downs Highway, in south-eastern MIRANI (Figure 118). It crops out in relatively hilly topography, forming Mount Spencer and Mount Shields (from which the unit is named) and the north-western end of the Whitehorse Mountains. In general the Mount Shields Granodiorite is very poorly exposed and outcrops are mostly decomposed. The unit was originally recognised and delineated by a slightly different radiometric response to the surrounding rocks.

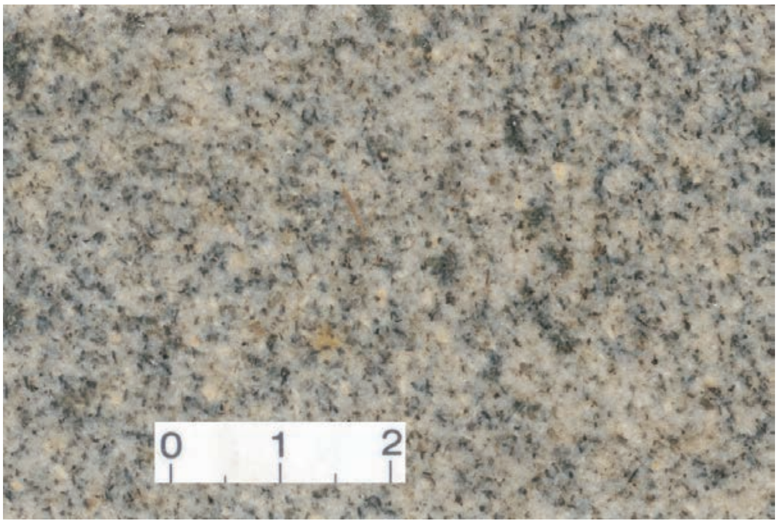

Figure 124. Scanned slab of fine-grained, equigranular biotite granodiorite from the type locality of the Mount Shields Granodiorite; track along powerline, 2.5km south-east of Mount Shields at MGA 696168 7624176 (QFG4424); scale is 2cm

Type locality

The type locality is designated as a group of large boulders of pale grey, fine-grained, equigranular muscovite-biotite granodiorite to granite (Figure 124) on a small ridge south-east of Mount Shields at MGA 696165 7624180. It comprises quartz (25%), K-feldspar (25%), plagioclase (45%), biotite (5%), muscovite (5%) opaques (1%) and accessory zircon and apatite. The micas are unaltered, but moderate sericite alteration occurs within the feldspars. The presence of abundant muscovite is consistent with the rock having an Alumina Saturation Index >1.1.

Lithology

The dominant rock type is a light grey, mostly fine-grained to locally coarse-grained, saccharoidal, equigranular biotite granodiorite to granite as at the type locality.

Geophysical response

The Mount Shields Granodiorite has a similar moderate potassium response to, but lower thorium and uranium than the surrounding Tally Ho Igneous Complex, thus being characterised by mottled pinkish hues rather than the greyish hues of the latter (Figure 119). It has much lower radiometric responses than the Whitehorse Granite to the south.

The granodiorite shows a similar low magnetic response to the Tally Ho Igneous Complex (Figure 120), except in the eastern half where the higher response may be due to north-trending andesite dykes. Magnetic susceptibility readings from four outcrops were in the range 0–36 x 10^{-5} SI units consistent with the regional response. The andesite and microdiorite dykes that cut the granodiorite have magnetic susceptibility readings that range from 800–1420 x 10^{-5} SI units.

Relationships and age

As noted the Mount Shields Granodiorite is in contact with Tally Ho Igneous Complex, but the relationship is not known. It is intruded by the Permian Whitehorse Granite and by highly magnetic equigranular microdiorite and porphyritic hornblende andesite dykes. It is probably late Carboniferous or early Permian.

MOUNT SPENCER GRANODIORITE

Introduction

The Mount Spencer Granodiorite crops out in the Connors Range in southern MIRANI and northern NEBO (Figure 118), straddling the Peak Downs Highway. Total outcrop area is ~75km^2 and is trapezoidal in outline. Its topography ranges from relatively subdued, undulating and partly cleared in the south-east near the highway, to relatively rugged and heavily vegetated in the north-west, where it includes Mount Adder and Boundary Gap Mount. In general the Mount Spencer Granodiorite crops out as scattered boulders, but locally some larger whaleback outcrops occur.

Type locality

The type locality is designated at MGA 684810 7620130, a road cutting on the Peak Downs Highway ~6km south-west of Mount Spencer homestead. This locality contains mostly medium grey, coarse-grained equigranular hornblende-biotite granodiorite. Dark grey fine-grained sub-rounded to rounded microdiorite enclaves are common. Epidote-chlorite alteration is in evidence with sporadic veins of quartz and chlorite up to 3cm wide, and common disseminated epidote grains and thin veinlets.

Lithology

The dominant rock type, as at the type locality, is pale grey to white, mostly medium to coarse-grained, equigranular biotite-hornblende granodiorite with common fine-grained dark grey to black equigranular microdiorite enclaves. It comprises quartz (25%), K-feldspar (15%), plagioclase (40%), hornblende (10%) biotite (5%) and opaques (3%). Zircon and apatite were observed as accessories. Common epidote-carbonate veins and alteration is present.

Dark grey equigranular biotite-hornblende quartz diorite or tonalite crops out locally, such as at MGA 683700 7622850. It comprises quartz (15%), K-feldspar (5–10%), plagioclase (55%), biotite (15%) hornblende (7%) and opaques (2%) and has common rounded to elongate mafic-rich xenoliths up to 15cm across.

Geophysical characteristics

The Mount Spencer Granodiorite has a low response in potassium, uranium and thorium, producing dark purple in composite images. The south-eastern corner of the unit has a slightly higher thorium response and produces dark grey hues (Figure 119).

The unit shows a moderate to high magnetic response (Figure 120). Magnetic susceptibility values show a roughly normal distribution from 200–2400 x 10^{-5} SI units with a mean of 1100.

Relationships and age

To the west the Mount Spencer Granodiorite intrudes the late Carboniferous to early Permian Leura Volcanics. It is intruded by dark grey, fine to medium-grained equigranular microdiorite and porphyritic hornblende diorite dykes of probable Permian age. Its relationship to other units in the Urannah Batholith that it is in contact with — the Tally Ho and Johnstone Igneous Complexes, Mount Maryvale, Featherstone and Epson Granodiorites and unnamed units — is not known. Some contacts to the south appear to be faults. The relationships suggest that it is early Permian, rather than late Carboniferous to early Permian as shown on the MIRANI and NEBO maps

PALMS LOOKOUT GRANODIORITE

Introduction

The Palms Lookout Granodiorite has been mapped over ~150km^2 in north-western MIRANI (Figure 118) from the Clark Range in the north to the south of Cattle Creek. The name is derived from Palms Lookout, which is a locality in the southern part of the Eungella National Park, overlooking the valley of Cattle Creek.

The extent is mainly based on the airborne geophysical data because of poor access. Most of the area is rugged and deeply dissected. It is also heavily vegetated (including tropical rainforest) except along the top of the range where it has been cleared for dairy farming. Typical exposures are house-sized boulders and rock platforms on the crests and flanks of ridges and hilltops, but these are not common. Most boulders have a moderately weathered rim with relatively fresh cores.

Type locality

The type locality is designated near Eungella Retreat in the headwaters of Broken River within the southern part of the Eungella National Park. At MGA 655955 7658490, large boulders and platforms in a rock pool are composed of grey, medium-grained, equigranular biotite-hornblende granodiorite (Figure 125a) cut by a dark greenish-grey aphyric, andesite dyke. Some dark grey, sub-rounded microdiorite xenoliths and minor quartz and aplite veins are also present.

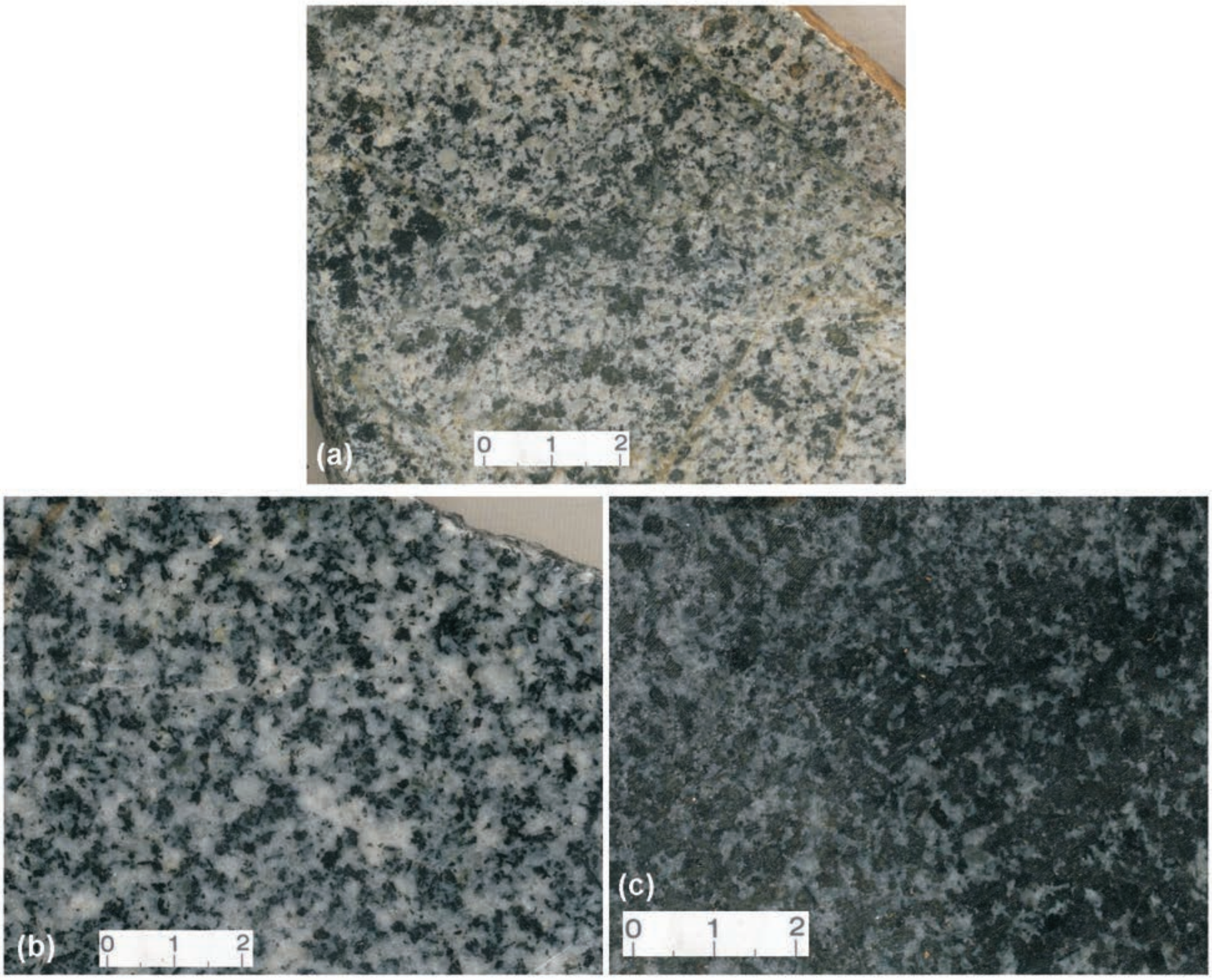

Figure 125. Palms Lookout Granodiorite; scale is 2cm
(a) Scanned slab of medium-grained biotite-hornblende granodiorite from the type locality of the Palms Lookout
(b) Scanned slab of medium-grained biotite-hornblende granodiorite. Descent from Eungella to Netherdale at MGA 655603 7662868 (QFG3404)
(c) Scanned slab of hornblende diorite. Same locality as (b)

Lithology

The main rock type is grey, fine to medium-grained, equigranular biotite-hornblende granodiorite that contains numerous fine-grained diorite and microdiorite xenoliths as at the type locality. Quartz (25%), plagioclase (40–50%), hornblende (~20%) and biotite (~2–5%) are the main constituents. Biotite is commonly altered to chlorite and opaque minerals. In a few places, for example at MGA 663700 7663450, south-east of Bull Mount, the granodiorite is strongly banded, showing “schlieren” textures with distinct, coarse, mafic-rich and leucocratic bands, but is otherwise similar mineralogically.

Some of the rocks are more mafic, probably being quartz diorite rather than granodiorite. For example, in the Broken River along the Crediton track in the southern part of the Eungella National Park at MGA 656840 7658080, grey, fine to medium-grained, hornblende-biotite quartz diorite comprises plagioclase (~60%), quartz (~10%), biotite (~15%), hornblende (~10%) and opaques (~3%). Some of the variation is illustrated by Figures 125b–c.

Fine to medium-grained, equigranular (hornblende)-biotite granite, mostly strongly chloritised and silicified, was observed locally.

Geophysical response

The Palms Lookout Granodiorite is characterised by a low response in potassium and thorium and a low to moderate uranium response, producing a distinctive dark blue hue in composite radiometric images that contrasts with the pinkish hues of most of the surrounding units (Figure 119).

The unit has a mostly moderate magnetic response, although it passes into a more strongly magnetic zone that rims the low magnetic area associated with the Morugo Granite (Figure 120). The reasons for this zone are uncertain. It may be due to hornfelsing by the Cretaceous Morugo Granite, or as speculated later, the latter granite may be zoned with a more mafic magnetic rim. Magnetic susceptibility values for the granodiorite are normally distributed from 200–2900 x 10^{-5} SI units with a mode at 1600.Values for the (altered) leucocratic granite show a bimodal distribution from 30–430 x 10^{-5} SI units with modes at 140 and 370.

Relationships and age

The relationship of the Palms Lookout Granodiorite to the Pisgah Igneous Complex to the south is not known, but the shape of the contact suggests that it is intruded by the Finch Hatton Granite. It is also intruded by the Cretaceous Morugo Granite, which occupies the valley floor of Cattle Creek. Dykes of dark green aphyric to slightly porphyritic andesite and porphyritic rhyolite cut the granodiorite. The former are probably Permian and related to a swarm of such dykes throughout the Urannah Batholith. The rhyolite dykes may also be Permian, but some could be Tertiary and related to the flows and plugs farther south near Nebo. The granodiorite is probably late Carboniferous or early Permian.

PISGAH IGNEOUS COMPLEX

Introduction

The Pisgah Igneous Complex has been mapped over ~300km^2 in the western part of the Urannah Batholith in the Clarke Range, Pisgah Range (from which the unit is named) and Connors Range of south-western MIRANI (Figure 118). It forms rugged, strongly dissected topography that is heavily vegetated and includes tropical rainforest. Access is difficult and restricted to a few forestry tracks.

Type locality

The type locality has been assigned to a stream outcrops in the West Branch of Nebo Creek around MGA 670760 7632080. At this locality the Pisgah Igneous Complex is represented by pink, medium to coarse-grained biotite granite (Figure 126a). It comprises K-feldspar (~45%), plagioclase (~25%), quartz (~23%), biotite (~5%) and secondary muscovite (~1%). Accessory minerals are apatite, zircon and opaques. Chlorite-epidote-silica veinlets are abundant. The granite is commonly cut by several generations of dykes. Rhyolite and dacite dykes are cut by andesite and younger basalt/dolerite dykes. Nearby to the west, grey, medium-grained, equigranular to slightly porphyritic biotite-hornblende granodiorite crops out.

Lithology

At MGA 670040 7632010, outcrop consists of medium to greenish grey, medium to coarse-grained, equigranular to slightly porphyritic biotite-hornblende granodiorite. This rock comprises quartz (~30%), plagioclase (~40%), K-feldspar (~5%), hornblende (~15%), biotite (~10%) and opaques (<5%), and accessory titanite, apatite and zircon. Small, angular to sub-rounded, dark grey, microdiorite xenoliths are common.

At MGA 677840 7644220, north of Screaming Creek, fine to medium-grained, moderately porphyritic biotite-hornblende granodiorite was observed (Figure 126b). This rock comprises quartz (~30%), plagioclase (~35%), K-feldspar (~10%), hornblende (~15%), biotite (~10%) and opaques (~2%). The granodiorite shows abundant angular to subrounded mafic-rich xenoliths of microdiorite from 2cm to 25cm across.

In the Crediton State Forest near Hazlewood Creek and Cockies Creek, very poorly exposed granite, microgranite, diorite and gabbro were observed. Due to the radiometric response this area has been included in the Pisgah Igneous Complex. Commonly, as at MGA 658070 7647300, pink fine-grained, equigranular biotite granite intruded by intermediate and felsic dykes was observed. Sericite and epidote-chlorite alteration and silicification are common, with abundant quartz, chlorite and sericite as infill in fractures and veinlets.

At MGA 659560 7645220 along the Crediton State Forest track on Clarks Range, dark greenish-grey, medium-grained, equigranular pyroxene gabbro was observed. It comprises clinopyroxene (~45%), orthopyroxene (~10%), chlorite (~15%), plagioclase (~30%), opaques (<5%) and accessory apatite.

Some of the variation within the complex is illustrated by Figures 126a–d.

Geophysical response

The Pisgah Igneous Complex is characterised by a moderate to high potassium response and low to moderate thorium and uranium responses that produce pale pinkish hues in composite images (Figure 119). These

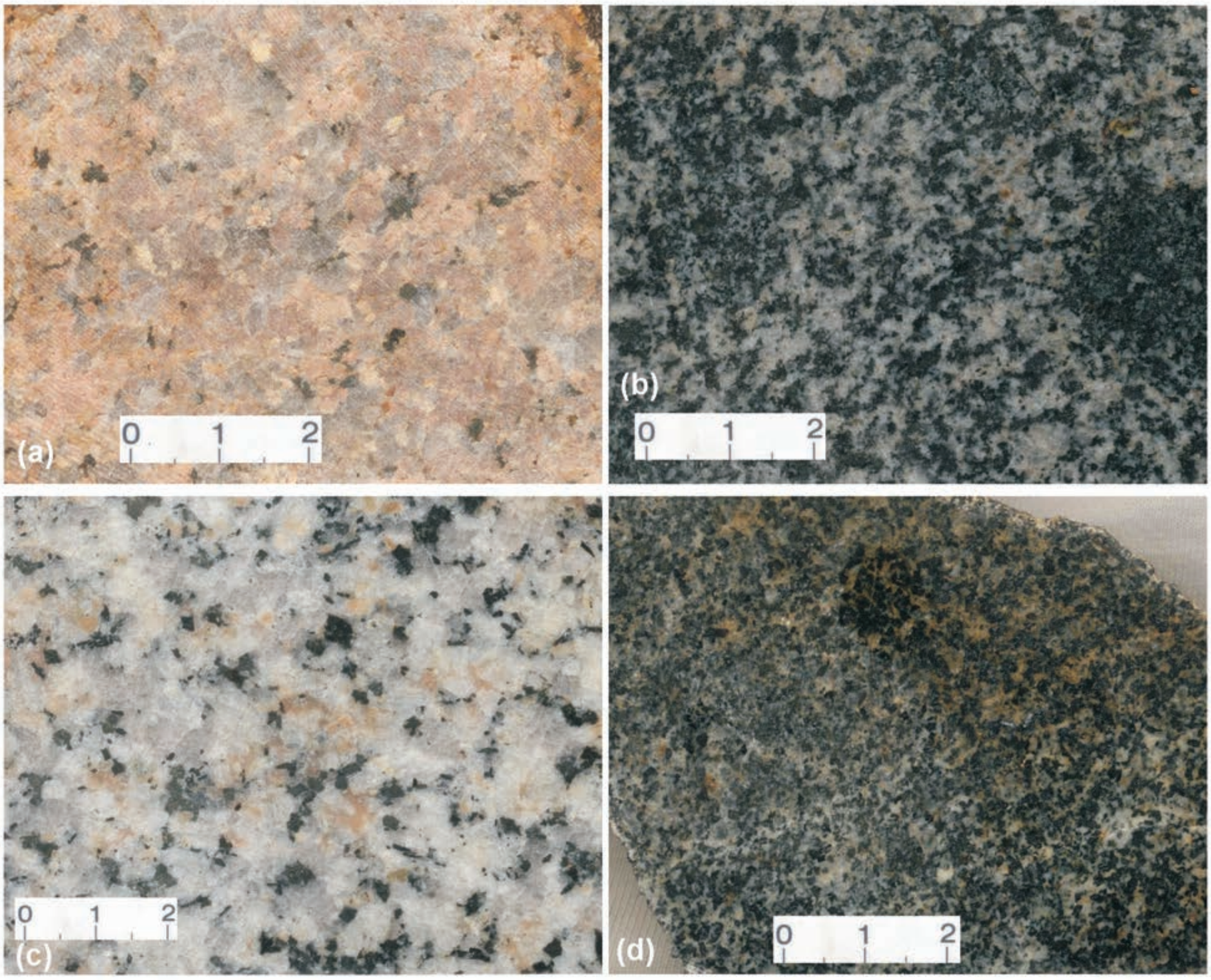

Figure 126. Pisgah Igneous Complex; scale is 2cm
(a) Scanned slab of medium-grained biotite granite from the type locality of the Pisgah Igneous Complex. About 12km north-west of Mount Adder, West Branch Nebo Creek at MGA 670766 7632081 (QFG4180)
(b) Scanned slab of fine to medium-grained, moderately porphyritic biotite-hornblende granodiorite with a mafic xenolith. Track between Blacks Creek and Screaming Creek at MGA 677840 7644220 (QFG3812)
(c) Scanned slab of relatively leucocratic hornblende-biotite granodiorite. About 9km north-west of Mount Adder at MGA 673338 7630841 (QFG4175
(d) Scanned slab of clinopyroxene-hornblende diorite. About 0.5km south-west of Mount Adder homestead along access road at MGA 669327 7630974 (QFG4161)

contrast with the darker hues of the Palms Lookout Granodiorite, Teemburra and Johnstone Creek Igneous Complexes and the Screaming Creek Gabbro and the bluish grey hues of the Tally Ho Igneous Complex and Gargett Granite. The data are locally of poor quality, where extreme topography resulted in levelling problems in processing the airborne radiometric data.

The complex has a moderate magnetic response that is generally lower than such units as the Uruba Granite, Teemburra and Mount Johnstone Igneous Complexes and Screaming Creek Gabbro, but higher than the Yarravale Creek Granite (Figure 120). More magnetic, north-north-west-trending linear features are probably due to mafic dykes. The magnetic susceptibility measurements from granite and granodiorite showed a skewed bimodal distribution with a strong mode at ~100 x 10^{-5} SI units and a lesser one at 800. Most values are <2500. A few small gabbro and diorite bodies within the complex have values that range from ~300–12000 x 10^{-5} SI units with peaks at 1600, 3700 and 5000.

Relationships and age

Relationships to adjacent plutonic units are uncertain, but the shape of the smaller circular or elliptical plutons such as the Yarravale Creek Granite, Uruba Granite and Screaming Creek Gabbro suggest they are younger. The complex is extensively intruded by mafic dykes and also some earlier north-trending felsic dykes. It probably intrudes the late Carboniferous or early Permian Leura Volcanics to the west, but may be overlain by the early Permian Mount Benmore Volcanics, although the contact is obscured by Tertiary basalt. It is probably early Permian.

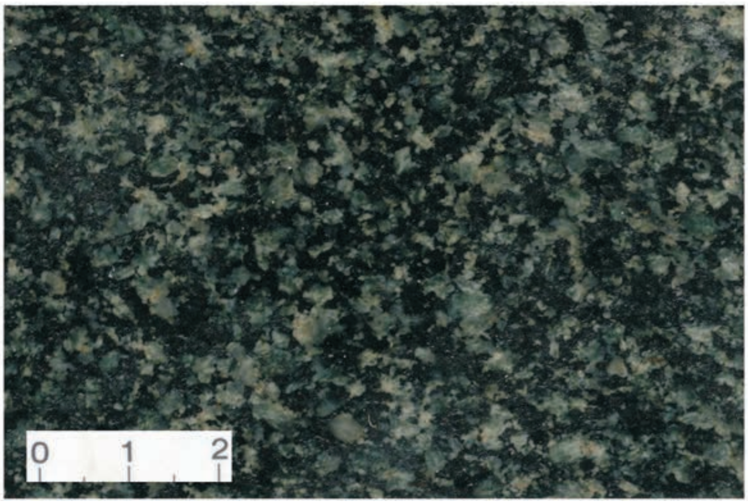

Figure 127. Scanned slab of pyroxene gabbro from the type area of the Screaming Creek Gabbro. About 9km south-west of Mount Jimmy Jacky in a tributary of Blacks Creek at MGA 675255 7640800 (QFG4468); scale is 2cm

SCREAMING CREEK GABBRO

Introduction

The Screaming Creek Gabbro crops out south of Station Creek and west of Screaming Creek (from which the unit is named), within the generally rugged and heavily vegetated topography of the Connors Range, in central MIRANI (Figure 118). It has no distinctive topographic expression, and in general outcrop is poor and very weathered, although fresher boulders occur locally.

Type locality

The type locality is designated between MGA 675255 7640800 and MGA 675254 7641430 along an unnamed tributary of Blacks Creek. The freshest rocks are boulders that have probably been transported only a short distance.

Lithology

The main rock type of the Screaming Creek Gabbro, as sampled at MGA 675250 7640800 in the type area, consists of a dark green to black, very coarse-grained, equigranular olivine-clinopyroxene-hornblende gabbro (Figure 127). Well twinned, unaltered, euhedral to subhedral plagioclase crystals forms around 55% of the rock. The dominant mafic mineral is hornblende (~25%) with subordinate clinopyroxene (~15%) and olivine (~5%). The hornblende locally forms ophitic crystals up to 4cm across. Accessory brown titanite (<0.5mm) and very minor small apatite is present. Some opaque oxides (probably magnetite, ~1–3%) are also present. Minor chlorite and sericite were observed as of alteration products of plagioclase and pyroxene. Some hornblende is uralitic after pyroxene.

A greenish-grey, coarse to very coarse-grained, layered, equigranular pyroxene-hornblende gabbro was observed at MGA 675254 7641430. The thin section revealed strong alteration of the plagioclase and pyroxene.

Geophysical characteristics

The gabbro is characterised by very low responses in all three radiometric channels resulting in dark grey to black hues on composite images (Figure 119).

It has a very strong magnetic response in airborne magnetic images (Figure 120). Magnetic susceptibility measurements range from 2000–13000 x 10^{-5} SI units for the gabbro.

Relationships and age

The Screaming Creek Gabbro probably intrudes the Pisgah Igneous Complex, although contacts were not observed. Rocks of the Pisgah Igneous Complex near the gabbro show common veining and alteration. Some finer-grained gabbro or dolerite dykes intrude both the Screaming Creek Gabbro and adjacent Pisgah Igneous Complex.

STONY CREEK GRANITE

Introduction

The Stony Creek Granite (~30km^2) crops out mainly in north-eastern NEBO, and extends into adjoining north-western CARMILA (Figure 118). The granite is relatively resistant to erosion and forms most of the Blue Mountains, a rugged mountain range with maximum relief of ~850m. The range is terminated abruptly in the north-east by a prominent, steep escarpment with abundant rock outcrops. Much of the granite is covered in dense rain forest. The unit is named after Stony Creek, which rises in the summit area of the Blue Mountains, and forms one of the main watercourses in the area.

Type locality

The type locality is at MGA 703755 7609107, beside an access track to telecommunication towers on the summit of the Blue Mountains. The granite forms very large boulders in this area.

Lithology

The compositional heterogeneity shown by the Stony Creek Granite and the complex relationships it shows with unit $CPgu_{ga}$ imply that it is a multiphase pluton.

The unit at the type locality is characterised by a well-developed quenched (porphyritic) texture. It consists of fine-grained (average grainsize of groundmass grains ~0.3mm), moderately porphyritic, leucocratic hornblende-biotite monzogranite. Phenocrysts (up to ~5mm long) consist of plagioclase and quartz. K-feldspar crystallised relatively late and is essentially confined to the groundmass, where it locally forms relatively large, anhedral, poikilitic grains (oikocrysts). Sparse granophyric intergrowths between quartz and K-feldspar are scattered throughout the groundmass.

Biotite (~3%) is the main mafic mineral, and is partly replaced by chlorite. The monzogranite also contains minor hornblende (~1%), and traces of opaque oxide and titanite. The main accessory and secondary minerals are zircon, apatite, allanite, sericite, chlorite, and epidote.

The unit, as currently delineated, is texturally and compositionally heterogeneous. Monzogranite examined ~1km farther north at MGA 704116 7610060, although mineralogically similar to that at the type locality, has a coarser grained groundmass and consequently, is only slightly porphyritic to uneven grained. The groundmass is characterised by the presence of abundant granophyric intergrowths between quartz and K-feldspar.

Rock types recorded elsewhere (mainly along Stony Creek, at or near the base of the mountain range) include leucocratic (muscovite-) biotite monzogranite, titanite-bearing hornblende-biotite quartz monzodiorite (?), and hornblende gabbro or diorite. The leucocratic monzogranite extends south to form Pine Mountain, but the more mafic rocks are poorly exposed (mainly as scattered pavements along Stony Creek).

The granite is locally characterised by the presence of pink, dyke-like alteration zones up to ~2cm wide.

Geophysical response

The unit is characterised by low to moderate potassium, low thorium and low to moderate uranium responses resulting in mainly blue, purple, and pink tones on a composite radiometric image. Areas showing blue and purple tones correspond approximately with zones of dense rainforest and more rugged terrain, and may be partly due to levelling problems.

The Stony Creek Granite shows moderate magnetic responses that contrast with the somewhat lower response of the Strathdee Granodiorite to the west. No magnetic susceptibility data are available.

Relationships and age

Relationships between the Stony Creek Granite and most adjacent units are uncertain as few contacts have been found. The felsic rocks, which make up most of the unit, are closely associated with unnamed unit $CPgu_{ga}$. Mafic–intermediate rocks of unit $CPgu_{ga}$ are locally well exposed along the lower and middle reaches of Stony Creek. Some of these outcrops have been included in the Stony Creek Granite because the exposures are too small to be shown at 1:100 000-scale. Some of these outcrops are cut by dykes of leucogranite interpreted to be related to the felsic granite forming Pine Mountain, whereas elsewhere, some mafic rocks contain inclusions of granite similar to that exposed in the type locality of the Stony Creek Granite. In addition, samples of granite examined between MGA 705014 7607680 and MGA 705451 7607741 have been partly recrystallised (hornfelsed), presumably by the emplacement of elements of unit $CPgu_{ga}$. Quartz monzodiorite of unit $CPgu_{ga}$ also locally intrudes and contains inclusions of gabbro from the same unit.

The Stony Creek Granite is interpreted to post-date the Strathdee Granodiorite. The unit is cut by numerous dykes of porphyritic rhyolite (~10–15m thick), aphyric to slightly porphyritic basalt/andesite (generally <5m thick), and porphyritic microgranite (up to ~25m thick). Some of the felsic dykes show fine flow-banding.

The age of the unit is uncertain but it is tentatively interpreted to have been emplaced in the late Carboniferous or early Permian.

STRATHDEE GRANODIORITE

Introduction

The Strathdee Granodiorite forms an irregular, elongate pluton of ~165km^2 with a north-easterly alignment, mainly in north-eastern NEBO, but extending into north-western CARMILA (Figure 118). The unit is deeply weathered and very poorly exposed — mainly as scattered boulders and pavements in erosion channels and watercourses. It forms low, undulating country over most of the outcrop area with scattered ridges and low hills (due to the presence of relatively resistant felsic–intermediate dykes). The unit forms rugged, extensively dissected country in the far east of NEBO, reflecting the presence of numerous felsic–intermediate dykes.

The unit is named after Strathdee pastoral holding, which encompasses some of the western part of the unit. It was depicted as unit **$CPgu_4$** on the first edition NEBO and CARMILA geological maps and Central Queensland GIS (Withnall & others, 2007).

Type locality

The designated type locality is at MGA 685845 7609127. The unit is relatively well exposed as a prominent bar across Cut Creek at this locality, upstream of the track crossing.

Lithology

The main rock types are grey or brown to dark reddish brown (weathered), fine to medium-grained, uneven-grained to slightly porphyritic hornblende-biotite granodiorite and biotite-hornblende granodiorite. Some granodiorite samples contain traces of titanite, allanite, and pyrite. Biotite is slightly more abundant than hornblende (total mafics ~7–8%) in the sample examined from the type locality. K-feldspar forms sparse, relatively large, anhedral, poikilitic grains. The rocks are commonly slightly to moderately altered. Chlorite, epidote, and sericite are the most common secondary minerals.

Minor biotite-hornblende quartz diorite, diorite, and biotite monzogranite have also been recorded in the unit. Mafic inclusions, up to ~30cm across, are common locally.

Geophysical response

The unit has low responses in all three channels west of Denison Creek, resulting in dark (blue) hues on a composite radiometric image, but to the east, potassium is slightly higher resulting in mottled (pink, green, dark blue) hues. The different tones may reflect the relative abundances of felsic–intermediate dykes in the two areas.

The granodiorite is characterised by low to moderate intensities on airborne magnetic images. Magnetic susceptibility readings recorded from several outcrops are in the range 100–900 x 10^{-5} SI units.

Relationships and age

The Strathdee Granodiorite intrudes the Leura Volcanics, and is intruded by the Whitehorse Granite. The unit is tentatively interpreted to post-date the Mount Maryvale Granodiorite and unit **$CPgu_1$**, and may pre-date the Featherstone, Carminya and Epsom Granodiorites.

The granodiorite is cut by numerous felsic to mafic dykes (most <10m thick) and by scattered aplite and leucogranite (some muscovite-bearing) dykes (up to ~30cm thick). It is also locally cut by thin (up to ~5cm thick) quartz veins.

The unit is unconformably overlain by coarse, semi-consolidated boulder conglomerate, feldspathic sandstone and conglomeratic sandstone of unit **TQf**, west of Funnel Creek.

The unit is tentatively regarded to be late Carboniferous–early Permian, but it has not been isotopically dated.

TALLY HO IGNEOUS COMPLEX

Introduction

This Tally Ho Igneous Complex crops out mainly in south-eastern MIRANI (Figure 118) on the eastern edge of the Connors Range, in the area drained by the headwaters of Tally Ho Creek (from which the unit is named) and Denison Creek and tributaries of Blacks Creek. It covers an irregular, north-west-trending area of ~100km^2. Topography is hilly and closely dissected and moderately timbered. Overall the outcrop is poor and highly decomposed. Fresher exposures are found in large boulders, low platforms and locally whaleback outcrops.

Type locality

The type locality is designated ~1.6km north-north-west of Mount Shields on the southern side of the Peak Downs Highway at MGA 693600 7627200. Boulders comprise pale grey, fine to medium-grained, equigranular hornblende-biotite granodiorite to tonalite (Figure 128a). Rare, dark grey, rounded to elongate microdiorite enclaves were observed. The granodiorite consists of quartz (20%), K-feldspar (<10%), plagioclase (~50%), biotite (~5–10%) and hornblende (5%). The biotite is generally unaltered.

Lithology

The oldest parts of this unit consist of diorite and granodiorite that have been locally sheared or foliated. They were intruded by and included as enclaves in the more abundant hornblende-biotite granodiorite and granite. Aplite and pegmatite associated with the younger granite intrude all earlier phases.

At the northern end of the Tally Ho Igneous Complex along Screaming Creek at MGA 678420 7641460, pale greenish-grey, seriate to porphyritic, medium to coarse-grained biotite-hornblende granodiorite boulders comprise quartz (25%), K-feldspar (10–15%), plagioclase (30–35%), hornblende (10–15%) and biotite (~5%). Traces of apatite, opaques and epidote were observed in thin section. Commonly the feldspars show moderate sericite alteration. The relatively large hornblende prisms (8–12mm) appear to be roughly aligned.

Farther south near the Peak Downs Highway in a creek crossing along the track to Whittingham homestead at MGA 692490 7628170, a possible net-veined complex consisting of granodiorite and quartz microdiorite was observed (Figure 128c). The dominant rock is pale grey, medium-grained granodiorite, which contains dark greenish-grey equigranular microdiorite enclaves. The granodiorite comprises quartz (~30%), K-feldspar (~5%) plagioclase (40–45%), uralitic hornblende (10–15%), and chlorite-altered biotite (~10%). Multiple small granodiorite veinlets cut the quartz microdiorite which comprises quartz (15–20%), plagioclase (45–55%), hornblende (25%), and biotite (~5%). Both rock types are cut by felsic dykes and leucocratic granite and pegmatite, which in turn are cut by basalt and andesite dykes.

Large boulders, platforms and whalebacks, near Mount Spencer south of Tally Ho Creek in the west, consist of medium-grained, equigranular, muscovite-biotite monzogranite to granodiorite (Figure 128b), in places intruded by andesite and microdiorite dykes. The rocks comprise quartz (25–30%), K-feldspar (20–30%, locally as poikilitic grains up to 7.5mm), plagioclase (30–40%, oscillatory zoned andesine to oligoclase), biotite (~5%) and subordinate muscovite (1–2%, as discrete flakes to 1mm or intergrown with biotite). Accessory zircon, apatite and minor opaques, probably sulphides were observed. The monzogranite commonly has dark grey to black, mostly rounded, fine-grained, equigranular biotite-rich microdiorite and diorite enclaves. Late-stage tourmaline pegmatites were also observed cutting the monzogranite. This area has anomalously higher potassium in the radiometric data as noted below. It is similar to rocks mapped as Mount Shields Granodiorite and is probably related.

Geophysical response

The Tally Ho Igneous Complex is well delineated by both the radiometric and magnetic data. The unit is characterised by a moderate potassium response and moderate to high thorium and uranium. This produces

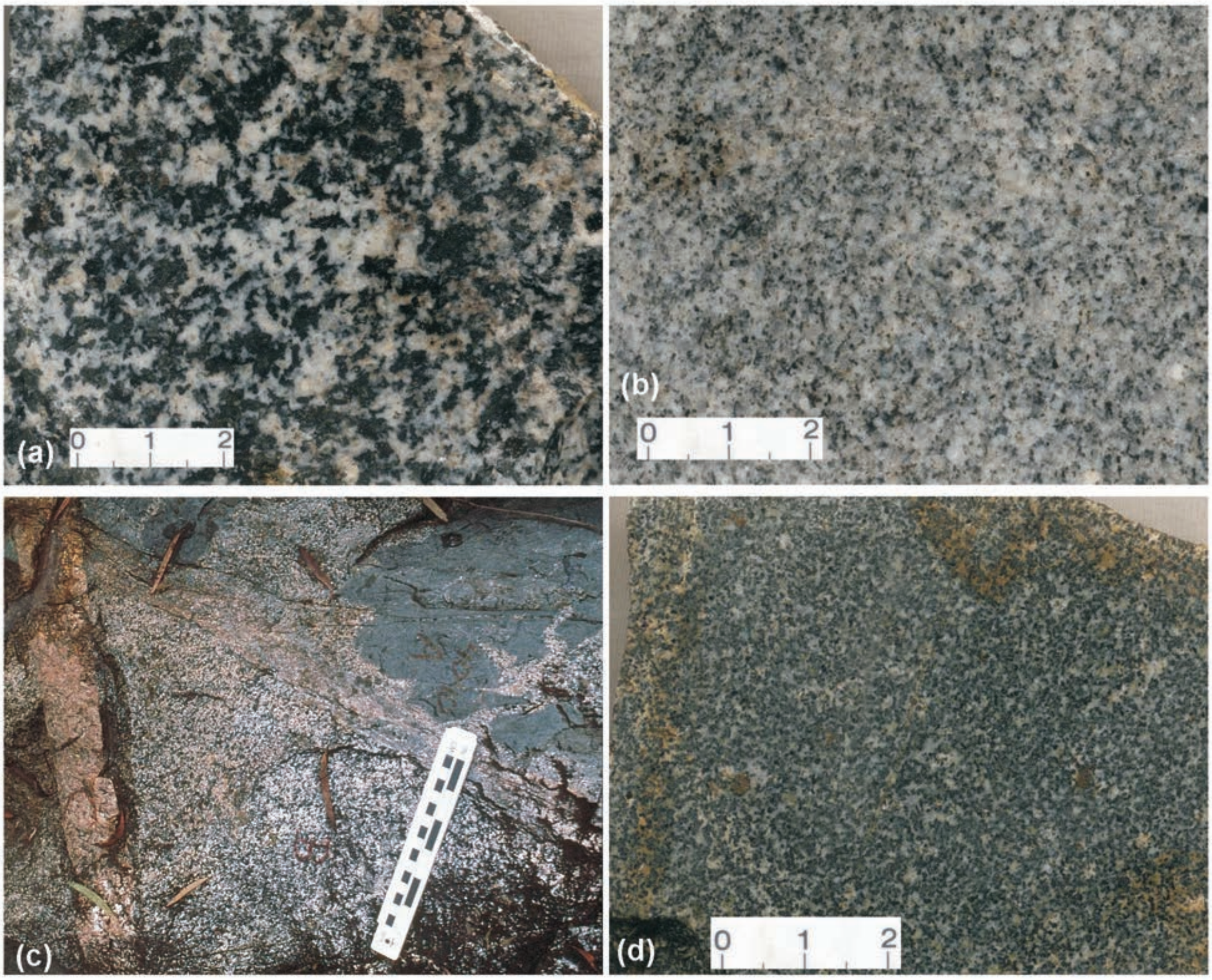

Figure 128. Tally Ho Igneous Complex; scale is 2cm in (a), (b) and (d)
(a) Scanned slab of equigranular hornblende-biotite granodiorite from the type locality of the Tally Ho Igneous Complex. About 1.6km north-north-west of Mount Shields on southern side of the Peak Downs Highway at MGA 693603 7627192 (QFG4045)
(b) Scanned slab of medium to coarse-grained muscovite-biotite granite. About 1km north-west of Mount Spencer at MGA 688000 7626550 (QFG4715)
(c) Enclaves of microdiorite in hornblende-biotite granodiorite; the complex contacts are suggestive of magma mingling. Along the track to Whittingham homestead at MGA 692490 7628170 (QFG4040)
(d) Scanned slab of fine-grained hornblende diorite. About 2.7km north-north-west of Mount Spencer at MGA 687493 7628327 (QFG4711)

distinctive pale bluish to locally greenish hues on composite radiometric images (Figure 119). An anomalous area around Mount Spencer has higher potassium and the resulting pinkish composite hues are similar to the rocks mapped as Mount Shields Granodiorite.

The characteristic radiometric response for the main part of the complex coincides very closely with an area of low magnetic response, except for dyke-like slightly more magnetic linear features (Figure 120). About 75% of magnetic susceptibility values for the granite and granodiorite were <100 x 10^{-5} SI units and the data showed a strong mode for values <10. Although, sporadic values up to 1600 were recorded, the data are consistent with the airborne magnetic response. The diorite and microdiorite enclaves have values erratically distributed from 300 to ~5000 x 10^{-5} SI units.

Relationships and age

The intrusive relationships of the Tally Ho Igneous Complex to surrounding units, such as the Mia Mia Igneous Complex to the east and Johnstone Creek Igneous Complex to the west, are not known, although the contact with the Mia Mia Igneous Complex is interpreted as partly faulted. The Tally Ho Igneous Complex is clearly intruded by the large elliptical pluton of the early Permian Whitehorse Granite. The complex is intruded by green, fine-grained, aphyric and porphyritic andesite and dolerite dykes. It has not been dated, but is tentatively assigned to the late Carboniferous or early Permian as for the rest of the Urannah Batholith in this area.

TEEMBURRA IGNEOUS COMPLEX

Introduction

This unit is mapped as three separate irregular bodies totalling ~75km^2 in central western MIRANI (Figure 118). The two largest bodies are between Pinnacle and Clark Ranges, mainly in the catchments of Endeavour and Rocky Creeks, but extending north to Teemburra Dam. The south-western body crops out in rugged, closely dissected and heavily forested topography. The central body is slightly less rugged and has more open forest, but is still closely dissected and characterised by a series of linear ridges that are probably dykes. Main access is along the Teemburra – Mia Mia State Forest track. A third smaller body included in the unit forms low hills along the Mackay–Eungella Road, west of Gargett. The name is derived from Teemburra Creek.

Type area

A type area is designated along the Mia Mia State Forest track, south-west of Teemburra Creek from MGA 673700 7650200 to Endeavour Creek at MGA 671200 7648160. As described below, the range of rocks includes equigranular to moderately porphyritic biotite granite and granodiorite and a net-veined complex of hornblende diorite and hornblende-biotite granodiorite.

Lithology

The unit incorporates a complex assemblage of rock types, but they show similar responses in both the magnetic and radiometric data so that they form a distinct mappable unit.

Along the Mia Mia State Forest track, south-west of Teemburra Creek, pale pink, equigranular to moderately porphyritic biotite syenogranite crops out (Figure 129a). This granite extends ~2km to the south-west along the track from MGA 673700 7650200. It comprises K-feldspar (~60%), quartz (~30%), plagioclase (~5%), biotite/chlorite (~4%) and opaques (~1%). Apatite and zircon were identified as accessory minerals.

Further along the track closer to Endeavour Creek, coarse-grained, pale grey, equigranular biotite-hornblende granodiorite was observed at MGA 672220 7647300 (Figure 129b). It comprises quartz (~30%), plagioclase (~40%), K-feldspar (~15%), hornblende (~5%), biotite (~10%), and opaques (~2%) and accessory apatite. Isotopic dating sample GA1138 was collected from this vicinity and may have been this rock type.

In Endeavour Creek at MGA 671200 7648160, a net-veined complex is exposed (Figure 129c–d). The darker component consists of dark grey, fine to medium-grained biotite-hornblende diorite cut by numerous veins of pale grey, fine to medium-grained, equigranular hornblende-biotite granodiorite. The granodiorite includes xenoliths of the diorite that have chilled and locally crenulate margins. The granodiorite ranges from leucocratic to melanocratic, suggesting that some hybridisation with the diorite has occurred. One melanocratic granodiorite examined in thin section is a tonalite comprising quartz (~20–25%), plagioclase (~20%), hornblende (~30%), biotite (~20%), and opaques (~5%). Dolerite or andesite dykes cut the outcrop.

Dark greenish grey equigranular hornblende quartz diorite or tonalite crops out along the track where it diverges from Endeavour Creek at MGA 669720 7647180 (Figure 129e). The quartz diorite is fresh and is fractured and jointed. It contains quartz (~15%), plagioclase (~25–30%), hornblende (~50%), opaques (~3%) and secondary alteration products including sericite, chlorite and epidote (around 5%).

The dominant rock type in the west near Plevna is pink, fine to coarse-grained, equigranular, hornblende-biotite granite (Figure 129f). Most exposures are strongly weathered except for moderately fresh kernels in the soil. The granite comprises quartz (~30%), K-feldspar (~40%), plagioclase (~20%), biotite (~5%), hornblende (~3%) and opaques (~2%) and accessory titanite and apatite. The granite contains some biotite-rich microdiorite xenoliths, 1–3cm across. The biotite in the xenoliths has been extensively altered to chlorite. Aplite and pegmatite dykes, as well as andesite and rhyolite dykes, intrude the granite.

Geophysical characteristics

Both parts of the complex are characterised by a relatively low radiometric response in all three channels producing purplish grey hues on composite images (Figure 119). These contrast with the pinkish hues of the more potassic Pisgah Igneous Complex.

The airborne magnetic response, particularly that of the north-eastern body is moderate and stronger than that of the Pisgah Igneous Complex (Figure 120). It also contrasts with the lower response of the Yarravale Creek Granite. Magnetic susceptibility values are in the range 0–2500 x 10^{-5} SI units, having a skewed distribution

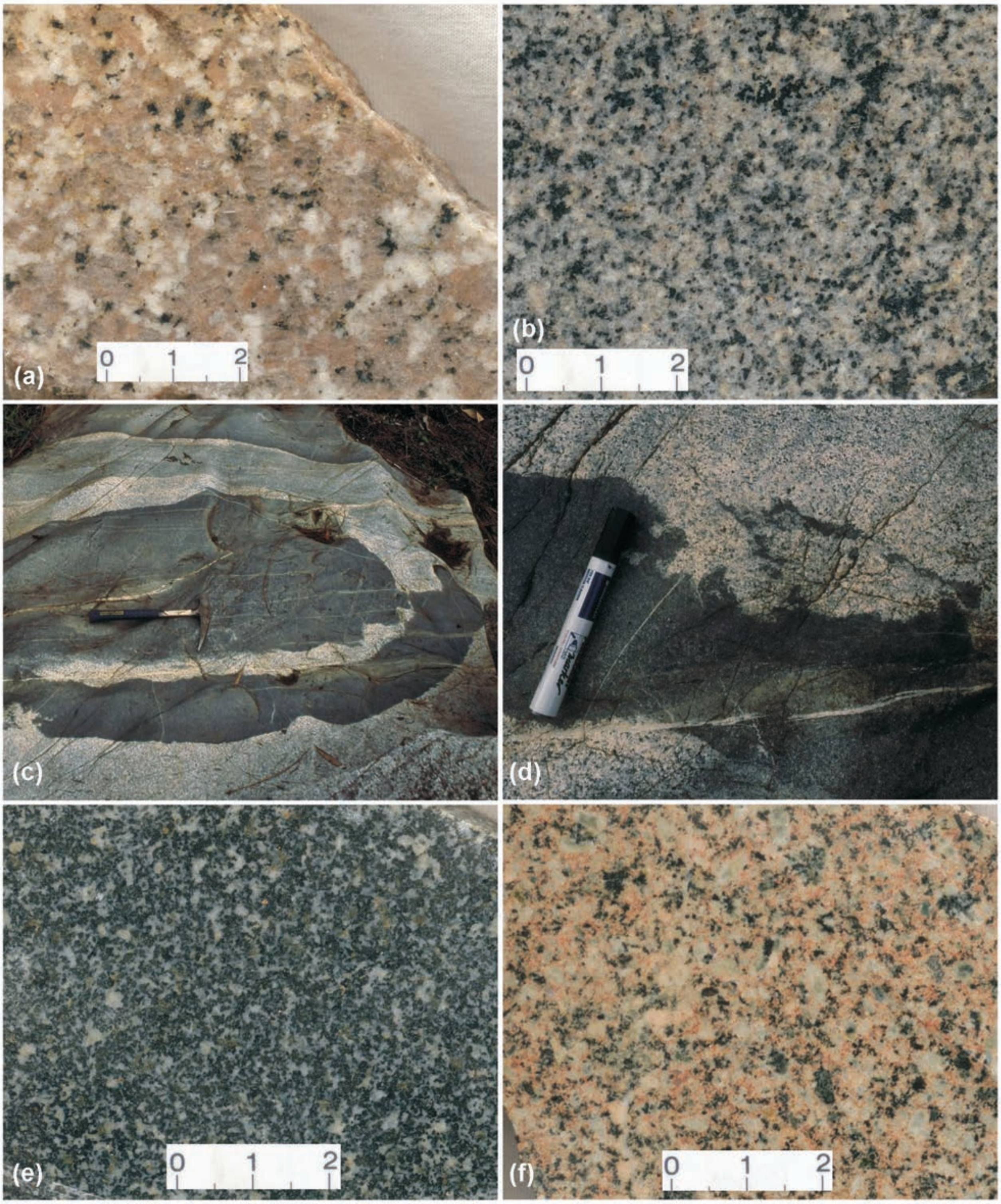

Figure 129. Teemburra Igneous Complex; scale is 2cm in (a), (b), (e) and (f)
(a) Scanned slab of equigranular biotite granite from the type area of the Teemburra Igneous Complex. Mia Mia State Forest Track 2km south-west of the crossing of Teemburra Creek at MGA 673701 7650215 (QFG3508)
(b) Scanned slab of equigranular hornblende-biotite granodiorite from the type area of the Teemburra Igneous Complex. Mia Mia State Forest Track 4km south-west of the crossing of Teemburra Creek at MGA 672859 7648368 (QFG3512)
(c) Enclaves of dolerite or microdiorite or dolerite in granodiorite from the type area of the Teemburra Igneous Complex. Note the complex contacts of the enclaves and streaky layering in the granodiorite, possibly due to magma mingling and hybridisation. Mia Mia State Forest Track crossing of Endeavour Creek 14km south-west of Pinnacle township at MGA 671200 7648160 (RSC022)
(d) Detail of crenulate (magma-mingling) contact between granodiorite and microdiorite. Same locality as (a)
(e) Scanned slab of equigranular hornblende quartz diorite. Mia Mia State Forest Track 1.5km west-south-west of the crossing of Endeavour Creek at MGA 669725 7647181 (QFG3518)
(f) Scanned slab of fine-grained hornblende-biotite granite. Crediton Forest Track 4.5km east of Plevna at MGA 663256 7643906 (RSC018)

about a mode at 300 and a mean of 750. Values from the less abundant dioritic rocks show a more irregular distribution up to ~5000 x 10^{-5} SI units with the main clusters of data around 100 and 1200.

Relationships and age

The two main areas of Teemburra Igneous Complex cut across the Pisgah Igneous Complex and may intrude it, and are separated by and probably intruded by the Yarravale Creek Granite. The Uruba Granite may also intrude the complex, because it separates the smaller body to the north from the central one. The complex is cut by two or more sets of dykes. One system appears to trend north-north-west, and consists mainly of moderately to highly porphyritic andesite. Due to their resistance to weathering some of the thicker dykes form prominent ridges. The other set trends north-west and consists mainly of rhyolite, which appear to be cut (and partly offset) by the andesite dykes. In the west, Tertiary basalt overlies the complex. Some associated basalt dykes were observed cutting the pink granite.

K–Ar dating of biotite and hornblende from sample GA1138, the location of which plots within the complex, yielded recalculated ages of 277Ma and 284Ma respectively (Webb & McDougall, 1968). Another sample (GA1137) that plots near the crossing of Teemburra Creek gave hornblende and biotite ages of 273Ma and 278Ma respectively. These may be minimum ages, but suggest that the unit is early Permian.

URUBA GRANITE

Introduction

The Uruba Granite mainly forms a roughly ovoid-shaped pluton of ~35km^2, south of Cattle Creek on the northern side of Teemburra Dam, in north-western MIRANI (Figure 118). The name is derived from a locality along the Mackay–Eungella road. The topography is relatively rugged and includes Mount Pinnacle and forms the divide between Cattle and Teemburra Creeks. In general the granite is poorly exposed and mostly decomposed with sporadic fresh kernels and boulders on hill slopes.

Another area of ~20km^2 assigned to the unit, mainly on the basis of geophysics, crops out on the northern side of Cattle Creek around Mount Castor and Mount Pollux.

Type area

The type area is designated on the ridges along the north-western side of Teemburra Dam between ~MGA 669900 7655300 and MGA 670700 7657100. Local groups of large boulders consist of pale pink, medium to coarse-grained, equigranular biotite granite (Figure 130a).

Lithology

The most common rock type is pale pink, medium to coarse-grained equigranular biotite granite as at the type locality. It comprises quartz (15–25%), K-feldspar (50–60%), plagioclase (15–10%), biotite (5%), chlorite (2%), opaques (2%) and muscovite (1%). In places the granite is sheared.

Commonly the Uruba Granite is intruded by fine to medium-grained equigranular and porphyritic microdiorite and microgranite dykes. At MGA 668735 7657280, white to cream, medium to coarse-grained muscovite pegmatite intrudes strongly decomposed equigranular granite.

The northern body was only examined around Mount Castor, for example at MGA 680310 7663180, where it is represented by fine to medium-grained equigranular (hornblende) biotite granodiorite that grades into porphyritic biotite-hornblende microdiorite containing hornblende and plagioclase phenocrysts. If this is typical, it should possibly be assigned to a separate unit or could possibly be a continuation of the Mia Mia Igneous Complex or Palms Lookout Granodiorite. Andesite, dacite and microdiorite dykes are common in this area.

Geophysical response

The Uruba Granite is characterised by moderate to high potassium and low to moderate thorium and uranium radiometric responses, resulting in bright pink hues on the composite images (Figure 119).

The granite shows a moderate to high response in airborne magnetic images (Figure 120), but magnetic susceptibility readings are lower than might be expected for this response. They show a normal distribution in the range 0–750 x 10^{-5} SI units with a mode at 360.

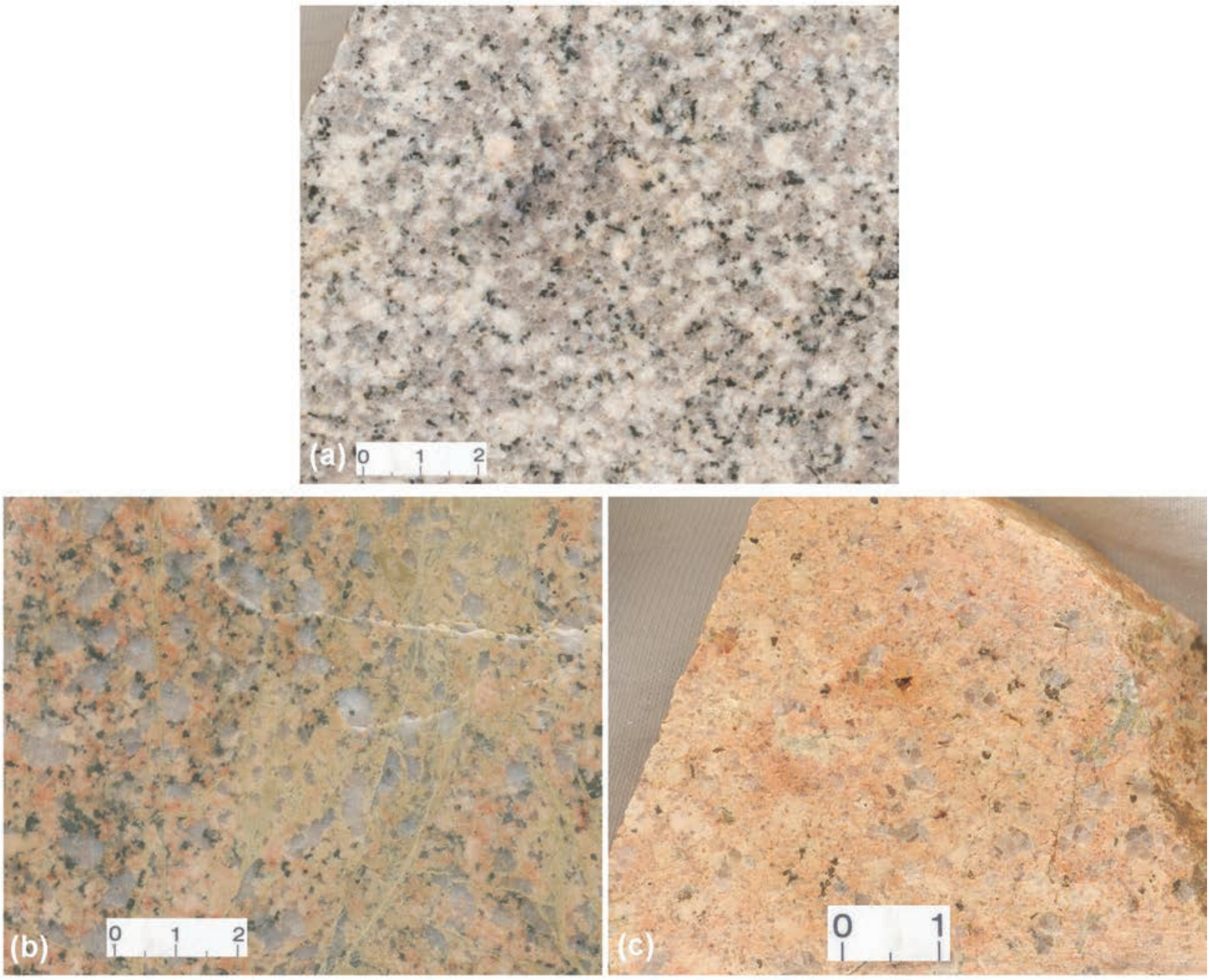

Figure 130. Uruba Granite and Yarravale Creek Granites; scale is in centimetres
(a) Scanned slab of medium-grained biotite granite from the type area of the Uruba Granite. Oaky Creek on the western side of Teemburra Dam at MGA 670476 7655789
(b) Scanned slab of biotite granite from the type locality of the Yarravale Granite; the sample is cut by zones of sericitic alteration. Quandong Creek at MGA 668406 7641936 (QFG4501)
(c) Scanned slab of biotite syenogranite from the northern pluton of Yarravale Granite; some of the K-feldspar is graphically intergrown with quartz. Credition State Forest Track at MGA 667420 7644950 (QFG3780)

Relationships and age

The relationships of the Uruba Granite to the adjacent Pisgah Igneous Complex, Teemburra Igneous Complex and the Gargett Granodiorite are unknown, but the ovoid outline of the pluton suggests that it may be younger. However, a late Carboniferous to early Permian age is postulated for it, and it is probably intruded by the Cretaceous Morugo Granite, which occupies the valley floor of Cattle Creek.

It is locally cut by felsic and mafic dykes as for the other Permo-Carboniferous rocks in the Urannah Batholith.

YARRAVALE CREEK GRANITE

Introduction

The Yarravale Creek Granite occurs in central western MIRANI (Figure 118), in the catchments of portions of Rocky Dam Creek, Quandong Creek and Yarravale Creek (from which the name is derived) in the southern part of the Crediton State Forest. It comprises two small plutons ~1km apart — a southern, roughly circular pluton ~5km across and an adjacent boomerang-shaped body to the north, with limbs ~4km long. The plutons were recognised by their magnetic response. The surrounding topography is very rugged and thickly forested, although the two plutons seem to be slightly recessive, occurring mainly in valleys. Vehicle access is limited to the State Forest track that crosses the northern pluton.

Type locality

The type locality is nominated in Quandong Creek in the middle of the southern pluton at MGA 668410 7641940. Pale to deep pink, medium-grained, porphyritic biotite granite crops out and consists of quartz (~35%), plagioclase (~30%), K-feldspar (~20%), biotite (~7%), hornblende (~3%). It is quartz-veined and fractured and partly altered to sericite and chlorite (Figure 130b).

Lithology

The northern body contains outcrops of pink, medium to coarse-grained, slightly porphyritic syenogranite (Figure 130c), but is very poorly exposed. A kernel from decomposed granite soil at MGA 667420 7644950 comprises K-feldspar (~55%), quartz (~25%), plagioclase (~15%), biotite/chlorite (~3%) and opaques (~1%). The K-feldspar, in places, shows graphic intergrowth textures with quartz (Figure 130c). Relatively large euhedral (up to 0.5mm) zircon crystals with apparent zoning were observed.

At the northern end of this body at MGA 668000 7646230, very dark grey, fine-grained, equigranular hornblende-pyroxene gabbro, together with microgranite and rhyolite dykes, was observed. The gabbro comprises plagioclase (~50%), clinopyroxene (~14%), hornblende (~12%), orthopyroxene (~10%), biotite (~8%), opaques (~5%) and accessory apatite. This gabbro is similar to others that crop out in parts of the adjacent Teemburra Igneous Complex.

At the eastern rim of the southern body along Quandong Creek at MGA 669880 7642330, dark green-speckled, light grey, medium to coarse-grained hornblende-phyric biotite hornblende granodiorite was observed in stream float. The granodiorite comprises plagioclase (~35%), K-feldspar (~25–30%), quartz (~20–25%), hornblende (~10%) and biotite (~10%) and accessory apatite.

Geophysical response

Because the plutons are small and mainly occur in deep valleys, the radiometric data is somewhat unreliable due to levelling difficulties. However, the main response seems to be moderate to high potassium and low to moderate thorium and uranium producing pinkish composite hues.

The airborne magnetic images show a low to moderate magnetic response that is significantly lower than that of the surrounding Teemburra and Pisgah Igneous Complexes (Figure 119). Magnetic susceptibility readings for the granites range from 0–110 x 10^{-5} SI units with a mode representing values <10. Values for the granodiorite and tonalite outcrops are much higher, in the range 700–2500 x 10^{-5} SI units with a mode at 1400. The overall relatively low response of the plutons suggests that granite is the dominant rock type. The granodiorite and tonalite may be minor components, the outcrops which mainly occur towards the margins as mapped, may in fact be part of the surrounding Pisgah Igneous Complex.

Relationships and age

The circular outline of the southern pluton suggests that it intruded the Teemburra and Pisgah Igneous Complexes, but it is probably still late Carboniferous or early Permian. It is intruded by aphyric rhyolitic dykes that may be Permian or possibly Tertiary.

EARLY PERMIAN PLUTONS

WAITARA GRANITE

Introduction

The Waitara Granite is a small, isolated intrusion in central NEBO (Figure 120). It crops out over ~1km^2, ~5km north-west of Waitara homestead (from which the name is derived). Although it forms a distinctive hill, there is little fresh outcrop.

Type locality

The type locality is at MGA 689600 7585900, where altered porphyritic granite comprises phenocrysts of euhedral plagioclase and a mafic mineral, replaced by aggregates of chlorite, calcite and epidote, in a groundmass of quartz, feldspar and minor chlorite.

Lithology and petrography

The Waitara Granite consists of pinkish-grey, fine to medium-grained, porphyritic biotite-hornblende monzonite to granite with plagioclase and hornblende phenocrysts. Outcrop throughout the unit is generally weathered and altered.

Some porphyry copper mineralisation has been intersected in drilling adjacent to the Waitara Granite. Advanced argillic alteration occurs both within the granite and in the Leura Volcanics around the southern margin of the pluton.

Geophysical response

The radiometric response is similar to that of the adjacent Leura Volcanics and has moderate potassium and relatively low thorium and uranium resulting in pink hues on composite images. It contrasts with the overall low response of the Mount Benmore Volcanics to the west.

The Waitara Granite as mapped has mainly a low magnetic response, but its southern margin lies on part of a semi-circular, ring-shaped, moderate to high magnetic feature ~7km in diameter that may be a ring dyke. It is not exposed, but lies under the alluvium just beyond the edge of the outcropping Mount Benmore Volcanics. The Waitara Granite outcrop could be part of this body, and its low magnetic response and topographic prominence could be due to the hydrothermal alteration. Magnetic susceptibility values measured at the type locality range from 158–766 x 10^{-5} SI units (average 473).

Relationships and age

The granite is mapped as intruding the early Permian Leura and Mount Benmore Volcanics, but no contact relationships were observed during the current survey. The age is uncertain, but is probably Permian.

WHITEHORSE GRANITE

Introduction

The Whitehorse Granite forms a large elliptical pluton within the eastern part of the Connors Range, 30km north-east of Nebo, in north-eastern NEBO and south-eastern MIRANI (Figure 118). It has an area of ~140km^2 It mainly forms undulating topography, but parts of it form more rugged topography, namely the Whitehorse Mountains (from which the name is derived), the Balaclava Mountains and the northern part of the Blue Mountains. In general the Whitehorse Granite is poorly exposed and is mostly decomposed.

Type locality

The type locality is designated at MGA 696680 7621680 on a ridge ~5km south-west of Mount Shields, where a group of large boulders consist of relatively fresh, pale pink, coarse-grained, seriate to porphyritic biotite granite (Figure 131a).

Lithology

The most common rock type is a pale pink, medium to coarse-grained, seriate biotite granite with very rare dark grey fine-grained, sub-rounded microdiorite xenoliths. A sample from MGA 696410 7621380 comprises quartz (10–15%), K-feldspar (50–60%), plagioclase (25–15%), biotite (7%), opaques (2%) and secondary muscovite (1%). In some areas the granite is strongly fractured with common (mesothermal) quartz veins, comb quartz and silicification of wall rocks. Some veins are up to several metres thick.

Commonly the Whitehorse Granite is intruded by fine to medium-grained equigranular diorite or gabbro dykes or small plugs and dykes of porphyritic hornblende andesite. At MGA 695590 7621675, dark grey equigranular pyroxene gabbro (Figure 131b) comprises clinopyroxene and orthopyroxene (together ~55%), plagioclase (~35%), hornblende (~5%), biotite/chlorite (~1%) and opaques (1–2%). Accessory titanite and apatite are present and alteration products include sericite, chlorite and calcite.

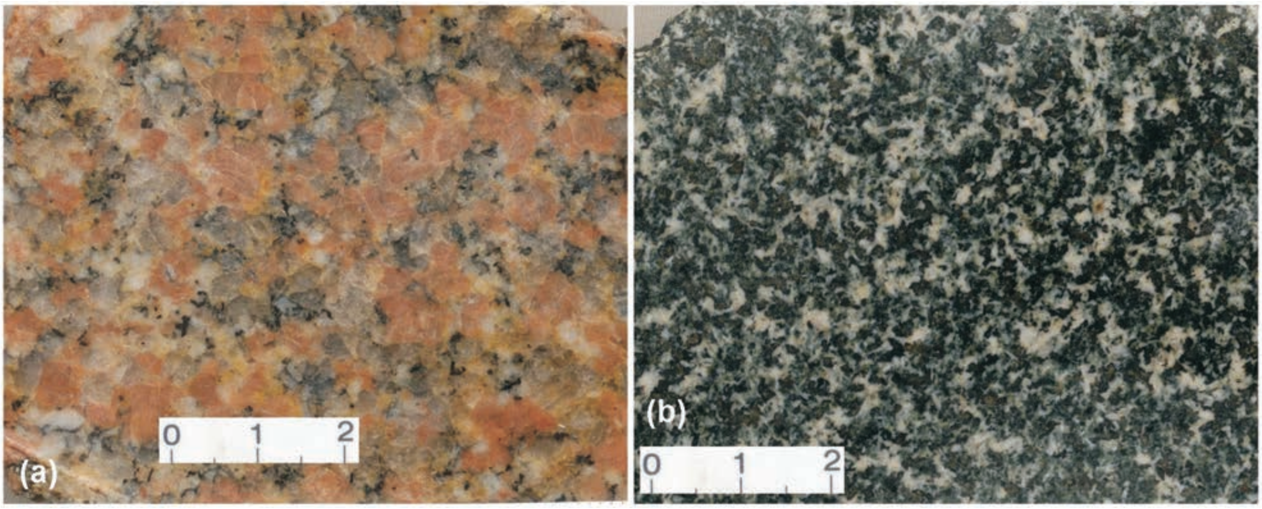

Figure 131. Whitehorse Granite; scale is 2cm
(a) Scanned slab of coarse-grained biotite granite from the type locality of the Whitehorse Granite. About 5km south-west of Mount Shields at MGA 696676 7621674 (QFG451)
(b) Scanned slab of pyroxene gabbro that intrudes the Whitehorse Granite at MGA 695590 7621691. About 1km west of the type locality (QFG4517)

Geophysical response

The Whitehorse Granite has a high potassium response throughout, and mostly high thorium and uranium resulting in white to pale yellowish hues that contrast strongly with the darker hues of all of the surrounding units (Figure 119). The main variation is a central core area ~5km in diameter that has moderate thorium and low to moderate uranium and an overall pinkish hue on composite images. No field observations were made in this core and its composition is not known. The data suggest that it is less fractionated.

The granite shows a relatively low to moderate response in airborne magnetic data that is slightly higher than the Tally Ho Igneous Complex to the north and similar to undivided granites of the Urannah Batholith to the south (Figure 120). However, undivided granites and the Mia Mia Igneous Complex to the east are much more strongly magnetic. Magnetic susceptibilities for the granite are mainly in the range 10–700 x 10^{-5} SI units with weak modes at 50 and 450 and minor sporadic values up to about 2000.

North-north-west to north-trending moderately magnetic linear features are evident and probably represent dykes. Magnetic susceptibilities for microdiorite and andesite dykes within the granite yielded readings from ~100–1700 x 10^{-5} SI units with a mode at 1000, so that they could well correspond with the linear features in the airborne magnetic images.

Relationships and age

The clearly crosscutting form of the Whitehorse Granite indicates that it intrudes all of the surrounding late Carboniferous plutonic units, namely the Mia Mia Igneous Complex, the Tally Ho Igneous Complex, the Mount Spencer Granodiorite and some undifferentiated Urannah Batholith units. However, various Tertiary and Quaternary sediments overlie the Whitehorse Granite, obscuring most contacts with the older units.

Granite from the type locality was dated by the SHRIMP method on zircons (see Appendix). The zircons yielded an early Permian age of ~285±2Ma (MSWD of 1.6, based on 15 of 19 analyses). The sample had no obviously inherited zircons.

UNNAMED CARBONIFEROUS TO PERMIAN PLUTONS

Numerous small intrusions, which were not considered significant enough to be named and which are of probable Carboniferous or early Permian age, crop out through the Connors Arch. On the maps they are designated by the symbols $\mathbf{Cg_g}$, $\mathbf{Cg_{mg}}$, **CPg**, $\mathbf{CPg_d}$ or where pervasively altered by $\mathbf{CPg_a}$.

Some of the plutons that were examined in more detail are described below.

(1) A small unnamed pluton of biotite-hornblende quartz monzodiorite to granodiorite assigned to unit **Cg** crops out ~3km north-west of Rosedale homestead in south-eastern CONNORS RANGE. It is ~3km long and up to 500m long, but because younger volcanic rocks (possibly Mount Buffalo Volcanics or felsic volcanic rocks basal to the Carmila beds) unconformably overlie it to the east, its original extent is uncertain. It forms a narrow topographic depression, between the younger volcanic rocks and older hornfelsed felsic volcanic rocks assigned to the Mountain View Volcanics. The basal conglomerate to the younger volcanics shows no evidence of contact metamorphism in thin section, whereas strong recrystallisation is evident in the rocks to the west.

The pluton is moderately magnetic (susceptibilities mostly 350–750 x 10^{-5} SI units, but locally 2000–3000) and is evident on the airborne geophysical data as a small magnetic high. The quartz monzodiorite is pink to grey, medium-grained and equigranular with aplite veins and has microdioritic xenoliths to 10cm. In thin section, the rocks consists of quartz (15–20%), K-feldspar (20–25%), mildly sericitised plagioclase (60% — andesine with oscillatory zoning), prismatic hornblende crystals to 1mm (up to 5%) and chloritised biotite (<2%). Titanite is an accessory mineral, and minor clinopyroxene is also present in one sample.

(2) A small body of greenish grey, medium-grained equigranular biotite granite assigned to unit **Cg** crops out in Magdalen Creek and can be traced for ~2km on the western edge of the Langdale Inlier in western MARLBOROUGH. It intrudes rhyolite assigned to the Broadsound Range Volcanics and is unconformably overlain by probable equivalents of the Leura Volcanics and Tartrus Rhyolite. To the west, it is faulted against the Carmila beds. The granite is partly altered, the plagioclase being strongly sericitised and the biotite chloritised. The alteration is more intense adjacent to a small knoll at MGA 757200 7478100, which has a cap of intensely argillised felsic volcanics (probably Tartrus Rhyolite). O'Brien (1994) also mapped a small body of medium-grained biotite granite ~500m across intruding the Broadsound Range Volcanics at MGA 758700 7472800 in the southern part of the Inlier.

(3) Along the western flank of the Connors Arch between Mount Mackenzie and Clive Creek in MOUNT BLUFFKIN, two unnamed bodies of leucocratic granite, microgranite and granophyre have been mapped. They are assigned to the unnamed unit $\mathbf{Cg_{mg}}$, and mainly intrude the Clive Creek Volcanics.

The largest is 6km long and 1.5km wide. It abuts the western margin of the Bora Creek Quartz Monzodiorite, but its relationship to that unit is not known. It crops out strongly as a ridge that contrasts with the more subdued topography of the Bora Creek Monzodiorite. In spite of the rather fractionated appearance of the rocks, the radiometric expression is a pinkish hue on the composite images rather than white, indicating that only K is enriched. The rocks are generally pink to pale orange and leucocratic, but show a range of textural types. At the southern end of the pluton, the rocks are porphyritic, containing up to 60% phenocrysts of plagioclase and subordinate rounded quartz, both up to 7mm across in a groundmass of fine-grained (0.1–0.5mm) quartz, K-feldspar, plagioclase and minor chloritised biotite. In the north the rocks include fine-grained equigranular to porphyritic granite to microgranite and medium-grained biotite leucogranite containing miarolitic cavities up to 3cm across, lined with quartz and feldspar crystals. Classic granophyre, consisting of finely intergrown K-feldspar and quartz up to 2mm across, also crops out.

Dykes of microgranite that intrude the northern part of the Bora Creek Quartz Monzodiorite may be related.

The smaller body to the south is 3km long and 1km wide and also consists of granophyre and fine-grained porphyritic leucogranite, containing phenocrysts of plagioclase to 5mm and subordinate quartz and biotite to 2mm. It is probably overlain unconformably by the Leura Volcanics.

(4) The Bora Creek Quartz Monzodiorite in eastern MOUNT BLUFFKIN is flanked on its northern side by another unnamed, probably composite granitoid body mapped as unit $\mathbf{Cg_{g}}$. It forms hilly topography and is difficult to distinguish from the Broadsound Range Volcanics on aerial photographs. It was observed in the hills and gullies to the south of Sarsfield Creek and on the western slope of Mount Larry, but its full extent is based on unpublished notes by J.F. Dear and radiometric interpretation. It has a whitish response on composite images, contrasting with the pinkish hues of the Broadsound Range Volcanics. The rocks are overlain unconformably by the Leura Volcanics at Mount Larry and along Sarsfield Creek. They are mainly of pink, fine to medium-grained, equigranular to seriate, locally partly granophyric biotite leucogranite, but locally it includes pinkish grey biotite-hornblende quartz monzodiorite or quartz monzonite, similar to rocks in the Bora Creek Quartz Monzodiorite and Burwood Complex. The leucogranite possibly post-dates the Bora Creek Quartz Monzodiorite, because a sample collected from close to the contact between the two units on the western slope of Mount Larry shows no evidence of recrystallisation in thin section.

(5) Numerous smaller bodies mapped as **CPg**, each with a complex distribution of different rock types, crop out along Kangaroo Creek north-east of Mountain View homestead, along Whelan Creek east of Marylands homestead and in the eastern part of Collaroy Station in north-eastern CONNORS RANGE. The size of these bodies is variable, but their relationship to each other and to the enclosing rocks is masked by poor outcrop. The bodies are best exposed along Kangaroo Creek north-east of Mountain View homestead. They intrude conglomerate, basalt/andesite, sandstone and siltstone mapped as the Mountain View Volcanics. The granites are overlain by coarse conglomerate that contain granite clasts and are probably part of the Leura Volcanics.

Most bodies comprise more than one rock type, and range from monzodiorite to syenogranite. Most rocks have low modal quartz contents, being typically quartz monzonite and quartz monzodiorite. The more felsic varieties contain higher modal quartz and are typically granophyric. The dominant mafic minerals are pyroxene and biotite; amphibole is only present as a pale green variety, commonly cored by pyroxene, and interpreted as being formed by alteration of pyroxene.

The diversity in the area is reflected by outcrops ~5km north-east of Marylands homestead. At MGA 731500 7554000, grey, fine to medium-grained quartz monzodiorite comprises quartz (7–10%, some in granophyric intergrowth with K-feldspar), K-feldspar (8–10%), andesine (~60%), augite (~10%), pale green amphibole (~5%), chlorite (~5%) and opaques. On a hill immediately north, fine to medium-grained porphyritic biotite monzogranite to syenogranite comprises quartz (~25%, commonly in granophyric intergrowth with K-feldspar), K-feldspar (~30%, associated with quartz), altered plagioclase (~15%), augite (~3%), pale green amphibole, chlorite, opaques and a trace of epidote.

Quartz monzodiorite from Kangaroo Creek comprises quartz (~15%), K-feldspar (~10%), plagioclase (~55%), augite (~10%), biotite (~3%), chlorite and opaques. A nearby sample has similar proportions but all the mafic phases are altered to chlorite and epidote. Granophyric granite in the headwaters of Palm Creek on eastern Collaroy comprises quartz (~30%), K-feldspar (~45%, in granophyric intergrowth with quartz), plagioclase (~15%), chlorite/epidote (~5%) and opaques (~5%).

Pale pink, medium-grained, hornblende biotite granite crops out beside Fuljames Creek west of Mountain View homestead. This rock comprises quartz (~25%), K-feldspar (~35%), plagioclase (~40%), chlorite (5–10%) and opaques. The extent of the pluton has not been determined. The granite appears to intrude the Mountain View Volcanics, but is overlain by conglomerate assigned to the Leura Volcanics.

Petrographically similar granitoids occur elsewhere in the northern CONNORS RANGE. The Mount Toobier Quartz Monzonite, Spring Valley Quartz Monzonite and Olympus Quartz Monzonite are similar. The Hazlewood Granite, one of a series of small granite bodies that intrude the Mountain View Volcanics near Clairview, is petrographically similar to the more felsic granophyric rocks described above.

A late Carboniferous age is most likely for these plutons based on their stratigraphic relationships.

(6) Diorite assigned to unit **CPg$_\mathbf{d}$** crops out over ~1km^2 in the headwaters of Tin Hut Creek near the boundary between Dacey and Killarney stations in central CONNORS RANGE. A sample comprises altered plagioclase, mostly enclosed in augite crystals (~55%), augite (~25%), chlorite (~20%, similar habit to augite) and opaques (~5%). The age is unknown. The diorite intrudes sandstone and siltstone of the Mountain View Volcanics.

(7) Deeply weathered, poorly outcropping granitoid also assigned to unit **CPg$_\mathbf{d}$** occurs on eastern Markwell and south-west Marylands stations in central CONNORS RANGE. The pluton is defined by its radiometric signature, being characterised by dark red tones on the composite images. The dark red radiometrics correspond to an area of recessive topography, consistent with the area corresponding to a granitoid pluton. The only solid outcrop found is in the headwaters of Hut Creek at MGA 726600 7541300, where diorite comprises altered plagioclase (~70%), augite (~10%) and various alteration products (including calcite, chlorite and epidote).

(8) Fine to medium-grained, pink to orange, biotite granite(?) forms a sheet-like pluton apparently overlying the Dacey Granite on its eastern margin. The relationship of the two plutons is unclear. Weathered and altered granite also occurs along the eastern margin of the Dacey Granite, and is interpreted as being similar to the granite in the sheet-like body. These granites are labelled **CPg** on CONNORS RANGE.

(9) A small quartz diorite intrusion ~1.5km long crops out near Clive Creek in MOUNT BLUFFKIN, and is assigned to unnamed unit **Pg$_\mathbf{d}$**, although it is similar to the South Creek Quartz Diorite and should probably be labelled **CPg$_\mathbf{d}$**. Another small pluton, similarly labelled, hosts the gold-bearing reefs in the Yatton goldfield ~7km east-south-east of Wahroonga homestead. It consists mainly of plagioclase (60%) as laths to 1.5mm with oscillatory zoning (calcic andesine to oligoclase) and hornblende (25%) as pale

green subhedral prismatic grains to 1mm containing sporadic clinopyroxene cores. Quartz (5%) is interstitial to the plagioclase, but K-feldspar appears to be lacking. Both plutons intrude Mountain View Volcanics.

(10) An elongate body of dolerite or gabbro intrudes the Carmila beds on the eastern flank of the Connors Arch, just north of the old Bruce Highway in eastern MOUNT BLUFFKIN. The dolerite body is ~4km long and up to 500m wide. It is parallel to strike and may be a sill. It is assigned to unit $\mathbf{Pg_d}$, and could be related genetically to the basalt flows in the Carmila beds.

The dolerite is partly altered, and consists of turbid to saussuritised, randomly orientated laths of plagioclase (60–70%) up to 2mm and interstitial clinopyroxene (10–20%) to 1mm, partly replaced by aggregates of chlorite (10–20%). Other alteration minerals include carbonate replacing both plagioclase and clinopyroxene, turbid masses of zeolite rosettes replacing plagioclase, and titanite or leucoxene partly replacing the opaque oxides leaving skeletal networks of magnetite lamellae.

(11) Several small gabbro bodies assigned to unit $\mathbf{Pg_d}$ intrude the Rookwood Volcanics along the eastern margin of the Marlborough Block in central MARLBOROUGH. Their age is uncertain, although they appear to post-date the emplacement of the Marlborough Block, and have hornfelsed mylonitised lithic sandstone and cleaved mudstone in the Rookwood Volcanics. They are only weakly magnetic, with susceptibilities in the range 60–275 x 10^{-5} SI units. One sample from Rock Wallaby Station, just south of the Bruce Highway at MGA 790650 7474350 consists of random laths of plagioclase (50%), ophitically enclosed by clinopyroxene crystals (30%). The pyroxene is partly replaced by pale green hornblende (20%) and minor acicular amphibole aggregates. Similar rocks were observed in the Rookwood Volcanics farther north adjacent to the Glenprairie road.

UNNAMED CARBONIFEROUS TO CRETACEOUS PLUTONS OF THE SOUTHERN URANNAH BATHOLITH

Although most of the larger areas of plutonic rocks in the Urannah Batholith have been assigned to named units, some smaller units or larger areas that have not been investigated fully, mainly due to difficult access have been left unnamed. Most are probably late Carboniferous to early Permian, but some in the east are suspected to include at least some Cretaceous plutons. Details of the unnamed units are given in Table 2.

DYKE SWARMS IN THE URANNAH BATHOLITH

A conspicuous feature of the Urannah Batholith is the abundance of felsic and mafic dyke swarms. They were not studied in detail, but their presence was observed in all Carboniferous to Permian units within the batholith, and similar dykes are documented from areas to the north of the project area (Paine & others, 1974; Levingston, 1981). This relationship can be observed from studying the airborne magnetic data, in which many of the dykes are characterised by a moderate to strong magnetic response and are represented by northerly trending linear features. Cretaceous plutons within the batholith such as the Morugo Granite appear to lack conspicuous linear features, although mafic dykes of inferred Cretaceous or Tertiary age intrude some of the plutons to the east of the main batholith.

Dykes were studied in detail by Allen (2000) in the Urannah Batholith near Urannah homestead, and many of her observations are valid in our project area. She estimated that mafic dykes comprise ~80% of the swarm and that altogether dykes make up 5–8% of the total area. Along with other workers (Paine & others, 1974; Hutton & others, 1998), she observed that the felsic dykes are the oldest discernible post-batholithic dykes, because they are typically cut by the mafic dykes but never intrude them. In our project area, the limited amount of orientation data suggests that they have different trends — felsic dykes have a north-westerly trend and the mafic dykes are distinctly northerly (Figure 154f,g). However, Allen (2000) noted that mafic dykes also had a prominent east–west subset, which is only slightly evident in our data.

The felsic dykes are dacitic to rhyolitic in composition. The dacite dykes are grey to greenish grey and up to 20m wide. They contain common mafic xenoliths ranging from ovoid with crenulated margins to angular and up to 50cm across. The dacite contains 20–50% phenocrysts and they comprise quartz, plagioclase and hornblende and locally biotite and/or clinopyroxene. Many of the dykes are moderately altered and secondary minerals include chlorite, epidote and calcite. Rhyolitic dykes are less common and are pink or grey and up to 10m wide. They are aphyric to porphyritic with small quartz and/or feldspar phenocrysts in a felsic groundmass that may also include microphenocrysts of biotite, hornblende and clinopyroxene. The rocks are commonly altered with feldspar replaced by sericite.

Table 2. Summary descriptions of unnamed late Carboniferous–Early Cretaceous Units in the Urannah Batholith

Unit	Extent	Lithology	Geophysical response (air-borne geophysical images)	Relationships	Age	Comments
CPgu	Extends over a large area (~325km^2) in the western part of CARMILA and adjoining eastern NEBO where it extends west as far as the Marlborough–Sarina road. Unit forms low, undulating to rough, mountainous country	Grey to brown, medium to fine-grained, uneven-grained to porphyritic (clinopyroxene-) biotite-hornblende granodiorite and hornblende-biotite granodiorite; pink or pale grey (locally), medium to fine-grained, uneven-grained to porphyritic biotite monzogranite (locally granophyric and generally leucocratic)	Predominantly pale pink to pale blue or white hues on a composite radiometric image (high potassium, low to moderate thorium and uranium); Low to moderately high magnetic intensities	Intrudes volcanic rocks tentatively assigned to the Mountain View Volcanics. Contacts with other units not observed. Cut by numerous felsic to mafic dykes.	Late Carboniferous–early Permian; some Early Cretaceous plutons may also be present.	Generally deeply weathered and poorly exposed. The unit was not examined in detail, due to difficulties in access.
$CPgu_1$	Several small, irregular pods, east and west of Denison Creek, NE NEBO (~13.5km^2). Forms undulating to hilly country with numerous boulders and scattered pavements	Pale pink to pale brown, medium-fine grained, even-grained (muscovite-) biotite monzogranite; K-feldspar > plagioclase; leucocratic (~3% biotite); traces of muscovite, opaques, chlorite, zircon; quartz and biotite grains commonly extensively recrystallised	Mainly pale pink to white hues on composite radiometric image (high potassium, moderate to high thorium and uranium; Low to moderate (locally) magnetic intensities	Cut by dykes of diorite, porphyritic rhyodacite?, highly porphyritic biotite microgranite; intruded by the Strathdee Granodiorite and Whitehorse Granite	Late Carboniferous–early Permian.	Relatively resistant to erosion; generally partly recrystallised
$CPgu_9$	Small pluton (~1km^2), 8km E of Nebo. Forms recessive topography against hills formed by $CPgu_{11}$	Pink to pinkish grey or red, medium to fine-grained, uneven grained to porphyritic biotite granite; commonly extensively altered; some altered diorite in the east	Pale pink to white hues on composite radiometric image (moderate to high potassium, thorium and uranium; Low to moderate magnetic intensity	Intrudes Leura Volcanics Relationship to $CPgu_{11}$ not known	Late Carboniferous–early Permian.	
$CPgu_{10}$	Small pluton (~1km^2), 8km NNE of Nebo. Forms low country at foot of hills formed by $CPgu_{11}$	Grey, medium to fine-grained, biotite-hornblende granodiorite; subordinate fine-grained diorite (commonly forms net-veined complexes with $CPgu_{11}$)	Pale pink to white hues on composite radiometric image (moderate to high potassium, thorium and uranium); Low magnetic intensity	May intrude Featherstone Granite	Late Carboniferous–early Permian.	
$CPgu_{11}$	Irregular pluton (~15km^2), 8km NE of Nebo. Forms hilly country.	Pink to cream or buff, fine to medium-grained biotite granite; commonly extensively altered	Pale pink to white hues on composite radiometric image (moderate to high potassium, thorium and uranium); Low magnetic intensity	Intrudes Leura Volcanics Cut by felsic and mafic dykes.	Late Carboniferous–early Permian.	

Table 2 (continued)

Unit	Extent	Lithology	Geophysical response (airborne geophysical images)	Relationships	Age	Comments
$CPgu_{ga}$	Forms scattered pods (~10km²) associated with granitic rocks, NE NEBO and western CARMILA; largest intrusion delineated is east of Mount Scott (SW CARMILA).	Dark grey, medium to fine-grained, uneven-grained to highly porphyritic clinopyroxene-hornblende gabbro, hornblende gabbro, biotite-hornblende quartz gabbro Coarse grains of brown or greenish brown hornblende locally abundant, with well-defined preferred orientations in places. Opaques common. Traces of titanite in places. Late-stage, interstitial quartz also relatively common in some rocks Commonly slightly to moderately altered; chlorite, sericite, epidote, calcite, and prehnite are the main secondary minerals.	Dark hues on composite radiometric image (low in all three channels); Mainly low magnetic intensities — southern part east of Mount Scott shows relatively high magnetic intensities.	Associated biotite monzogranite (Stony Creek Granite) in bed of Stony Creek at MGA 705014 7607680 is partly recrystallised, implying the gabbro post-dates the monzogranite Elsewhere, associated with Mount Scott Granite and is cut by thin dykes of pink leucogranite (up to ~15cm thick) presumably related to the Mount Scott Granite, and by scarce dacite (?) dykes.	Late Carboniferous-early Permian. Intrusion is associated with Mount Scott Granite and may be of similar age (Early Cretaceous?)	Generally deeply weathered and poorly exposed. Consequently, relationships with adjoining units are generally uncertain Texturally and to lesser extent, compositionally heterogeneous, in particular the pod exposed along Stony Creek (NE NEBO).
$CKgu_d$	Forms several small pods (total area ~4km²) in northern and central CARMILA. Unit forms low rises and ridges covered with boulders, as well as scattered pavements in bed of Carmila Creek.	Grey, medium to fine-grained, even-grained to slightly porphyritic gabbro, quartz gabbro, diorite, quartz diorite, quartz monzodiorite Clinopyroxene is the main mafic mineral in most mafic samples examined — generally accompanied by hornblende + opaque oxide ± orthopyroxene ± quartz (primary) ± K-feldspar ± pyrite Hornblende is generally the dominant mafic mineral in the more felsic rocks; K-feldspar and quartz (commonly intergrown) are also relatively common — + minor clinopyroxene ± biotite ± magnetite Ranges from relatively fresh, to moderately altered; chlorite, actinolite, epidote, sericite, calcite are the main secondary minerals Locally contains sparse mafic inclusions, up to ~10cm across	Generally too small to be distinguishable from adjacent units on airborne radiometric and magnetic images.	Relationships with adjacent units uncertain; no contacts were found.	Uncertain. Either late Carboniferous–early Permian or Early Cretaceous.	Augite-hypersthene gabbro with a well-developed intergranular texture forms a small pavement in the bed of Carmila Creek at MGA 736992 7578395; Augite, rather than hornblende, is the main mafic mineral in nearby outcrops of quartz monzodiorite; subordinate biotite, hornblende, and actinolite are also present

Table 2 (continued)

Unit	Extent	Lithology	Geophysical response (air-borne geophysical images)	Relationships	Age	Comments
$CKgu_g$	Forms a discontinuous north-westerly to northerly trending belt (~127km^2) in central CARMILA, where it forms part of the Connors and Mount Funnel Ranges. Also forms low undulating country south of the Three Sisters.	Pale pink, brown or grey, medium to fine-grained, uneven-grained to moderately porphyritic biotite granite, biotite granodiorite, hornblende-biotite granodiorite, biotite-hornblende granodiorite, biotite-hypersthene-hornblende granodiorite or tonalite; Granophyric intergrowths between quartz and K-feldspar common; Main accessory and secondary minerals are opaque oxide, titanite, allanite, chlorite, sericite, epidote, pyrite	Paler hues (mottled pink and blue) due to moderate potassium and low to moderate thorium and uranium) than the adjacent Mountain View Volcanics; Moderate magnetic intensities	Intrudes Mountain View Volcanics; contacts with adjacent Carmila beds not observed	Uncertain — either late Carboniferous-early Permian or Early Cretaceous	Not examined in detail; granodiorite is the dominant rock type in the areas examined; extensively weathered (decomposed) in places; Walker (1985) also reported monzodiorite, monzonite, microdiorite, syenite, diorite, trondhjemite, and aplite in the Prendergast Creek area, W of Carmila, and interpreted them to be Mesozoic
CKg_{bx}	Several small pods (<1km^2) delineated in the headwaters of southern tributaries of Prendergast Creek (west of Carmila)	Grey to pink, medium to fine-grained, extensively fractured and brecciated granitic rocks, with alteration assemblages dominated by quartz + tourmaline ± pyrite (now limonite) ± epidote ± carbonate (Walker, 1985)	Too small to be distinguishable from enclosing granite of unit $CKgu_g$ on radiometric and magnetic images	Enclosed by unit $CKgu_g$, which is interpreted to pre-date the breccia and to have contributed most of the fragments	Uncertain — either late Carboniferous–early Permian or Early Cretaceous	Descriptions summarised from exploration company report (Walker, 1985); Interpreted to form pipe-like structures, which cut the enclosing granite; Characterised by pervasive tourmaline-quartz alteration

Mafic dykes are generally much narrower than the felsic dykes and are mostly <2m wide although some up to 10m have been observed. Analyses presented by Allen (2000) show that they range from basalt to andesite. Allen noted that the youngest dykes are fine-grained and relatively narrow (<1m) and of basaltic composition. They consist of plagioclase laths, brown hornblende containing clinopyroxene cores and opaque minerals, with interstitial chlorite, epidote and carbonate. Some dolerite dykes are up to 12m wide and consist of plagioclase, clinopyroxene and opaque minerals. Brownish hornblende commonly mantles the clinopyroxene. Andesite dykes are greenish and variably altered consisting of sericitised plagioclase and epidote and chlorite after amphibole.

Magnetic susceptibility values measured on mafic dykes show a strong mode for values <100 x 10^{-5} SI units, but the data show a subsidiary mode at ~750 and a ‘tail’ of values extending to about 6000. Dacite dykes have a similar response but the tail of values extends only to about 2000. Rhyolite dykes are generally weakly-magnetic with most values <50 x 10^{-5} SI units. This suggests that most of the linear magnetic features are probably large mafic dykes or dacite dykes.

Allen & others (1998) dated a felsic dyke by SHRIMP and obtained an age of 283.9±5.2Ma. This is similar in age to the Whitehorse Granite. Its ovoid shape suggests that it is one of the youngest Permian components of the batholith, and the felsic dykes could be related to it. It is also similar to the age obtained on a felsic ignimbrite in the Mount Benmore Volcanics during our project (see above). Attempts to date the mafic dykes by K–Ar, Rb–Sr and Ar–Ar have produced ages ranging from 273–244Ma on hornblende, 265–229Ma on pyroxene and 247–203Ma on plagioclase (Webb & McDougall, 1968; Allen, 2000). Allen (2000) concluded that the K–Ar system was probably disturbed and therefore these are all minimum crystallisation ages.

GEOCHEMISTRY OF CARBONIFEROUS TO PERMIAN GRANITOIDS OF THE CONNORS ARCH AND SOUTHERN URANNAH BATHOLITH

Based on SHRIMP dating (see Appendix), the granitoids of the Connors Arch can be divided into an early Carboniferous group (the Burwood Complex) and a late Carboniferous group. For the latter, analyses are available for the Bora Creek Quartz Monzodiorite, Camp Creek Granite, Dacey Granite, Olympus Granite, Sambo Quartz Monzonite and South Creek Quartz Diorite. They are plotted with the late Carboniferous to early Permian granitoids of the Urannah Batholith in Figures 132 and 133.

The early Carboniferous rocks have higher FeO_{total}, TiO_2 and P_2O_5 than the late Carboniferous rocks indicating that they may be a separate suite, although they are similar on other plots. They also show mild Sr depletion and Y enrichment in the multi-element plot in Figure 134, whereas the opposite is shown by the late Carboniferous rocks. The plot of Ba vs Sr suggests that plagioclase fractionation was the main process in both groups.

The late Carboniferous rocks of the Connors Arch are similar to the late Carboniferous to Permian rocks of the Urannah Batholith, but along with the early Carboniferous rocks show generally higher K_2O, Rb and Th. They fall in the high K_2O field of Peccerillo & Taylor (1976), whereas the Urannah Batholith rocks are mostly intermediate in K_2O except at the high SiO_2 end of their range.

Analyses of the granitoids of similar age in the Auburn Arch and the Urannah Batholith overlap in most plots, but the latter are generally higher in CaO and the less silica-rich granitoids are generally lower in Ba and P_2O_5. Many of the more silica-rich Urannah Batholith samples are lower in Th.

The Urannah rocks mostly range from metaluminous to mildly peraluminous. However, a cluster of samples show ASI values >1.1 and high P_2O_5. These are from the Mount Shields Granodiorite and an area of Tally Ho Igneous Complex. Much of the Tally Ho Complex is hornblende-bearing and clearly I-type, but these anomalous samples all contain at least minor muscovite, and contain biotite but no hornblende. The presence of muscovite and the high ASI values suggest that these are S-type granites, although the significance of this is not known. Both the Mount Shields Granodiorite and the part of the Tally Ho Complex where these samples were collected are anomalously high in the K channel in the airborne radiometric data and are clearly related.

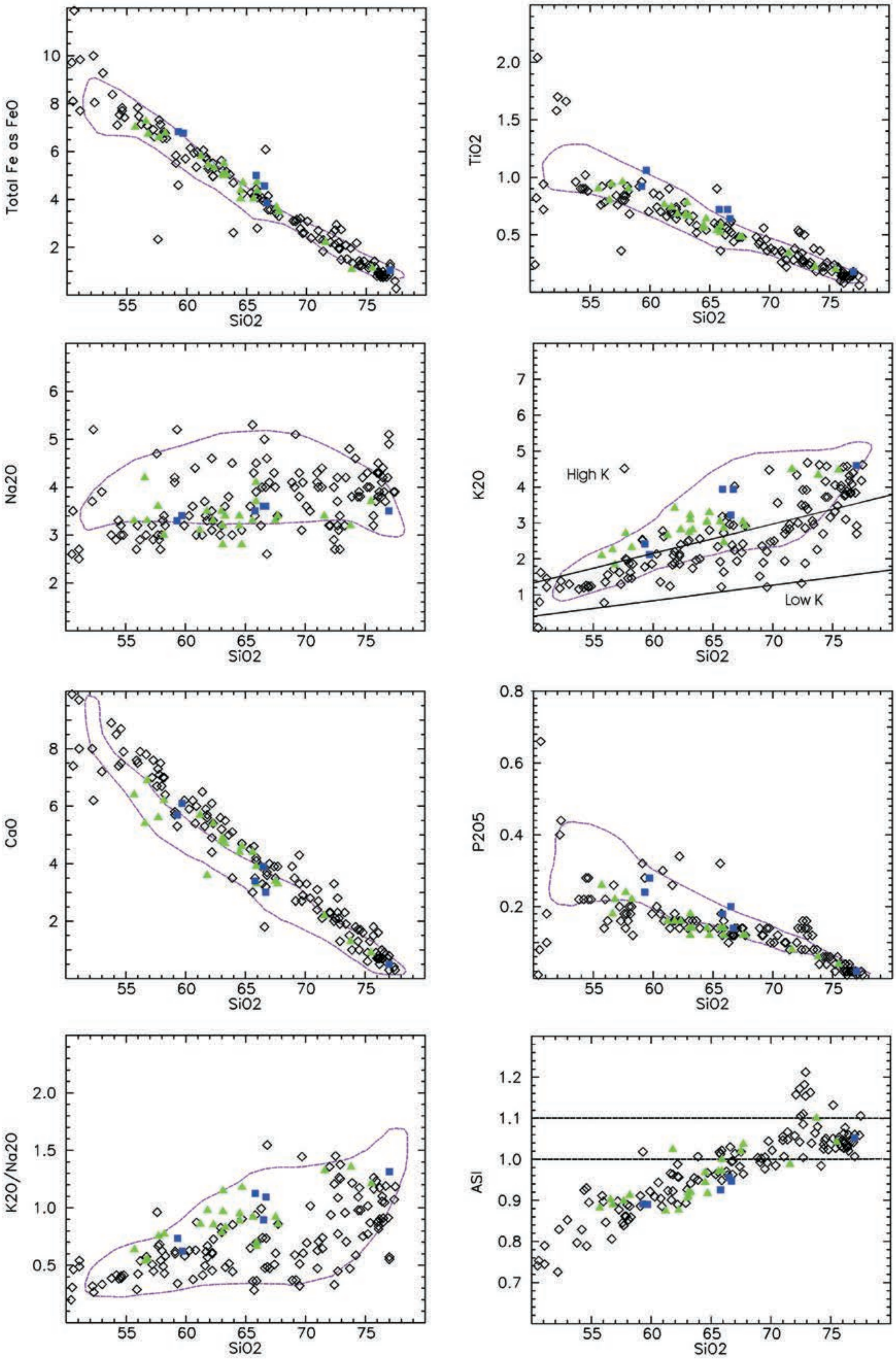

Figure 132. Variation diagrams for Carboniferous to Permian plutonic rocks from the Connors–Urannah area showing selected major elements in weight percent and the Alumina Saturation Index (ASI) vs SiO_2 in weight percent. Symbols are Early Carboniferous plutons (blue squares), Late Carboniferous plutons (green triangles), Late Carboniferous to Permian Urannah Batholith (black diamonds). The fields are for the Late Carboniferous to Early Permian plutonic rocks of the Auburn Arch.

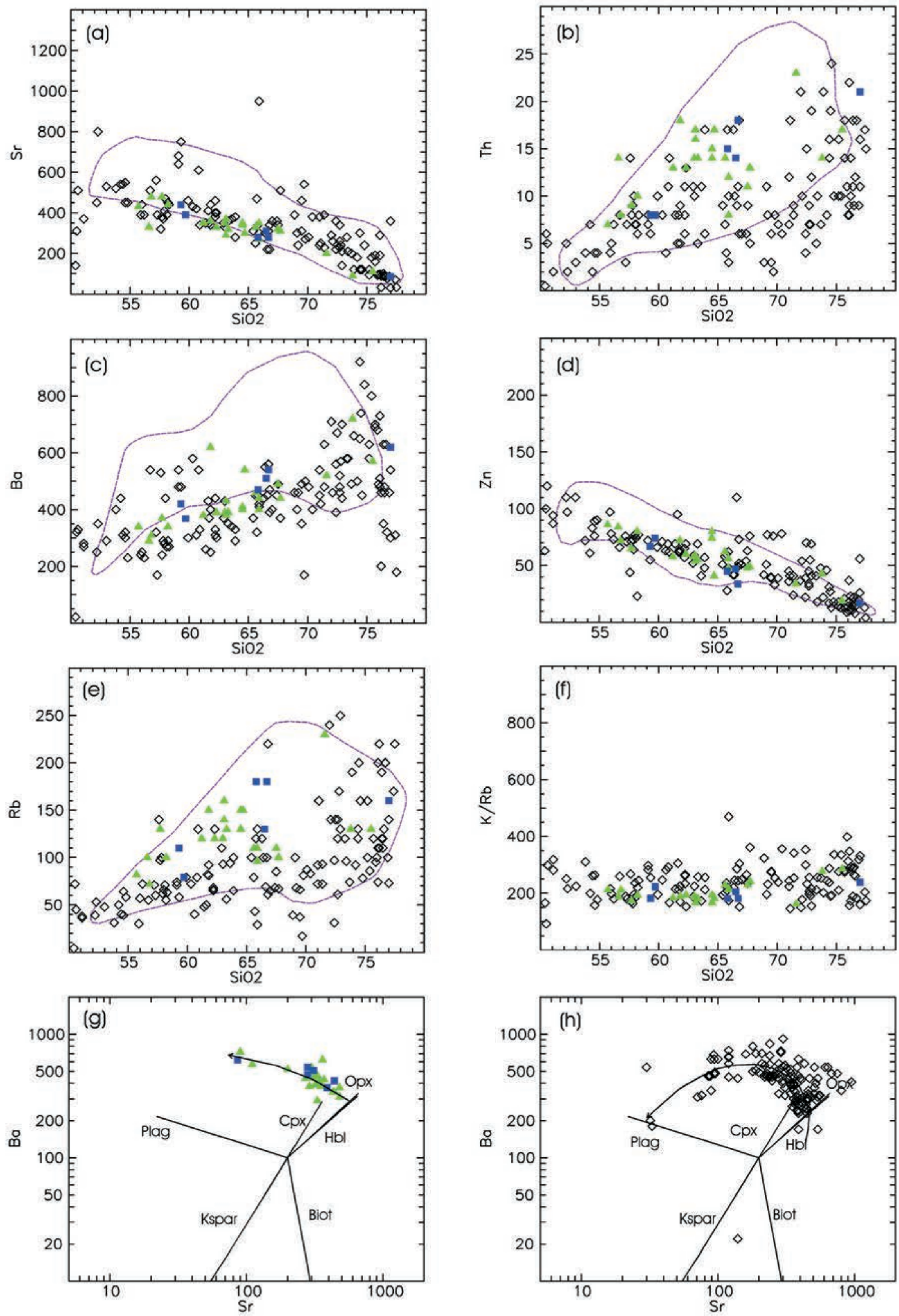

Figure 133. Variation diagrams for Carboniferous to Permian plutonic rocks from the Connors–Urannah area showing selected trace elements in parts per million and K/Rb vs SiO_2 in weight percent. The fields are for the Late Carboniferous to Early Permian plutonic rocks of the Auburn Arch. Mineral vectors in (g) and (h) are from Rollinson (1993, page 161) and show fractional crystallisation trends for Ba and Sr for the various minerals shown. The arrowed lines show approximate overall fractionation trends for the samples plotted. Symbols are Early Carboniferous plutons (blue squares), Late Carboniferous plutons (green triangles), Late Carboniferous to Permian Urannah Batholith (black diamonds).

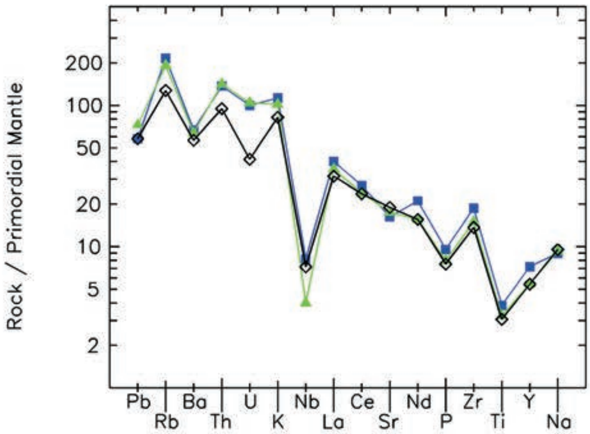

Figure 134. Spider diagrams normalised against the primordial mantle values of McDonough (1987) for average analyses of samples in the range 55–70% SiO_2 for granitoid groups from the Connors–Urannah area: Early Carboniferous (blue), Late Carboniferous (green) and Late Carboniferous to Early Permian Urannah Batholith(magenta)

CRETACEOUS PLUTONS

BEN MOHR IGNEOUS COMPLEX

Introduction

The Ben Mohr Igneous Complex is a wedge-shaped composite stock with an area of ~50km^2 ~13km west of Eton township, in eastern MIRANI (Figure 135). In the west, it forms a cluster of rugged, heavily vegetated hills the tallest being Ben Mohr at 746m (from which the unit is named). The terrain is very rugged on the lower slopes, and is covered in dense rainforest, which gives way to open woodlands towards the summits. The complex is interpreted to extend east to Mount Kinchant based on magnetic data, although there is little outcrop in the intervening area along Sandy Creek.

Type locality

Most of the area over the core of the Ben Mohr Igneous Complex is rather difficult to access. A type locality is designated in the northern part of the core, north-west of Blue Mountain, near MGA 694075 7648000, where house-sized boulders of pale grey, fine to medium-grained, porphyritic granite or granodiorite crop out (Figure 136a). It comprises plagioclase (30–35%), K-feldspar (~25%), quartz (20–25%), biotite (~10%), hornblende and clinopyroxene (together ~5%) and magnetite (~3%). The rock is characterised by euhedral, oligoclase laths to 5mm in a finer groundmass. Accessories are zircon, apatite and minor titanite. The sample that was isotopically dated was collected from here.

Lithology

The Ben Mohr Igneous Complex has been mapped as a central core consisting dominantly of granitic rocks flanked to the west, north and east by dominantly gabbro and diorite with subordinate granite and granodiorite.

The central granitic core is itself concentrically zoned. The zone boundaries run roughly parallel to the outline of the core, which was described by Ley (1982). Petrographic details are taken from that report.

The core (mapped as $Kgbm_g$) is pale grey to pinkish grey, fine to medium-grained porphyritic granite, composed of equal amounts of pink, partly perthitic orthoclase (~30%) and white oligoclase (~25%), quartz (~25%), biotite (~10%), hornblende and augite (together ~5%, but commonly replaced by chlorite and calcite). Titanite, magnetite, apatite and zircon are present as accessories.

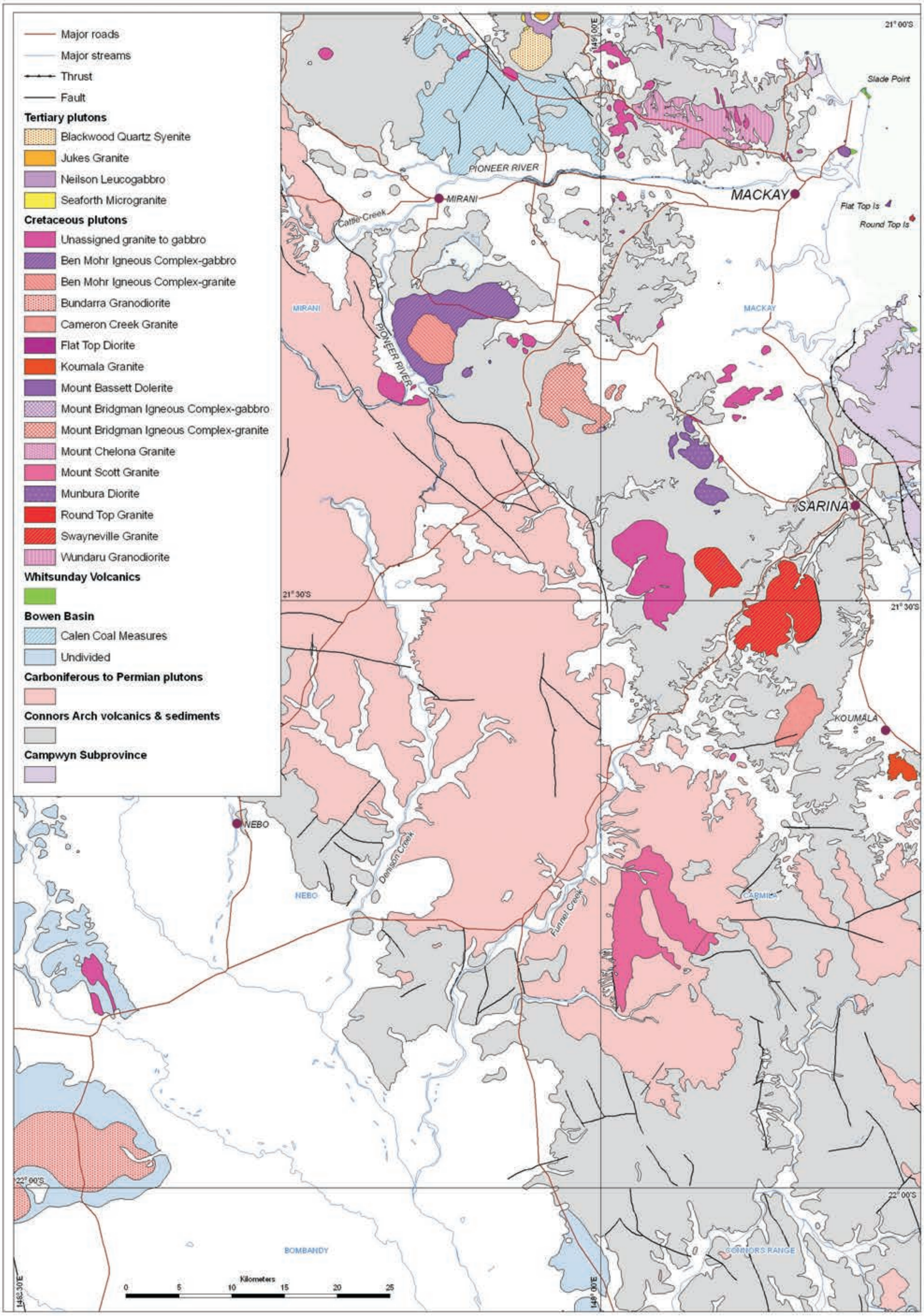

Figure 135. Distribution of Cretaceous to Tertiary igneous rocks of the Mackay–Nebo area

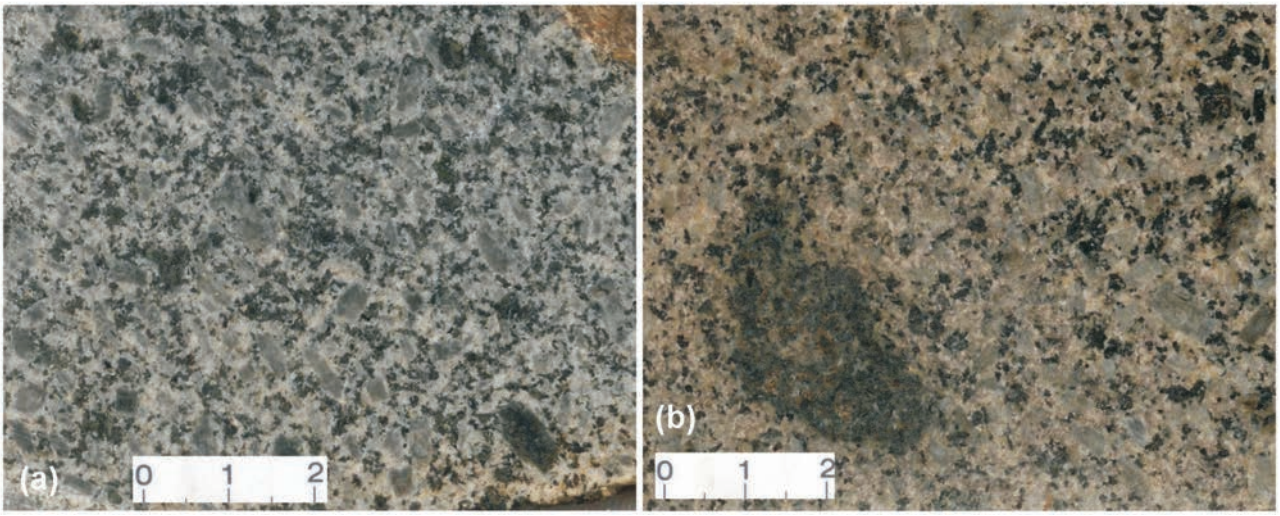

Figure 136. Ben Mohr Igneous Complex; scale is 2cm
(a) Scanned slab of clinopyroxene-hornblende-biotite granodiorite or monzogranite from the type locality of the Ben Mohr Igneous Complex. About 1km north-west of Blue Mountain at MGA 694075 7648000 (QFG3672)
(b) Scanned slab of hornblende-biotite granite from the north-western margin of the central core of the Ben Mohr Igneous Complex. In Bong Bong Creek ~2km west-north-west of Ben Mohr at MGA 690863 7646880 (QFG4313)

The granite shows a gradational boundary outwards into pale grey, coarse to very coarse-grained hornblende-biotite granodiorite to tonalite. The granodiorite is invariably massive and relatively unfractured, and forms a shell <100m wide around the central core. This gradational contact suggests that the granite is a differentiate of the granodiorite magma. The granodiorite comprises plagioclase (~40%), K-feldspar (~15%), quartz (~15%), pyroxene (~15% mostly augite and minor hypersthene), chloritised biotite (~7%), hornblende (~3%) and opaques (2-3%). Titanite, magnetite, apatite and minor small zircon were observed as accessories.

To the north and west of the granite core, the dominantly mafic outer zone of the complex consists of diorite and gabbro (mapped as $Kgbm_b$). The diorite forms a peripheral rim a few hundred metres wide having a sharp contact with the granodiorite. This implies a time break between the emplacement of the diorite and the later granodiorite. The relative proportions of mafic minerals within the diorite are variable. Ratios of hornblende and augite appear to change from north to south. In the north, diorite mainly contains augite, and to the south near Pinevale, hornblende dominates. Both rock types contain similar amounts of biotite.

Dark-grey to brownish-grey, medium-grained, equigranular pyroxene (augite) diorite was described from near the Royal George copper workings at MGA 691050 7647450 near the north-western contact with the granite core of the complex. It comprises plagioclase (~50%), augite (~20%), quartz (~10%), orthoclase (~10%), biotite (~5%) and hornblende (~2%). Sericite and chlorite alteration were observed. Main accessories are opaque oxides and apatite.

At the northern extent of the complex at MGA 690600 7649400 near Hill 357, fine-grained, dark greenish-grey to black, equigranular microgabbro/diorite comprises plagioclase (~45%), hornblende (~20%), biotite (~10%), quartz (~10%), K-feldspar (~10%), pyroxene (~2%) and magnetite (~2%). Traces of apatite, zircon and epidote were noted. The zircon tends to occur as inclusions in biotite.

Towards the southern end of the Ben Mohr Igneous Complex, near the Pinevale prospect on Pinevale Creek at MGA 692300 7643900, dark grey, fine to medium-grained, equigranular hornblende diorite comprises plagioclase (~50%), hornblende (20–25%), augite (~7%), K-feldspar (~5%), quartz (~5%), chloritised biotite (~5%) and magnetite (3–5%). Apatite, titanite, zircon and epidote were detected as accessories. The rocks are commonly altered giving them a greenish colour, due to biotite being chloritised, pyroxene being uralitised, and plagioclase and pyroxene being epidotised.

Smaller intrusive bodies have been observed in the Ben Mohr Igneous Complex, such as at Blue Mountain at MGA 694700 7647500, where dark grey, siliceous quartz-feldspar porphyry is interpreted to intrude the granodiorite and diorite.

South of Junction Crossing, just west of the Peak Downs Highway near Rusty Knob, unnamed granitic and dioritic intrusions could be related to the Ben Mohr Igneous Complex, but have been mapped separately due to their lower magnetic responses.

Noteworthy is that all known mineral occurrences within the Ben Mohr Igneous Complex occur at the contacts of the granite/granodiorite core with the diorite. At the Royal George and Pinevale Creek prospects there is evidence for mineralisation being associated with faults trending north-east.

Geophysical response

The two-fold subdivision of the complex is reflected in the airborne geophysical data (Figure 119). The granitic core is represented by strong responses in all three channels and resultant yellow to white hues on composite radiometric images. The outer, more mafic rocks are represented by low responses in all channels, resulting in dark purple and grey, although the data are somewhat degraded because of the variation in relief. The area north of Ben Mohr has a more heterogeneous response and may include screens of Carmila beds, although it is very strongly magnetic indicating that gabbroic rocks are present.

The airborne magnetic data also reflect the two-fold subdivision and correspond well with the radiometric data. The outer gabbroic subunit is characterised by very strong values (Figure 120). The central granite core shows a composite zoned pattern with central zone of higher values (that correspond with Ben Mohr and Mount McBryde), surrounded by a ring of low to moderate response. These may correspond with the subdivisions of Ley (1982).

The magnetic susceptibilities for the gabbroic phase shows a continuous spread of values from 100–5000 x 10^{-5} SI units with no particular mode, a mean of 2300 and sporadic higher values up to 7500. The granite phase has values from 1100–3700 x 10^{-5} SI units with modes at about 1400 and 2200 and a mean of 1900.

The southern rim of hornfelsed Carmila beds shows a moderate response, but it is uncertain whether this is due to mineralogical changes caused by the contact metamorphism or a continuation of the igneous complex to the south at shallow depth.

Relationships and age

The Ben Mohr Igneous Complex intrudes and has strongly hornfelsed the Permian Carmila beds. It is Early Cretaceous, based on SHRIMP dating of zircon from a granodiorite sample (QFG3672) collected at MGA 694070 7648020 (see Appendix). The age obtained was 131.8±1.6Ma for 19 of 21 analyses (MSWD 1.13).

BUNDARRA GRANODIORITE

Introduction

The Bundarra Granodiorite was defined by Jensen & others (1966). It crops out mainly in the south-western corner of NEBO (Figure 135) and is ~65km^2 in area. It is the largest intrusive body in the eastern part of the Bowen Basin. Outcrop of the unit is mostly poor as it is extensively weathered. The pluton forms a distinct topographic basin surrounded by a sharp rim of hills formed by hornfels.

Type locality

The type locality is herein designated on a rocky knoll at MGA 653565 7567580 in the western part of the pluton in HILLALONG. Outcrop consists of pale grey, medium-grained, equigranular to slightly porphyritic hornblende-biotite granodiorite or tonalite with scattered plagioclase phenocrysts to 8mm.

Lithology

The Bundarra Granodiorite consists of grey to locally pale pink, medium to coarse-grained, equigranular to porphyritic, leucocratic, titanite-bearing hornblende-biotite granodiorite to tonalite and quartz diorite. Small plagioclase phenocrysts to 8mm are common and hornblende prisms and biotite flakes to 1.5cm. Sparse dioritic inclusions to 3cm across and minor aplite and microgranite dykes are present.

The granodiorite is locally gneissic and variably deformed and altered. The reason for the gneissic foliation is uncertain given that the pluton is Cretaceous. It may be a magmatic flow foliation or a ductile deformation fabric related to forceful emplacement of a partly crystallised magma.

Geophysical response

The radiometric response of the pluton is mostly low in all channels, although potassium is slightly elevated so that locally it has deep pinkish hues on composite images. The eastern part of the pluton has slightly higher responses, probably due to colluvial wash from the surrounding hornfelsed Back Creek Group, which has strong values in all channels.

The pluton has a strong magnetic response that extends well beyond the mapped margins, suggesting that it is only partly unroofed. Alternatively some of the strong response outside the contact may be due to hornfelsing. No magnetic susceptibility data are available.

Relationships and age

The Bundarra Granodiorite has intruded undivided Back Creek Group. It has imposed a distinct metamorphic aureole on the surrounding sedimentary rocks, in common with the Gotthardt Granodiorite and the Mount Barker Granodiorite, which intrude the Bowen Basin farther west (Hutton & others, 1998). Copper mineralisation has been found in the hornfelsed zone, associated with veins probably emanating from the granitoid body.

An age of Early Cretaceous has been determined for the Bundarra Granodiorite. Three ages ranging from 121.8±6.3Ma to 129.7±8.6Ma were determined using fission track dating on zircon by Marshallsea (1986) who noted that these data correspond well with a K–Ar age of 126Ma from the pluton (Green & Webb, 1974). The closeness of these ages indicates that the pluton cooled relatively quickly and that the zircon ages are close to the emplacement age of the body.

CAMERON CREEK GRANITE

Introduction

The Cameron Creek Granite is a small pluton (~4km^2) that forms most of the rugged, mountainous country in the Black Mountain area west of Koumala in north-western CARMILA (Figure 135). The extent of the Cameron Creek Granite has only been approximately delineated because of the rugged terrain and poor outcrop. The unit is covered in dense tropical rainforest. Numerous swiftly flowing, ephemeral streams have their source in the unit. Cameron Creek, from which the unit takes its name, is one of the main watercourses draining the area.

Type locality

The designated type locality is in Cameron Creek at MGA 726750 7611300. *In situ* outcrops of the granite were not found during the traverse along Cameron Creek, but the creek bed and adjacent slopes are littered with numerous very large granite boulders.

Lithology

Dark pink, fine to medium-grained (mainly medium-grained with an average grainsize ~1.5 mm), uneven-grained to slightly porphyritic biotite-hornblende monzogranite is the dominant rock type represented in the boulders in the middle and upper reaches of Cameron Creek and adjacent hillslopes. The granite contains abundant pink K-feldspar, as well as sparse plagioclase phenocrysts up to ~5mm long, and scattered, angular to rounded enclaves, up to ~3cm across, of mainly brown to dark grey, recrystallised silicic volcanic rocks. Poorly to moderately well-developed granophyric intergrowths between quartz and K-feldspar are also scattered throughout the granite.

The Cameron Creek Granite is leucocratic with only ~3% mafic minerals. Hornblende appears to be slightly more abundant than biotite in most samples examined. The biotite flakes have been extensively replaced by chlorite, whereas hornblende grains are generally unaltered or only partly altered. The granite also contains minor opaques, as well as traces of titanite (in interstices) and allanite. Epidote (mainly in interstices), sericite (after plagioclase), chlorite (mainly after biotite and in interstices), and secondary biotite (in interstices) are the most common secondary minerals. Feldspar grains are generally turbid.

Geophysical response

The unit is characterised by pale pink to blue tones on a composite radiometric image, and is indistinguishable from the surrounding Carmila beds. It has only low to moderate responses in all three channels in spite of its leucocratic nature. This may be partly due to levelling problems in the data caused by the strong topographic relief. The granite shows moderate responses on aeromagnetic images, consistent with the average magnetic susceptibility reading of 475 x 10^{-5} SI units. The magnetic response extends beyond the mapped boundary, suggesting that the granite is more extensive or has shallowly dipping contacts.

Relationships and age

The granite contains inclusions of silicic volcanic rocks thought to be derived from the adjacent Carmila beds. Their presence, and the absence of granite clasts in massive conglomerate (Carmila beds) exposed in Cameron Creek downstream of the granite, are interpreted to indicate that the Cameron Creek Granite intrudes the Carmila beds.

The unit was most probably emplaced in the Early Cretaceous as for similar topographically prominent leucocratic granites in the area.

FLAT TOP DIORITE

Introduction

The Flat Top Diorite forms most of Flat Top Island (the origin of the name), a small island ~600m long located ~3km offshore from the mouth of the Pioneer River at Mackay at MGA 733200 7658500 (Figure 135).

Type locality

Extensive pavements of dark grey, medium-grained, even-grained hornblende diorite or gabbro are present on the eastern side of the island. They are mainly unaltered to slightly altered, with only traces of epidote and chlorite detected in some hand specimens.

Lithology

The unit is made up of two main rock types. The main component is dark grey, medium-grained, even-grained hornblende diorite or gabbro as at the type locality. The other component of the unit is biotite granite forming a very well-exposed net-veined complex with the diorite. The granite is pale pink, medium grained and equigranular, and contains ~5–10% biotite. The granite is much fresher than that forming Round Top Island, a further 2km offshore, and contains only traces of epidote.

Geophysical response

The island is too small for the radiometric response to be considered reliable, although it is relatively low in all channels.

In the airborne magnetic images, it lies on a south-east trending magnetic ridge that extends off a major area of strong magnetic response that underlies much of the coastal plain around Mackay, and which is thought to be due to a major mafic intrusion at shallow depth.

Relationships and age

The complex is cut by fine-grained, mafic dykes 30–50cm wide. On the south-eastern corner of the island, massive hornfelsed volcanic breccia and pink, recrystallised, slightly porphyritic andesite or dacite (?) appear to form a screen between mainly diorite to the east and north and biotite granite to the south and west. The screen is cut by composite dykes up to 2m wide, consisting of mafic (dioritic–gabbroic) fragments in a granitic matrix. The volcanic rocks are tentatively correlated with the Campwyn Volcanics.

The diorite is likely to be Cretaceous like the other dioritic rocks in the Mackay area.

KOUMALA GRANITE

Introduction

The Koumala Granite (~4.5km^2) is a felsic unit, which forms a prominent, north-westerly trending ridge with three prominent knolls (known as the Three Sisters), in central-northern CARMILA (Figure 135), ~4km to the south-south-east of the hamlet of Koumala (from which the name is derived). Elsewhere, the granite is deeply weathered and forms low country, which is mainly used for growing sugar cane.

Type locality

The designated type locality is at MGA 733990 7604850, in the summit area of one of the Three Sisters. Access to the locality is gained via the access road to a nearby telecommunications tower. The unit is relatively well exposed in this area as scattered boulders and bouldery outcrops.

Lithology

Pale to medium pink, fine to medium-grained (average grainsize of groundmass components ~1.5mm), uneven-grained to slightly porphyritic, leucocratic biotite monzogranite crops out at the type locality. The granite contains scattered, small (up to ~5mm long), subhedral to anhedral phenocrysts of plagioclase and quartz. Pink K-feldspar is more abundant than plagioclase. Biotite (~2–3%) is the main mafic mineral. Accessory and secondary minerals include opaques, chlorite (after biotite and in interstices), sericite (mainly after plagioclase), and rare epidote. Scattered, small irregular miarolitic cavities, at least partly filled or filled with coarse K-feldspar and quartz grains, were detected in some of the rocks exposed at the type locality.

The granite contains rare, medium-grained, even-grained, rounded to ovoid, mafic enclaves up to ~4cm across.

The granite is texturally and mineralogically heterogeneous. Samples examined nearby at MGA 733706 7605037, for example, are syenogranite, characterised by well-developed granophyric intergrowths between quartz and K-feldspar. Biotite (~1–2%) is also scarcer than at the type locality, and the rocks are more even grained.

Geophysical response

The Koumala Granite shows mainly pale pink hues on a composite radiometric image reflecting high potassium and moderate thorium and uranium responses. It is readily distinguished from the enclosing Quaternary fan and flood-plain deposits, which are characterised by dark blue to black hues.

The unit is characterised by low to moderate responses on aeromagnetic images, consistent with average magnetic susceptibility readings of 476 x 10^{-5} SI units and 352 x 10^{-5} SI units recorded at and near the type locality, respectively. The aeromagnetic images imply the unit is much more extensive beneath a shallow cover of Quaternary deposits, and that it is largely enclosed by a narrow zone of hornfelsed country rocks (characterised by high magnetic responses). The data also imply some of the small areas of poorly exposed, deeply weathered granite in the Sandy Creek – Arrowroot Creek area (to the south of the Three Sisters), which are delineated as undivided Urannah Batholith (unit CKgu), may form part of the Koumala Granite.

Relationships and age

The granite intrudes and has extensively hornfelsed basalt/andesite currently tentatively assigned to the Carboniferous Mountain View Volcanics. The age of the unit is uncertain, but it is tentatively interpreted to be Early Cretaceous.

MORUGO GRANITE

Introduction

The Morugo Granite is an elongate east-trending pluton along the valley of Cattle Creek between Gargett and Morugo (from which the unit is named) in northern MIRANI (Figure 135). The unit is strongly recessive, very poorly exposed and highly decomposed, and is commonly covered by Quaternary scree and colluvium from the steep valley sides. However, locally along the edges of the valley in some of its side gorges, platform exposures and large rounded boulders have been observed.

Type locality

The type locality for the Morugo Granite is ~3.5km west of Morugo at MGA 657680 7661270, and has fresh boulders of coarse-grained equigranular hornblende-biotite granodiorite (Figure 137a). It comprises quartz (~20%), K-feldspar (~20%), plagioclase (~40%), biotite (~10%), hornblende (~5%) and opaques (3%). The feldspars and the mafic minerals are partly altered to sericite and chlorite respectively. Less common alteration minerals include epidote and calcite. Titanite and apatite were observed as accessory minerals.

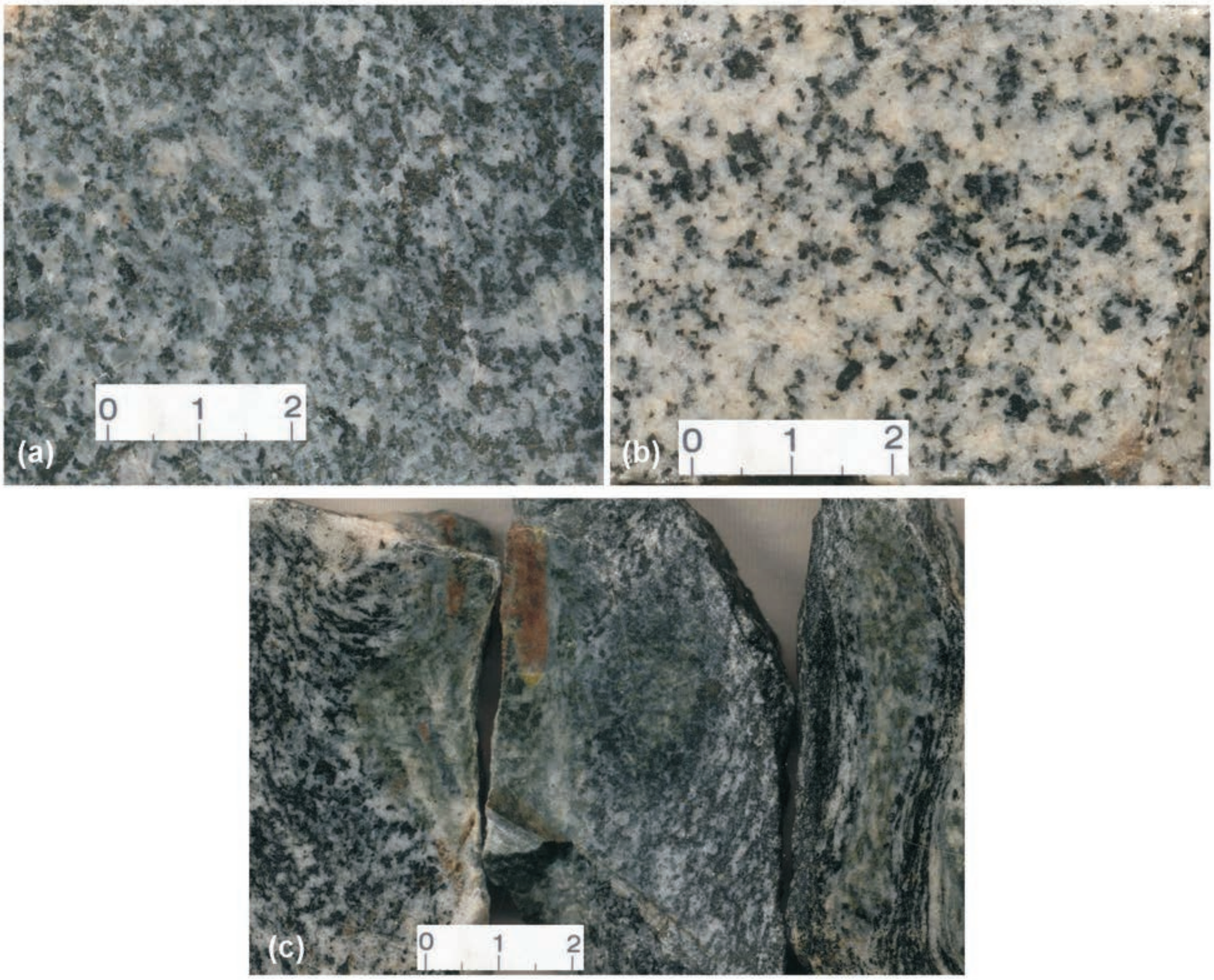

Figure 137. Morugo Granite; scale is 2cm
(a) Scanned slab of hornblende-biotite granodiorite from the type area of the Morugo Granite. 3.5km west of Morugo at MGA 657680 7661270 (QFG4304)
(b) Scanned slab of hornblende-biotite granodiorite. Descent on the road from Eungella to Netherdale at MGA 656110 7662042 (QFG3407)
(c) Scanned slabs of gneissic granitoid. Near Cattle Creek at ~3km east-north-east of Morugo at MGA 663698 7663437 (QFG3681)

Lithology

The main rock type of the Morugo Granite consists of fine to medium-grained, equigranular hornblende-biotite granite or granodiorite (Figure 137b). It is mostly very decomposed, although relatively fresh boulders or cores were observed at a few localities and some fresh platforms occur along Cattle Creek.

Another outcrop of granodiorite was observed along Ovens Loop Road near Cattle Creek at MGA 671290 7662260. The dominant mafic mineral in this outcrop is biotite, which occurs as 3–5% black to greenish, altered flakes, up to 1mm. Only traces of hornblende are present along with accessory brown titanite and allanite. Some biotite-rich, fine-grained, sub-rounded to rounded xenoliths of microdiorite are present.

In other outcrops hornblende is the dominant mafic mineral. For example at MGA 670270 7660830, fresh kernels of light greenish-grey medium to coarse-grained biotite-hornblende granodiorite comprises quartz (~10%), K-feldspar (~25%), plagioclase (~45%), hornblende (~15%) and biotite (~5%) in addition to accessory opaques, apatite and titanite.

North-east of Morugo in the headwaters of Cattle Creek at MGA 663700 7663400, strongly foliated, medium-grained, equigranular hornblende-biotite granitic gneiss crops out (Figure 137c). It contains dark grey, fine-grained, sub-rounded to elongate microdiorite enclaves and multiple schlieren and consists of quartz (~40–45%, commonly recrystallised grains), plagioclase (~25–35%), K-feldspar (~5–15%), biotite (~10–12%), hornblende (~5%) and opaques (~3%). Accessory minerals include titanite, epidote, apatite and zircon. The relationships are uncertain, but the gneissic rocks could represent large rafts or enclaves within the Morugo Granite. Nearby, unfoliated, more leucocratic biotite-hornblende granodiorite cuts the gneiss. Gneissic rocks have also been observed in the Bundarra Granodiorite, another Cretaceous pluton that intrudes the Permian Back Creek Group, south of Nebo. The reason for the gneissic foliation is uncertain given that the plutons are Cretaceous. It may be a magmatic flow foliation or related to forceful emplacement of a partly crystallised magma.

On elevated positions within the Cattle Creek valley, mafic rocks were observed within the mapped extent of the Morugo Granite, but their relationship to the granitic rocks is not known. They range from hornblende diorite to gabbro. At MGA 666460 7660150, south of Kowari near Clemens Creek, very dark greenish-grey, coarse-grained equigranular gabbro was found in outcrop on the southern hill slope, but no contact with the granite and granodiorite could be located. In places the gabbro displays layering. It comprises plagioclase (~55%), clinopyroxene (~30%), orthopyroxene (~14%) and minor opaques (~1%). Minor hornblende may also be present in parts of the outcrop. In places the gabbro and diorite are brecciated.

Along the road to Eungella Heights at MGA 655770 7661140, medium-grey, fine-grained, equigranular (biotite) hornblende tonalite with minor titanite was observed. This rock is fractured and altered. The diorite comprises quartz (~25%), plagioclase (~45%), hornblende (~15%, strongly uralitised), biotite/chlorite (~7%), opaques (3–5%) and accessory titanite and apatite. Quartz and chlorite veins with alteration halos are evident and malachite staining occurs sporadically. Altered, greenish-grey, equigranular to seriate biotite-hornblende granodiorite crops out nearby, commonly containing xenoliths of dark grey, fine-grained microdiorite. Common quartz and chlorite epidote veins and malachite and azurite staining were observed.

Geophysical response

The large variation in relief in Cattle Creek valley resulted in levelling problems in the radiometric data which are not reliable, particularly at the western end.

The pluton shows a low magnetic response that has a moderately to strongly magnetic rim that may correspond with more mafic rocks described above (Figure 120). The valley floor corresponds well with the low magnetic response in the airborne magnetic images and the boundary of the magnetic low has been taken as the pluton boundary. However, it is possible that the unit is a zoned pluton with a rim of more mafic rocks, and the boundary may be better taken outside the magnetic rim.

Magnetic susceptibility values for the unit show complex populations that are not consistent with the low response of the unit, suggesting that the fresher outcrops observed do not truly reflect the properties of recessive part of the unit overall. They support the notion that the magnetic rim may be part of the pluton. Granite outcrops in the centre of the unit show two populations, one with 30–100 x 10^{-5} SI units, which may reflect the dominant phase, and another population with values between 350 and 850. The granodiorite outcrops are more magnetic, with two populations, one in the range 100–2300 (with modes at 400 and 1500) and another population from 3000–5000. Diorite and gabbro values show a skewed distribution from 300–3000 with modes at 600 and 2000.

Relationships and age

The Morugo Granite probably intrudes the Palm Lookout Granite, because of the absence of obvious dykes on the magnetic images. Such dykes are common in the surrounding units. However, rare dykes have been observed in outcrop, such as at MGA 660470 7661320, where the granite is intruded by a porphyritic microgranite or microdiorite dyke. Felsic dykes intrude the gneissic granodiorite near Morugo.

K–Ar dating of granodiorite sampled near the road to Eungella at MGA 656200 7662680 (GA792) gave Early Cretaceous ages of 130±1Ma and 129±1Ma from biotite and hornblende respectively (Webb & McDougall, 1964) . The concordant nature of the ages from different minerals suggests that the crystallisation age is close to 130Ma. This is identical to K–Ar ages obtained from the Wundaru Granodiorite to the east and the SHRIMP age from the Ben Mohr Igneous Complex to the south-east.

MOUNT BASSETT DOLERITE

Introduction

The Mount Bassett Dolerite crops out as a low east–west trending ridge that includes Mount Bassett (from which the name is derived), ~2.5km north-east of the centre of Mackay. The unit is well exposed in several quarries (Mount Bassett Quarry, Old Mount Bassett Quarry and Quarry 2963B). Swarms of dykes cutting

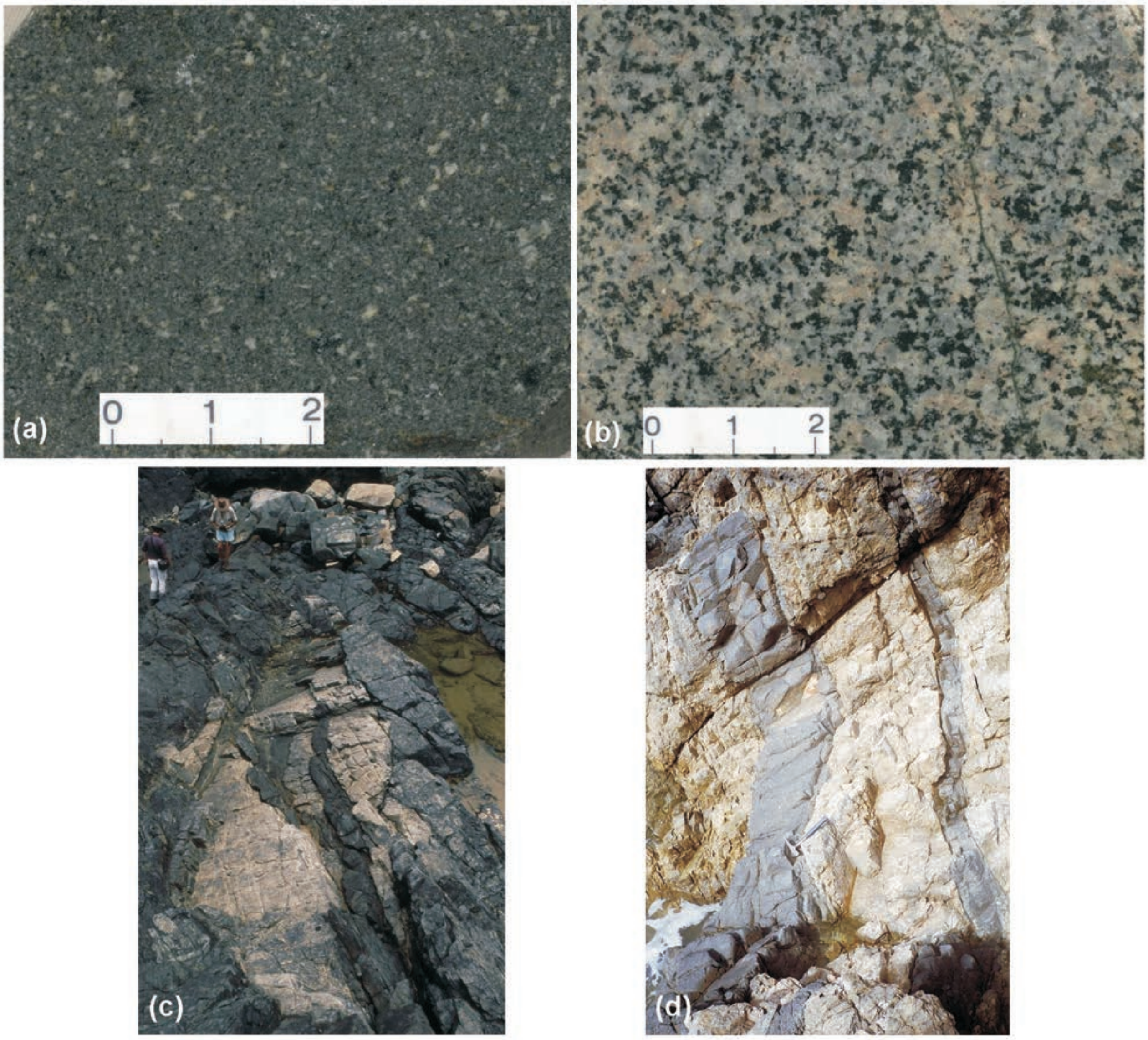

Figure 138. Mount Bassett Dolerite and related rocks; scale is 2cm in (a) and (b)
(a) Scanned slab of porphyritic dolerite or andesite. Mount Bassett Quarry at MGA 729286 7663336 (QFG3710)
(b) Scanned slab of fine-grained hornblende-biotite granodiorite from a dyke intruding Mount Bassett Dolerite. Mount Bassett Quarry at MGA 729191 7663349 (QFG3711)
(c) Dolerite dyke swarm with screens of light coloured quartzose sandstone tentatively mapped as Campwyn Volcanics. Northern end of Blacks Beach, ~12km north of Mackay at MGA 727343 7671371 (RSC025)
(d) Dolerite dykes cutting rhyolitic ignimbrite of the Whitsunday Volcanics. 800m south of Slade Point at MGA 731452 7668494 (PBCO010)

older rocks and exposed on some of the headlands such as Slades Point and along Blacks Beach are probably also part of this unit (Figure 138c–d).

Type locality

The type locality is designated at MGA 729400 7663550 on the north-eastern side of Mount Bassett, a rounded hill ~75m high, where the Mackay Harbour Board operates a large rock-fill and rip-rap quarry. The dominant rock is very dark grey to black, aphyric to porphyritic dolerite with dykes of quartz diorite or quartz monzodiorite and late-stage thinner basalt or andesite dykes that intrude all of the other rocks. The dolerite is well jointed with wide joint spacing in places, which enables the quarrying of large blocks.

Lithology

The dominant rock at Mount Bassett is very dark grey to black, aphyric to slightly porphyritic dolerite (Figure 138a). The unit appears to be a complex of amalgamated dykes and sheets that may pass out into a zone where the dykes are separated by screens of country rocks. The dolerite has a variety of textures from very fine-grained and porphyritic to coarser-grained and equigranular. The coarser-grained rocks commonly have an intersertal texture of interlocking plagioclase (labradorite) laths to 0.5–3mm (70–80%) with interstitial clinopyroxene (10–20% and commonly replaced by chlorite) and opaque oxides (up to 10%). Finer-grained variants have a similar composition, but the groundmass is finer (<0.5mm) and they have phenocrysts of plagioclase to 3mm and clinopyroxene to 1mm as single crystals or as glomeroporphyritic aggregates to 3mm. Rare crystals of brown hornblende were noted in one thin section. Some also contain minor interstitial quartz. Most of the rocks are partially altered and the plagioclase is commonly turbid, the clinopyroxene replaced by chlorite and the opaque oxides by leucoxene.

Steeply dipping dykes up to 3m wide of pale grey to pink, altered quartz monzodiorite to granodiorite intrude the dolerite in the quarries (Figure 138b). They consist of quartz (10–20%), highly turbid, sericitised feldspar (70–80%, mainly plagioclase, but probably some K-feldspar that is graphically intergrown with quartz), green hornblende (5–10%), chlorite (<5%, possibly after biotite) and opaques (<5%).

Also present are dykes of andesite or microdiorite containing flakes of chlorite, probably after biotite to 1mm in finer-grained groundmass of turbid plagioclase, subordinate chlorite and leucoxene and minor interstitial quartz. Some have plagioclase phenocrysts to 2mm.

Dolerite dykes along Blacks Beach range from aphyric to strongly porphyritic. The aphyric ones have a well-developed intersertal texture with laths of plagioclase (*ca* 70%, 0.5–2mm) with interstitial green uralitic amphibole after clinopyroxene (25%) and opaque oxides (5%). Strongly porphyritic varieties also crop out, and they contain ~25% normally zoned plagioclase phenocrysts up to 1cm long in a very fine-grained groundmass with a similar texture and composition to the aphyric dolerite.

Dolerite farther west may also be related to the Mount Bassett Dolerite, for example dykes exposed in Farleigh Quarry, and the mafic bodies mapped as intruding the Cretaceous Wundaru Granodiorite.

Geophysical response

As expected, the Mount Bassett Dolerite has a relatively low response in all radiometric channels and has purple hues in composite images.

Mount Bassett lies over a strong magnetic anomaly that lies at the southern end of a moderate to strong, north-trending magnetic ridge. Farther north, this ridge lies offshore from Blacks Beach, where there are abundant dolerite dykes. These may be related to the Mount Bassett Dolerite. Prominent north to north-north-west-trending magnetic lineaments are also a feature of the area to the west and are probably due to dolerite dykes. Magnetic susceptibility values for the Mount Bassett Dolerite are irregularly distributed in the range 300–4000 x 10^{-5} SI units with peaks at 400 and 1700.

Relationships and age

The Mount Bassett Dolerite appears to intrude rhyolite of the Early Cretaceous Whitsunday Volcanics, Permian Carmila beds and the Late Devonian to early Carboniferous Campwyn Volcanics. It has not been dated isotopically, but a Cretaceous age is likely.

MOUNT BRIDGMAN IGNEOUS COMPLEX

Introduction

The Mount Bridgman Igneous Complex is an oval shaped stock of ~25km^2 in eastern MIRANI (Figure 135). It forms rugged, heavily vegetated topography with an elevation up to 620m at Mount Bridgman, which is ~7km south of Eton and from which the name is derived.

Type locality

The type locality is designated at MGA 703930 7638560 on a ridge 2km south of Mount Bridgman. Outcrops at the locality consist of dark pink, medium-grained porphyritic syenogranite, which comprises quartz (~35%), perthitic K-feldspar (~55%), plagioclase (~10%), biotite (~2%), hornblende (~2%), opaques (~1%) and accessory titanite and apatite. Common greenish-grey ellipsoidal microdiorite enclaves, mostly 1–2cm, were observed (Figure 137a).

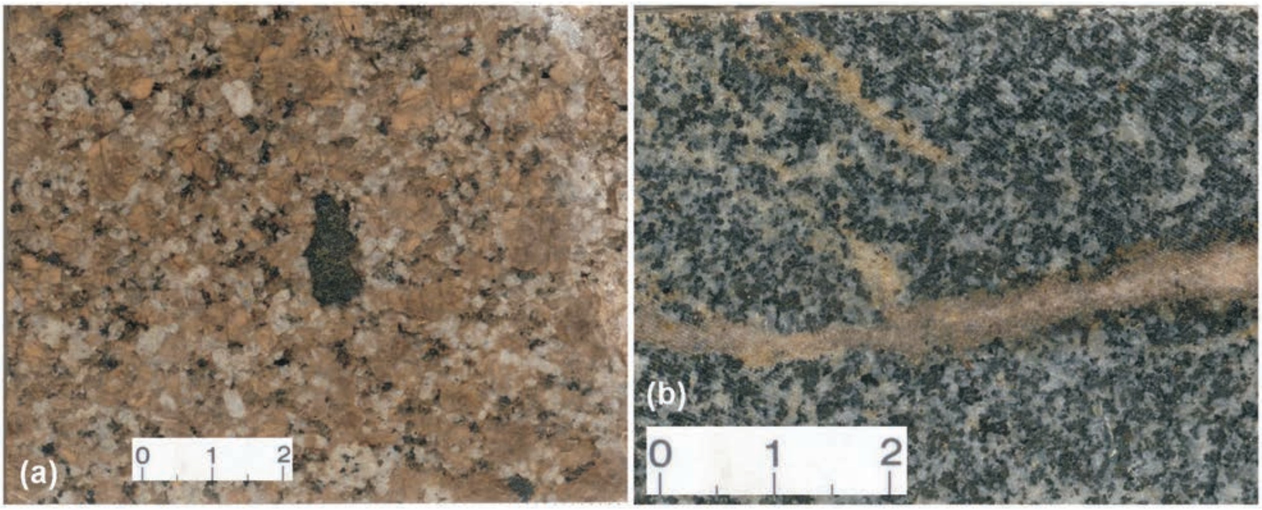

Figure 139. Mount Bridgeman Igneous Complex; scale is 2cm
(a) Scanned slab of medium-grained hornblende-biotite syenogranite with a small mafic enclave. From the type locality of the Mount Bridgman Igneous Complex at MGA 703930 7638560 2km south of Mount Bridgman (QFG4089)
(b) Scanned slab of medium-grained, equigranular hornblende quartz diorite cut by an aplite vein. About 4km east-south-east of Mount Bridgman 707490 7639520, (QFG4191)

Lithology

The dominant rock type is a dark pink, medium-grained, porphyritic syenogranite with scattered microdiorite enclaves as described above.

The granitic rocks are flanked to the south by a small body of dominantly diorite to granodiorite and minor gabbro. Floaters of mafic rocks indicate that smaller bodies of mafic rocks probably occur elsewhere, but they have not been delineated on the map. At MGA 705900 7637400 along the upper slopes of a ridge to the east of Hogans Pocket, house-sized boulders of dark-grey, medium-grained, equigranular granodiorite were observed. These rocks comprise quartz (~20%), K-feldspar (~15%), plagioclase (~35%), biotite (~15%), hornblende (~5%), opaques (~5%), titanite (~1–2%) and common accessory apatite, as well as minor zircon. Minor euhedral epidote is also present.

Near MGA 707490 7639520, 4km east of Mount Bridgman, amongst syenite and diorite boulders, very dark greenish-grey, medium to coarse-grained, equigranular hornblende quartz diorite was sampled (Figure 139b). It comprises quartz (~5%), K-feldspar (~10%), plagioclase (~40%), hornblende (~35%), opaques (~3%) and titanite (~2%). Euhedral apatite crystals up to 1mm were observed in thin section.

Geophysical response

The Mount Bridgman Igneous Complex has a very strong response in all three radiometric channels and is white on composite images (Figure 119). The gabbroic phase is too small to register a separate response.

The airborne magnetic data suggest that the Mount Bridgman Igneous Complex is zoned. The main granite stock is represented by an area of moderate to strong magnetic response, rimmed to the north and west by a zone of low response (Figure 120). The more magnetic area is part of a larger magnetic unit that extends ~10km farther to the east-north-east under Quaternary cover along the valley of Sandy Creek. However, because of the recessive nature of the rocks in this area it is likely that they are different to those exposed in the Mount Bridgman Igneous Complex. Magnetic susceptibilities for the granite have a range of 160–1300 x 10^{-5} SI units with a mode at about 900. All sites were within the magnetic zone as shown in the airborne data.

The granodiorite, diorite and gabbro are part of a zone of very strong magnetic response that lies outside the granite stock. The radiometric response in this zone suggests that it is mainly Carmila beds, and the magnetic response may reflect the effects of hornfelsing in the Carmila beds, or it may be a continuation of the mafic rocks at shallow depth. Magnetic susceptibilities measured on two outcrops of diorite were in the range 1300–2600 x 10^{-5} SI units and one gabbro outcrop was in the range 6300–7800.

Relationships and age

The Mount Bridgman Igneous Complex intrudes and has hornfelsed the early Permian Carmila beds. It is probably Early Cretaceous like the lithologically similar Ben Mohr Igneous Complex.

MOUNT CHELONA GRANITE

Introduction

The Mount Chelona Granite forms a prominent rocky hill, Mount Chelona (from which the name is derived), ~5km north of Sarina, on the eastern side of the Bruce Highway in southern MACKAY (Figure 135). Numerous very large boulders and whalebacks characterise the unit.

Type locality

The granite as described below is very well exposed in an abandoned quarry on the south-eastern side of Mount Chelona at MGA 729300 7634000, which is designated the type locality.

Lithology

The unit consists of pale pink, medium to coarse-grained, moderately porphyritic, biotite monzogranite or possibly granodiorite (Figure 140a). Subhedral to anhedral plagioclase phenocrysts up to ~2cm long are common. Biotite (~5–8%), mainly as discrete flakes, is the dominant mafic mineral. The granite also contains sparse rounded to ovoid, mafic inclusions (medium-grained, even-grained) up to ~15cm across. It is cut by thin (<20cm thick), irregular pegmatite dykes consisting mainly of pink K-feldspar, quartz and chlorite.

The granite is moderately altered. Plagioclase phenocrysts and groundmass grains are commonly pale pink due to the exsolution of fine hematite. Biotite flakes have been extensively replaced by secondary muscovite and minor chlorite. Sericite is also relatively common, mainly as a partial replacement of plagioclase. Minor epidote and calcite are also present.

Geophysical response

The granite is characterised by relatively high radiometric responses for potassium, thorium and uranium, and consequently it is characterised by white hues on composite radiometric images.

The unit is distinguished as a magnetic low surrounded by a prominent, strongly magnetic rim of country rocks that lies well outside the mapped extent of the body, and may be reflecting a hornfelsed rim. This suggests that the recessive area covered by Cainozoic sediments to the east may be underlain by granite. The central low magnetic area also has a circular, slightly magnetic zone suggesting that the pluton may be zoned. Magnetic susceptibility measurements from the unit are in the range 390–920 x 10^{-5} SI units and may be from this magnetic variant.

Relationships and age

The granite intrudes poorly-exposed rocks of the Mountain View Volcanics. It has not been isotopically dated, but is interpreted to be Cretaceous.

MOUNT SCOTT GRANITE

Introduction

The Mount Scott Granite forms an elongate, northerly trending pluton (~60km^2) ~9km south-east of Wandoo homestead, in the south-western part of CARMILA (Figure 135). It is a felsic, leucocratic granite, which is relatively resistant to erosion. The unit forms rugged, extensively dissected, mountainous country on the edge of the coastal escarpment and characterised by numerous bouldery outcrops. It includes Mount Scott (852m), from which the unit is named.

Type locality

The designated type locality is ~550m north-east of Mount Scott, at MGA 709850 7591000. Scattered boulders (some very large) crop out at this locality. The granite is poorly exposed in most of the summit area of the mountain.

Lithology

The unit at the type locality consists mainly of pink, fine to medium-grained, uneven-grained, leucocratic biotite monzogranite. The monzogranite contains ~2% biotite, which has been completely replaced by chlorite and minor secondary titanite. A characteristic feature is the presence of numerous irregular miarolitic cavities

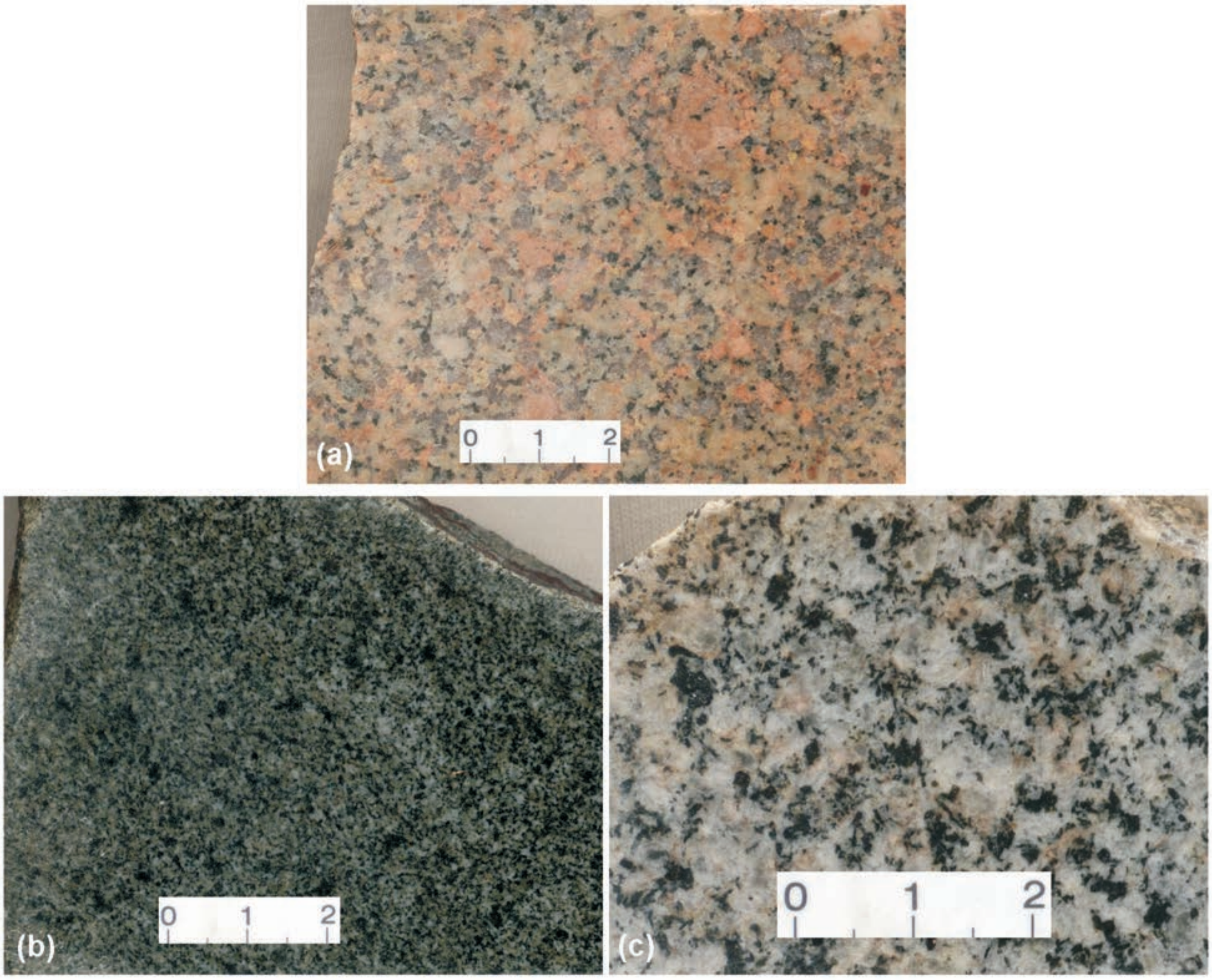

Figure 140. Other Cretaceous plutons; scale is 2cm
(a) Scanned slab of medium-grained biotite granite from the type locality of the Mount Chelona Granite. Mount Chelona Quarry at MGA 729311 7633975 (QFG3458)
(b) Scanned slab of fine-grained hornblende-clinopyroxene diorite or gabbro from the type locality of the Munbura Diorite. Abandoned quarry on the southern side of Scrubby Mount at MGA 715300 7637450 (QFG4072)
(c) Scanned slab of fine to medium-grained, equigranular biotite-hornblende granodiorite from the type locality of the Wundaru Granodiorite. Near the Bruce Highway, south of Wundaru at MGA 713500 7666380 (QFG3720)

up to ~3cm across. The cavities are commonly partly filled or filled with epidote + quartz ± tourmaline (?). The granite is cut by rare dykes, up to ~50cm wide, of pink, fine-grained, slightly porphyritic leucogranite.

Monzogranite examined farther north, in the Sandy Creek area at MGA 710930 7594260, is characterised by a well-developed granophyric texture. Biotite flakes (~3%) are mainly unaltered. The monzogranite contains traces of opaques, epidote, chlorite, and zircon (mainly interstitial), as well as secondary biotite (as aggregates of fine flakes in interstices, some with radiating extinction). A boulder examined ~100m farther south at MGA 710920 7594165 displays a well-developed quenched texture, with numerous phenocrysts of quartz (up to ~3mm across), K-feldspar (up to ~5mm long), and plagioclase (up to ~3mm long) in a fine-grained groundmass (average grainsize ~0.3mm) characterised by granophyric intergrowths between quartz and K-feldspar.

Granitic rocks exposed in the lower western flank of Mount Scott (at MGA 707990 7589250 and MGA 707760 7589430) are miarolitic, granophyric, leucocratic (~2% mafics), and rich in K-feldspar and thus appear to be syenogranite. Some of the mafic grains appear to have been hornblende (now completely replaced by mainly chlorite and secondary biotite). The rocks also contain minor biotite and opaques, as well as traces of allanite (generally fresh), zircon (as relatively coarse grains), and epidote (in interstices).

Geophysical response

The Mount Scott Granite has high potassium, moderate to high thorium and moderate uranium responses resulting in pale pink hues on composite images, similar to those of the surrounding unit CPgu. The magnetic response is low to moderate and cannot be distinguished from that of the surrounding unit either.

Relationships and age

Hornblende gabbro or diorite of unit $CPgu_{ga}$ forms a prominent bar in a creek bed (at MGA 710297 7591331) near the eastern edge of the escarpment. The mafic rocks are cut by several dykes (up to ~15cm thick) of pink leucogranite, presumably related to the Mount Scott Granite. Gabbro or diorite, interlayered with Mount Scott Granite, is also exposed farther east, in the upper part of the ridge leading down from the escarpment edge. The gabbro/diorite–granite complex in this area is cut by rare dykes of slightly porphyritic to aphyric dacite (?).

Granite exposed in the lower western flank of Mount Scott (at MGA 707990 7589250, MGA 707760 7589430) is cut by dykes of pink, fine-grained, slightly porphyritic leucogranite (up to ~5m wide), as well as by rare dykes of hornblende gabbro or diorite.

Contacts with adjacent rock units were not found elsewhere.

Felsic leucogranite broadly similar to the Mount Scott Granite forms relatively low country extending north of Mount Scott at least as far as the Pint Pot Creek area. The leucogranite has been delineated as part of unit CPgu, of probable late Carboniferous – early Permian age. It differs from the Mount Scott Granite in the following aspects:

- the leucogranite does not form mountainous country with abundant outcrops and large boulders — rather it is deeply weathered and poorly exposed,
- miarolitic cavities have not been found,
- granophyric textures are poorly developed in the samples examined in detail — in contrast to the well-developed granophyric textures present in the Mount Scott Granite,
- plagioclase is relatively abundant in leucogranite of unit CPgu,
- the leucogranite is cut by numerous felsic to mafic dykes, and
- the leucogranite is enriched in TiO_2, P_2O_5, Ba, and Sc and depleted in As and Pb, compared to the Mount Scott Granite.

The age of the Mount Scott Granite is uncertain. The bold outcrop style and felsic, K-feldspar rich character of the unit have been interpreted to indicate that the Mount Scott Granite is Early Cretaceous. In addition, miarolitic granite has not been reported in late Carboniferous–early Permian granites of the Urannah Batholith. However, the presence of rare dacite (?) and hornblende gabbro or diorite dykes in places may indicate the unit is significantly older (late Carboniferous – early Permian).

MUNBURA DIORITE

Introduction

The Munbura Diorite comprises four small stocks that form resistant ridges and spurs on the eastern edge of the Connors Range, ~7km south-west of the township of Munbura in south-eastern MACKAY (Figure 135). They include Mount Alice and Scrubby Mountain.

Type locality

The type locality is an old quarry at MGA 715300 7637500 on the southern side of Scrubby Mountain. The dominant rock is medium-dark grey, fine to medium-grained, equigranular diorite (Figure 140b).

Lithology and petrography

The dominant rock is a medium-dark grey, fine to medium-grained, equigranular diorite or gabbro consisting of plagioclase (~65%), clinopyroxene (~15%), amphibole and chlorite (15% replacing pyroxene) and opaque minerals (5%).

Moderately chlorite-altered, greenish-grey, coarse-grained, porphyritic, clinopyroxene diorite was observed on the north-eastern slope of a ridge south of Mount Alice, although most of the field observations in the unit were of microdiorite. The diorite comprises plagioclase (andesine ~60%, including phenocrysts), clinopyroxene (15%), chlorite (20%, replacing clinopyroxene), calcite (< 5%) and opaque minerals (3%).

Geophysical response

On radiometric images, the Munbura Diorite has low responses in all three channels. The stock at Scrubby Mountain has particularly low responses and is dark grey to black on composite images. However, the pale to dark bluish grey hues of the others are not particularly distinguishable from the adjacent Carmila beds.

The magnetic response for the stocks of Munbura Diorite is variable suggesting that they could be mapped as separate units. The Scrubby Mount stock is associated with a strong anomaly, whereas Mount Alice shows a low response like the surrounding Carmila beds. The southern stock has a moderate response. Magnetic susceptibility measurements from the Scrubby Mount stock are in the range 1000–3200 x 10^{-5} SI units consistent with the strong anomaly. Two outcrops of microdiorite in the non-magnetic Mount Alice stock had values in the range 20–250 x 10^{-5} SI units.

Relationships and age

The Munbura Diorite intrudes and has hornfelsed fine-grained sedimentary rocks of the Permian Carmila beds. The age is not known precisely, but a Cretaceous age is likely.

ROUND TOP GRANITE

Introduction

The Round Top Granite crops out on Round Top Island, a small, rocky island (from which the name is derived) ~5.5km offshore from the mouth of the Pioneer River near Mackay (Figure 135).

Type locality

Round Top Island around MGA 735200 7657100 is designated as the type locality.

Lithology

The unit consists of pale brown, medium-grained, even-grained leucogranite. The granite is moderately to extensively altered, containing virtually no unaltered mafic minerals. Plagioclase grains are commonly green, due to sericitisation. Minor secondary iron oxide staining is also common. Quartz appears to be relatively scarce and the unit may be a syenite or monzonite rather than granite.

Geophysical characteristics

The unit is characterised by high responses in potassium, thorium and uranium resulting in white hues on composite images.

It lies at the intersection of the south-east-trending magnetic ridge through Flat Top Island and a dyke-like curvilinear feature from the south-west. Mo magnetic susceptibility measurements are available.

Relationships and age

The granite is surrounded by sea so relationships are unknown. It is tentatively regarded as Cretaceous.

SWAYNEVILLE GRANITE

Introduction

The name Swayneville Granite is given to two plutons ~12km south-west of Sarina, on the either side of the old Marlborough–Sarina road near Bells Gap in southern MACKAY (Figure 135). The larger pluton has an area of 35km^2 and the smaller one is 11km^2. The plutons form relatively rugged terrain on the edge of the Connors Range. Moderate to large boulders along the ridges, sporadic pavements in larger creeks and weathered outcrops in the gullies characterise the unit. The name is derived from Swayneville School in southern MACKAY.

Type area

The type area is designated along Middle Creek in the northern pluton, where a variety of rock types ranging from biotite granite to granodiorite, monzonite and monzodiorite are exposed.

Lithology

The unit is mainly pale pink to red or pale grey, fine to coarse-grained, equigranular to moderately porphyritic, plagioclase-rich biotite monzogranite (or possibly biotite granodiorite). Subhedral to anhedral plagioclase phenocrysts up to ~2cm long are common. In some outcrops quartz and K-feldspar are graphically intergrown. Biotite (~5–8%), mainly as discrete flakes, is the dominant mafic mineral, although in some outcrops, opaque oxides are the main dark mineral in the rock. The granite also contains sparse, rounded to ovoid, medium-grained, equigranular mafic inclusions; some with irregular margins are up to 15cm across. Thin (<20cm thick) irregular pegmatite dykes consisting mainly of pink K-feldspar, quartz and chlorite cut the granite.

The granite is moderately altered. Plagioclase phenocrysts and groundmass grains are commonly pale pink due to the exsolution of fine hematite. Biotite flakes have been extensively replaced by secondary muscovite and minor chlorite. Sericite is also relatively common, mainly as a partial replacement of plagioclase. Minor epidote, mainly as replacement of plagioclase is common and calcite is also present.

Although the unit consists mainly of granite or granodiorite, a variety of other rock types including quartz monzodiorite, diorite and gabbro have also been recorded and form either enclaves or intrusions. For example, at MGA 717700 7625150, west of Middle Creek, a coarse grained, pink to pale grey granite phase is intimately mixed with a dark blue, finer-grained phase (diorite to granodiorite) that forms both veins and xenoliths in the granite, suggesting that magma mingling occurred during the emplacement of the plutons. Fine-grained mafic and felsic dykes are also common throughout the complex.

Because of the variation within the unit, it may be better named Swayneville Igneous Complex like the Ben Mohr and Mount Bridgeman Igneous Complexes.

Geophysical response

The radiometric response of the unit is variable reflecting the variety of rocks within the complex. Potassium shows a generally low response, and uranium and thorium are low to moderate. Hues on composite images range from pale green to dark grey and purple. Relatively high responses in all channels giving whitish composite hues are evident in the southern pluton in the valley south of Bates Gap.

The unit generally has a strong magnetic response that is continuous between the two outcrop areas and extends to the south-west suggesting that at depth the unit forms a single, roughly circular pluton ~10km in diameter. No magnetic susceptibility measurements are available.

Age and relationships

The Swayneville Granite intrudes sedimentary and volcanic rocks assigned to the early Permian Carmila beds. Although it has not been isotopically dated, it is interpreted to be Cretaceous.

WUNDARU GRANODIORITE

Introduction

The Wundaru Granodiorite is aligned east–west and ~13km long and ~4km wide in north-western MACKAY (Figure 135). The name is derived from Wundaru Siding along the North Coast Railway. The granodiorite is very poorly exposed and forms low, recessive topography adjacent to the Bruce Highway between Glenella and The Leap. Outcrops are mostly strongly decomposed, although in a few places such as to the west and south west of Wundaru Siding, some fresh kernels have been found. In the east, unnamed Cretaceous diorite intrudes the Wundaru Granodiorite forming low ridges.

Type locality

The type locality is designated as a small group of large boulders next to the Bruce Highway, south of Wundaru Siding at MGA 713500 7666380. The boulders are light to medium-grey, fine to medium-grained, equigranular, titanite-bearing biotite-hornblende granodiorite (Figure 140c). It comprises quartz (~20%), plagioclase (~35–40%), K-feldspar (~25–30%), hornblende (~5%), biotite (2%) and opaques (mostly pyrite, 2%). Accessories are titanite (~1%) and apatite. Some sericite and chlorite alteration was identified.

Lithology

Moderately altered to fresh, light grey, fine to medium-grained, equigranular titanite-biotite-hornblende granodiorite can be found as boulder-sized kernels in grus, mostly around the Wundaru area.

Geophysical characteristics

The Wundaru Granodiorite is characterised by low to moderate responses in all three channels and is represented on composite images by mottled pale yellow, green and mauve hues that are not too dissimilar to the surrounding Carmila beds.

The granodiorite shows a high response in airborne magnetic images. In the east it is difficult to distinguish from the regional magnetic high that is thought to reflect the presence of a large batholith at shallow depth in the Mackay area. However, the western half of the unit is clearly delineated from the low magnetic response of the Carmila beds, suggesting that the unexposed batholith does not extend there. Magnetic susceptibility readings for the granodiorite are in the range 500–2700 x 10^{-5} SI units. More highly magnetic north-north-west-trending linear features are probably due to the dolerite and diorite dykes. The microdiorite and dolerite dykes yielded readings around 3000 x 10^{-5} SI units.

Relationships and age

The Wundaru Granodiorite intrudes a dominantly volcanic part of the Permian Carmila beds to the north. To the south the Carmila beds consist mainly of sedimentary rocks.

North-north-west-trending dyke swarms consisting of dolerite and microdiorite assigned to the unnamed dioritic unit (**Kg$_d$**) intrude the Wundaru Granodiorite. In some places near Farleigh, the dykes are concentrated enough to be mapped as polygons, although it is likely that they contain screens of granodiorite. Trachyte and rhyolite dykes thought to be related to the Tertiary rhyolite and trachyte intrusions around The Leap also cut the Wundaru Granodiorite in places.

Most of the Wundaru Granodiorite is covered by a veneer of young Cainozoic sediments, not shown on the geology map.

During the 1982 Urban Geology mapping of MACKAY, a sample of the Wundaru Granodiorite from MGA 713295 7666840 near Wundaru was submitted to AMDEL for K–Ar dating of biotite and hornblende (AMDEL, 1983, unpublished). The sample (DA30, DA31) yielded the same age of 130±1Ma for both minerals. The concordant nature of the dates from two minerals suggests that this is probably close to the original age and the Wundaru Granodiorite is thus Early Cretaceous.

UNNAMED CRETACEOUS GRANITOIDS

A complex of unnamed granitoids and dioritic rocks (assigned to units **Kg** and **Kg$_d$** respectively) has been mapped in an area of rugged, heavily forested terrain in the Running Creek area in south-west MACKAY extending into CARMILA. This is based mainly on traverses along Running and Raspberry Creek where a variety of fine-grained rocks including granite, granodiorite, syenite and diorite was observed. However, there is some doubt about the extent of the rocks as mapped. The radiometric and magnetic responses in this area are mostly indistinguishable from the surrounding Carmila beds, although two areas mapped as diorite (assigned to **Kg$_d$**) have slightly lower radiometric responses and slightly higher magnetic response.

Areas of unnamed granitoids assigned to unit **Kg** have also been mapped in the coastal plain to the north in MACKAY and eastern MIRANI. These are mostly very strongly weathered and represented by coarse sandy soils. East of Scrubby Mount, weathered fine-grained leucocratic granite crops out. The granite comprises granophyric K-feldspar and quartz intergrowths (75%), subhedral quartz grains (10%), subhedral K-feldspar (10%), ~2% chlorite (altered biotite) and sparse opaque grains. The rocks are inferred to be Cretaceous because they are east of the main belt of Permo-Carboniferous granitoids in the Urannah Batholith. However, it is still possible that they could be Carboniferous, because rocks assigned to the early Carboniferous Mountain View Volcanics lie to the south-east. They are associated with an area of relatively low magnetic response cut by north-north-west-trending magnetic lineaments, which may be a southern continuation of a Cretaceous dolerite dyke swarm that includes the Mount Bassett Dolerite.

To the south, the magnetically low domain is bounded by a zone of high magnetic response that may be a continuation under the Cainozoic cover of the Munbura Diorite or similar rocks that crop out to the west. Similarly, another magnetic high that extends northwards under the Cainozoic deposits of the coastal plain to the Pioneer River may be in part due to subcropping granitoids, which could explain the recessive nature of this area. The anomaly extends north of the Pioneer River, where the Carmila beds are intruded by abundant dolerite and microdiorite dykes and small stocks as described below. It is possible that the area is underlain at shallow depth by a batholith. The postulated batholith need not necessarily be mafic, because some Cretaceous felsic rocks (for example in the Mount Bridgman and Ben Mohr Igneous Complexes) are magnetic. The extent of these postulated subcropping granitoids is shown on Figure 4.

Dark greenish grey, very fine to fine-grained microdiorite or dolerite and medium greenish -grey, medium-grained, equigranular hornblende diorite intrude the Wundaru Granodiorite as dykes or small stocks assigned to $\mathbf{Kg_d}$, for example at Farleigh Quarry at MGA 719400 7667130. The texture of the diorite is variable from coarsely porphyritic to equigranular. The porphyritic variants comprise coarse-laths of twinned plagioclase (10–40%) and some phenocrysts of hornblende (~5%) in a matrix of plagioclase, hornblende and some opaques. Chlorite, sericite and calcite alteration minerals are present and some of the amphibole may be uralitic replacement of clinopyroxene. Microdiorite or dolerite dykes consist of plagioclase (65%), clinopyroxene and uralitic hornblende (20%), chlorite (10%) and opaques (<10%). Some of these mafic rocks are comparable with those in the Mount Basset Dolerite and could possibly be the same unit. Swarms of similar dykes occur along the coast north of Mackay.

Bloomer (1994) dated plagioclase phenocrysts from a dolerite intrusion cutting the Calen Coal measures, near Calen to the north of the study area. The age of 148±2Ma is somewhat older than the ages (mostly ~130Ma) of the various granitoids that have been dated in the area and which are intruded by similar dolerite and diorite dykes. It is possible that the dyke is Permian and that thermal metamorphism by the Cretaceous and Tertiary intrusions has caused resetting.

TERTIARY PLUTONIC ROCKS

MOUNT JUKES INTRUSIVE COMPLEX

Introduction

The Mount Jukes Intrusive Complex is an oval-shaped complex of stocks of ~4km^2, on the northern side of the Bruce Highway, centred ~4km north-east of Kuttabul. The complex was named by Clarke & others (1971) as the Mount Jukes Syenite Complex, but because it also contains a range of rock types other than syenite, the name has been changed. The complex incorporates the peaks of Mount Jukes and Mount Blackwood. Champion (1984) studied the complex in detail, and Stephenson (1985) gave a summary description of the four main components, the Blackwood Quartz Syenite, Neilson Leucogabbro, Jukes Granite and Seaforth Microgranite.

Lithology

Mount Blackwood consists of equigranular, medium grained, greenish grey quartz syenite, the **Blackwood Quartz Syenite**. According to Stephenson (1985) it consists of quartz (8%), alkali feldspar (54%), plagioclase (15%), granophyric intergrowths (7%), amphibole, biotite and clinopyroxene (13%), iron oxide (2%) and accessory apatite and zircon. Rounded microsyenite xenoliths up to 40cm were observed (Figure 141c), for example at MGA 701968 7673110. Stephenson (1985) also recorded mafic xenoliths up to 20cm, and suggested that the mafic material and the syenite were intruded synchronously.

Minor phases of the syenite are present as ring dykes and other dykes intruding the outer margins of the gabbro and its aureole.

The **Neilson Leucogabbro** is far more recessive and deeply weathered, forming a broad annular valley around Mount Jukes in the northern part of the complex. The valley is partly occupied by Neilson Creek and a tributary. Equigranular, coarse-grained quartz gabbro, was observed in Nielsen Creek at MGA 702275 7675325. According to Stephenson (1985), the average gabbro contains plagioclase (75%), biotite, augite and olivine pseudomorphs (total ferromagnesians, 17%), apatite (3%), ilmenite (3%) and rare quartz (2%) with accessory K-feldspar and zircon. The texture is dominated by the euhedral to subhedral plagioclase laths, the other minerals being mainly interstitial. The low colour index is noteworthy.

The **Jukes Granite** is a small pluton of 1–2km^2 forming the steep-sided, flat-topped peak of Mount Jukes at MGA 702590 7676500 (Figure 141a), within the centre of the Neilson Leucogabbro. The pluton consists of hypersolvus syenogranite (Figure 141b). It contains microperthitic alkali feldspar (70%), quartz (24%), granophyric intergrowths (4%) and minor clinopyroxene, biotite, magnetite and ilmenite (2%). A variety of accessory minerals, some within miarolitic cavities, include zircon, allanite, tourmaline, chlorite, calcite,

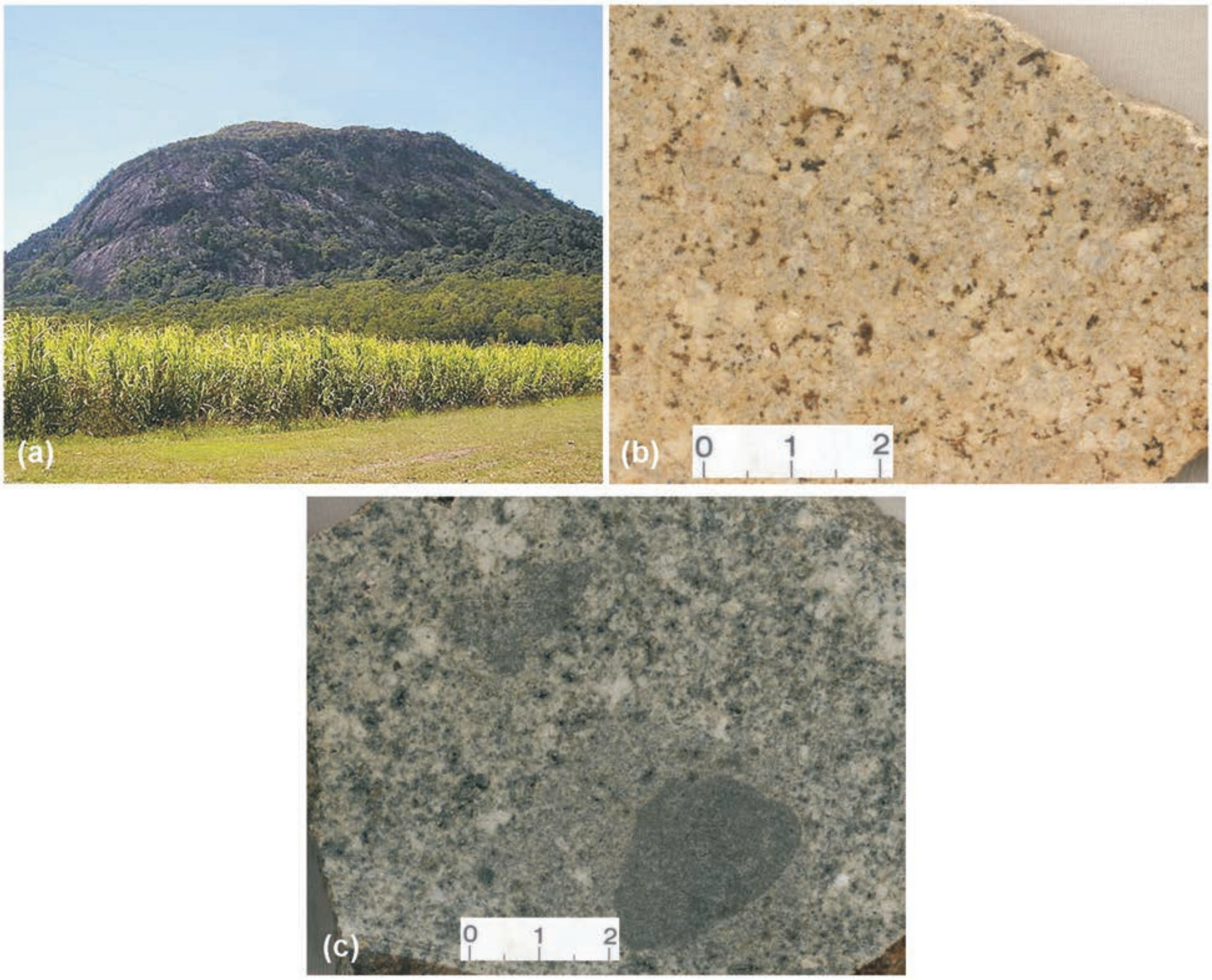

Figure 141. Mount Jukes Intrusive Complex
(a) Mount Jukes from the south-west
(b) Scanned slab of syenogranite from the Mount Jukes Granite. Southern flank of Mount Jukes at MGA 702703 7675643 (QFG3619); scale is 2cm in (b) and (c)
(c) Scanned slab of quartz syenite from the Mount Blackwood Quartz Syenite containing a composite xenolith of microdiorite in microsyenite (?). Road to transmission tower on Mount Blackwood at MGA 702035 7673027 (QFG3613)

molybdenite and a Nb-REE oxide. The Jukes Granite is locally brecciated along its margins, suggesting that it was forcefully emplaced, although stoped blocks are also present, including a large block of hornfelsed Carmila beds.

Radial and concentric microgranite dykes with a variety of textures occur around the Jukes Granite. Several small intrusions, as at MGA 701200 76776300, ~500m across of porphyritic, partly granophyric microgranite cut the northern and western part of the hornfelsed rim of the Neilson Leucogabbro and were named the **Seaforth Microgranite** by Stephenson (1985). Some leucocratic porphyritic dykes are also interpreted to be related to the Seaforth Microgranite. According to Stephenson (1985), the microgranite is a fine-grained, aphanitic rock with K-feldspar phenocrysts, 1–4mm in size, comprising up to 10% of the rock. The K-feldspar is microperthitic and some phenocrysts have fine granophyric rims. The groundmass consists of very fine-grained K-feldspar (60–70%), quartz (30–40%) and is partly granophyric. Accessories include minor iron oxides (ilmenite and magnetite), zircon and apatite. Some quartz-epidote veining was observed. Stephenson (1985) suggests that the Seaforth Microgranite was intruded after the Nielson Leucogabbro. Its relation to the Jukes Granite is not known, but Stephenson suggested that its finer grain size and chemical details suggest it is the youngest main phase in the intrusive complex.

Geophysical response

The radiometric data are probably not reliable because of the strong relief in the area, but in general, the Blackwood Quartz Syenite is characterised by a high potassium response and low to moderate thorium and uranium resulting in pinkish composite hues (Figure 119). The Jukes Granite appears to be high in all three channels and has whitish composite hues. The Neilson Leucogabbro appears to be low in all channels.

The complex is mostly characterised by a high airborne magnetic response, except for the Jukes Granite, which has a low response, contrasting with the surrounding Neilson Leucogabbro (Figure 120). There is little contrast between the Neilson Leucogabbro and the Blackwood Quartz Syenite. The magnetic susceptibility of the Blackwood Quartz Syenite ranges from 80–1700 x 10^{-5} SI units, whereas the leucogabbro ranges from 1230–3115 x 10^{-5} SI units with a normal distribution about a mean of about 2215. The susceptibility of the Jukes Granite is in the range 10–260 x 10^{-5} SI units, consistent with the airborne data.

Relationships and age

The Mount Jukes Intrusive Complex intrudes the Permian Calen Coal Measures and Carmila beds. The Neilson Leucogabbro produced a narrow hornfelsed aureole that stands up as a prominent rim. The order of emplacement of the phases is Neilson Leucogabbro, Blackwood Quartz Syenite, Jukes Granite, and probably Seaforth Microgranite.

The complex is Oligocene, based on K–Ar dating by McDougall & Slessar (1972), who obtained ages of 34Ma and 33Ma (recalculated) on biotite and alkali feldspar from the Blackwood Quartz Syenite. Similar ages were obtained from the Cape Hillsborough Volcanics to the north.

MOUNT CHRISTIAN GRANODIORITE

Introduction

The Mount Christian Granodiorite is a small intrusion of ~0.3km^2 that crops out 3km north-west of Ilbilbie, in north-eastern CARMILA. It is characterised by subdued topography and forms a low, north-easterly trending ridge, which crosses the Bruce Highway. The unit is named after Mount Christian railway siding, ~4km to the north-west.

Type locality

The unit is very well exposed in a cutting at MGA 742795 7600915 on the recently built Sarina–Carmila tramway, where it has been quarried for ballast. This is the designated type locality for the unit.

Lithology

The unit consists of pale grey, fine-grained, slightly porphyritic, leucocratic biotite granodiorite, containing numerous small plagioclase phenocrysts up to ~3mm long, as well as scattered phenocrysts of quartz up to ~1mm across and biotite up to ~1.5mm long. Some quartz phenocrysts have slightly embayed or corroded margins. Biotite (~3–5%), pleochroic from dark reddish brown to pale yellow, is the main mafic mineral. K-feldspar is present in minor amounts and is confined to interstices between plagioclase laths where it locally forms granophyric intergrowths with quartz.

The granodiorite is slightly altered, calcite and sericite being the main secondary minerals. Traces of chlorite (after biotite) are also present in some samples.

Geophysical response

The granodiorite could not be distinguished from adjacent units using the geophysical data. It has low to moderate potassium, thorium and uranium radiometric responses that result in mainly blue to bluish pink hues on composite images.

It has a low magnetic response. No magnetic susceptibility measurements were made.

Relationships and age

The granodiorite was emplaced as a sill-like body into thin to medium-bedded mudstone and feldspathic sandstone, and massive rhyolitic ignimbrite of the early Permian Carmila beds. The gently dipping contact between the two units is well exposed in the cutting on the western side of the tramline. The granodiorite has a chilled margin with fine flow banding present locally. The chilled margin also contains rare small enclaves of mudstone, although the sedimentary rocks adjacent to the contact do not show any significant hornfelsing.

The age of the granodiorite is poorly constrained. It is tentatively regarded as having been emplaced in either the Early Cretaceous or Tertiary.

WEST HILL GRANODIORITE

Introduction

The West Hill Granodiorite (~2.5km^2) forms most of West Hill Island, from which the name is derived. The island is ~11km north-east of Carmila in CARMILA, and is separated from the mainland by a narrow strip of unconsolidated estuarine and coastal deposits, which are exposed during extra-low tides and provide a connection between the island and mainland. The granodiorite forms low cliffs, rocky headlands, and other prominent outcrops around the coastline of the island. It also forms a small rocky headland on the mainland opposite West Hill Island.

Type area

The type area is designated on the eastern and southern sides of the island, extending from MGA 757980 7583320 to MGA 758115 7584205. The unit is well exposed in this area, mainly in cliff faces.

Lithology

The granodiorite consists of dark grey to locally dark greenish grey (altered), very fine-grained (average grainsize of groundmass grains < 0.3mm), slightly porphyritic hornblende granodiorite. Phenocrysts consist of plagioclase laths up to ~8mm long (most <3mm) and rare hornblende laths up to ~1mm long. Sparse glomeroporphyritic aggregates up to ~5mm in diameter of plagioclase phenocrysts and microphenocrysts are also present. Greenish brown hornblende (~4–5%) is the main primary mafic mineral in the samples examined from the island. Chlorite is relatively common, mainly as aggregates of fine grains in interstices and also after hornblende. The rocks also contain scattered granules of opaque minerals and minor epidote (mainly as a replacement of plagioclase and in interstices).

Greenish grey granodiorite forming the headland on the mainland, opposite West Hill Island, contains abundant epidote and chlorite, the primary mafic minerals having been virtually completely replaced.

The granodiorite on the island is characterised by the presence of numerous closely spaced joints and irregular fine layering or flow banding. In contrast, it forms massive outcrops on the nearby mainland, commonly with well-developed flow banding.

The unit is locally cut by epidote-rich veins, up to ~3cm wide.

Geophysical response

The western part of the West Hill Granodiorite (the only part covered by the geophysical survey) has a low to moderate potassium response and very low thorium and uranium radiometric responses that result in dark red tones on a composite image. The magnetic response is low to moderate on aeromagnetic images. No magnetic susceptibility readings were made.

Relationships and age

The granodiorite intrudes the Campwyn Volcanics and is overlain by unconsolidated Cainozoic deposits.

The age of the unit is poorly constrained. The granodiorite is texturally distinct from any of the known early Cretaceous (or older) intrusives in the region. It is, therefore, tentatively interpreted to have been emplaced in the Tertiary.

GEOCHEMISTRY OF THE CRETACEOUS AND TERTIARY PLUTONIC ROCKS

Tectonically, the Cretaceous to Tertiary in central Queensland is characterised by crustal extension and graben development, as distinct from the Carboniferous to Triassic which is characterised by convergence and subduction-related igneous activity (Gust & others, 1996; Bryan & others, 1996; Korsch & Totterdell, 1996). However, the geochemistry of the intrusive rocks does not reflect this change in tectonic setting. The analyses of the Cretaceous rocks in Figures 142 and 143 overlap those of the Urannah batholith and Connors Arch and there are no criteria that can be used to separate them. Like the Palaeozoic rocks, they are Sr undepleted and slightly Y depleted and the similar chemistry indicates that they were probably derived from melting similar sources.

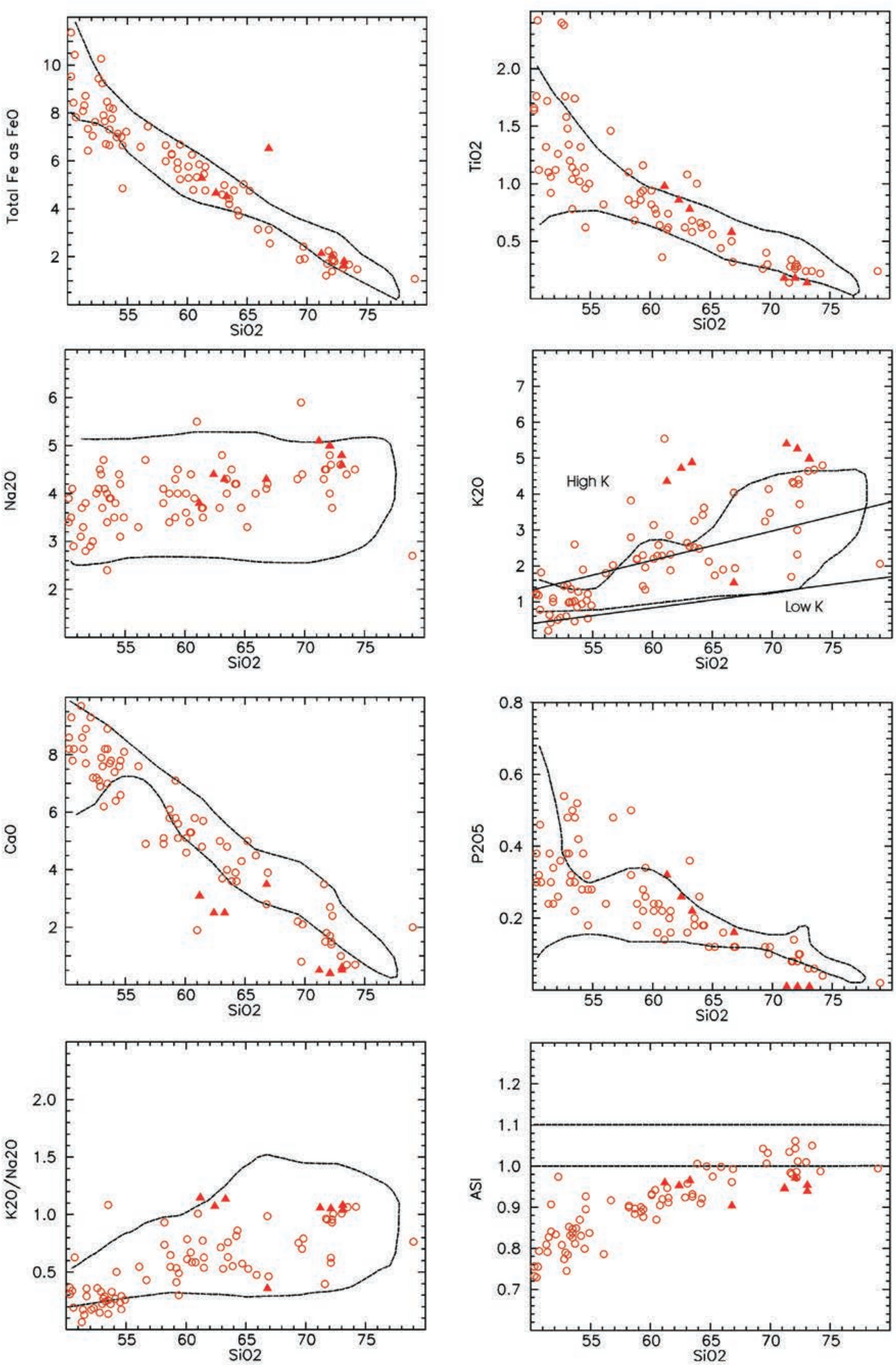

Figure 142. Variation diagrams for Cretaceous and Tertiary plutonic rocks from the Connors–Urannah area showing selected major elements in weight percent and the Alumina Saturation Index (ASI) vs SiO_2 in weight percent. Symbols are Cretaceous plutons (brown circles) and Tertiary plutons (red triangles). The fields are for the Late Carboniferous to Early Permian plutonic rocks of the Auburn Arch.

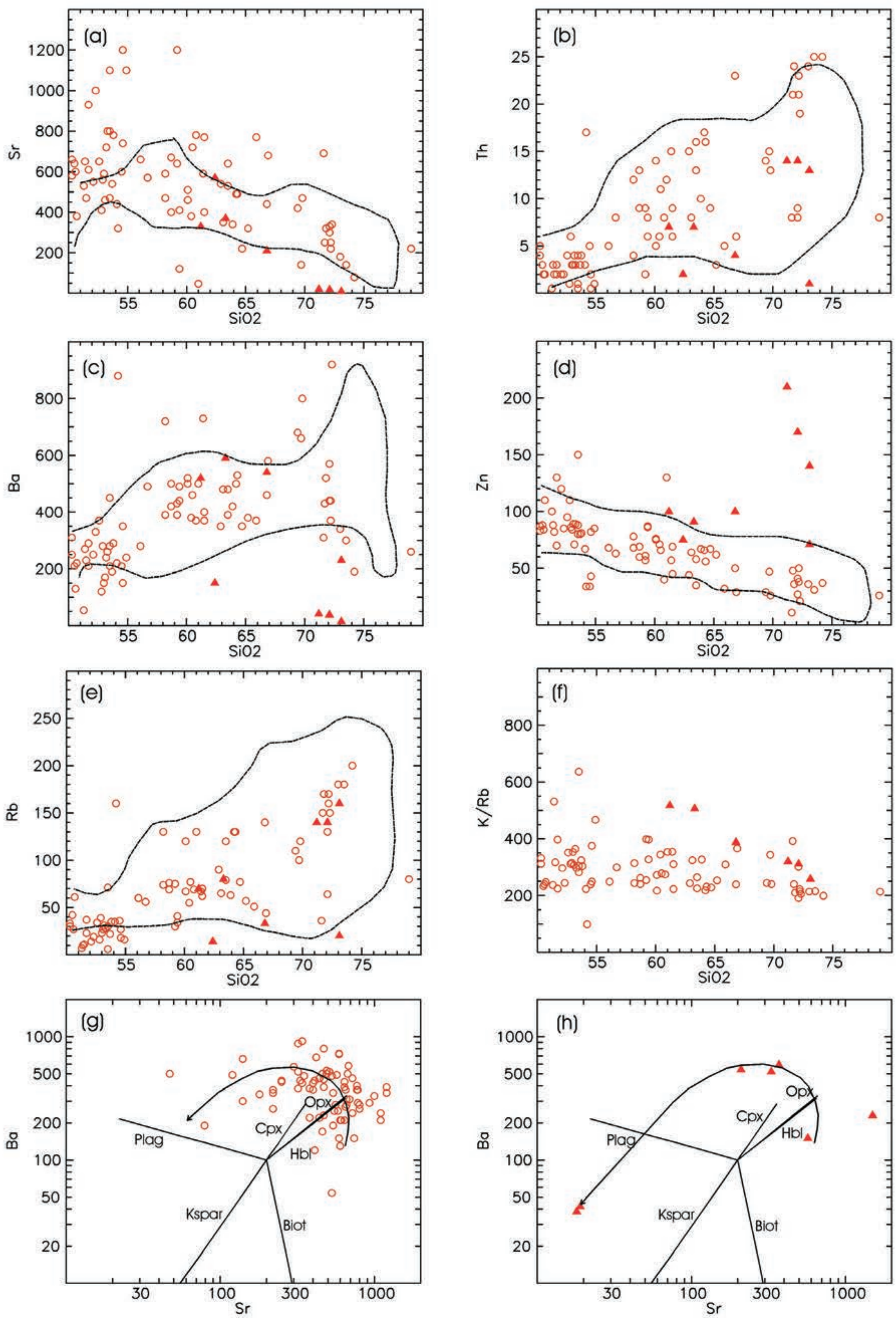

Figure 143. Variation diagrams for Cretaceous and Tertiary plutonic rocks from the Connors–Urannah area showing selected trace elements in parts per million and K/Rb vs SiO_2 in weight percent. The fields are for the Late Carboniferous to Early Permian plutonic rocks of the Connors Arch. Mineral vectors in (g) and (h) are from Rollinson (1993, page 161) and show fractional crystallisation trends for Ba and Sr for the various minerals shown. The arrowed lines show approximate overall fractionation trends for the samples plotted. Symbols are Cretaceous plutons (brown circles) and Tertiary plutons (red triangles).

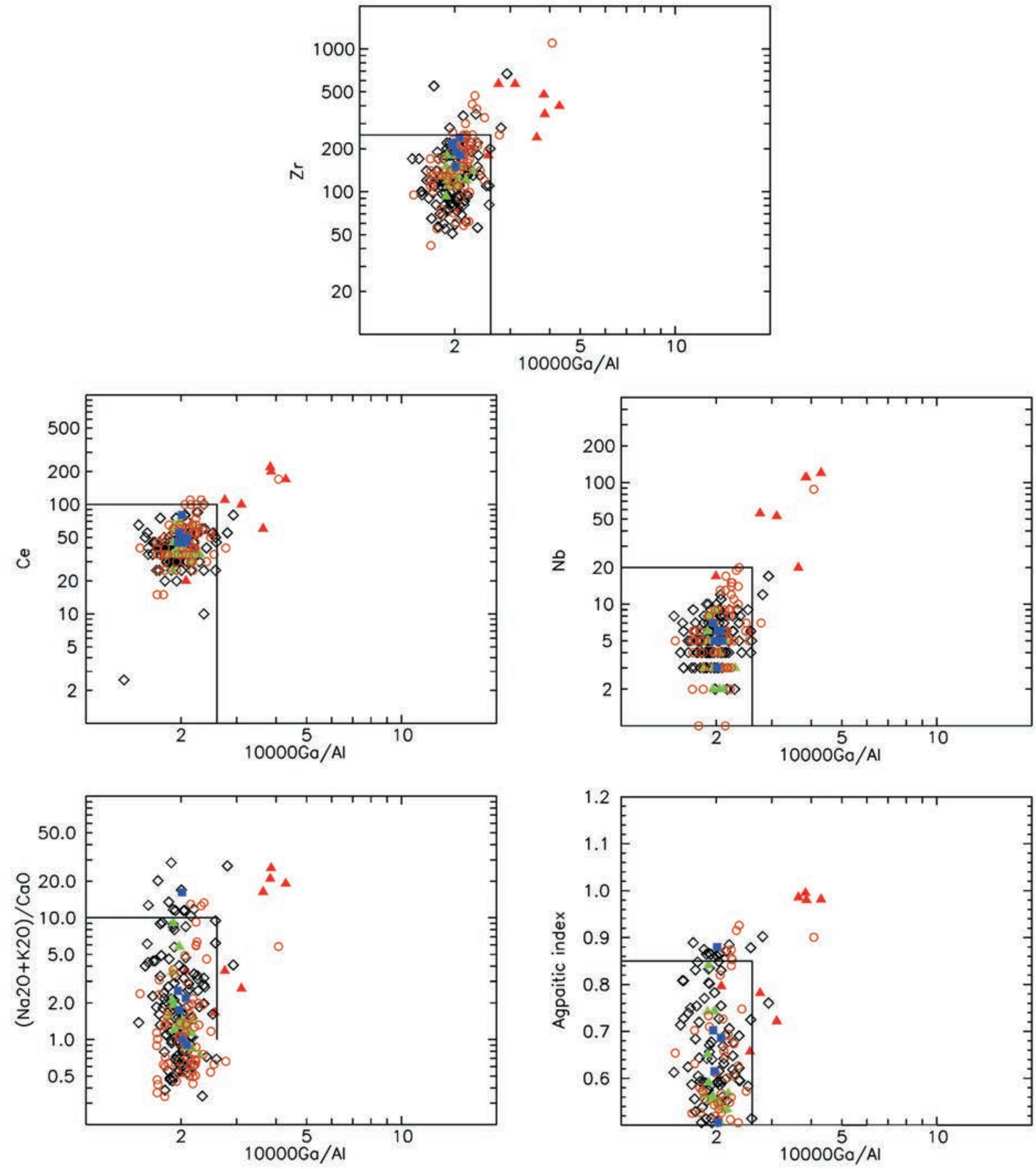

Figure 144. Plots of selected trace elements in parts per million and major element ratios vs 1000Ga/Al for for Carboniferous to Permian and Cretaceous and Tertiary plutonic rocks from the Connors–Urannah area. Agpaitic Index is molar (Na_2O+K_2O)/Al_2O_3). Fields for orogenic granites in the bottom left corners are from Whalen & others (1987). Symbols are as shown in Figures 109, 133 and 142.

However, Tertiary plutonic rocks from the Mount Jukes Intrusive Complex, which range from unfractionated to highly fractionated, are significantly different. They display A-type chemistry in the plots of Whalen & others (1987) (Figure 144) consistent with the 'within-plate' setting suggested by the Rb vs Y+Nb plot (Figure 146). K_2O, Zn, Zr, Ce, Nb and Ga/Al is higher than in the Cretaceous granitoids (Figures 142 and 143). The Agpaitic Index of four of the samples is ~1 suggesting that they are close to being peralkaline (Figure 144). A sample from a dacite dyke that is tentatively assigned to the Cretaceous has high Ga/Al and is probably Tertiary. The Tertiary rocks are Sr depleted and Y enriched (Figure 145) indicating a source above the eclogite zone.

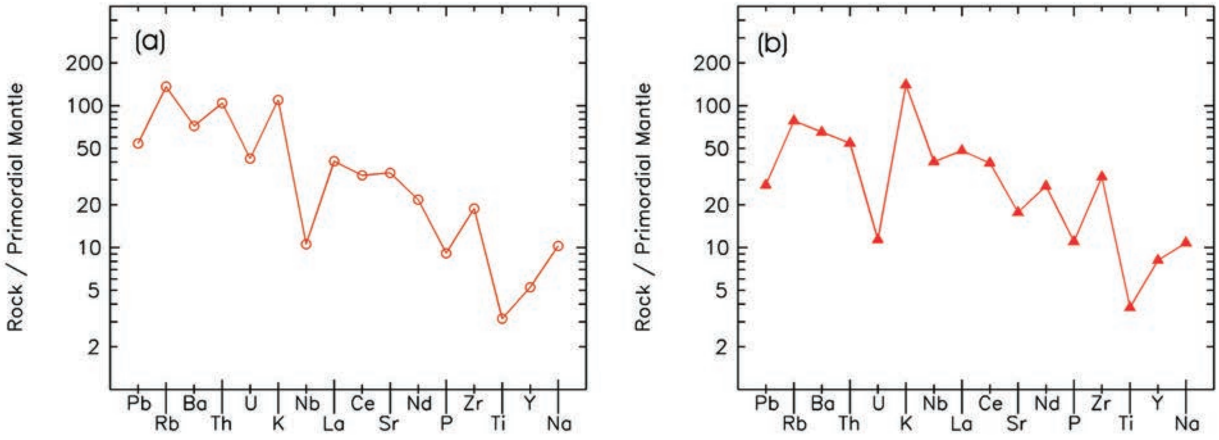

Figure 145. Spider diagrams normalised against the primordial mantle values of McDonough (1987) for average analyses of samples in the range 55–70% SiO_2 for granitoid groups from the Connors–Urannah area: (a) Cretaceous plutons; and (b) Tertiary plutons.

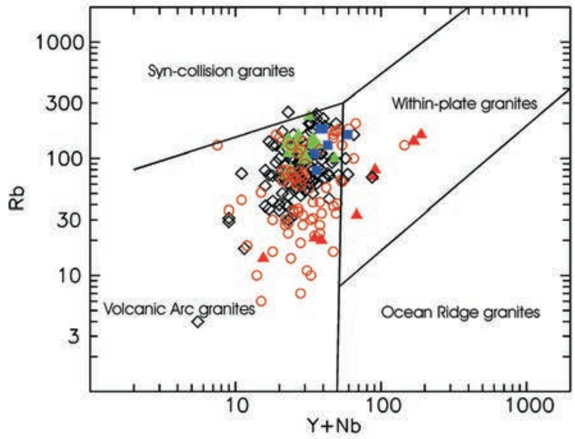

Figure 146. Plots of Rb vs Y+Nb in parts per million for plutonic rocks from the Connors–Urannah area. Fields are from Pearce & others (1984).
Symbols are as shown in Figures 109, 133 and 142.

PERMIAN PLUTONIC ROCKS IN AND ADJACENT TO THE MARLBOROUGH BLOCK

CLEETHORPES GRANODIORITE

Introduction

This name is given to a large embayed, somewhat circular pluton ~100km^2 in area straddling the Bruce Highway east from Marlborough township (Figure 28). The name is derived from Cleethorpes homestead. The granodiorite forms low relief compared with the ultramafic rocks of the Princhester Serpentinite, and is very poorly exposed, and partly covered by alluvium along Marlborough Creek and its tributaries.

Type locality

The type locality is at MGA 795010 7469730 at the crossing of Marlborough Creek by the Coonumburra road. A pavement of fresh, grey, medium-grained, equigranular hornblende-biotite granodiorite crops out in the creek bed just upstream of the causeway.

Lithology

The only fresh outcrop examined was that at the type locality, although the weathered material in new cuttings along a realignment of the Bruce Highway provided useful information on the character of the unit, and indicates that it is relatively uniform.

The granodiorite is pale grey, medium-grained and equigranular. A thin section from the type locality consists of: quartz (25%) to 3mm; K-feldspar (10%) as sporadic anhedral microcline grains to 5mm, poikilitically enclosing plagioclase and the mafic minerals; plagioclase (55%) as subhedral laths of andesine, mostly <3mm and showing only weak oscillatory zoning; biotite (5%) as slightly chloritised, dark brown flakes to 1.5mm; and hornblende (5%) as brownish green, prismatic crystals to 2mm. Accessory minerals include opaque oxides and minor titanite and zircon. Dioritic xenoliths up to 20cm with rounded, elliptical outlines are common.

Geophysical response

The Cleethorpes Granodiorite has a moderate to strong potassium response and low uranium and thorium that result in strong reddish hues on composite radiometric images.

The pluton has a moderate magnetic response that contrasts with the low response of the Marlborough Metamorphics and the very strongly magnetic Princhester Serpentinite. Magnetic susceptibility measurements at the type locality were 1400–2200 x 10^{-5} SI units, and measurements on weathered material were 100–800 x 10^{-5} SI units.

Relationships and age

The Cleethorpes Granodiorite lies within the Marlborough Block, and has intruded and hornfelsed the Palaeozoic Marlborough Metamorphics and ultramafic rocks of the Princhester Serpentinite. K–Ar dating of biotite and hornblende from three samples (GA1053A and 1053B from the type locality, and GA5256 from nearby) gave Early or Middle Triassic ages ranging from 235±5Ma to 243±5Ma (Webb *in* Malone & others, 1969, table 3; Webb & McDougall, 1968, table XIV; ages adjusted for decay constants of Steiger & Jäger, 1977). The plotted locations on MARLBOROUGH and in the Central Queensland GIS are based on conversion of the yard grid references of Webb & McDougall (1968) and are not accurate. These are minimum ages and could have been partly reset. Therefore, the granodiorite is probably in the range late Permian or Early Triassic.

COPPERVILLE GRANODIORITE

Introduction

This name is given to a small pluton in central eastern MARLBOROUGH (Figure 28). It is ~2.3km^2 in area, cropping out along the Glenprairie road, ~11km north of Marlborough township and north-west of Copperville homestead, from which the unit is named. The unit forms recessive topography that contrasts with the surrounding, more resistant Glenprairie beds, which have been hornfelsed by the granodiorite and Aitken Creek Gabbro.

Type area

The type area is along the Glenprairie road from MGA 796510 7484580 to MGA 796710 7485130, and includes a variety rocks including grey, medium-grained, equigranular, hornblende-biotite granodiorite, quartz diorite or diorite and porphyritic microdiorite.

Lithology

Only one sample has been examined in thin section. It is a medium-grained, equigranular to seriate hornblende-biotite granodiorite. It consists of: quartz (25%) to 2mm; K-feldspar (20%) as sporadic, anhedral microcline crystals to 7mm, poikilitically overgrowing plagioclase, biotite and hornblende; plagioclase (45%) as subhedral laths to 2mm, showing strong oscillatory zoning from andesine to oligoclase; biotite (5%) as dark brown subequant flakes to 2mm, only slightly chloritised; hornblende (5%) as bluish green poikilitic prisms to 3mm; and accessory titanite and opaque oxides. The quartz diorite, in hand specimen, is grey, usually medium-grained and has plagioclase phenocrysts up to 5mm; hornblende is probably dominant over biotite. The microdiorite has phenocrysts of plagioclase to 3mm and hornblende to 3mm in a very fine-grained groundmass.

Geophysical response

The unit has moderate potassium, thorium and uranium responses that result in pinkish grey hues indistinguishable from the adjacent Glenprairie beds.

The unit forms a magnetically low area, but it may be reversely magnetised because it has moderately high magnetic susceptibility (800–2500 x 10^{-5} SI units).

Relationships and age

The Copperville Granodiorite intrudes the Permian Glenprairie beds. It is in mapped contact with the Aitken Creek Gabbro, but the relationship is not known. The K–Ar ages discussed below suggest that the granodiorite may be younger.

K–Ar dating of biotite and hornblende from GA1054 and GA5265, granodiorite samples from the type area, gave Early Triassic ages of 244±5Ma to 248±5Ma (Webb *in* Malone & others, 1969, table 3; Webb & McDougall, 1968, table XIV; ages adjusted for decay constants of Steiger & Jäger, 1977). Two diorite samples (GA1163 and GA5266) gave similar K–Ar biotite and hornblende ages ranging from 243±5Ma to 250±5Ma. Allowing for the possibility of resetting, the Copperville Granodiorite is regarded as latest Permian or Early Triassic.

AITKEN CREEK GABBRO

Introduction

As exposed, the Aitken Gabbro forms an L-shaped pluton ~10km^2 in area, ~12km north of Marlborough township in central eastern MARLBOROUGH. The name is derived from Aitken Creek, which drains the outcrop area. The gabbro is well exposed and forms two prominent ridges, one on the western side of the Glenprairie road and the other to the north of the Belah Valley road.

Type locality

The type area of the Aitken Creek Gabbro is along the Glenprairie road from MGA 797060 7486060 to MGA 796360 7487930, and includes varieties of dark grey, medium to coarse-grained gabbro, variously containing olivine, hypersthene, hornblende or biotite in addition to plagioclase, augite and magnetite.

Lithology

The Aitken Creek Gabbro was examined along the Glenprairie and Belah Valley roads and consists dominantly of dark grey, medium to coarse-grained hornblende-pyroxene gabbro. Some gabbros show aligned plagioclase and elongate mafic mineral aggregates, but no clearly defined layering was observed. Large ophitic crystals of pyroxene or hornblende up to 3cm are present in some outcrops.

Two thin sections from the type area were examined. Both contain ~60% laths of plagioclase (labradorite or bytownite) up to 7mm long, and 25% subequant to subelongate augite to 2.5mm. In the sample from MGA 797060 7486030, green hornblende (10%) rims and partly replaces the augite and also forms discrete grains up to 2mm; olivine (5%) forms cores to hornblende and augite, and is partly altered to iddingsite.

The other sample is from MGA 796360 7487930 at the northernmost extent of the type area. It contains hypersthene (5%) as subequant grains to 1mm and dark reddish brown biotite (5%), commonly rimming magnetite grains, but also as larger poikilitic flakes to 3mm that are conspicuous in hand specimen. Both rocks contain up to 5% magnetite grains to 1mm across.

Geophysical response

As expected from its mafic nature, the Aitken Creek Gabbro has very low responses in all three radiometric channels and is dark grey to black on composite images.

It has a very strong magnetic response, producing an elliptical annular pattern, surrounding a relatively less magnetic zone. The annulus is ~11km long and 6km wide, trending north-east. Only the western and southern parts of the annulus are exposed, the remaining parts, including the inner zone, are covered by Quaternary alluvium. The inner zone may be a more felsic pluton. Magnetic susceptibilities are mostly in the range 3000–12 000 x 10^{-5} SI units (and rarely up to 26 000 x 10^{-5} SI units).

Relationships and age

The Aitken Creek Gabbro intrudes the Permian Glenprairie beds. It is mapped in contact with the Copperville Granodiorite, but the relationship is not known. The K–Ar ages discussed below suggest that the granodiorite may be younger and this is consistent with the outcrop pattern. It is possible that the more poorly magnetic, unexposed inner zone of the magnetic anomaly described above could be a later intrusion similar to the Copperville Granodiorite.

K–Ar dating of biotite and hornblende from GA1164 and GA5264, hornblende diorite or gabbro samples from the Glenprairie road, gave ages of 249±5Ma to 255±5Ma, straddling the Permian–Triassic boundary (Webb *in* Malone & others, 1969, table 3; Webb & McDougall, 1968, table XIV; ages adjusted for decay constants of Steiger & Jäger, 1977). The samples are plotted within the Copperville Granodiorite on MARLBOROUGH, but this is based on conversion of the yard grid references reported by Webb & McDougall (1968). The reported coordinates or conversion may not have been accurate, because the locations as plotted on the Saint Lawrence First edition 1:250 000 geological map show them in what is now mapped as Aitken Creek Gabbro. Sample GA5263 from a small body of hornblende gabbro near the Belah Valley road was also dated and gave an age of 253±5Ma. It may be related to the Aitken Creek Gabbro.

The age range is slightly older than that for the Copperville Granodiorite, although allowing for experimental error (±2%), there is some overlap. Allowing for the possibility of resetting by a later thermal pulse, the Aitken Creek Gabbro is probably late Permian.

RACECOURSE CREEK GABBRO

Introduction

The Racecourse Creek Gabbro crops out as an elongate slightly arcuate body aligned east–west near Racecourse Creek (from which the name is derived), ~7km south of Marlborough township (Figure 28). It has an area of ~5km^2.

Type locality

The only outcrops examined in this survey are along Coonumburra Road near Marlborough homestead. The outcrop at MGA 794610 7468180 is designated as the type locality and consists of dark greenish grey, medium to coarse-grained hornblende-augite gabbro.

Lithology

The unit consists of hornblende-augite gabbro as at the type locality. In thin section it consists of plagioclase (50%) as subhedral laths of labradorite to 3mm, augite (25%) as sub-ophitic crystals to 3mm and cores in hornblende (20%), which forms ophitic crystals to 5mm and rims on the clinopyroxene. Magnetite forms discrete grains to 1mm and also small vermiform inclusions in some augite grains.

Geophysical response

The gabbro has a relatively low response in all three radiometric channels, although not quite as low as for the adjacent Princhester Serpentinite so that it produces purple hues rather than appearing black on composite images.

It is has a strong magnetic response in the airborne data, consistent with the measured magnetic susceptibility, which is in the range 5000–10 000 x 10^{-5} SI units.

Relationships and age

The Racecourse Creek Gabbro crops out along the southern margin of the Cleethorpes Granodiorite, but the relationship between them is not known. A K–Ar hornblende age of 245±5Ma was determined for this body (GA5257; Webb *in* Malone & others, 1969, table 3; Webb & McDougall, 1968, table XIV; age adjusted for decay constants of Steiger & Jäger, 1977). It is therefore probably similar in age to the granodiorite and may be late Permian or Early Triassic.

MAGOG GABBRO

Introduction

This name was first given by Harbort (2001) and Harbort & others (2001) to gabbro intruding the Marlborough Block, but was not published or defined. The rocks were not examined during the survey, because the Marlborough Block was considered to be outside the original scope of the project. It is described briefly here for completeness. The gabbro crops out in the Magog Range ~10km north-east of Marlborough township (Figure 28), and forms several prominent hills including Mount Magog (from which the name is derived) and Mount Gog. The exposed area is only ~12km^2, but the geophysical data suggests that it may be more extensive under cover to the north and extend to The Cousins, totalling ~30km^2. Because we did not examine the unit, no type area is designated.

Lithology

The unit was described in Harbort's map legend as coarse to very coarse-grained hornblende gabbro with minor hornblende monzonite, although Kirkegaard & others (1970, table 4) described it as biotite-hornblende gabbro. It is probably similar to the Racecourse Creek Gabbro.

Geophysical response

Although the airborne radiometric data show some effects of levelling difficulties due to the rugged terrain, the Magog Gabbro generally has the very low response in all three radiometric channels that is typical of a gabbro and is represented by dark grey to black hues on the composite images.

It has a very strong magnetic response that indicates that it probably extends under cover to the north.

Age and relationships

The Magog Gabbro intrudes the Marlborough Metamorphics and may be intruded by the Og Syenite. Webb & McDougall (1968, GA5259 in table XIV) reported an age of 242±5Ma from Mount Moriah on PRINCHESTER (age adjusted for decay constants of Steiger & Jäger, 1997). Harbort (2001) and Harbort & others (2001) presented results of $^{40}Ar/^{39}Ar$ step-heating dating that included the Magog Gabbro and indicated plateau ages at ~255±2Ma and 242±3Ma. The latter was interpreted as a later thermal pulse that partially reset many of the other ages in the Marlborough Block, suggesting that the gabbro is late Permian. Harbort & others (2001) used the ages of these undeformed plutons in the Marlborough Block to constrain the age of emplacement of the block to ~253Ma.

OG SYENITE

Introduction

This name was first given by Harbort (2001) and Harbort & others (2001) to quartz syenite intruding the Marlborough Block, but was not published or defined. As for the Magog Gabbro, these rocks were not examined during the survey, but are described briefly here for completeness. The rocks crop out in the Magog Range ~10km north-east of Marlborough township and include Mount Og. The exposed area is only ~5.5km^2. Because the unit was not examined , no type area is designated.

Lithology

The unit was described in Harbort's map legend as coarse-grained biotite syenite.

Geophysical response

The Og Syenite has a low to moderate response in potassium and low responses in thorium and uranium and is represented by dark pinkish hues on the composite images. However, the radiometric data are probably unreliable due to levelling difficulties during processing because of the rugged terrain. It has a moderate magnetic response.

Age and relationships

The Og Syenite intrudes the Marlborough Metamorphics and is in contact with and may be intruded by the Magog Gabbro. Harbort (2001) and Harbort & others (2001) presented results of $^{40}Ar/^{39}Ar$ step-heating biotite dating that included the Og Syenite and indicated plateau ages at ~242±3Ma. This was interpreted as a later thermal pulse that partially reset many of the other ages in the Marlborough Block, suggesting that the syenite is late Permian.

Unnamed intrusions

Some small intrusions of diorite or gabbro, probably similar to the Racecourse Creek Gabbro, were mapped by Harbort (2001) south-west of Marlborough township and are assigned to unit $\mathbf{PRg_b}$. They were not examined in this survey.

Harbort also mapped some small intrusions, here assigned to unit $\mathbf{Pg_s}$, which he described as pegmatitic to coarse-grained tourmaline-garnet-muscovite granite. They are mapped within and adjacent to the Cleethorpes Granodiorite and Magog Gabbro and may intrude them. The rocks appear to be undeformed. Harbort (2001) presented results of $^{40}Ar/^{39}Ar$ step-heating dating of muscovite that indicated plateau ages that ranged from 251–254Ma, suggesting that the rocks are late Permian. Webb & McDougall (1968, table XVI, sample GA5258) dated muscovite from a pegmatite in PRINCHESTER to the east that gave a Late Triassic age of 223Ma (age adjusted for decay constants of Steiger & Jäger, 1977). The significance of this young age is not known.

STRUCTURAL GEOLOGY

AUBURN ARCH

The oldest rocks in the Auburn Arch are inferred to be the Yerilla Metamorphics that include multiply deformed biotite gneiss, mica schist and amphibolite. They are associated with deformed granitoids such as the Donore Granite Gneiss (foliated biotite granite and orthogneiss) and Horse Granite Gneiss (foliated biotite leucogneiss and mesocratic biotite ortho-gneiss). SHRIMP dating of the Donore Granite Gneiss gave an age of 349±6Ma (Tournaisian), which is inferred to be a magmatic age. The structure of these rocks is poorly known. The foliation in both the Yerilla Metamorphics and Donore Granite Gneiss generally dips steeply and strikes north-north-west (Figure 147a–b), although the dips in the latter unit are locally shallow as at the dated outcrop, and could reflect thrusting or even extension.

Other Carboniferous granitoids in the Auburn Arch include both foliated and non-foliated types. Foliated units include the Evandale Tonalite, Glissons Granodiorite and Coonambula Granodiorite. The foliation is weaker than in the orthogneiss units and defined by alignment of biotite, elongate xenoliths and quartz grains. It is moderately to steeply dipping and variable in strike (Figure 147d), although the Coonambula Granodiorite is characterised by shallowly dipping streaky layering and foliation (Figure 147c). The foliation in these granitoids may be partly igneous in origin, particularly that in the Coonambula Granodiorite.

The timing of the deformation and metamorphism is uncertain. It records an earlier deformation event than the main Hunter–Bowen Orogeny, because an unconformity between the early Permian Narayen Volcanics and foliated granite is well exposed at MGA 277465 7166200 near Giarka homestead (see pages 43–44 and Figure 17a,b). Cobbles of the foliated granite occur in the basal conglomerate. A similar unconformable relationship occurs between foliated granites and Carboniferous or Permian volcanic rocks tentatively assigned to the Narayen beds in the northern part of BARAKULA at MGA 263150 7120750. SHRIMP dating of some of the foliated Evandale Tonalite has given an age of 319±7Ma, and inherited zircon within the Coonambula Granodiorite gave an imprecise age of ~320Ma. The non-foliated Boam Creek Quartz Monzodiorite gave an age of 319±5Ma. It intrudes volcanic rocks assigned to the Torsdale Volcanics, which are not obviously deformed, and which gave a SHRIMP age of 324±4Ma.

In the Narayen beds, there are open folds at least in the Mount Narayen and Auburn areas. Dip reversals can be observed over distances in the order of 30m. Near Giaka homestead, towards the contact with the Yerilla Metamorphics, the rocks are much more strongly deformed, and have a strong cleavage and the rudites have flattened and elongated clasts similar to those in the Camboon Volcanics in the Gogango Thrust Zone. The reason for the stronger deformation is unknown, but it may be related to thrusting, and it could have juxtaposed the unit against the Yerilla Metamorphics. This may be a continuation of the Gogango Thrust Zone that is largely obscured by the late Permian to Early Triassic granitoids of the Rawbelle Batholith.

The lack of deformation in the Torsdale Volcanics and Camboon Volcanics in the Auburn Arch is illustrated by the plot of poles to bedding and igneous foliation in Figure 147e. The rocks dominantly dip shallowly to the west towards the Taroom Trough of the Bowen Basin to which they form the basement. The relatively few easterly dips are from the western limb of the Prospect Anticline. The Back Creek Group west of the Auburn

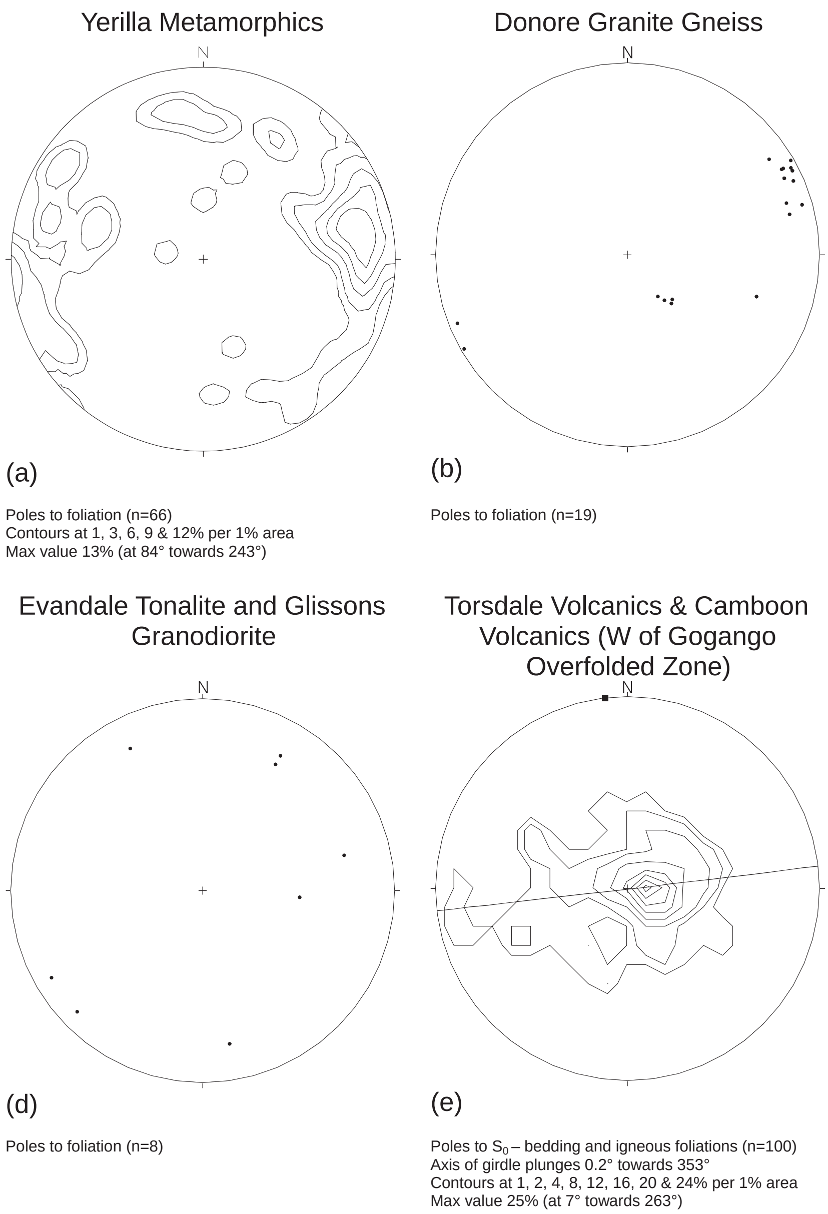

Figure 147. Structural data from the Auburn Arch

Arch has a similar attitude (Figure 154e) suggesting that the arching was largely due to the later Hunter–Bowen Orogeny.

The granites of the Auburn Arch are cut by several north-trending lineaments outlined in the airborne magnetic data as zones of demagnetisation up to 500m wide. The most prominent lineament extends south for ~100km from the Prospect Creek area in north-eastern THEODORE. Another lineament splays off it midway along its length and continues parallel to it, ~5km to the east, for ~50km to the south. Both lineaments appear to die out in the southern part of CRACOW, where less well-defined north-east to north-north-east trending lineaments are evident. Farther south, the granitoids are cut by a swarm of north-west-trending magnetic dykes that appear to obscure discrete linear features. The type of movement on these lineaments is not known, but appears to have been minimal, because in most cases they do not appear to form unit boundaries or displace them.

GOGANGO OVERFOLDED ZONE

The **Gogango Overfolded Zone** is one of the most significant structural features in the study area. It is characterised throughout by the development of strong east-dipping slaty cleavage (Figure 148) in mudstone and siltstone, although sandstone and volcanic rocks also commonly have a well-developed foliation, generally expressed as an anastomosing fracture cleavage or dissolution cleavage (Figure 150c). In more

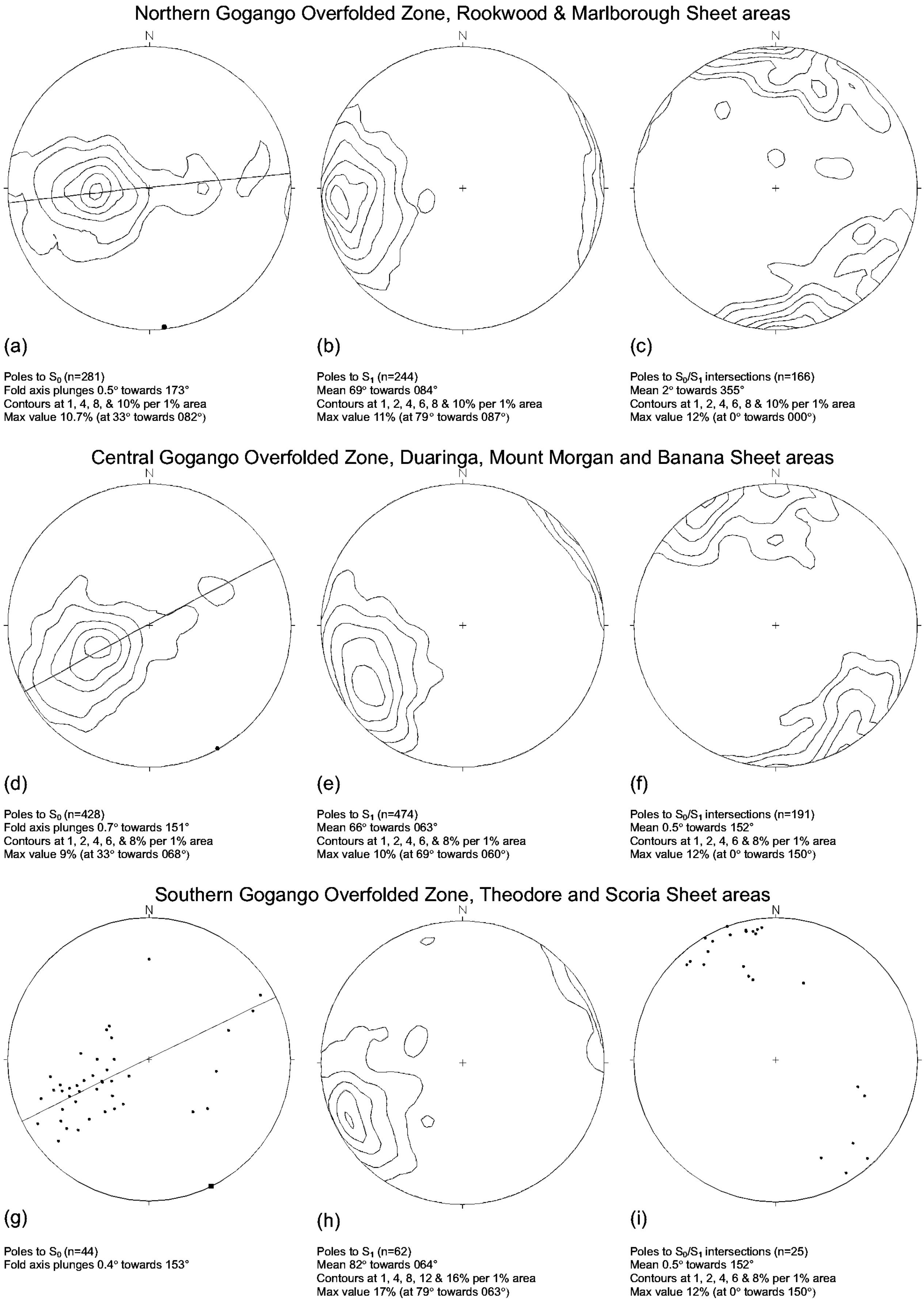

Figure 148. Structural data from the Gogango Overfolded Zone

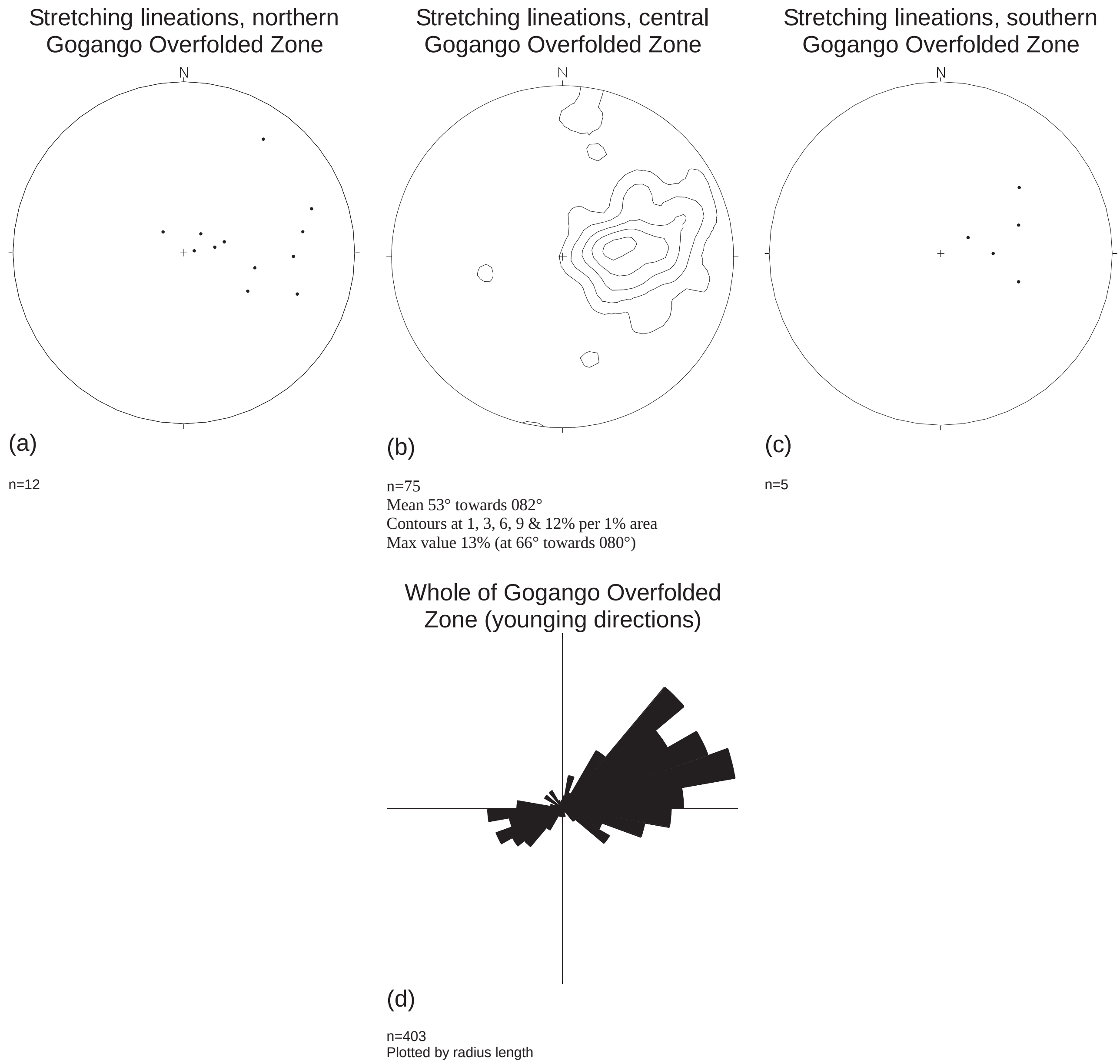

Figure 149. Structural data from the Gogango Overfolded Zone (continued)

intense zones, clasts in rudites and arenites are strongly flattened and commonly stretched (Figure 150d–e). Stretching lineations generally plunge east (Figure 149), and shear-sense indicators such as small-scale duplexes (Figure 150b,f) are consistent with an east-over-west transport. The intensity of deformation increases eastwards towards the major thrusts that form the western margin of the Rookwood Volcanics and the Yarrol Province.

In the northern part of ROOKWOOD, the western bounding thrust of the Yarrol Province is named the Develin Thrust. Farther south it appears to split into two lines, possibly due to a later out-of-sequence thrust, as discussed below. In southern MOUNT MORGAN and northern BANANA, the bounding thrust is named the Rannes Thrust. The Develin and Rannes Thrusts may be the same structure, but the Biloela Basin obscures continuity.

The most intensely deformed rocks observed were in the Gogango Range between Rannes and the Capricorn Highway mainly in the south-western part of MOUNT MORGAN and north-western BANANA. Volcanic rocks with strong fabrics (including flattened and stretched clasts) continue in a narrow zone at least 2km wide along the western margin of the Biloela Basin at least as far south as Drumberle in western SCORIA. These rocks crop out adjacent to another interpreted thrust, the Grevillea Thrust, which separates these deformed rocks from less deformed rocks assigned to the Yaparaba Volcanics that are considered to be part of the Yarrol Province. The Grevillea Thrust can be traced to the north-north-west under the Biloela Basin using the magnetic data, and appears to be a separate structure from the Rannes Thrust, although they probably intersect.

Figure 150. Deformation in the Gogango Overfolded Zone
(a) Overturned folds in undivided Back Creek Group in the Gogango Overfolded Zone. Cutting on old Emerald–Rockhampton railway line at MGA 798519 7375600 (IWGG499)
(b) Imbricate stack of small scale thrust faults indicating east over west movement. Cutting on old Emerald–Rockhampton railway line at MGA 798920 7375477 (IWGG498)
(c) Spaced dissolution cleavage in sandstone from undivided Back Creek Group. About 1km north-west of Mount MacIntosh at MGA 801771 7364486 (IWGG557)
(d) Stretched clasts in volcanic conglomerate of the Camboon Volcanics. Capricorn Highway ~9km west-south-west of Gogango at MGA 802491 7375130 (IWGG512)
(e) Stretched pebbles in conglomerate of the Camboon Volcanics. About 3.5km south-east of Mount Wheal at MGA 203312 7355479 (IWGG702)
(f) Small-scale thrust duplex in siliceous siltstone of the undivided back Creek Group. Leichhardt Highway ~4km north-east of Rannes township at MGA 208699 7334938

In ROOKWOOD and DUARINGA, field observations in the Gogango Overfolded Zone, aided by interpretation of the radiometric data, has outlined alternating belts of volcanic rocks, undivided Back Creek Group and Boomer Formation. These generally show a consistent eastward younging and have been interpreted as an imbricate stack of thrust sheets. Thrusts have been interpreted where younging is inconsistent with known stratigraphic relationships (*e.g.* massive mudstone in the lower part of the undivided Back Creek Group apparently overlying the Boomer Formation, or volcanic rocks overlying undivided Back Creek Group).

The plots in Figures 148 and 149 demonstrate the dominant, moderate dip of bedding (maximum concentrations in the plots at around 30°) towards the east to east-north-east and associated eastward younging throughout the belt. The general trends change from east-north-east in the central and southern sectors to north in the northern sector. The slaty cleavage generally has the same strike with mainly easterly dips. The cleavage dips are steeper than those for bedding, consistent with the dominant younging and a westward vergence.

The elongation of the clusters of poles to bedding suggests some folding with subhorizontal axes trending between south and south-south-east, which agrees with the plots of bedding-cleavage intersections in Figure 148. Mesoscopic fold closures are present locally. Although some limbs are overturned (Figure 150a), most folds are upright, and the description “overfolded” zone is somewhat of a misnomer. In our database, only 27 out of 403 measurements where younging could be demonstrated were on overturned beds with westward younging; another 91 measurements with westward younging were on beds that were right-way-up. Thus the **Gogango Thrust Belt** may be a more appropriate term for the belt. The folds indicated by the reversal of younging are probably thrust propagation folds in many cases.

Fergusson (1991) estimated that crustal shortening across the zone was 60%, consistent with the intensity of cleavage development. The zone terminates relatively abruptly to the west of Marlborough and farther north the Bowen Basin succession is only gently folded. The termination is probably a complex zone of linked tear faults that are the south-westerly continuation of the Stanage Fault Zone (Morand, 1993a; Henderson & others, 1993; Leitch & others, 1994; Holcombe & others, 1997a). The latter has been interpreted as a major tear fault system to the nappe emplacement of the Marlborough Block with dextral displacement of ~50km.

WEST OF THE GOGANGO OVERFOLDED ZONE

In western ROOKWOOD and MARLBOROUGH (extending into MOUNT BLUFFKIN), two anticlinal structures have been recognised, one forming the southern end of the Connors Arch, and the other referred to here as the **Leura Anticlinorium**. The intervening Apis Creek Syncline passes northwards into the Strathmuir Synclinorium in MARLBOROUGH. The structures are less well-defined south of Leura homestead towards the Mackenzie River and are replaced by a complex pattern of very open basin-and-dome folds. West of the Leura Anticlinorium, dips are relatively gentle, and folds are upright and open with overall subhorizontal northerly-trending axes (Figure 151a and c). In spite of the open nature of the folds, the mudstone and some sandstone still have a pronounced cleavage that dips to the east (Figures 151b and 152). The relatively shallow dip of the cleavage locally (such as around Mount Benmore homestead) relative to that farther east in the Gogango Overfolded Zone proper may be due to later regional arching in the vicinity of the Leura Anticlinorium. Several low-angle thrusts have also been recognised. They record east-over-west movement and can be recognised where the Mount Benmore Volcanics apparently overlie the Carmila beds.

In southern DUARINGA, several anticlinal cores of Camboon Volcanics have been mapped and may be a continuation of this zone.

In the western part of BANANA extending south-east into SCORIA, the Camboon Volcanics have local zones of relatively strong cleavage, and the Woolein beds are pervasively cleaved. The undivided Back Creek Group is moderately to strongly cleaved west of the Camboon Volcanics, although the cleavage weakens along the Leichhardt Highway south of Police Camp Creek. The area south of here was not examined by us, but was described by and Dear & others (1971) and included in the **Dawson Folded Zone** of Derrington (1962).

In this zone, north of Banana, the Barfield and Flat Top Formations define a series of folds reflected in the plot in Figure 151d. They include the Fergusson Syncline, which is an asymmetric structure with a gently dipping western limb and a steep eastern limb (the same sense of asymmetry as in the Gogango Overfolded Zone). Dear & others (1971) reported that ‘fracture cleavage’ is developed throughout the Dawson Folded Zone in the finer-grained sedimentary rocks and that the boundary with the Gogango Overfolded Zone was transitional. The boundary between the Camboon Volcanics and undivided Back Creek Group in BANANA is interpreted as a thrust, at least in the north, where the volcanic rocks apparently overlie the younger

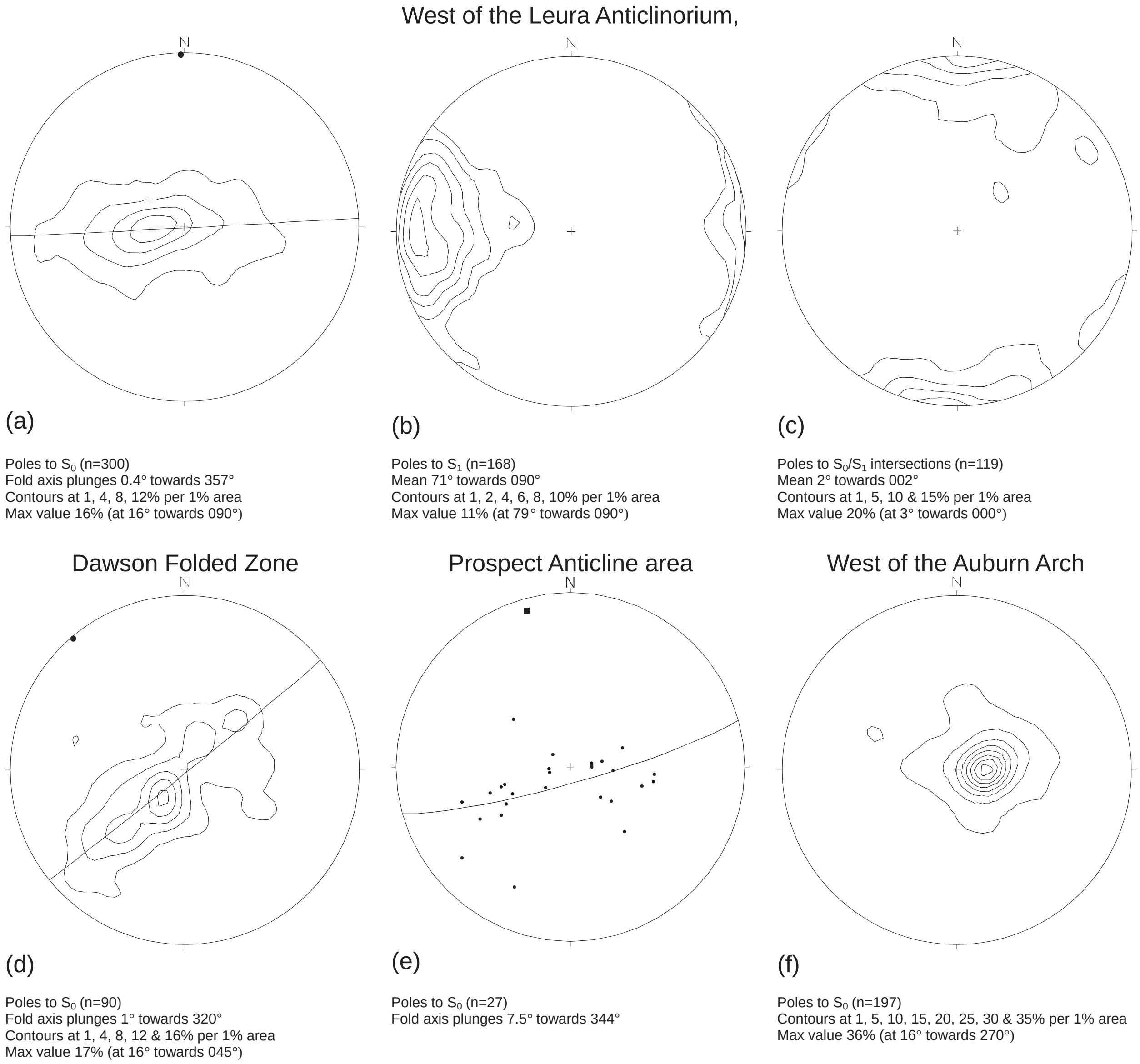

Figure 151. Structural data from the Back Creek Group west of the Gogango Overfolded Zone

Figure 152. Gently dipping sandstone and mudstone of the Boomer Formation west of the Gogango Overfolded Zone. Note the strong crosscutting cleavage, even in the thick, competent sandstone beds. Access road to Roselea homestead at MGA 768246 7420013 in western ROOKWOOD (IWGG160)

sediments. Farther south on the eastern limb of the Fergusson Syncline, which is locally overturned, the boundary may be stratigraphic.

The western boundary of the Dawson Folded Zone is marked by the Banana Thrust, which thrusts the Barfield Formation westward over the Gyranda Subgroup. At its southern end in northern THEODORE, the thrust swings eastward towards the core of the Auburn Arch. South-west of this thrust, the Camboon Volcanics and other Permian rocks lie on the eastern limb of the Mimosa Syncline and dip gently to the west (Figure 151f).

In eastern THEODORE, between the Auburn Arch and the southern extension of the Gogango Overfolded Zone, relatively open folds deform the Permian rocks, the most prominent of which is the Prospect Creek Anticline (Figure 151e). It is bounded to the west by the Dry Creek Fault, which separates the anticline from the Auburn Arch. On the east is the Prospect Creek Fault, which is probably a thrust. Farther east, the Drumberle Fault separates the folded zone from the strongly cleaved rocks of the Gogango Overfolded Zone. A cleavage is generally not developed in the Prospect Creek Folded Zone.

EAST OF THE GOGANGO OVERFOLDED ZONE

As already noted, the Rookwood Volcanics are interpreted as defining the leading edge of a major thrust sheet that overlies the more deformed rocks of the Gogango Overfolded Zone, and defines the western margin of the Yarrol Province. From north to south, segments of the western-bounding thrust are named the Develin, Comanche and Rannes Thrusts.

The Rookwood Volcanics and the underlying Youlambie Conglomerate and overlying Moah Creek beds are much less deformed the rocks to the west. This is illustrated in Figure 153d–e by some data collected in RIDGELANDS and MOUNT MORGAN by the Yarrol Project Team. In the Moah Creek area, bedding is relatively shallowly dipping with no well-defined fold directions, and slaty cleavage is relatively rare.

In the Develin Creek area (Figure 153a), the plot of data collected partly by Rod Holcombe (UQ) defines an open girdle suggesting fold axes plunging moderately to the north. Although a cleavage is present in the sedimentary rocks, the volcanic rocks do not have a foliation like that in the Gogango Overfolded Zone. South-west of Home Hill homestead, an area of Moah Creek beds has been mapped overlying the Rookwood Volcanics and is interpreted as the core of an open syncline.

The relationships of the large outcrop belt of Rookwood Volcanics west of the Comanche Thrust in the area around Rookwood and Ohio homesteads are uncertain. The sinuous boundaries transect bedding trends in the surrounding Back Creek Group and the belt is inferred to be thrust bound to both the east and west. The western-bounding fault may represent the Comanche Thrust (the main leading edge of the thrust sheet), and the eastern-bounding fault could be a later out-of-sequence thrust that has resulted in younger undivided Back Creek Group rocks from the underlying sheet being thrust over the Rookwood Volcanics. Its location farther north is inferred by linking the main belt with two small outcrop areas of Rookwood Volcanics. The Develin Thrust that forms the western margin of the Rookwood Volcanics north from here could be a continuation of this inferred thrust rather than the Comanche Thrust, hence its separate name. South-east of Rookwood in northern DUARINGA, several smaller outcrop areas of Rookwood Volcanics alternating with Back Creek Group have also been mapped, either from fieldwork and photo-interpretation or by magnetic interpretation. These could represent a succession of imbricate thrusts. The rocks mapped as Back Creek Group could stratigraphically overlie the Rookwood Volcanics, rather than being thrust, and therefore could possibly be assigned to the Moah Creek beds (which are of course a correlative of the Back Creek Group).

East of the Rookwood Volcanics in the Craigilee area in eastern ROOKWOOD extending into RIDGELANDS, a belt of older Silurian to early Carboniferous rocks including the Craigilee beds, Mount Alma Formation and Rockhampton Group are folded by an open anticlinal structure (the Craigilee Anticline) interpreted by Holcombe & others (1997a) to be a breached fault-propagation fold above a major thrust. Farther east, the rocks of the Yarrol Province are commonly only weakly folded and rarely cleaved, for example in the Mount Morgan – Dee Range area, where the sequence dips shallowly west-south-west (Figure 153f).

East of the Grevillea Thrust, which is the eastern bounding fault of the Gogango Overfolded Zone south of the Biloela Basin, the Yaparaba Volcanics are also only weakly deformed and the few dips measured are relatively shallow as shown in Figure 153i. Farther south, the Rawbelle Batholith obscures the Gogango Overfolded Zone and the position of the Grevillea Thrust is uncertain. The Nogo beds lie east of the Rawbelle Batholith and are here inferred to be part of the Yarrol Province (Nogo Subprovince). Their structure has not been studied in detail either, but bedding defines a girdle, suggesting open folding plunging shallowly to the

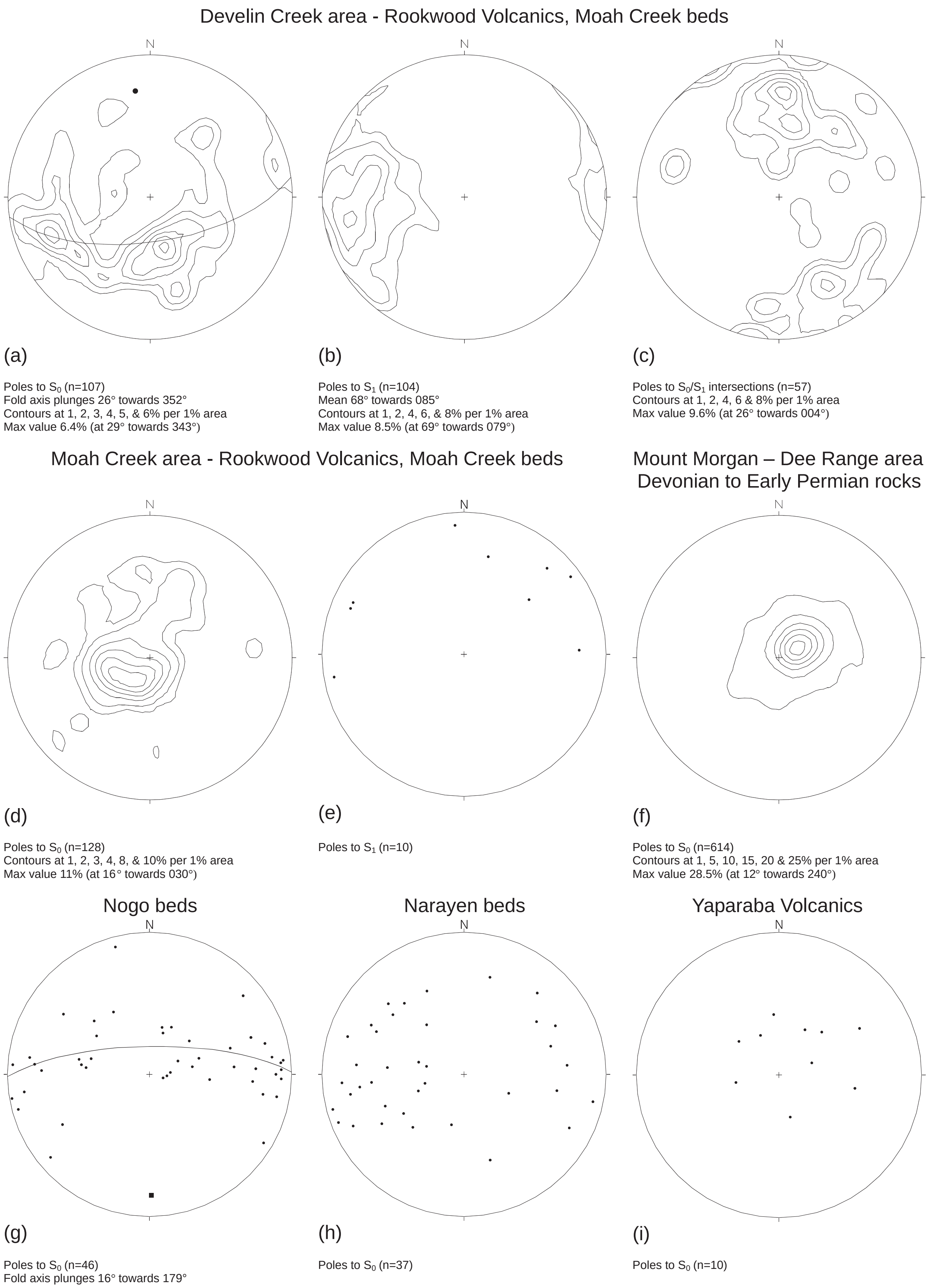

Figure 153. Structural data from east of the Gogango Overfolded Zone

south (Figure 153g). Dips in the Narayen beds are moderate, but are too scattered to define a pattern (Figure 153h), possibly due to disruption by the intrusion of the Rawbelle Batholith.

CONNORS ARCH

The Connors Arch is dominated by volcanic and granitic rocks that form basement to the Bowen Basin. Because the Carmila beds overlap in age with the Leura Volcanics and Mount Benmore Volcanics, they are also considered to be part of the Connors Arch and not the Bowen Basin.

Day & others (1978) proposed that the Connors Arch formed the eastern margin of the Bowen Basin during the early Permian and that the Permian sedimentary rocks to the east formed in a separate deep-water basin, the Grantleigh Trough, which included the Gogango Overfolded Zone. Previously, Malone (1964) and Dickins & Malone (1973) thought that the eastern edge of current outcrop of the Bowen Basin (against the Connors Arch) was due to erosion against a structurally uplifted margin and considered that thickening of the marine succession towards this margin indicated that the Bowen Basin originally extended over it to the east, probably beyond the present coastline.

Stratigraphic, sedimentological and structural studies in recent years (Fielding & others, 1994, 1997a,b; Fergusson, 1991; Fergusson & others, 1994), and confirmed here, have led to the conclusion that the Gogango Overfolded Zone is simply a part of the Bowen Basin that was more intensely deformed by thrusting during the late Permian to Early Triassic Hunter–Bowen Orogeny. In addition, no basement-clast conglomerates that might indicate a basin margin or shoaling onto an emergent Connors–Auburn Arch, are evident on either side of the Connors Arch in the Back Creek Group, and palaeocurrents on both sides are dominantly westward-directed (Fielding & others, 1997a). An eastward increase in sandstone in the undivided Back Creek Group is consistent with a shoreline to the east.

In the Gogango Overfolded Zone, Fergusson (1991) interpreted that the Connors Arch, as now exposed, is a later structural feature. He interpreted the rocks he studied south of the main part of the Arch as possibly the upper part of a passive-roof duplex or antiformal stack of fault bound slivers of the underlying basement, and that the Arch plunges southwards under the Gogango Overfolded Zone. Farther north, the structure of the main part of the Arch appears to be simply a broad anticline, and the plot of bedding and igneous foliation (Figure 154a) illustrates the open nature of the structure.

In general the rocks of the Connors Arch are unfoliated, except for a cleavage in the Leura Volcanics on the eastern margin in the south. The granitic rocks are undeformed except for the Mia Mia Complex along the eastern margin of the Urannah Batholith where the rocks are commonly sheared and foliated. As discussed below, this deformation may be related to the Mia Mia Fault Zone, which forms the eastern margin of the batholith against the Carmila beds in this area.

The Carmila beds crop out mainly to the east of the Connors Arch and overall dip mainly shallowly to the east, particularly in the south between Clairview and the Apis Creek area (Figure 154c), where they conformably overlie the volcanic-dominated succession. At the southern end of the main part of the Arch, the Carmila beds have been traced around the ‘nose’ and crop out on the western side near Tartrus homestead. Between Clairview and Saint Lawrence, the Carmila beds alternate with belts of Carboniferous volcanic rocks, possibly due to a series of thrusts or high-angle reverse faults. These may be a continuation of the Gogango Overfolded Zone or related to the Chelona Thrust that is interpreted to be the western margin of the Campwyn Volcanics.

In the Mackay–Sarina area, the eastern part of the Connors Arch is represented by late Carboniferous or early Permian granitic rocks and the Carmila beds are faulted against them along the Mia Mia Fault Zone. To the east the Carmila beds are gently folded into a very open basinal structure or syncline that plunges to the north-west (Figure 154b). In the Koumala area they are flanked to the east and south by older volcanic rocks of the Connors Arch, namely the Mountain View Volcanics. Farther north, outcrop is obscured by Cainozoic cover and probable Cretaceous granitic rocks. North of Mackay, the Carmila beds may unconformably overlie the Campwyn Volcanics on the east, although the nature of the relationships cannot be determined because of poor exposure and an abundance of Cretaceous igneous intrusions.

The Mia Mia Fault Zone has been mapped for ~50km along the edge of the Urannah Batholith in MIRANI. It forms two parallel faults up to 5km apart that bound the Mia Mia Igneous Complex, a belt of foliated and sheared granitoid. The eastern margin of the zone is termed the Mia Mia East Fault and the western margin is the Mia Mia West Fault.

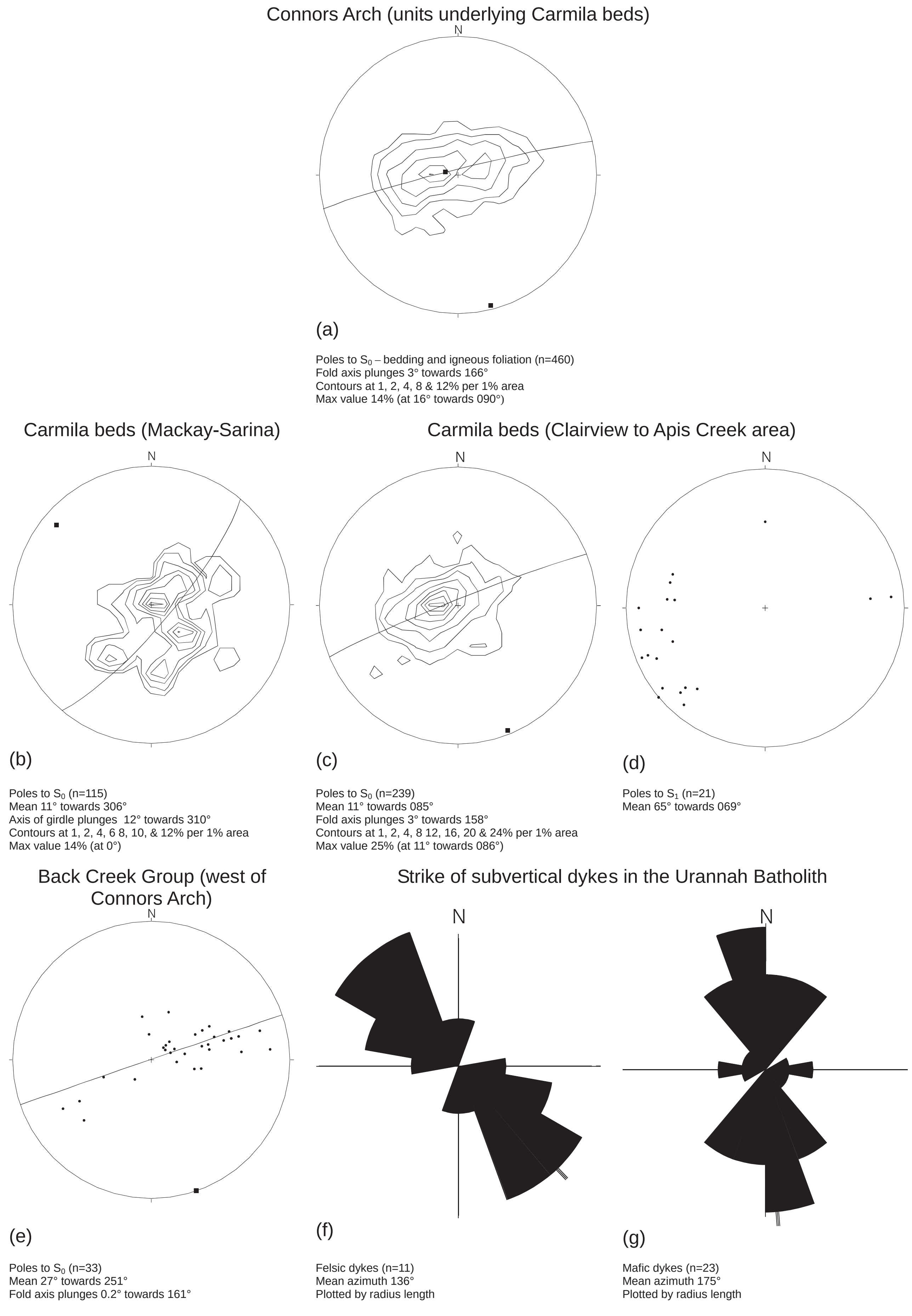

Figure 154. Structural data from the Connors Arch

The fault system has not been mapped south of MIRANI, but the boundary between the Mount Whelan Volcanics and Mountain View Volcanics in CARMILA and CONNORS RANGE, although not currently mapped as faulted, is linear and on strike with the Mia Mia Fault and could be a continuation of it. If so, current mapping would suggest that it is partly obscured by unnamed granites of the Urannah Batholith that could be younger. Farther north, it also appears to be obscured by the eastern contact of the Finch Hatton Granite, although that contact could be controlled by the fault.

The detailed structure within the fault zone was not studied so it is not possible to draw any conclusions about its kinematics. The few measurements available on the foliation indicate that it is steeply dipping. The wide zone of distributed shear in the Mia Mia Igneous Complex suggests that it is more than a simple normal fault along which the Urannah Batholith has been uplifted, although that may have been the latest phase of movement on it. The shearing does not appear to have affected the Carmila beds and they may post-date the earlier movement. The Mia Mia Fault could have been a zone of dextral strike-slip movement in the late Carboniferous. Murray & others (1987) proposed a tectonic model for the New England Fold Belt in which there was a change from a convergent continental margin to a dextral transform margin in the mid-Carboniferous due to the collision of a mid-ocean ridge with the offshore trench. Evans & Roberts (1980) also suggested that a dextral shear couple formed many of the late Palaeozoic tectonic features of eastern Australia.

Other faults within the Connors Arch trend north-east to south-east, although some trend parallel to the belt itself. Most are probably normal faults and may reflect extension during various volcanic episodes.

CAMPWYN VOLCANICS

The structure of the Campwyn Volcanics has been described by Fergusson & others (1994) and Bryan & others (2003b). North of Mackay the sequence dips regionally to the west and is probably overlain disconformably by the Carmila beds. Dips are mostly gentle to moderate (<30°) with local gentle folds and monoclines. Fergusson & others (1994) attributed this deformation to fault-bend folding due to movement over irregularities in fault surfaces, and they suggested that the south-west dip and small-scale thrust-faults are consistent with east-directed thrusting.

The Campwyn Volcanics south of Mackay are more strongly deformed, particularly at Dudgeon Point and south of Sarina between Green Hill and Cape Palmerston. In these areas, the rocks are commonly overturned with beds dipping east at angles as low as 45° and they have a strong east-dipping cleavage. The vergence is consistent with westerly-directed thrusting comparable with that in the Gogango Overfolded Zone and Yarrol Province to the south. These overturned rocks are juxtaposed to the west against subhorizontal Carmila beds and Bryan & others (2003b) suggested that this boundary is probably a major thrust ramp or synclinal breakthrough fault associated with a major east-dipping thrust. Jensen & others (1966) mapped an anticline within the Campwyn Volcanics (the Campwyn Anticline), and Bryan & others suggested that this may correspond with the fault propagation anticline associated with this structure. The western boundary of the Campwyn Volcanics can be delineated in the airborne magnetic data, by a contrast between the weakly but variable response of the Campwyn Volcanics against the strongly magnetic Mountain View Volcanics and the uniformly weakly magnetic Carmila beds. The boundary is interpreted as as a thrust, here referred to as the Chelona Thrust. The Sarina Fault mapped by Jensen & others (1966) appears to be west of this boundary within the Mountain View Volcanics and is not the major bounding fault.

Bryan & others (2003b) suggested that the thrust stepped out eastwards north of Dudgeon Point, possibly along a tear fault that may correspond with a prominent lineament along the Pioneer River. To the south of this tear fault, the Campwyn Volcanics would lie entirely within the hanging wall of the thrust, whereas to the north, they would lie in the footwall. This could explain the differences in structure between the areas, possibly including the difference in direction of thrusting noted by Fergusson & others (1994).

The thrusting is attributed to the late Permian to Early Triassic Hunter–Bowen Orogeny. Bryan & others (2003b) also noted a range of strike-slip and dip-slip faults associated with local folding of the strata in the northern part of the Campwyn Volcanics. They related these to regional sinistral wrench faulting in the Late Cretaceous and during the formation of Tertiary basins.

SOUTH OF CHARON POINT

The rocks between the Marlborough Block and Charon Point comprise the Late Devonian to early Carboniferous Tanderra Volcanics, which are unconformably overlain by the early Permian Glenprairie beds,

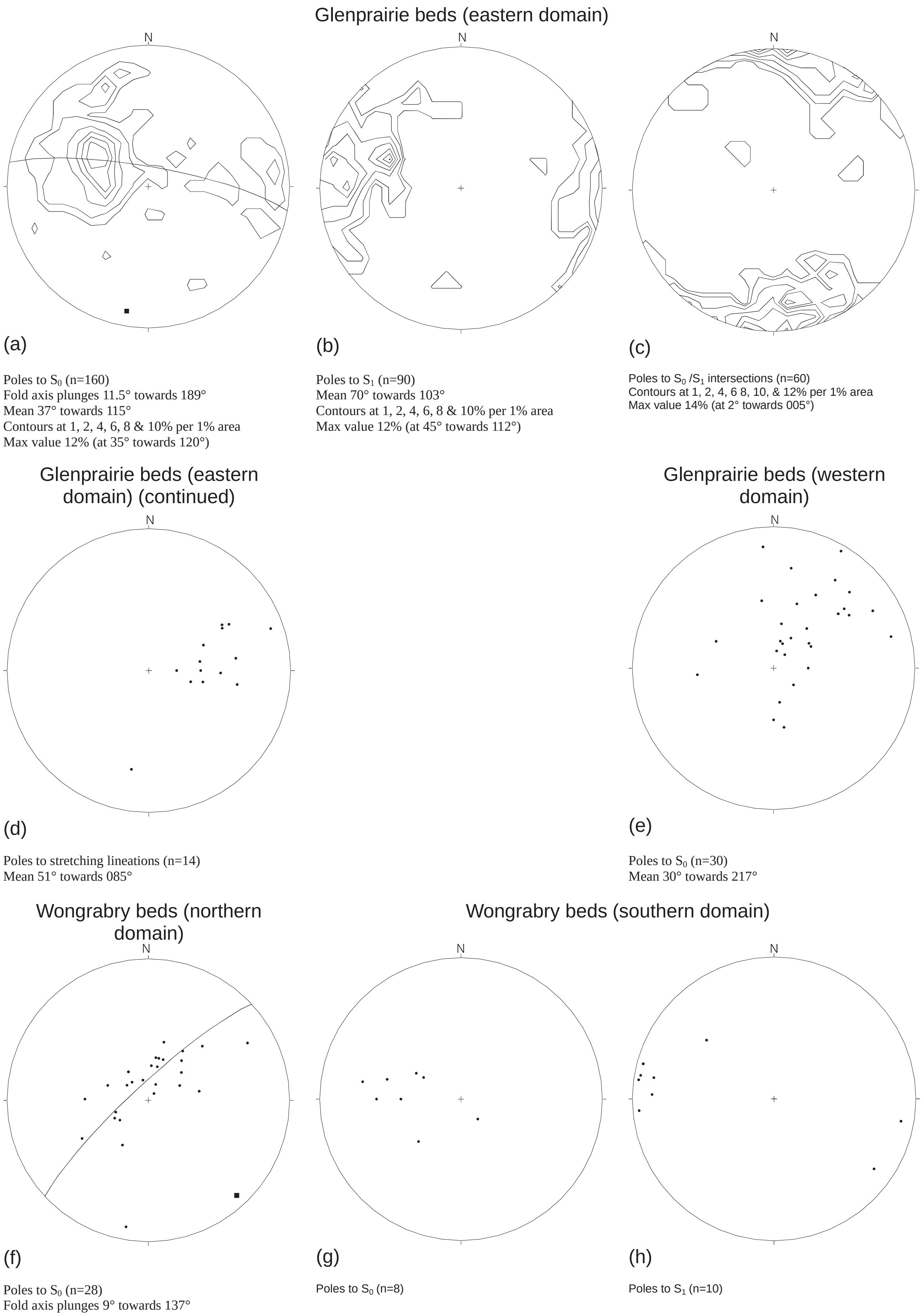

Figure 155. Structural data from south of Charon Point

Figure 156. Deformation in the Glenprairie beds
(a) Strongly cleaved felsic volcaniclastic rock. About 1km north-west of Glenprairie homestead at MGA 801402 7495700 (IWSC0970)
(b) Poorly sorted volcaniclastic conglomerate with strongly stretched pebbles. 1.7km north-west of Glenprairie homestead at MGA 801733 7496583 (IWSC0974)
(c) Strongly cleaved sandstone near the thrust contact with the Wongrabry beds. About 5km south-south-east of Oakleigh homestead at MGA 791941 7490374 (IWSC1223)

which are in turn overlain by the early Permian Wongrabry beds. The early Permian Rookwood Volcanics flank the Marlborough Block in the south.

Few structural data are available from the Tanderra Volcanics, but in general dips are shallow. In the south, inliers within the Glenprairie beds interpreted as anticlinal cores have been more deformed and have a cleavage and lineation similar to that in the surrounding Glenprairie beds.

The Glenprairie beds can be divided into two domains. The eastern domain is a north–south belt from the southern contact with the Rookwood Volcanics to the shoreline of Broad Sound near Bald Hills homestead. The western domain extends west from near Tanderra homestead.

The eastern domain is characterised by an overall moderate easterly dip of bedding (Figure 155a) and stronger deformation. Where it is most intense, near Glenprairie homestead, the deformation is manifest by strongly flattened and stretched pebbles and cobbles. Elsewhere, the mudstone has a strong slaty cleavage, and the sandstone and conglomerate also have a well-developed foliation defined by anastomosing fractures and spaced cleavage defined by seams rich in sericite and chlorite. Aligned flakes of fine-grained muscovite also occur through the groundmass of the felsic volcanic rocks, and form a strongly schistose fabric wrapping around quartz and feldspar crystal fragments. Biotite defines the foliation in sandstone south of Glenprairie, indicating that the metamorphic grade there was in the upper part of the greenschist facies.

The cleavage has a moderate to steep easterly dip (Figure 155b). Cleavage-bedding intersections indicate subhorizontal axes (Figure 155c) and the vergence is indicative of an anticline to the west. However, the

Wongrabry beds that lie to the west are younger, suggesting that the contact between the units is a thrust. The rocks along the contact in the headwaters of Landsborough Creek are locally strongly foliated and disrupted, resembling block-in-matrix melange (for example at MGA 792800 7492200) consistent with a faulted contact. The thrust vector was from the east, as indicated by the plot of stretching lineations (Figure 155d).

The Wongrabry beds can also be divided into two domains. The southern domain, south of Tanderra homestead has similar structure to the Glenprairie beds although the cleavage is not as intense and a stretching lineation was not recorded. The small amount of data indicates an overall dip of bedding to the east, and the rocks have a steep cleavage.

Near Tanderra homestead, the trend of the Wongrabry beds changes to predominantly north-west and the data indicate that the rocks mainly dip to the south-west, but are also deformed by open folds that plunge shallowly to the south-east (Figure 155f–h). In the adjacent western domain of Glenprairie beds the overall strike is also to the north-west with a shallow to moderate dip to the south-west (Figure 155e), consistent with the Glenprairie beds underlying the Wongrabry beds. Some slices of Glenprairie beds have been mapped alternating with the Wongrabry beds in this area but it is not known whether they represent fold hinges or thrust slices. The main contact between the two units appears to be at least partly a fault that truncates the northerly trends of the southern domain of Wongrabry beds and the north-trending thrust contact.

The north-north-easterly trends of the Back Creek Group to the west are truncated by the north-westerly trends of the Wongrabry beds and the contact is likely to be a thrust, probably a continuation of the Develin–Comanche Thrust System to the south of the Marlborough Block.

The contact relationship of the Glenprairie beds to the Rookwood Volcanics that crop out along the margins of the Marlborough Block is uncertain. SHRIMP dating and fossil evidence discussed previously in this report indicate that the Glenprairie beds are older. The contact trends north-east and is probably a thrust or a strike-slip fault, because it is strongly oblique to bedding trends and truncates the boundary between units defined by different radiometric responses in the Glenprairie beds. If it is a thrust, it may be an out-of-sequence thrust like that forming the contact of the over-riding Marlborough Block with the Gogango Overfolded Zone. Alternatively, a strike slip fault could be a westerly continuation of the Stanage Bay Fault that has been interpreted as a tear fault forming the northern limit of the Gogango Overfolded Zone (Morand, 1993a; Henderson & others, 1993; Leitch & others, 1994; Holcombe & others, 1995, 1997a). The deformation in the Glenprairie beds may be due to an easterly stepping of the Gogango Overfolded Zone along the northern side of such a tear fault.

Other evidence for the fault being a major crustal boundary is provided by the geochemistry. The Rookwood Volcanics have affinities with basalts erupted in a spreading back-arc basin, but the basalt of comparable age in the Wongrabry beds only ~20km to the north have affinities of basalt erupted onto thick continental crust.

CONCLUSIONS

The South-Connors-Auburn-Gogango Project has provided a much more detailed lithostratigraphic and temporal framework on which future research and mineral exploration in central Queensland can be based.

The oldest rocks in the Auburn Arch are an assemblage of gneissic metasedimentary rocks and metabasalt intruded by deformed granitic rocks. Metamorphism and deformation probably occurred in the early Carboniferous at about 340Ma based on SHRIMP dating of the Donore Granite Gneiss.

The volcanic rocks of the Auburn Arch are mostly late Carboniferous to early Permian. The oldest age obtained from the predominantly felsic Torsdale Volcanics is 325Ma in the central part of the area. Ignimbrite previously thought to be about 340Ma is now known to be late Carboniferous at about 315Ma. The youngest age in the Torsdale Volcanics is about 300Ma (from the northern part of the unit), and is from an ignimbrite unconformably overlain by basaltic rocks assigned to the Camboon Volcanics. However, in the south, there may be a gradation between the units, because a succession of alternating felsic ignimbrite and mafic flows and clastic rocks passes into the dominantly basaltic rocks. The mixed package is also mapped as Camboon Volcanics, but SHRIMP dating suggests that it may have overlapped in age with the Torsdale Volcanics farther north.

Emplacement of extensive granitic rocks in the Auburn Arch was probably synchronous with eruption of the Torsdale Volcanics, and they are broadly similar geochemically.

Mapping and SHRIMP U-Pb zircon dating suggests four major magmatic episodes in the Connors Arch. An early Carboniferous (older than ~330Ma) mafic to felsic magmatic event is represented by the Mountain View Volcanics and minor plutonic rocks, the Burwood Complex as well as inherited zircon in some of the younger plutons. A late Carboniferous felsic magmatic event at around 310–320Ma is represented by extensive ignimbritic units, Broadsound Range Volcanics and Whelan Creek Volcanics and numerous small granitic plutons. These are separated by a regional unconformity from an assemblage of volcanic and sedimentary rocks that includes some ignimbritic units such as the Lotus Creek Rhyolite, but is best represented by the heterogeneous Leura Volcanics, which show a complete range of compositions from basalt through andesite to rhyolite. SHRIMP U-Pb zircon ages range from 300 to 290Ma. Most of the plutonic rocks (gabbro to granite) of the Urannah Batholith were probably also emplaced during this interval. The Leura Volcanics are overlain, probably unconformably by the Lizzie Creek Volcanic Group, which includes the largely basaltic Benmore Volcanics, Collaroy Volcanics and Ametdale Volcanics and some rhyolitic units such as the Mount Buffalo Volcanics. It includes the Carmila beds, a largely fluvial to lacustrine succession that also contains basaltic and rhyolitic volcanic rocks that at least partly overlies the Benmore Volcanics. SHRIMP dates overlap the Leura Volcanics and range from about 295 to 285Ma.

Geochemistry of the basaltic rocks from both the Auburn and Connors Arches is consistent with the rocks having formed as an Andean-type continental margin volcanic arc on relatively thick crust, but the some of the early Permian rocks show geochemical patterns suggestive of thinner crust, perhaps related to the onset of extension that formed the Bowen Basin.

In addition to the Carmila beds, local development of other early Permian lacustrine sequences have been recognised overlying the volcanic rocks, including the Woolein Formation and Goodedulla beds and are interpreted as related to the early rifting phase of the Bowen Basin.

Rocks in the northern part of the adjacent Yarrol Province, the Campwyn and Tanderra Volcanics, have geochemical affinities consistent with formation in an intra-oceanic island arc and are probably similar to the Late Devonian Lochenbar Suite recognised farther south in the Yarrol Province.

In the Late Carboniferous to early Permian, the Youlambie Conglomerate was deposited in the central Yarrol Province contemporaneously with the upper part of the Torsdale Volcanics, whereas in the north the Glenprairie beds are equivalent to the Leura Volcanics.

In the southern part of the project area, the Yaparaba Volcanics and Nogo beds, which are mainly thought to be early Permian, include some rocks that are similar geochemically to the Late Devonian Lochenbar Suite, so it is possible that rocks of both ages may be present in those units as currently mapped. The early Permian Narayen beds and rest of the Nogo beds are probably contemporaneous with the Camboon Volcanics and formed on thick continental crust.

Within the adjacent Yarrol Province, eruption of the early Permian Rookwood Volcanics, a sequence of mainly submarine basalt with MORB-like geochemical affinities, probably coincided with early extensional phase of the Bowen Basin.

The Rawbelle Batholith consists of granitoids that mostly have late Permian to Early Triassic ages and can be divided into two main I-type geochemical suites, the Tandora and Wingfield Suites. A third suite of early Permian granitic rocks, the Coonambula Suite has some characteristics of S-type granites. Some of the units as mapped include rocks of two or more of these suites and need further mapping to separate these components. The early Permian I-type Eidsvold and Lookerbie Igneous Complexes form a fourth suite.

The Gogango Overfolded Zone along the eastern edge of the Bowen basin is actually a belt of easterly-dipping thrust slices that include some of the underlying late Carboniferous to early Permian volcanic rocks and the lower part of the Back Creek Group up to and including equivalents of the Barfield Formation. The boundary between the Gogango Overfolded Zone and the Yarrol Province is a system of major thrust faults.

ACKNOWLEDGEMENTS

The successful completion of this project would not have been possible without the assistance of many people, but it is difficult to list them all. However, the authors would like to acknowledge the following.

Temporary wages hands and some full-time technical staff are thanked for their assistance and congenial company in the field, in particular Stan Briggs, Jack Ryle, John Hembrow, Geoff Webb, Taffy Tengu and Dave

Morwood. Logistics were organised by Mark Livingstone with his characteristic efficiency. Brad John, who was manager of the Central Queensland Project from 1996 to 1999, provided encouragement and administrative support. Geophysical images were generated with the assistance of David Searle and Richie Huber.

Staff of the Graphics Services Unit are thanked for their skill and artistry. The digitising of the compilation maps was mostly done by Tony Nieuwenberg and final map production was by by Col Roberts, Bob Rapkins and Ross Lane under the supervision of Bob Blight and Noel Gatehouse.

Field data and samples collected by Bob Barker and Jan Domagala as part of the GSQ Yarrol Project were used to compile the geology of the Rookwood Volcanics, and Paul Blake spent two weeks examining the Campwyn Volcanics to make comparisons with units in the Yarrol Province farther south.

Dr Rod Holcombe of the University of Queensland provided maps and field data collected by him and his colleagues and students from the Rookwood and Marlborough areas. The late Dr John Dear gave us initial advice on the stratigraphy of the Connors Arch based on his many years of mapping and mineral exploration for Marlborough Gold Mines Ltd. His widow, Beverley, is thanked for providing us with his note books and aerial photographs which proved to be of great assistance in providing information on areas too difficult to access in the time we had available. Mark Fanning of PRISE at the Australian National University provided geochronological support and Dr David Champion of Geoscience Australia is thanked for initially pointing out the existence of separate suites of granitic rocks in the geochemical data.

The report was reviewed and edited by Dr Cec Murray (Regional Geoscience Manager) with his usual attention to detail. Sharon Beeston expertly undertook the desktop publishing of the completed manuscript.

Finally, we would like to thank the hundreds of property owners throughout the project area for willingly providing access to their properties.

REFERENCES

AITCHISON, J.C. & IRELAND, T.R., 1995: Age profile of ophiolitic rocks across the Late Palaeozoic New England Orogen, New South Wales: implications for tectonic models. *Australian Journal of Earth Sciences*, **42**, 11–23.

AITCHISON, J.C., BLAKE, M.C. Jr, FLOOD, P.G. & JAYKO, A.S., 1994: Palaeozoic ophiolitic assemblages within the southern New England Orogen of eastern Australia: implications for growth of the Gondwana margin. *Tectonics*, **13**, 1135–1149.

AITCHISON, J.C., IRELAND, T.R., BLAKE, M.C. Jr. & FLOOD, P.G., 1992: 530Ma zircon age for ophiolite from the New England Orogen: oldest rocks known from eastern Australia. *Geology*, **20**, 125–128.

ALLEN, C.M., 2000: Evolution of a post-batholith dike swarm in central coastal Queensland, Australia: arc-front to backarc. *Lithos*, **51**, 331–349.

ALLEN, C.M., CHAPPELL, B.W., WOODEN, J.L., & WILLIAMS, I.S., 1994: Ages, compositions, and sources of the Urannah Batholith. *In* Henderson, R.A., & Davis, B.K. (Editors): Extended Conference Abstracts — New developments in geology and metallogeny: Northern Tasman Orogenic Zone. *Contributions of the Economic Geology Research Unit, Key Centre in Economic Geology and Geology Department, James Cook University of North Queensland*, **50**, 107–110.

ALLEN, C.M., WILLIAMS, I.S., STEPHENS, C.J. & FIELDING, C.R., 1998: Granite genesis and basin formation in an extensional setting: the magmatic history of the northernmost New England Orogen. *Australian Journal of Earth Sciences,* **45**, 875–888.

AMDEL, 1983: Geochronology report and data, Job 4785/83, reported 27 April 1983. Report to Geological Survey of Queensland.

ANDERSON, J.C., 1985: Geology of the Fort Cooper Coal Measures interval. *In* Bowen Basin Coal Symposium. *Geological Society of Australia, Abstracts* **17**, 87–92.

AUSTRAL MINING (QUEENSLAND) PTY LTD, 1958: Plevna oil shale basin. Eungella, Queensland. Report held by the Queensland Department of Mines & Energy as CR191.

BAKER, E.M. & STUART, N., 1981: A-P 2813M Plevna Final Report for the period ending 18.12.81 (Oil Shale). Jacia Mine Management & Consulting Services. Report held by the Department of Mines & Energy as CR9989.

BAKER, J.C., FIELDING, C.J., CARITAT, P.DE & WILKINSON, M.M., 1993: Permian evolution of sandstone composition in a complex back-arc extensional to foreland basin: the Bowen Basin, eastern Australia. *Journal of Sedimentary Petrology*, **63**, 881–893.

BALL, L.C., 1910: Coal at Black Rock, near Mackay. *Queensland Government Mining Journal*, **11**, 283–284.

BALL, L.C., 1927: Oil shale in the Eungella district. *Queensland Government Mining Journal*, **28**, 306.

BALL, L.C., 1928: Report on exposures of oil shale in the Dawson River bed. *Queensland Government Mining Journal*, **29**, 298–299.

BEESTON, J.W., 1972: A specimen of *Auracarioxylon arberi* (Seward) Beeston comb. nov. from Queensland. *Geological Survey of Queensland Publication* **352**, 17–20, (*Palaeontological Paper*, **27**).

BEESTON, J.W., 1975: An early Permian molluscan fauna from the Youlambie Conglomerate, Yarrol Basin, with a revision of the genus *Montospira* Maxwell 1964. *Queensland Government Mining Journal*, **76**, 394–401.

BELLAMY, D.E., 1976: Kariboe Layered Gabbro. B.Sc. (Honours) thesis University of Queensland.

BENDALL, C., 1996: A comparative study of an ancient VHMS deposit and a modern seafloor sulphide deposit. B.Sc. (Honours) thesis, James Cook University of North Queensland.

BISCHOFF, K., DERRIMAN, M., & HALLEY, S., 1986: A-P 4277M, Mount Saul, Rosehall Gold Project, report on 1986 exploration. Peko-Wallsend Operations Ltd. Report held by the Department of Mines & Energy as CR16901.

BLAKE, P.R., SIMPSON, G.A., FORDHAM, B.G. & HAYWARD, M.A., 1998: The Yarrol fore-arc basin: a complex suite of volcanic facies and allocthonous limestone blocks. *In* Geoscience for the new Millenium, 14th Australian Geological Convention, Townsville, July, 1998. *Geological Society of Australia, Abstracts* **49**, 42.

BLOOMER, J.J., 1994: Stratigraphy of the Calen district. B.Sc. (Honours) thesis University of Queensland.

BRADSHAW, M. & CHALLINOR, A.B., 1992: Regional geology and stratigraphy — Australasia. *In* Westermann, C.E.G. (Editor): *The Jurassic of the circum-Pacific*. Cambridge University Press, Cambridge, 162–180.

BRADSHAW, M. & YEUNG, M., 1990: The Jurassic palaeogeography of Australia. *Bureau of Mineral Resources, Australia, Record* **1990/76**, *Palaeogeography* **26**.

BRADSHAW, M. & YEUNG, M., 1992: *Palaeogeographic atlas of Australia. Volume 8: Jurassic*. Bureau of Mineral Resources, Australia.

BRIGGS, D.J.C., 1979: Lower Permian Aulostegida (brachiopoda: productida) of eastern Australia. B.Sc. (Honours) Thesis, University of Queensland.

BRIGGS, D.J.C., 1993: Time control in the Permian of the New England Orogen. *In* Flood, P.G. & Aitchison, J.C. (Editors): *New England Orogen, eastern Australia*. Department of Geology and Geophysics, University of New England, Armidale, 283–291.

BRIGGS, D.J.C., 1998: Permian Productidina and Strophalosiidina from the Sydney–Bowen Basin and New England Orogen: systematics and biostratigraphic significance. *Memoir of the Association of Australasian Palaeontologists*, **19**, 1–258.

BRIGGS, D.J.C. & WATERHOUSE, J.B., 1982: Summary of formations and faunas of the Permian Back Creek Group in the south-eastern Bowen Basin, Queensland. *Papers of the Department of Geology, University of Queensland*, **10**, 69–82.

BROOKS, J.H., 1968: Departmental diamond drilling programme magnetite deposits, Hawkwood area. *Queensland Government Mining Journal*, **69**, 537–545.

BRUCE, M.C., 1999: Development of the eastern Australian margin from late Proterozoic through Palaeozoic: evidence from petrology, geochemistry and geochronology of ultramafic-mafic complexes within the Marlborough and South Island terranes of the northern New England Fold Belt. Ph.D. thesis, University of Queensland.

BRUCE, M.C. & NIU, Y., 2000a: Evidence for Palaeozoic magmatism recorded in the Late Neoproterozoic Marlborough ophiolite, New England Fold Belt, central Queensland. *Australian Journal of Earth Sciences*, **47**, 1065–1076.

BRUCE, M.C. & NIU, Y., 2000b: Early Permian supra-subduction assemblage of the South island terrane, Percy Isles, New England Fold Belt, central Queensland. *Australian Journal of Earth Sciences*, **47**, 1077–1085.

BRUCE, M.C., NIU, Y., HARBORT, T.A. & HOLCOMBE, R.J., 2000: Petrological, geochemical and geochronological evidence for a Neoproterozoic ocean basin recorded in the Marlborough terrane of the northern new England Fold belt. *Australian Journal of Earth Sciences*, **47**, 1053–1064.

BRYAN, S.E., ALLEN, C.M., HOLCOMBE, R.J. & FIELDING, C.R., 2004b: U–Pb zircon geochronology of Late Devonian to Early Carboniferous extension-related silicic volcanism in the northern New England Fold Belt. *Australian Journal of Earth Sciences,* **51**, 645–664.

BRYAN, S.E., CONSTANTINE, A.E. & STEPHENS, C.J., 1997: Early Cretaceous volcano - sedimentary successions along the eastern Australian continental margin: Implications for the break-up of eastern Gondwana. *Earth and Planetary Science Letters*, **153**, 85–102.

BRYAN, S.E., CONSTANTINE, A.E., STEPHENS, C.J., EWART, A., SCHON, R.W, & PARIANOS, J., 1996: The Whitsunday Volcanic province (central Queensland) and the Gippsland/Otway Basin (Victoria): a comparison of Early Cretaceous rift-related volcano-sedimentary successions. *In* Mesozoic Geology of the Eastern Australia Plate Conference 23–26 September 1996. *Geological Society of Australia Extended Abstracts* **43**, 124–133.

BRYAN, S.E., EWART, A., STEPHENS, C.J., PARIANOS, J. & DOWNES, P.J., 2000: The Whitsunday Volcanic Province, Central Queensland, Australia: lithological and stratigraphic investigations of a silicic-dominated large igneous province. *Journal of Volcanology and Geothermal Research*, **99**(1–4), 55–78.

BRYAN, S.E., FIELDING, C.R., HOLCOMBE, R.J. & COOK, A. 2004a: Reply. Stratigraphy, facies architecture and tectonic implications of the Upper Devonian Campwyn Volcanics of the northern New England Fold Belt. *Australian Journal of Earth Sciences,* **51**, 453–458.

BRYAN, S.E., FIELDING, C.R., HOLCOMBE, R.J., COOK, A. & MOFFITT, C.A. 2003a: Stratigraphy, facies architecture and tectonic implications of the Upper Devonian Campwyn Volcanics of the northern New England Fold Belt. *Australian Journal of Earth Sciences,* **50**, 377–401.

BRYAN, S.E., HOLCOMBE, R.J. & FIELDING, C.R., 2001: Yarrol terrane of the northern New England Fold Belt: forearc or backarc? *Australian Journal of Earth Sciences,* **48**, 293–316.

BRYAN, S.E., HOLCOMBE, R.J. & FIELDING, C.R., 2003b: Reply. Yarrol terrane of the northern New England Fold Belt: forearc or backarc? *Australian Journal of Earth Sciences,* **50**, 278–293.

BUNNY, M.R., 1971: A to P 97C. Geology of the Calen Authority to Prospect (coal) held by Petrocarb Exploration NL. Report held by the Department of Mines & Energy as CR3551.

BURCH, G.J., 1999: The geology and mineralisation of the Mount Mackenzie region, central south-eastern Queensland. B.Sc. Honours Thesis, Australian National University.

BURROWS, P.E., 2004: Mines and mineralisation in the Rookwood, Ridgelands and Rockhampton 1:100 000 sheet areas, central Queensland. *Queensland Geological Record* **2004/03**.

CAMERON, J.B., 1960: The Mulgildie Basin. *In* Hill, D. & Denmead, A.K. (Editors): The Geology of Queensland. *Journal of the Geological Society of Australia*, **7**, 301–302.

CAMERON, W.E., 1903: Additions to the geology of the Mackay and Bowen Districts. *Geological Survey of Queensland, Publication* **181**.

CAMPE, G. & RICHARDS, D., 1968: Report of Authority to Prospect 404M Rannes, central Queensland. Noranda Australia Limited. Report held by the Department of Mines & Energy as CR2422.

CHAMPION, D.C., 1984: Geology and geochemistry of the Mount Jukes Intrusive Complex. B.Sc. Honours Thesis, James Cook University of North Queensland.

CHAPPELL, B.W. & WHITE, A.J.R., 1974: Two contrasting granite types. *Pacific Geology*, **8**, 173–174.

CHIU CHONG, E.S., 1964: Coal resources — Styx River coalfield (Styx No 3 State Mine area). *Queensland Government Mining Journal*, **65**, 331–337.

CLARE, A.P., 1993: Subaqueous basaltic volcanism in the early Permian Grantleigh Trough, central eastern Australia. *In* Flood, P.G. & Aitchison, J.C. (Editors): *New England Orogen, eastern Australia*. Department of Geology and Geophysics, University of New England, Armidale, 599–608.

CLARKE, D.E., PAINE, A.G.L. & JENSEN, A.R., 1971: Geology of the Proserpine 1:250 000 Sheet area, Queensland. *Bureau of Mineral Resources, Australia, Report* **144**.

COLTON, H.C., 1970: Geology of the Banana Reserve. *Geological Survey of Queensland, Record* **1970/1**.

COOK, P.J. & MAYO, W., 1977: Sedimentology and Holocene history of a tropical estuary Broad Sound, Queensland. *Bureau of Mineral Resources, Australia, Bulletin* **170**.

COOK, P.J. & POLACH, H.A., 1973: A chenier sequence at Broad Sound, Queensland, and evidence against a Holocene high sea level. *Marine Geology,* **14**, 253–268.

COOKSON, I.C. & DETTMANN, M.E., 1958: Some trilete spores from Upper Mesozoic deposits in the eastern Australian region. *Proceedings of the Royal Society of Victoria,* **70**, 95–128.

COOKSON, I.C. & EISENACH, A., 1958: Microplankton from Australia and New Guinea Upper Mesozoic sediments. *Proceedings of the Royal Society of Victoria,* **70**, 19–78.

CRANFIELD, L.C., CARMICHAEL, D.C. & WELLS, A.T., 1994: Ferruginous oolite and associated lithofacies from the Clarence–Moreton and related basins in south-east Queensland. **In** Wells, A.T. & O'Brien, P.E. (Editors): Geology and petroleum potential of the Clarence–Moreton Basin, NSW and Queensland. *Australian Geological Survey Organisation, Bulletin* **241**, 144–163.

CROUCH, S.B.S. & PARFREY, S.M., 1999: Geology of the Berserker Subprovince, Northern New England Orogen. *Queensland Government Mining Journal*, **99**(1164), 15–25.

DAY, R.W., 1995: GEOMAP 2005 Program: the key to unlocking Queensland's mineral wealth. *Queensland Government Mining Journal*, **96**(1126), 463–468.

DAY, R.W., MURRAY, C.G. & WHITAKER, W.G., 1978: The eastern part of the Tasman Orogenic Zone. *Tectonophysics*, **48**, 327–364.

DAY, R.W., WHITAKER, W.G., MURRAY, C.G., WILSON, I.H. & GRIMES, K.G., 1983: Queensland Geology. A companion volume to the 1:2 500 000 scale geological map (1975). *Geological Survey of Queensland, Publication* **383**.

DE JERSEY, M.J., 1963: Jurassic spores and pollen grains from the Marburg Sandstone. *Geological Survey of Queensland, Publication* 313.

DE JERSEY, M.J., 1964: Appendix 2 Palynological Reports. *In*, Hoyling, N.H.V. & Stewart, H.W.J.: Well completion report, APE Abercorn 1 well. Report for Amalgamated Petroleum Exploration Pty Ltd. Report held by the Department of Mines & Energy as CR1282.

DE JERSEY, N.J., 1979: Palynology of the Permian–Triassic transition in the western Bowen Basin. *Geological Survey of Queensland, Publication* **374**, *Palaeontological Paper* **46**.

DEAR, J.F., 1963: Upper Palaeozoic biostratigraphy of the Yarrol Basin in the vicinity of Monto. Ph.D. Thesis, University of Queensland.

DEAR, J.F., 1968: The geology of the Cania district. *Geological Survey of Queensland, Publication* **330**.

DEAR, J.F., 1972: Preliminary biostratigraphic subdivision of the Permian brachiopod faunas in the northern Bowen Basin and their distribution throughout the Basin. *Geological Survey of Queensland, Report* **49**.

DEAR, J.F, 1977: Report on exploration for 1977 Authority to Prospect 1445M Broadsound range area, central Queensland. Layton & Associates, Australian Consolidated Exploration Pty Ltd. Report held by the Department of Mines & Energy as CR6556.

DEAR, J.F, 1986a: A-P 3234M, report on exploration for six monthly period 19.3.85 -19.9.85. Marlborough Mining Pty Ltd. Report held by the Department of Mines & Energy as CR14872 (confidential).

DEAR, J.F, 1986b: A-P 3234M, Broadsound Range, six monthly report, period 19.09.85-19.03.86. Marlborough Mining Pty Ltd. Report held by the Department of Mines & Energy as CR15487 (confidential).

DEAR, J.F., 1994a: Major cycles of volcanism in the southern Connors Arch. *In* Holcombe, R.J., Stephens, C.J. & Fielding, C.R. (Editors): *1994 Field Conference, Capricorn region, central coastal Queensland*. Geological Society of Australia Inc. (Queensland Division), 31–45.

DEAR, J.F., 1994b: Exploration Permit 7225M Broadsound Range. Final report on exploration including report for the period 31st May 1993 to 29th March 1994. Marlborough Gold Mines Ltd. Report held by the Department of Mines & Energy as CR25795 (confidential).

DEAR, J.F., 1995: Exploration Permit Minerals 10006 Mount Mackenzie southern Connors Arch. Report on exploration for the twelve monthly period ended 29th March 1995. Marlborough Gold Mines Ltd. Report held by the Department of Mines & Energy as CR27381 (confidential).

DEAR, J.F., McKELLAR, R.G. & TUCKER, R.M., 1971: Geology of the Monto 1:250 000 Sheet area. *Geological Survey of Queensland, Report* **46**.

DEAR, J.J., 1985: A-P 3234m, Broadsound Range, report on area relinquished March, 1984. Report held by the Department of Mines & Energy as CR13338.

DENTON, M.G., 1994: The metamorphic petrology and geochemistry of the Princhester area, Marlborough, central-eastern Queensland. B.Sc. (Honours) thesis University of Queensland.

DERRINGTON, S.S., 1962: The tectonic framework of the Bowen Basin. *Australasian Oil and Gas Journal,* **8**(4), 26–29.

DERRINGTON, S.S., GLOVER, J.J.E. & MORGAN, K.H., 1959: New Names in Queensland Stratigraphy. Permian of the south-eastern Part of the Bowen Syncline. Central Bowen Syncline. *Australasian Oil and Gas Journal*, **5**(8), 27–35.

DERRINGTON, S.S. & MORGAN, K.H., 1960: South-eastern and south-central Bowen Basin. *In* Hill, D. & Denmead, A.K. (Editors): The geology of Queensland. *Journal of the Geological Society of Australia*, **7**, 204–212.

DEWEY, J.F., 2003: Ophiolites and lost oceans: rifts, ridges, arcs, and/or scrapings? *In* Dilek, Y. & Newcomb, S. (Editors): Ophiolite Concept and the Evolution of Geological Thought. *Geological Society of America Special Paper* **373**, 153–158.

DICKINS, J.M., 1964a: Correlation and subdivision of the Permian of western and eastern Australia. *Report of the International Geological Congress*, *Abstracts,* **22**, 115–116.

DICKINS, J.M., 1964b: Permian macrofossils from Homevale and from the Mount Coolon 1:250 000 Sheet area. *In* Malone, E.J., Corbett, D.W.P. & Jensen, A.R. (Editors): Geology of the Mount Coolon 1:250 000 Sheet area. *Bureau of Mineral Resources, Australia, Report* **64**.

DICKINS, J.M., 1966. Permian Marine macrofossils from the Bowen and Mackay 1:250 000 sheet areas. *In* Malone, E.J., Jensen, A.R., Gregory, C.M. & Forbes, V.R.: Geology of the southern half of the Bowen 1:250 000 Sheet area, Queensland. *Bureau of Mineral Resources, Australia, Report* **100**, 68–87.

DICKINS, J.M., 1972. Permian marine macrofossils from the Mundubbera and Monto sheet areas. *In* Mollan, R.G., Forbes, V.R., Jensen, A.R., Exon, N.F. & Gregory, C.M.: Geology of the Eddystone, Taroom and western part of the Mundubbera Sheet areas, Queensland. *Bureau of Mineral Resources, Australia, Report* **142**, 106–120.

DICKINS, J.M., 1982: Permian to Triassic changes in life. *In* Roberts, J. & Jell, P.A. (Editors): *Dorothy Hill Jubilee Memoir*. Proceedings of the Association of Australasian Palaeontologists, University of Queensland, 297–303.

DICKINS, J.M., 1983: The Permian Blenheim Subgroup of the Bowen Basin and its time relationships. *In, Proceedings of the Symposium on the Permian Geology of Queensland, 14–16 July 198*2, Brisbane. Geological Society of Australia Inc., Queensland Division, 269–274.

DICKINS, J.M. & MALONE, E.J., 1973: The Bowen Basin. *Bureau of Mineral Resources, Australia, Bulletin* **130**.

DICKINS, J.M., MALONE, E.J. & JENSEN, A.R., 1964: Subdivision and correlation of the Permian Middle Bowen beds, Queensland. *Bureau of Mineral Resources, Australia, Report* **70**.

DONG, G.Y. & ZHOU, T., 1996: Zoning in the Carboniferous – Lower Permian Cracow epithermal vein system, central Queensland, Australia. *Mineralium Deposita*, **31**, 210–224.

DRAPER, J.J., 1988: Permian limestone in the south-eastern Bowen Basin, Queensland: an example of temperate carbonate deposition. *In* Nelson, C.S.(Editor): Non-Tropical Shelf Carbonates — Modern and Ancient. *Sedimentary Geology*, **60**, 155–162.

DRAPER, J.J., PALMIERI, V., PRICE, P.L., BRIGGS, D.J.C. & PARFREY, S.M., 1990: A biostratigraphic framework for the Bowen Basin. *In* Beeston, J.W. (Compiler): *Bowen Basin Symposium 1990 Proceedings*. Geological Society of Australia Inc., Queensland Division, Brisbane, 26–35.

DUNSTAN, B., 1901: Geology of the Dawson and Mackenzie Rivers, with special reference to the occurrence of anthracitic coal. *Geological Survey of Queensland, Publication* **155**.

EVANS, P.R. & ROBERTS, J., 1980: Evolution of central eastern Australia during the late Palaeozoic and early Mesozoic. *Journal of the Geological Society of Australia*, **26**, 325–340.

EWART, A., SCHON, R.W. & CHAPPELL, B.W., 1992: The Cretaceous volcanic-pluton province of the central Queensland (Australia) coast - a rift related 'calc-alkaline' province. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* **83**, 327–345.

EXON, N.F., 1976: Geology of the Surat Basin, Queensland. *Bureau of Mineral Resources, Australia, Bulletin* **166**.

FALKNER, A.J. & FIELDING, C.R., 1990: Late Permian coal-bearing depositional systems of the Bowen Basin. *In* Beeston, J.W. (Compiler): *Bowen Basin Symposium 1990 Proceedings*. Geological Society of Australia Inc., Queensland Division, Field Conference, 1990, 36–41.

FAULKNER, J. & McKENZIE, P., 1965: The Mirani Kuttabul Coal Prospecting Area, Mackay, A to P 4C. BHP Company Ltd. Report held by the Department of Mines & Energy as CR1525.

FERGUSON, K.M., DUNGAN, M.A., DAVIDSON, J.P. & COLUCCI, M.T., 1992: The Tatara–San Pedro volcano, 36°S, Chile: a chemically variable, dominantly mafic magmatic system. *Journal of Petrology*, **33**, 1–43.

FERGUSSON, C.L., 1991: Thin-skinned thrusting in the northern New England Orogen, central Queensland, Australia. *Tectonics*, **10**, 797–806.

FERGUSSON, C.L., CARR, P.F., FANNING, C.M. & GREEN T.J. 2001: Proterozoic–Cambrian detrital zircon and monazite ages from the Anakie Inlier, central Queensland: Grenville and Pacific–Gondwana signatures. *Australian Journal of Earth Sciences*, **48**, 857–866.

FERGUSSON. C.L., HENDERSON, R.A. & LEITCH, E.C., 1994: Tectonics of the New England Fold Belt in the Rockhampton–Gladstone region, central Queensland. *In* Holcombe, R.J., Stephens, C.J. & Fielding, C.R. (Editors): 1994 *Field Conference, Capricorn region, central coastal Queensland*. Geological Society of Australia Inc. (Queensland Division), 1–16.

FERGUSSON, C.L., HENDERSON, R.A., LEWTHWAITE, K.J., PHILLIPS, D. & WITHNALL, I.W. 2005. Structure of the Early Palaeozoic Cape River Metamorphics, Tasmanides of north Queensland: evaluation of the roles of convergent and extensional tectonics. *Australian Journal of Earth Sciences*, **52**, 261–277.

FERGUSSON, C.L., HENDERSON, R.A., WITHNALL, I.W., FANNING, C.M., PHILLIPS, D., LEWTHWAITE, K.J., 2007: Structural, metamorphic, and geochronological constraints on alternating compression and extension in the Early Paleozoic Gondwanan Pacific margin, north-eastern Australia. *Tectonics*, **26**(3), TC3008.

FERGUSSON, C.L., HENDERSON, R.A., WRIGHT, J.V. 1994: Facies in a Devonian–Carboniferous volcanic fore-arc succession, Campwyn Volcanics, Mackay district, central Queensland. *Australian Journal of Earth Sciences*, **41**(4), 287–300.

FIELDING, C.R., 1989: Hummocky cross-stratification from the Boxvale Sandstone Member in the northern Surat Basin, Queensland. *Australian Journal of Earth Sciences*, **36**, 469–471.

FIELDING, C.R., FALKNER, A.J., KASSAN, J. & DRAPER, J.J. 1990: Permian and Triassic depositional systems in the Bowen Basin. *In* Beeston, J.W. (Compiler): *Bowen Basin Symposium 1990 Proceedings*. Geological Society of Australia Inc., Queensland Division, Field Conference, 1990, 21–25.

FIELDING, C.R., HOLCOMBE, R.J. & STEPHENS, C.J., 1994: A critical evaluation of the Grantleigh Trough, east-central Queensland. *In* Holcombe, R.J., Stephens, C.J. & Fielding, C.R. (Editors): *1994 Field Conference, Capricorn region, central coastal Queensland*. Geological Society of Australia Inc. (Queensland Division), 17– 30.

FIELDING, C.R., STEPHENS, C.J. & HOLCOMBE, R.J., 1997a: Permian stratigraphy and palaeogeography of the eastern Bowen Basin, Gogango Overfolded Zone and Strathmuir Synclinorium in the Rockhampton–Mackay region, central Queensland. *In* Ashley, P.M. & Flood, P.G. (Editors): Tectonics and Metallogenesis of the New England Orogen, *Geological Society of Australia, Special Publication*, **19**, 80–95.

FIELDING, C.R., STEPHENS, C.J. & HOLCOMBE, R.J., 1997b: Submarine mass wasting as an indicator of the onset of foreland thrust loading — late Permian Bowen Basin, Queensland, Australia. *Terra Nova*, **9**, 14–18.

FIELDING, C.R., STEPHENS, C.J., KASSAN, J., & HOLCOMBE, R.J., 1995: Revised palaeogeographic maps for the Bowen Basin, central Queensland. *In* Follington, I.L., Beeston, J.W., & Hamilton, L.H., (Editors): *Bowen Basin 1995, Proceedings.* Geological Society of Australia Inc., Coal geology Group, Brisbane, 7–15.

FLOOD, P.G., JELL, J.S. & WATERHOUSE, J.B., 1981: Two new early Permian stratigraphic units in the south-eastern Bowen Basin, central Queensland. *Queensland Government Mining Journal*, **82**, 179–184.

FOSTER, C.B., 1979: Permian plant fossils of the Blair Athol Coal measures, Baralaba Coal measures and basal Rewan Formation of Queensland. *Geological Survey of Queensland, Publication* **372**, *Palaeontological Paper* **45**.

FOSTER, C.B., 1980: Report on Tertiary spores and pollen from core samples from the Hillsborough and Duaringa Basins, submitted by Southern Pacific Petroleum NL. *Geological Survey of Queensland Record* **1980/2**.

FOSTER, C.B., 1982: Illustrations of early Tertiary (Eocene) plant microfossils from the Yaamba Basin, Queensland. *Geological Survey of Queensland, Publication* **381**.

FRETZDORFF, S., LIVERMORE, R.A., DEVEY, C.W., LEAT, P.T. & STOFFERS, P., 2002: Petrogenesis of the back-arc East Scotia Ridge, South Atlantic Ocean. *Journal of Petrology,* **43**, 1435–1467.

GARCIA, M.O., 1978: Criteria for the identification of ancient volcanic arcs. *Earth Science Reviews*, **14**, 147–165.

GARRAD, P.D., OSBORNE, J., REES, I.D. & SULLIVAN, T.D., 2000: *Queensland Minerals – a summary of major mineral resources, mines and projects, 1st edition*. Queensland Department of Mines and Energy.

GARRAD, P.D. & WITHNALL, I.W., 2004a: Mineral occurrences and District Analysis — Banana, Theodore and Scoria 1:100 000 Sheet areas, central Queensland. *Queensland Geological Record* **2004/2**.

GARRAD, P.D. & WITHNALL, I.W., 2004b: Mineral occurrences — St Lawrence and Port Clinton 1:250 000 Sheet areas, central Queensland. *Queensland Geological Record* **2004/7**.

GEOLOGICAL SURVEY OF QUEENSLAND, 1988: *Bowen Basin Solid Geology, Queensland 1:500 000 geology map*. Queensland Department of Mines.

GLOVER, J.E., 1954: Geology of the Banana–Theodore–Cracow area, A to P 21P. Associated Australian Oil Fields NL. Report held by the Department of Mines & Energy as CR45.

GOSCOMBE, P.W., 1968: Coal at Theodore. *Queensland Government Mining Journal*, **69**, 55–65.

GRADSTEIN, F.M., OGG, J.G. & SMITH, A.G., 2004: *A Geologic Time Scale 2004*. Cambridge University Press.

GRAHAM, J., 1966: The geology of a layered magnetite- anorthosite gabbro and associated rocks in a selected exposure near Hawkwood Station. B.Sc. (Honours) thesis University of Queensland.

GRAY, A.R.G., 1972: Deep stratigraphic core drilling in the Mulgildie Basin and proposal of a new name — Abercorn Trough. *Queensland Government Mining Journal*, **73**, 378–382.

GRAY, A.R.G., 1975: Bundamba Group — stratigraphic relationships and petroleum prospects. *Queensland Government Mining Journal*, **76**, 310–324.

GRAY, A.R.G. & HEYWOOD, P.B., 1978: Stratigraphic relationships of Permian strata between Cockatoo Creek and Moura. *Queensland Government Mining Journal,* **79**, 651–664.

GREEN, D.C. (Editor), 1975: *Isotope Geology Laboratory Report No. 2 1971–1974*. Department of Geology and Mineralogy, University of Queensland, St Lucia.

GREEN, D.C. & WEBB, A.W., 1974: Geochronology of the northern part of the Tasman Geosyncline. *In* Denmead, A.K., Tweedale, G.W. & Wilson, A.F. (Editors): *The Tasman Geosyncline — A Symposium*. Geological Society of Australia Inc., Queensland Division, Brisbane, 275–291.

GREEN, P.M., CARMICHAEL, D.C., BRAIN, T.J., MURRAY, C.G., McKELLAR, J.L., BEESTON, J.W. & GRAY, A.R.G., 1997: Lithostratigraphic units in the Bowen and Surat basins, Queensland. *In* Green, P.M. (Editor): The Surat and Bowen Basins south-east Queensland. *Queensland Minerals and Energy Review Series*, Queensland Department of Mines & Energy, 41–108.

GRIBBLE, R.F., STERN, R.J., BLOOMER, S.H., STÜBEN, D., O'HEARN, T. & NEWMAN, S., 1996: MORB mantle and subduction components interact to generate basalts in the southern Mariana Trough back-arc basin. *Geochimica et Cosmochimica Acta*, **60**, 2153–2166.

GRIBBLE, R.F., STERN, R.J., NEWMAN, S., BLOOMER, S.H. & O'HEARN, T., 1998: Chemical and isotopic composition of lavas from the northern Mariana Trough: implications for magma genesis in back-arc basins. *Journal of Petrology,* **39**, 125–154.

GRIMES, K.G., 1980: The Tertiary geology of north Queensland. *In* Henderson, R.A. & Stephenson, P.J. (Editors): *The Geology and Geophysics of Northeastern Australia*. Geological Society of Australia Inc., Queensland Division, Brisbane, 329–347.

GRIMES, K.G., 1988: Cainozoic geology, south-east Queensland. *In* Hamilton, L.H. (Editor): *Field Excursions Handbook for the Ninth Australian Geological Convention*. Geological Society of Australia Inc., Queensland Division, Brisbane, 53–80.

GUST, D., BLEVIN, P., CHAPPELL, B. & STEPHENS, C., 1996: Early Mesozoic magmatism of the New England Orogen: space, time and compositional relationships. *In* Mesozoic Geology of the Eastern Australia Plate Conference 23–26 September 1996. *Geological Society of Australia Extended Abstracts* **43**, 224–227.

HANMER, S. & PASSCHIER, C., 1991: Shear-sense indicators: a review. *Geological Survey of Canada Paper*, 90–17.

HARBORT, T.A., 2001: Structure and tectonic synthesis of the Marlborough Block, northern New England Fold belt, Australia. Ph.D. Thesis, University of Queensland.

HARBORT, T., HOLCOMBE, R.J., VASCONCELOS, P. & FIELDING, C.R., 2001: Latest Permian emplacement of the Marlborough Block duplex: the major mountain-building phase of the Hunter–Bowen Orogeny in the northern NEFB. *In*, *2001: a structural odyssey*. The Specialist Group in Tectonics and Structural Geology Field Conference, Ulverstone, Tasmania, February 2001. Geological Society of Australia, Abstracts, **64**.

HEKEL, H., 1972: Pollen and spore assemblages from Queensland Tertiary sediments. *Geological Survey of Queensland, Publication* **355**.

HECKEL, P.H. & CLAYTON, G., 2006: The Carboniferous System. Use of the new official names for the subsystems, series, and stages. *Geologica Acta*, **4**, 403–407.

HENDERSON, R.A. & FERGUSSON, C.L., 2004: Discussion. Stratigraphy, facies architecture and tectonic implications of the Upper Devonian to Lower Carboniferous Campwyn Volcanics of the northern New England Fold Belt. *Australian Journal of Earth Sciences*, **51**, 451–452.

HENDERSON, R.A., FERGUSSON, C.L., LEITCH, E.C., MORAND, V.J., REINHARDT, J.J. & CARR, P.F., 1993: Tectonics of the northern new England Fold Belt. *In* Flood, P.G. & Aitchison, J.C. (Editors): *New England Orogen, eastern Australia*. Department of Geology and Geophysics, University of New England, Armidale, 505–515.

HEYWOOD, P.B., 1974: Geology of the Theodore district. B.Sc. Honours Thesis, University of Queensland.

HICKEY, R.L., FREY, F.A. & GERLACH, D.C., 1986: Multiple sources for basaltic arc rocks from the southern volcanic zone of the Andes (34°–41°S): trace element and isotopic evidence for contributions from subducted oceanic crust, mantle, and continental crust. *Journal of Geophysical Research*, **91**, 5963–5983.

HICKEY-VARGAS, R., ROA, H.M., LOPEZ-ESCOBAR, L. & FREY, F.A., 1989: Geochemical variations in Andean basaltic and silicic lavas from the Villarrica –Lanin volcanic chain (39.5°S): an evaluation of source heterogeneity, fractional crystallization and crustal assimilation. *Contributions to Mineralogy and Petrology*, **103**, 361–386.

HILL, D., (Editor), 1953: *Geological map of Queensland*. Department of Mines, Queensland.

HILL, D., 1957: Springsure — 4 mile Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes*.

HILL, D. & DENMEAD, A.K. (Editors) 1960: The Geology of Queensland. *Journal of the Geological Society of Australia*, **7**.

HILL, D., PLAYFORD, G. & WOODS, J.T. (Editors), 1966: *Jurassic Fossils of Queensland*. Queensland Palaeontographical Society, Brisbane.

HOFMANN, G.W., 1989: Queensland's questionnaire on geoscience mapping. *Queensland Government Mining Journal*, **90**, 463–468.

HOLCOMBE, R.J., FIELDING, C.R. & STEVENS, C.J., 1995: Tear fault termination of the fold-thrust belt in northern New England Orogen. *Geological Society of Australia Abstracts*, **40**, 72.

HOLCOMBE, R.J. & JELL, J.S., 1983: Geology of Cracow Station area, *In* Waterhouse, J.B. (Editor), *1983 field conference. Permian of the Biloela–Moura–Cracow area, 11–13 June 1983*. Geological Society of Australia. Queensland Division, 69–74.

HOLCOMBE, R.J., STEPHENS, C.J., FIELDING, C.R., GUST, D., LITTLE, T.A., SLIWA, R., KASSAN, J., MCPHIE, J. & EWART, A., 1997a: Tectonic evolution of the northern New England Fold Belt: the Permian–Triassic Hunter–Bowen event. *In* Ashley, P.M. & Flood, P.G. (Editors): *Tectonic and Metallogenesis of the New England Orogen. Geological Society of Australia Special Publication,* **19**, 52–65.

HOLCOMBE, R.J., STEPHENS, C.J., FIELDING, C.R., GUST, D., LITTLE, T.A., SLIWA, R., McPHIE, J. & EWART, A., 1997b: Tectonic evolution of the Northern New England Fold Belt: Carboniferous to early Permian transition from active accretion to extension. *In* Ashley, P.M. & Flood, P.G. (Editors) *Tectonics and Metallogenesis of the New England Orogen. Geological Society of Australia Special Publication,* **19**, 66–79.

HOLMES, P.R., 1983: GSQ Mundubbera 9, Preliminary lithologic log and composite log. *Geological Survey of Queensland, Record* **1983/41**.

HOYLING, N.H.V. & STEWART, H.W.J., 1964: Well completion report, APE Abercorn 1 well. Report for Amalgamated Petroleum Exploration Pty Ltd. Report held by the Department of Mines & Energy as CR1282.

HUTTON, L.J., GRIMES, K.G., LAW, S.R. & McLENNAN, T.P.T., 1998: *Mount Coolon, 1:250 000 geological series second edition - explanatory notes*. Department of Mines and Energy, Queensland, SF55–7.

HUTTON, L.J., WITHNALL, I.W., BULTITUDE, R.J., von GNIELINSKI, F.E. & LAM, J.S., 1999a: South Connors – Auburn – Gogango Project: progress report on investigations during 1998. *Queensland Geological Record* 1999/7.

HUTTON, L.J., WITHNALL, I.W., RIENKS, I.P., BULTITUDE, R.J., HAYWARD, M.A., von GNEILINSKI, F.E., FORDHAM, B.G. & SIMPSON, G.A., 1999b: A preliminary Carboniferous to Permian magmatic framework for the Auburn and Connors Arches, central Queensland. *In* Flood, P.G. (Editor): *Regional geology, tectonics and metallogenesis, New England Orogen*. Earth Sciences, University of New England, Armidale, NSW, 223–232.

INAL STAFF, 1975: Nickeliferous laterite deposits of the Rockhampton area, Queensland. *In* Knight, C.L. (Editor): *Economic Geology of Australia and Papua New Guinea. 1. Metals*. The Australasian Institute of Mining and Metallurgy, Melbourne, 1001–1006.

IRVINE, T.N. & BARAGAR, W.R.A., 1971: A guide to the chemical classification of the common volcanic rocks. *Canadian Journal of Earth Science*, **8**, 523–548.

JACK, R.L. & ETHERIDGE, R. Jr, 1892: The Geology and Palaeontology of Queensland and New Guinea. *Geological Survey of Queensland, Publication* **92**.

JAVES, I.R., 1972: Palaeontology and stratigraphy of the Gebbie Creek – Exmoor area, northern Bowen Basin, east central Queensland. B.Sc. Honours Thesis, University of Queensland.

JENSEN, A.R., 1968: Upper Permian and Lower Triassic sedimentation in part of the Bowen Basin, Queensland. *Bureau of Mineral Resources, Australia, Record* **1968/55**.

JENSEN, A.R., 1972: *Mackay. Queensland 1:250 000 Geological Series Explanatory Notes*. Bureau of Mineral Resources, Australia, SF/55–8.

JENSEN, A.R., 1975. Permo-Triassic stratigraphy and sedimentation in the Bowen Basin, Queensland. *Bureau of Mineral Resources, Australia, Bulletin* **154**.

JENSEN, A.R., GREGORY, C.M. & FORBES, V.R., 1964: Geology of the Taroom 1:250 000 Sheet area and of the western part of the Mundubbera 1:250 000 Sheet area, Queensland. Bureau of Mineral Resources, Australia, Record 1964/61 (unpublished).

JENSEN, A.R., GREGORY, C.M., & FORBES, V.R., 1966: Geology of the Mackay 1:250 000 Sheet area Queensland. *Bureau of Mineral Resources, Geology and Geophysics, Australia*, *Report* **104**.

JOHNSON, D.P., 1983. Development of Permian coal measure lithofacies at Goonyella, Queensland. *In, Proceedings of the Symposium on the Permian Geology of Queensland, 14–16 July 1982*, Brisbane. Geological Society of Australia Inc., Queensland Division, 289–293.

JONES, A.T. & FIELDING, C.R., 2004: Sedimentological record of the late Paleozoic glaciation in Queensland, Australia. *Geology* **32**(2), 153–156.

JONES, J.A., STEPHENS, C.J. & EWART, A., 1996: Constraints on the early Permian and late carboniferous of the northern New England Fold belt from the Camboon Volcanics and the Torsdale beds. *Geological Society of Australia, Abstracts* **41**, 222.

JONES, P.J. (compiler) 1995: *AGSO Phanerozoic timescale 1995: wall chart and explanatory notes*. Oxford University Press, Melbourne.

KASSAN, J., 1993: Basin analysis of the Triassic succession, Bowen Basin, Queensland. Ph.D. Thesis, University of Queensland.

KELLY, S.M.B., 1986: Bowesite: a new lapidary material. *The Australian Gemmologist*, **16**(1), 5–8.

KING, K., 1999: Petrogenesis of the Cadarga Creek Granodiorite. B.Sc. (Honours) thesis, Queensland University of Technology.

KIRKEGAARD, A.G., 1970: Duaringa, Queensland, 1:250 000 geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes* SF55-16.

KIRKEGAARD, A.G., SHAW, R.D. & MURRAY, C.G., 1966: The Geology of the Rockhampton and Port Clinton 1:250 000 Sheet areas. Geological Survey of Queensland, Record 1966/1.

KIRKEGAARD, A.G., SHAW, R.D. & MURRAY, C.G., 1970: Geology of the Rockhampton and Port Clinton 1:250 000 Sheet areas. *Geological Survey of Queensland, Report* 38.

KNUTSON, J., 1989: Peak Range. *In* Johnson, R.W. (Editor): *Intraplate volcanism in eastern Australia and New Zealand*. Cambridge University Press, Cambridge, 100–101.

KOPPE, W.H., 1974a. The Exmoor Formation — an addition to stratigraphic nomenclature in the north-western Bowen Basin. *Queensland Government Mining Journal,* **75**, 280–286.

KOPPE, W.H., 1974b: Departmental drilling in the Calen Coal Measures. *Geological Survey of Queensland, Record* **1974/36**.

KOPPE, W.H., 1975: Departmental drilling in the Calen Coal Measures. *Queensland Government Mining Journal*, **76**, 406–409.

KOPPE, W.H. 1978: Review of the stratigraphy of the upper part of the Permian succession in the northern Bowen Basin. *Queensland Government Mining Journal*, **79**(915), 35–45.

KORSCH, R.J & TOTTERDELL, J.N., 1996: Mesozoic deformational events in eastern Australia and their impact on onshore sedimentary basins. In Mesozoic Geology of the Eastern Australia Plate Conference 23–26 September 1996. *Geological Society of Australia Extended Abstracts* **43**, 308–318..

LAING, A.C.M., 1960: North, Central and Eastern portions of the Bowen Basin. *In* Hill, D. & Denmead, A.K. (Editors): The Geology of Queensland. *Journal of the Geological Society of Australia*, **7**, 203–204.

LAM, J.S., 1998: A review of company exploration for metalliferous deposits in the Mundubbera 1:250 000 sheet area *Queensland. Geological Record* **1998/04**.

LAM, J.S., 2004: A review of company exploration and metalliferous mineralisation in the Mackay 1:250 000 sheet area, central Queensland. *Queensland Geological Record* **2004/04**.

LAM, J.S., 2005: A review of mines and metalliferous mineralisation in the Mundubbera 1:250 000 sheet area, Queensland. *Queensland Geological Record* **2005/01**.

LAM, J.S. & JACKSON C.J., 1998: Mining and production history of the Cracow Gold and Mineral Field from 1932–1976. *Queensland Geological Record* **1998/02**.

LAM, J.S. & von GNIELINSKI, F.E., 2004: A review of mines and metalliferous mineralisation in the Mackay special 1:250 000 sheet area (including the Bundarra pluton porphyry copper deposits). *Queensland Geological Record* **2004/05**.

LE BAS, M.J., LE MAITRE, R.W., STRECKEISEN, A., & ZANETTIN, B., 1986: A Chemical Classification of Volcanic Rocks based on the Total Alkali-Silica Diagram. *Journal of Petrology*, **27**, 745–750.

LE MAITRE, R.W. (Editor), 1989: *A classification of igneous rocks and a glossary of terms: recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks*. Blackwell Scientific Publications, Oxford.

LEADBEATTER, D.E., 1992: Geology of the Eidsvold Goldmine, Eidsvold, south-east Queensland. B.Sc. (Honours) Thesis, University of Queensland.

LEITCH, E.C., FERGUSSON, C.L., HENDERSON, R.A. & MORAND, V.J., 1994: The Late Palaeozoic arc flank and fore-arc basin sequence of the New England Fold belt in the Stanage Bay region, central Queensland. *Australian Journal of Earth Sciences*, **41**, 301–310.

LEVINGSTON, K.R., 1981: Geological evolution and economic geology of the Burdekin River region, Queensland. *Bureau of Mineral Resources, Australia, Bulletin* **208**.

LEY, M., 1982: Authority to Prospect 3339M 'Ben Mohr' and Authority to Prospect 3288M 'Tally Ho' combined six monthly report to December 1982. Getty Oil Development Company Ltd. Report held by the Department of Mines & Energy as CR11544.

LO GRASSO, G., 1992: Geology of the Calen Coal Measures, North Queensland. B.Sc. (Honours) thesis James Cook University of North Queensland.

LUDWIG, K. R., 2000: SQUID 1.00, A User's Manual. *Berkeley Geochronology Center Special Publication*. **No. 2**.

MACKENZIE, D.E., 1993: Geology of the Featherbed Cauldron Complex, north Queensland: Part 1 — eruptive rocks and post-volcanic sediments. *Australian Geological Survey Organisation Record* **1993/82**.

MAITLAND, A.G., 1889: Geological features and mineral resources of the Mackay district. *Geological Survey of Queensland, Publication* 53.

MALLETT, C.W., 1983: Depositional environments of the Rangal Coal Measures, southern Bowen Basin. *Proceedings of the Symposium on the Permian geology of Queensland*. Geological Society of Australia Inc., Queensland Division, Brisbane, 281–288.

MALLETT, C.W., FLOOD, P.G. & LEDGER, P., 1983: Sedimentation models for the Baralaba Coal Measures — Moura, Queensland. *In* Waterhouse J.B. (Editor): *1983 field conference. Permian of the Biloela–Moura–Cracow area, 11–13 June 1983*. Geological Society of Australia. Queensland Division, 51–68.

MALONE, E.J., 1964: Depositional evolution of the Bowen Basin. *Journal of the Geological Society of Australia*, **11**, 263–282.

MALONE, E.J., 1970: St Lawrence, Queensland, 1:250 000 geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes SF55-12*.

MALONE, E.J., CORBETT, D.W.P. & JENSEN, A.R., 1964: Geology of the Mount Coolon 1:250 000 Sheet area, Queensland. *Bureau of Mineral Resources, Australia, Report* **64**.

MALONE, E.J., JENSEN, A.R., GREGORY, C.M. & FORBES, V.R., 1966: Geology of the southern half of the Bowen 1:250 000 Sheet area, Queensland. *Bureau of Mineral Resources, Australia, Report* **100**.

MALONE, E.J., OLGERS, F. & KIRKEGAARD, A.G., 1969: Geology of the Duaringa and St Lawrence 1:250 000 Sheet areas, Queensland. *Bureau of Mineral Resources, Australia, Report* **121**.

MALONE, E.J., OLGERS, F. & KIRKEGAARD, A.G., 1970: Saint Lawrence, Queensland, 1:250 000 geological series. *Bureau of Mineral Resources, Australia, Explanatory Notes SF55-12*.

MARSHALLSEA, S.J., 1986: Fission track analysis of intrusive rocks from the northern Bowen Basin. Department of Geology, University of Melbourne.

MARTIN, K.R., 1981: Deposition of the Precipice Sandstone and the evolution of the Surat Basin in the Early Jurassic. *The APEA Journal*, **21**, 16–23.

McCLUNG, G., 1981: Review of the stratigraphy of the Permian Back Creek Group in the Bowen Basin, Queensland. *Geological Survey of Queensland Publication* **37**, *Palaeontological Paper* **44**.

McDONOUGH, V.F., 1987: Chemical and isotopic systematics of basalts and peridotite xenoliths: implications for the composition and evolution of the Earth's mantle. Ph.D. Thesis, Australian National University.

McDOUGALL, I. & SLESSAR, G.C., 1972: Tertiary volcanism in the Cape Hillsborough area, north Queensland. *Journal of the Geological of Australia*, **18**, 401–408.

McFARLANE, M.J., 1983: Laterites. *In* Goudie, A.S. & Pye, K. (Editors): *Chemical sediments and geomorphology*. Academic Press, London, 7–58.

McINNES, P. 1974: The Hawkwood Layered Gabbro Intrusion. B.Sc. (Honours) thesis University of Queensland.

McKELLAR, J.L., 1974: Jurassic miospores from the upper Evergreen Formation, Hutton Sandstone and basal Injune Creek Group, north-eastern Surat Basin. *Geological Survey of Queensland, Publication* **361**, *Palaeontological Paper*, **35**.

McKELLAR, R.G., 1967: The geology of the Cannindah Creek area, Monto district, Queensland. *Geological Survey of Queensland, Publication* **331**.

McLEAN-HODGSON, J. & KEMPTON, N.H., 1981: The Oakey–Dalby region, Darling Downs coalfield: stratigraphy and depositional environments. *Geological Society of Australia, Coal Geology*, **1**(4), 165–177.

MESSENGER, P.R., 1994: Appendix 9. Geology, volcanology and petrology of the Develin Creek VHMS deposits. *In* EPM 7585 8076 8388 9328 9329 9332 9376 9377 9417 9418 9419 9478 9589 9590 9591 9615 9668 9669 9803 9898 9968 10009 10032 10103 10143 10144 10243 10244, Fitzroy Project, Annual report for period ended 31/12/94. Queensland Metals Corporation Limited. Report held by the Department of Mines & Energy as CR26354.

MICHAELSEN, P., HENDERSON, R.A., CROSDALE, P.J. & FANNING, C.M. 2001: Age and significance of Platypus Tuff Bed a regional reference horizon in the Upper Permian Moranbah Coal Measures, north Bowen Basin. *Australian Journal of Earth Sciences*, **48**, 183–192.

MILBURN, D., 1992: EPM 5721, Nob Creek, final report. Queensland Metals Corporation Limited. Report held by the Department of Mines & Energy as CR24114.

MOLLAN, R.G., DICKINS, J.M., EXON, N.F. & KIRKEGAARD, A.G., 1969: The geology of the Springsure 1:250 000 Sheet area, Queensland. *Bureau of Mineral Resources, Australia, Report* **123**.

MOLLAN, R.G., EXON, N.F. & FORBES, V.R., 1965: Notes on the geology of the Eddystone 1:250,000 Sheet area. *Bureau of Mineral Resources, Australia, Record* **1965/ 98**.

MOLLAN, R.G., FORBES, V.R., JENSEN, A.R., EXON, N.F. & GREGORY, C.M., 1972: Geology of the Eddystone, Taroom and western part of the Mundubbera Sheet areas, Queensland. *Bureau of Mineral Resources, Australia, Report* **142**.

MOORE, S., 1999: Petrogenesis of the Cheltenham Creek Monzogranite and Delubra Quartz Gabbro. B.Sc. (Honours) thesis, Queensland University of Technology.

MORAND, V.J., 1993a: The Broome Head Metamorphics: high grade metamorphism in the northern New England Orogen. *In* Flood, P.G. & Aitchison, J.C. (Editors): *New England Orogen, eastern Australia*. Department of Geology and Geophysics, University of New England, Armidale, 591–598.

MORAND, V. J., 1993b: Structure and metamorphism of the Calliope Volcanic Assemblage: implications for Middle to Late Devonian orogeny in the northern New England Fold Belt. *Australian Journal of Earth Sciences* **40**, 257–270.

MORAND, V.J., 1998: Structure of the Broome Head Metamorphics and related rocks in the Shoalwater Bay area, northern New England Fold Belt. *Australian Journal of Earth Sciences,* **45**, 155–167.

MORGAN, F., 1993: The Geology of the Late Triassic Rosehall Caldera. B.Sc. (Honours) thesis University of Queensland.

MORTON, C.C., 1955: Coal resources, Tooloombah Creek area, Styx coalfield. *Geological Survey of Queensland, Publication* **281**, 1–36.

MUNT, A.D., 1962: Operation Caviare. Technical Report 10, Carpentaria Exploration Co. Pty Ltd. Report held by the Department of Mines & Energy as CR879.

MURRAY, C.G., 1969: The petrology of the ultramafic rocks of the Rockhampton district, Queensland. *Geological Survey of Queensland, Publication* **343**.

MURRAY, C.G., 1974: Alpine-type ultramafics in the northern part of the Tasman Geosyncline — possible remnants of Palaeozoic ocean floor. *In* Denmead, A.K., Tweedale, G.W. & Wilson, A.F. (Editors): *The Tasman Geosyncline — a Symposium*. Geological Society of Australia Inc., Queensland Division, Brisbane, 161–181.

MURRAY, C.G., 1975: Rockhampton, Queensland 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes SF 56–13*.

MURRAY, C.G., 1986: Metallogeny and tectonic development of the Tasman Fold Belt System in Queensland. *Ore Geology Reviews*, **1**, 315–400.

MURRAY, C.G., 1990: Tasman Fold Belt in Queensland. *In* Hughes, F.E. (Editor): *Geology of the Mineral Deposits of Australia and Papua New Guinea*. The Australasian Institute of Mining and Metallurgy, Melbourne, 1431–1450.

MURRAY, C.G., 1994: Yarrol Project 1993–2000 — a review of available information, data requirements and mapping priorities. *Queensland Geological Record* **1994/18**.

MURRAY, C.G. 2007: Devonian supra-subduction zone setting for the Princhester and Northumberland Serpentinites: implications for the tectonic evolution of the northern New England Orogen. *Australian Journal of Earth Sciences*, **54**(7), 899–925.

MURRAY, C.G. & BLAKE, P.R. 2005: Geochemical discrimination of tectonic setting for Devonian basalts of the Yarrol Province of the New England Orogen, central coastal Queensland: an empirical approach. *Australian Journal of Earth Sciences* **52**(6), 993–1034.

MURRAY, C.G., BLAKE, P.R., HUTTON, L.J., WITHNALL, I.W., HAYWARD, M.A., SIMPSON, G.A. & FORDHAM, B.G., 2003: Discussion. Yarrol terrane of the northern New England Fold Belt: forearc or backarc? *Australian Journal of Earth Sciences*, **50**, 271–293.

MURRAY, C.G., FERGUSSON, C.L., FLOOD, P.G., WHITAKER, W.G. & KORSCH, R.J., 1987: Plate tectonic model for the Carboniferous evolution of the New England Fold Belt. *Australian Journal of Earth Sciences*, **34**, 213–236.

MUSCIO, V., 1994: Structural analysis of the Nob Creek region, Marlborough Block, central Queensland. B.Sc. (Honours) thesis University of Queensland.

MUTTER, J.C. & KARNER, G.D., 1980: The continental margin of north-eastern Australia. *In* Henderson, R.A. & Stephenson, P.J. (Editors): *The Geology and Geophysics of Northeastern Australia*. Geological Society of Australia Inc., Queensland Division, Brisbane, 47–69.

NELSON, C.H., 1982: Modern shallow-water graded sand layers from storm surges, Bering Shelf: a mimic of Bouma sequences from turbidite systems. *Journal of Sedimentary Petrology*, **52**, 537– 545.

NEWMAN, C.R., 1988: Geology and mineralisation of the SW Zone, Rosehall Caldera, SE Queensland. B.Sc. (Honours) thesis, Australian National University.

NISHIYA, T., WATANABE, T., YOKOYAMA, K. & KURAMOTO, Y., 2003: New isotopic constraints on the age of the Halls Reward Metamorphics, North Queensland, Australia: Delamerian metamorphic ages and Grenville detrital zircons. *Gondwana Research,* **6**, 241–249.

NITKIEWICZ, B. 1972: The geology of the Narayen–Glenwood area. B.Sc. (Honours) thesis, University of Queensland.

NOON, T.A., 1982a: Stratigraphic drilling report — GSQ Monto 5. *Queensland Government Mining Journal*, **83**, 450–456.

NOON, T.A., 1982b: GSQ Duaringa 1-2R and 3-5RD - preliminary lithologic logs and composite logs. Geological Survey of Queensland, Record 1982/40.

NOON, T.A., 1984a: Oil shale in Queensland. *Geological Survey of Queensland, Record* **1984/8**.

NOON, T.A., 1984b: Review of oil shale in Queensland. *Geological Survey of Queensland, Record* **1984/56**.

O'BRIEN, E., 1994: Volcanic character of the "Langdale Inlier" southern Connors Arch, Marlborough district, central Queensland. B.Sc. (Honours thesis), University of Queensland.

O'CONNELL, 1995: Geology and structure of the Aeroview area, Rockhampton region, central Queensland: implications for mineralisation of the Lower Permian Rookwood Volcanics. B.Sc. (Honours) Thesis, University of Queensland.

O'HANLEY, D.S., 1995: *Serpentinites: recorders of tectonic and petrological history*. Oxford Monographs on Geology and Geophysics, 32. Oxford University Press, New York.

OLGERS, F., WEBB, A.W., SMIT, J.A.J. & COXHEAD, B.A., 1964: The Geology of the Gogango Range, Queensland. *Bureau of Mineral Resources, Australia, Record* **1964/55**.

PAINE, A.G.L., 1972: Proserpine, Queensland. 1:250 000 Geological Series. *Bureau of Mineral Resources, Australia, Explanatory Notes SF55-04*.

PAINE, A.G.L., CLARKE, D.E. & GREGORY, C.M., 1974: Geology of the northern half of the Bowen 1:250 000 Sheet area, Queensland (with additions to the geology of the southern half). *Bureau of Mineral Resources, Australia, Report* **145**.

PALMIERI, V., 1975: Micropalaeontological report on core samples from boreholes drilled at "The Narrows". Geological Survey of Queensland unpublished file report.

PARFREY, S.M., 1984a: Permian Marine Invertebrate Macrofossils — GSQ Mundubbera 11. *Geological Survey of Queensland, Record* **1984/34**.

PARFREY, S.M., 1984b: Permian Marine Invertebrate Macrofossils — GSQ Mundubbera 9–10. *Geological Survey of Queensland, Record* **1984/37**.

PARFREY, S.M., 1986: Early Permian invertebrates from the Camboon Andesite near Biloela, south-eastern Bowen Basin. *Geological Survey of Queensland, Publication* **387**, 57–67.

PARFREY, S.M., 1988: Biostratigraphy of the Barfield Formation, south-eastern Bowen Basin, with a review of the fauna from the Ingelara and lower Peawaddy Formations, south-western Bowen Basin. *Queensland Department of Mines, Report* **1**.

PATEN, R.J., 1967: Microfloral distribution in the Lower Jurassic Evergreen Formation of the Boxvale area, Surat Basin, Queensland. *Queensland Government Mining Journal,* **68**, 345–349.

PATERSON, M., 1994: Structure and petrogenesis of the host rocks and mineralisation at the Nob Creek prospect, Marlborough Block, central Queensland. B.Sc. (Honours) thesis University of Queensland.

PEABODY AUSTRALIA PTY LTD, 1993: EPM 3469, Herbert Creek, report on area relinquished May 1993. Report held by the Department of Mines & Energy as CR24921.

PEARCE, B.R., 1971: Report on deep drilling Callide Valley groundwater investigation. Irrigation and water Supply Commission of Queensland, Groundwater Report 167.

PEARCE, J.A., 1983: Role of the sub-continental lithosphere in magma genesis at active continental margins. *In* Hawkesworth, C.J. & Norry, M.J., (Editors): *Continental Basalts and Mantle Xenoliths*, 230 – 249.

PEARCE, J.A., HARRIS, B.W. & TINDLE, A.G., 1984: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *Journal of Petrology,* **25**, 956–983.

PECCERILLO, A. & TAYLOR, S., 1976:Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, northern Turkey. *Contributions to Mineralogy and Petrology*, **58**, 63–81.

PICKETT, J.W., 1992: Early Carboniferous rugose corals from Long Island, off Proserpine, Queensland. *Geological Survey of New South Wales, Palaeontological Report* **91/3**.

PRICE, P.L., 1981: Palynological report — Alick Creek No. 1. Enclosure 8. In Houston Oil & Minerals Australia, Inc: HOM Alick Creek 1, Well Completion Report. Report held by the Department of Mines & Energy as CR8677.

PRICE, P.L., 1997: Permian to Jurassic palynostratigraphic nomenclature of the Bowen and Surat Basins. *In* Green, P.M. (Editor): The Surat and Bowen Basins south-east Queensland. *Queensland Minerals and Energy Review Series*, Queensland Department of Mines & Energy, 137–178.

QMC EXPLORATION PTY LTD, 1995: EPM 7585, 8076, 8388, 9328, 9329, 9332, 9376, 9377, 9417, 9418, 0419, 9478, 9589, 9590, 9591, 9615, 9668, 9669, 9803, 9898, 9968, 10009, 10032, 10103, 10143, 10144, 10243, 10244 Fitzroy Project, Annual Report for period ended 31/12/94. Report held by the Department of Mines & Energy as CR26354 (confidential).

QUINN, G.W., 1985: Geology of the Rangal Coal Measures and equivalents. *In* Bowen Basin Coal Symposium. *Geological Society of Australia, Abstracts* **17**, 93–100.

RANDS, W.H., 1887: Report on the Eidsvold Goldfield. *Geological Survey of Queensland, Publication* **43**.

RANDS, W.H., 1892: Styx River Coalfields. *Geological Survey of Queensland, Publication* **84**, 1–10.

RANDS, W.H., 1895: Second report on the Eidsvold Goldfield. *Geological Survey of Queensland, Publication* **102**.

RANDS, W.H., 1901: Third report on the Eidsvold Goldfield, with notes on McKonkey Creek diggings, and Antimony Lode. *Geological Survey of Queensland, Publication* **160**.

REEVES, F., 1947: Geology of the Roma district, Queensland, Australia. *American Association of Petroleum Geologists, Bulletin* **31**, 1341–1371.

REID, J.H., 1924: Permo-Carboniferous geology of Queensland, additional notes. *Queensland Government Mining Journal*, **25**, 46– 48.

REID, J.H., 1927: The Mulgildie Coalfield, Upper Burnett district. *Queensland Government Mining Journal*, **28**, 183–189.

REID, J.H., 1929: Coal prospects, Mackay district. *Queensland Government Mining Journal*, **30**, 156–158.

REID, J.H., 1931: Quarry sites for the Outer Harbour Scheme, Mackay district. *Queensland Government Mining Journal*, **32**, 315.

REID, J.H., 1939: Merion and Junee, Mackenzie Rivers. *Queensland Government Mining Journal*, **40**, 221.

REID, J.H., 1942: The Tertiary oil shales of Plevna–Eungella area. *Queensland Government Mining Journal*, **43**, 2–4.

REID, J.H., 1944: Dawson Coalfield, Baralaba. *Queensland Government Mining Journal*, **45**, 204–205.

REID, J.H., 1945a: The Dawson River area. *Queensland Government Mining Journal*, **46**, 296–299.

REID, J.H., 1945b: Baralaba Coalfield. *Queensland Government Mining Journal*, **46**, 354–363.

REID, J.H., 1946: Geological reconnaissance of the Nebo district coal areas. *Queensland Government Mining Journal*, **47**, 10–13.

REID, J.H. & MORTON, C.C., 1928: Central Queensland Geological Section. *Queensland Government Mining Journal*, **29**, 384–389.

REISER, R.F. & WILLIAMS, A.J., 1969: Palynology of the Lower Jurassic sediments of the northern Surat Basin, Queensland. *Geological Survey of Queensland, Publication* **339**.

RIENKS, I.P., WILLMOTT, W.F., & STEPHENSON, P.J., 1984: *Geological sites in central and northern Queensland. Geological Elements of the National Estate in Queensland Report* **3**. Geological Society of Australia Inc, Queensland Division, Brisbane.

RIGBY, J.F., 1972: The flora of the Kaloola Member of the Baralaba Coal Measures, central Queensland. *Geological Survey of Queensland Publication* **352**.

ROLLINSON, H.R., 1993: *Using Geochemical Data: Evaluation, Presentation, Interpretation*. Longman Scientific & Technical, Harlow, UK.

RUNNEGAR, B.N., 1969: The Permian faunal succession in eastern Australia. *In* Dickens, J.M. (Editor): The Permian of Australia Symposium. *Geological Society of Australia, Special Publication* **2**, 73–99.

RUNNEGAR, B.N., 1979: Ecology of Eurydesma and the Eurydesma fauna, Permian of eastern Australia. *Alcheringa*, **3**, 261–285.

RUNNEGAR, B.N. & McCLUNG, G., 1973: New names for marine Permian rock units in the northern Bowen Basin, Queensland. *Queensland Government Mining Journal,* **74**, 441–442.

SAUNDERS, A.D. & TARNEY, J., 1979: The geochemistry of basalts from a back-arc spreading centre in the East Scotia Sea. *Geochimica et Cosmochimica Acta*, **43**, 555–572.

SENIOR, B.R., 1979: Mineralogy and chemistry of weathered and parent sedimentary rocks in south-west Queensland. *BMR Journal of Australian Geology and Geophysics,* **4**, 111–124.

SENIOR, B.R. & MABBUTT, J.A., 1979: A proposed method of defining deeply weathered rock units based on regional geological mapping in south-west Queensland. *Journal of the Geological Society of Australia,* **26**, 237–254.

SHEPHERD, S.R.L., 1939: Oil shale at Eungella. *Queensland Government Mining Journal*, **40**, 91.

SHINJO, R., CHUNG, S-L., KATO, Y. & KIMURA, M., 1999: Geochemical and Sr –Nd isotopic characteristics of volcanic rocks from the Okinawa Trough and Ryuku Arc: implications for the evolution of a young, intracontinental back arc basin. *Journal of Geophysical Research*, **104**, 10591–10608.

SPAGGIARI, C.V., GRAY, D.R. & FOSTER, D.A., 2003: Tethyan- and Cordilleran-type ophiolites of eastern Australia: implications for the evolution of the Tasmanides. *In* Dilek, Y., & Robinson, P. T. (Editors): Ophiolites in Earth History. *Geological Society of London, Special Publication* **218**, 517–539.

STAINES, H.R.E. & KOPPE, W.H., 1979: The geology of the north Bowen Basin. *Queensland Government Mining Journal*, **80**, 172–195.

STAINES, H.R.E. & KOPPE, W.H., 1980: The geology of the north Bowen Basin. *In* Henderson, R.A. & Stephenson, P. J. (Editors): *The Geology and Geophysics of Northeastern Australia.* Geological Society of Australia Inc., Queensland Division, 279–298.

STEIGER, R.J. & JÄGER, E., 1977: Subcommission on geochronology. Convention on the use of decay constants in geo- and cosmochronology. *Earth and Planetary Science Letters*, **36**, 359– 362.

STEPHENS, C.J., O'CONNELL, S.J., HOLCOMBE, R. J., FIELDING, C.R., EWART, A. & MESSENGER, P.R. 1996: MORB in continental settings: the significance of the Permian Rookwood Volcanics to studies of the evolution of eastern Australian lithosphere. *Geological Society of Australia Abstracts* **41**, 418.

STEPHENSON, P.J., 1985: Tertiary volcanic plutonic rocks of the Cape Hillsborough Mount Jukes area. *In* Johnson, D.P. & Stevens, A.W. (Editors): *Guide to the Permian geology of the Mackay–Collinsville–Townsville region, north-eastern Queensland*. Geological Society of Australia Inc., Queensland Division, 46–61.

STEVENS, N.C., 1983: Camboon Volcanics. *In* Waterhouse, J.B. (Editor): *1983 field conference. Permian of the Biloela–Moura–Cracow area, 11–13 June 1983*. Geological Society of Australia Inc., Queensland Division, 22–25.

STEWART, H.W.J. & GOUGH, K., 1963: Well completion report, Amalgamated Petroleum Mulgildie No. 1. Report held by the Department of Mines & Energy as CR1133.

SUN, S-S. & McDONOUGH, W.F. 1989. Chemical and isotopic systematics of oceanic basalts. *In* Saunders, A.D. & Norry, M.J. (Editors): Magmatism in the Ocean Basins. *Geological Society of London Special Publication* **42**, 313–345.

SUTHERLAND, F.L., 1981: Migration in relation to possible tectonic and regional controls in eastern Australian volcanism. *Journal of Volcanology and Geothermal Research*, **9**, 181–213.

SUTHERLAND, F.L., ROBERTSON, A.D. & HOLLIS, J.D., 1989: Monto. *In* Johnson, R.W. (Editor): *Intraplate Volcanism in eastern Australia and New Zealand*. Cambridge University Press, Cambridge and Australian Academy of Science, Canberra, 106–107.

SUTHERLAND, F.L., STUBBS, D. & GREEN, D.C., 1978: K–Ar ages of Cainozoic Volcanic Suites, Bowen–St Lawrence hinterland, north Queensland (with some implications for tectonic models). *Journal of the Geological Society of Australia*, **24**, 447–460.

SWARBRICK, C.F.J., 1974: Oil shale resources of Queensland. *Geological Survey of Queensland, Report* **83**.

SWARBRICK, C.F.J., GRAY, A.R.G. & EXON, N.F., 1973: Injune Creek Group — amendments and an addition to stratigraphic nomenclature in the Surat Basin. *Queensland Government Mining Journal*, **74**, 57–63.

SYMONDS, P.A., COLWELL, J.B., STRUCKMEYER, J.B., WILLCOX, J.B. & HILL, P.J., 1996: Mesozoic rift basins off eastern Australia. *In* Mesozoic Geology of the Eastern Australia Plate Conference 23–26 September 1996. *Geological Society of Australia Extended Abstracts* **43**, 528–544.

TARNEY, J., WYBORN, L.A.I., SHERATON, J.W. & WYBORN, D., 1987: Trace element differences between Archean, Proterozoic and Phanerozoic crustal components — implications for crustal growth processes. *In* Ashwal, L.D. (Editor): Workshop on the growth of continental crust. *Lunar and Planetary Institute, Technical Report*, **88.02**, 139–140.

TAYLOR, S., 1988: First six monthly report for the period 15.05.87-14.11.87, A-P 4751M, Mount Lookerbie, central Queensland. Placer Exploration Ltd. Report held by the Department of Mines & Energy as CR18326.

TERENCE WILLSTEED & ASSOCIATES, 2001: Independent valuation report — coal exploration tenements. *In: Macarthur Coal 2001 IPO Prospectus*, section 11, 92–116.

THAYER, T.P., 1967: Chemical and structural relations of ultramafic and feldspathic rocks in alpine intrusive complexes. *In* Wiley, P.J. (Editor): *Ultramafic and Related Rocks*. John Wiley & Sons, New York, 222–239.

TORMEY, D.R., FREY, F.A. & LOPEZ-ESCOBAR, L., 1995: Geochemistry of the active Azufre–Planchon–Peteroa volcanic complex, Chile (35°15'S): evidence for multiple sources and processes in a Cordilleran arc magmatic system. *Journal of Petrology*, **36**, 265–298.

TURNER, S., HAWKESWORTH, C., VAN CALSTEREN, P., HEATH, E., MACDONALD R. & BLACK S., 1996: U-series isotopes and destructive plate margin magma genesis in the Lesser Antilles. *Earth and Planetary Science Letters*, **142**, 191–207.

UNITED GEOPHYSICAL CORPORATION, 1965: Mackenzie seismic survey. Report held by the Department of Mines & Energy as CR1772.

URQUHART, G., 1962: Report on low grade bedded ironstone deposits in the Marburg–Bundamba strata of Queensland. Report for Consolidated Zinc Pty Ltd. Report held by the Department of Mines & Energy as CR840.

VEEVERS, J.J., RANDAL, M.A., MOLLAN, R.G., & PATEN, R.J., 1964: The geology of the Clermont 1:250 000 Sheet area, Queensland. *Bureau of Mineral Resources, Australia, Report*, **66**.

WAGER, L.R., BROWN, G.M. & WADSWORTH, W.J., 1960: Types of igneous cumulates. *Journal of Petrology*, **1**, 73–85.

WALKER, M.D., 1985: Authority to Prospect 3888M "Carmila": Six Monthly Report to Queensland Mines Department, 16th November 1984 to 15th May 1985. B.P. Minerals Australia Ltd for Seltrust Mining Corporation Pty Ltd. Report held by the Department of Mines & Energy as CR14643.

WALKOM, A.B., 1915–1917: Mesozoic floras of Queensland. Part I. *Geological Survey of Queensland, Publication* **252**, 8–51, 257, 1–67, 259, 1–47.

WALKOM, A.B., 1919: Mesozoic floras of Queensland. Parts III & IV. *Geological Survey of Queensland, Publication* **263**, 7–78.

WASS, R., 1965: The marine Permian formations of the Cracow district, Queensland. *Proceedings of the Royal Society of New South Wales*, **98**(3), 159–168.

WATERHOUSE, J.B., 1983: Back Creek Group, **In** Waterhouse, J.B. (Editor): *1983 field conference. Permian of the Biloela–Moura–Cracow area, 11–13 June 1983*. Geological Society of Australia. Queensland Division, 26–50.

WATERHOUSE, J.B., 1986: Late Palaeozoic Scyphozoa and Brachipoda (*Inarticulata, Strophomenida, Productida* and *Rhynchonellida*) from the south-east Bowen Basin, Australia. *Palaeontographica*, **193A**, 1–36, 42–76.

WATERHOUSE, J.B., 1987a: Late Palaeozoic Brachipoda (*Arthyrida, Spiriferida* and *Terabratulida*) from the south-east Bowen Basin, east Australia. *Palaeontographica Abt A*, **196**, 1–56.

WATERHOUSE, J.B., 1987b: Late Palaeozoic Mollusca and correlations from the south-east Bowen Basin, east Australia. *Palaeontographica Abt A*, **198**, 129–233.

WATERHOUSE, J.B., BRIGGS, D.J.C. & PARFREY, S.M., 1983: Major faunal assemblages in the early Permian Tiverton Formation near Homevale Homestead, north Bowen Basin, Queensland. *Proceedings of the Symposium on the Permian geology of Queensland.* Geological Society of Australia Inc., Queensland Division, Brisbane.

WATERHOUSE, J.B., & JELL, J.S., 1983: The sequence of Permian rocks and faunas near Exmoor Homestead, south of Collinsville, north Bowen Basin, Queensland. *Proceedings of the Symposium on the Permian geology of Queensland.* Geological Society of Australia Inc., Queensland Division, Brisbane.

WEBB, A.W., 1960: The geology of the Eidsvold igneous complex. B.Sc. (Honours) Thesis, University of Queensland.

WEBB, A.W. & McDOUGALL, I., 1964: Granites of Lower Cretaceous age near Eungella, Queensland. *Journal of the Geological Society of Australia*, **11**(1), 151–154.

WEBB, A.W. & McDOUGALL, I., 1967: Isotope dating evidence on the age of the Upper Permian and Middle Triassic. *Earth and Planetary Science Letters*, **2**, 483–488.

WEBB, A.W. & McDOUGALL, I., 1968: The geochronology of the igneous rocks of eastern Queensland. *Journal of the Geological Society of Australia*, **15**, 313–346.

WEBB, J.A., 1977: Stratigraphy and palaeontology of the Bukali area, Monto district, Queensland. *Papers Department of Geology University of Queensland*, **8**(1), 37–70.

WELLMAN, P., 1978: Potassium-Argon ages of Cainozoic volcanic rocks from the Bundaberg, Rockhampton, and Clermont areas of eastern Queensland. *Proceedings of the Royal Society of Queensland*, **89**, 59–64.

WELLMAN, P. & McDOUGALL, I., 1974: Cainozoic igneous activity in eastern Australia. *Tectonophysics*, **23**, 49–65.

WHALEN, J.B., CURRIE, K.L. & CHAPPELL, B.W., 1987: A-type granites: geochemical characteristics, discrimination and petrogenesis. *Contributions to Mineralogy and Petrology*, **95**, 407– 419.

WHITAKER, W.G., MURPHY, P.R. & ROLLASON, R.G., 1974: Geology of the Mundubbera 1:250 000 Sheet area. *Geological Survey of Queensland, Report* **84**.

WHITE, M.E., 1963a: Report on 1962 plant fossil collections. *Bureau of Mineral Resources, Australia, Record* **1963/1**.

WHITE, M.E., 1963b: Report on east Bowen plant fossil collection. *Bureau of Mineral Resources, Australia, Record* **1963/33**.

WHITE, W.C. & BROWN, G.A., 1963: Preliminary report on the geology of the Mackay region, Queensland. Area 93P and the southern part of 94P. Report held by the Department of Mines & Energy as CR1033.

WHITEHOUSE, F.W., 1936: A note on some fossil plants collected by Mr J.E. Ridgway near Hawkwood. Report, Geological Survey of Queensland.

WHITEHOUSE, F.W., 1953: The Mesozoic environments of Queensland. *Australian and New Zealand Association for the Advancement of Science*, **29**, 83–106.

WHITEHOUSE, F.W., 1955: Geology of the Queensland portion of the Great Australian Artesian Basin. Appendix G in *Artesian Water Supplies in Queensland*. Department of the Co-ordinator General and Public Works, *Queensland Parliamentary Papers, A*., 56.

WHITEHOUSE, F.W. & REID, J.H., 1939: Grasstree mine and goldfield, Sarina. *Queensland Government Mining Journal*, **40**, 48.

WIGHTMAN, D., 1992: EPM 4277, Mount Saul, Final Report 12/5/92. Peko-Wallsend Operations Ltd. Report held by the Department of Mines & Energy as CR23899.

WILSON, M.M. & MATHISON, C.I., 1968: The Eulogie Park Gabbro, a Layered Basic Intrusion from eastern Queensland. *Journal of the Geological of Australia*, **15**, 139–158.

WINCHESTER, J.A. & FLOYD, P.A., 1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements. *Chemical Geology*, **20**, 325–344.

WITHNALL, I.W., BLAKE P.R., CROUCH, S.B.S., TENISON WOODS, K., HAYWARD, M.A., LAM, J.S., GARRAD, P. & REES, I.D., 1995. Geology of the southern part of the Anakie Inlier, central Queensland. *Queensland Geology* **7**.

WITHNALL, I.W., HUTTON, L.J., BURCH, G., HAYWARD, M.A. & BLAKE, P.R., 2000: Late Palaeozoic magmatism in the northern New England Orogen — evidence from U–Pb SHRIMP dating in the Yarrol and Connors Provinces, central

Queensland. *In* Searching for a sustainable future: 15th Australian Geological Convention, Sydney, 3rd–7th July, 2000. *Geological Society of Australia, Abstracts* **No 59**, 550.

WITHNALL, I.W., HUTTON, L.J., GARRAD, P.D., JONES, M.R. & BLIGHT, R.K. J., 2002: *North Queensland Gold and Base Metal Study Stage 1– Georgetown GIS*. Geological Survey of Queensland, Department of Natural Resources and Mines, digital data (including explanatory notes) released on CD-ROM.

WITHNALL, I.W., HUTTON, L.J., RIENKS, I.P., BULTITUDE, R.J., von GNIELINSKI, F.E., LAM, J.S., GARRAD, P.D. & JOHN, B.H., 1998a: South Connors – Auburn – Gogango Project: progress report on investigations during 1997. *Queensland Geological Record* **1998/1**.

WITHNALL, I.W., GOLDING, S.D., DOBOS, S.K. & REES, I.D., 1996: New K–Ar ages for the Anakie Metamorphic Group evidence for an extension of the Delamerian Orogeny into central Queensland. *Australian Journal of Earth Science*, **43**, 567–572.

WITHNALL, I.W., JOHN, B.H., HUTTON, L.J., LAM, J.S., BULTITUDE, R.J., von GNIELINSKI, F.E., RIENKS, I.P. & GARRAD, P.D., 1997: South Connors–Auburn–Gogango Project. *In* Beeston, J.W. (Compiler): *Proceedings of the Queensland Development 1997 Conference, 13–14 November, Brisbane*. Department of Mines and Energy, 57–60.

WITHNALL, I.W., JOHN, B.H., HUTTON, L.J., RIENKS, I.P., BULTITUDE, R.J., von GNEILINSKI, F.E., LAM, J.S., GARRAD, P.D., 1998b: South Connors–Auburn–Gogango Project: Summary of investigations for 1996 and 1997. *Queensland Government Mining Journal,* **99** (June), 14 – 21.

WITHNALL, I.W., NIEUWENBURG, A., BLIGHT, R.L. & YARROL-SCAG Project Teams, 2007: Central Queensland Region Geoscience Dataset, Version 2, Yarrol-Connors-Auburn GIS. Geological Survey of Queensland, Department of Mines & Energy, digital data released on DVD.

WOOD, G.R, 1984: Palynological examination of core samples from GSQ Mundubbera 9, 10 & 11. *Geological Survey of Queensland, Record* **1984/30**.

WORSLEY, M.R., 1995: The controls on gold mineralization at the Golden Plateau mine, Cracow, Queensland, Australia. Unpublished PhD thesis, Townsville, James Cook University of North Queensland.

WYBORN, L.A.I., WYBORN, D., CHAPPELL, B.W., SHERATON, J., TARNEY, J.F., COLLINS, W.J. & DRUMMOND, B.J., 1988: Geological evolution of granite compositions with time in the Australian continent — implications for tectonic and mantle processes. *Geological Society of Australia, Abstracts*, **21**, 434–435.

WYBORN, L.A.I., WYBORN, D., WARREN, R.G. & DRUMMOND, B.J., 1992: Proterozoic granite types in Australia: implications for lower crustal composition, structure and composition. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **83**, 201–209.

YANG, K. & SECCOMBE, P.K., 1997: Geochemistry of mafic and ultramafic complexes of the northern Great Serpentinite Belt, New South Wales: implications for first-stage melting. *In* Ashley, P.M. & Flood, P.G. (Editors): Tectonics and Metallogenesis of the New England Orogen. *Geological Society of Australia Special Publication*, **19**, 197–211.

YARROL PROJECT TEAM, 1997: New insights into the geology of the northern New England Orogen in the Rockhampton–Monto region, central coastal Queensland: progress on the Yarrol Project. *Queensland Government Mining Journal*, **98** (May), 11–26.

ZELLMER, G.F., HAWKESWORTH, C.J., SPARKS, R.S.J., THOMAS, L.E., HARFORD, C.L., BREWER, T.S. & LOUGHLIN, S.C., 2003: Geochemical evolution of the Soufrière Hills volcano, Montserrat, Lesser Antilles volcanic arc. *Journal of Petrology*, **44**, 1349–1374.