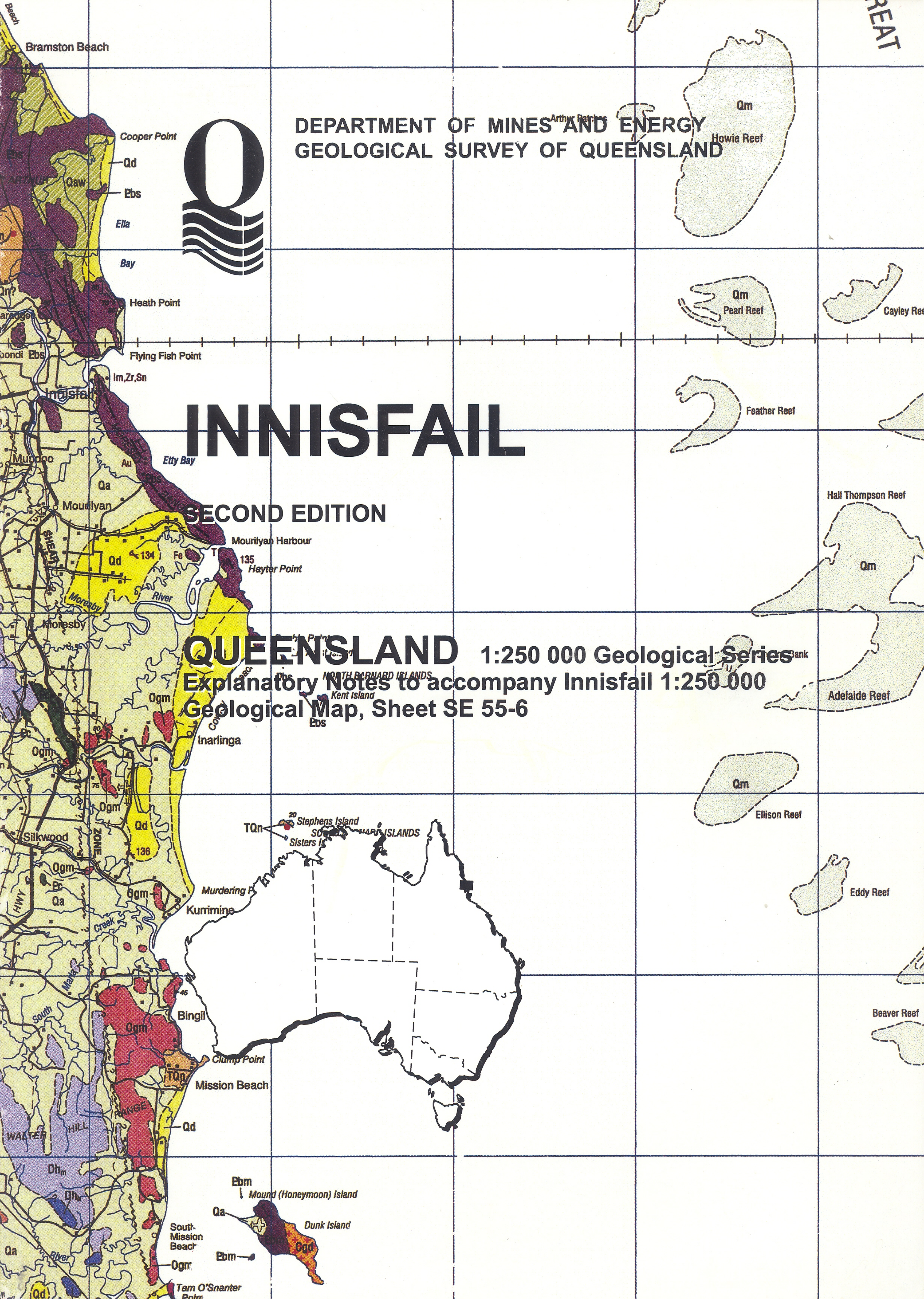
DEPARTMENT OF MINES AND ENERGY
GEOLOGICAL SURVEY OF QUEENSLAND

INNISFAIL

SECOND EDITION

QUEENSLAND 1:250 000 Geological Series

Explanatory Notes to accompany Innisfail 1:250 000 Geological Map, Sheet SE 55-6



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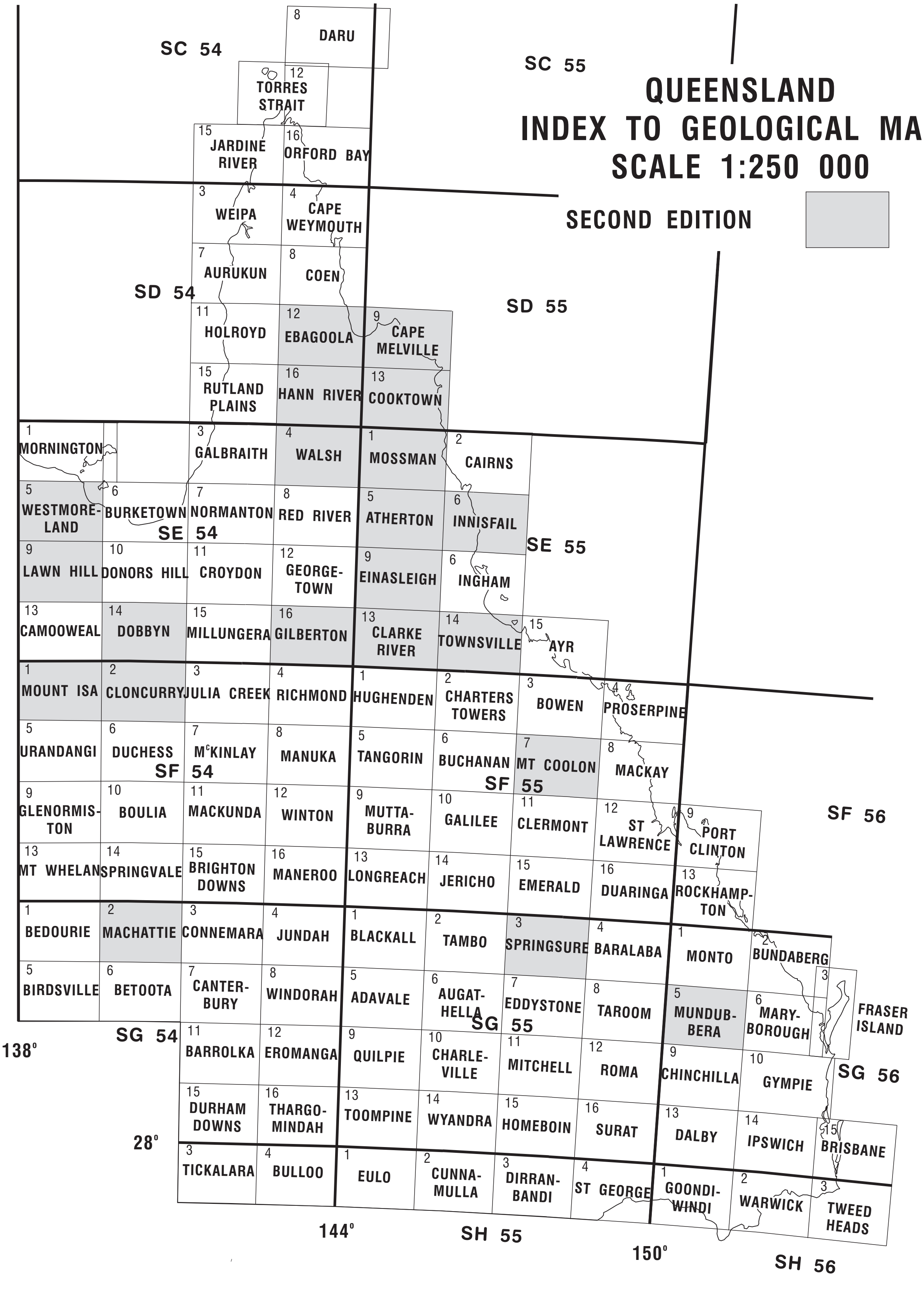

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QUEENSLAND
1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

INNISFAIL

SECOND EDITION

SHEET SE 55-6

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SUMMARY

The oldest rocks in the Innisfail 1:250 000 Sheet area are those of the **Barnard Province** (**Barnard Metamorphics** and **Babalangee Amphibolite**) or, possibly, the **Cowley Ophiolite Complex**. The Barnard Metamorphics consist mainly of multiply and complexly deformed and metamorphosed pelites and psammopelites, the metamorphic grade ranging from lower greenschist to upper amphibolite–lower granulite facies. Quartzo-feldspathic gneisses commonly contain coarse sillimanite, andalusite and unaltered cordierite. The supracrustal rocks are tentatively regarded as Neoproterozoic–Cambrian?. They may correlate with metamorphic assemblages which crop out farther south in the Townsville–Charters Towers region and in the Anakie Inlier. Amphibolite of the Neoproterozoic? Babalangee Amphibolite forms scattered outcrops in the northern part of the province.

Scattered outcrops of extensively altered mafic–ultramafic rocks in the Cowley–Silkwood area have been assigned to the Cowley Ophiolite Complex, of uncertain age. They may have formed in the Proterozoic, to have been tectonically emplaced during the Hunter–Bowen Orogeny, in the Permian–Triassic.

The Barnard Metamorphics are extensively intruded by Ordovician granites (**Tam O'Shanter Granite**, **Mission Beach Granite Complex**) of the **Macrossan Province**. Three distinct compositional groups are represented — mafic and felsic I-types? and felsic S-types. Samples of the felsic S- and I?-types have yielded early and late Ordovician isotopic ages, respectively. The ages overlap with those of granites in the Charters Towers region to the south and with igneous clasts from conglomerate lenses in the Hodgkinson Province to the north and north-west.

Rocks of the Barnard Province are tectonically juxtaposed against Hodgkinson Province rocks to the west along the Russell–Mulgrave Shear Zone and associated faults. These faults and shear zones were active in the Permian–Triassic during the Hunter–Bowen Orogeny. Movement indicators in most places indicate an east-block-up sense of shear. The only known exception is in the Bramston Point area where a west-block-up movement sense and a significant component of sinistral strike-slip shearing is indicated. The Russell–Mulgrave Shear Zone may mark the position of a significantly older basement structure which was responsible for the juxtaposition of rocks of the Barnard and Hodgkinson Provinces.

Rocks of the **Hodgkinson Formation**, the most extensive unit in the early–middle Palaeozoic **Hodgkinson Province** crop out west of the Barnard Province. The unit consists mainly of turbidity-current deposits, which have been metamorphosed (mainly to the greenschist facies) and deformed. Diagnostic fossils have not been found in rocks of the unit exposed in the Innisfail Sheet area. Elsewhere, the formation is mainly Devonian.

Extensive granite emplacement occurred in the sheet area in the Carboniferous–Permian. The igneous activity also involved extensive subaerial, silicic volcanism (**Glen Gordon Volcanics**). The intrusive and extrusive igneous rocks form part of the recently defined **Kennedy Province**. I-type granites dominate in the southern part of the area (mainly in the **Tully** and **northern Ingham Batholiths**), whereas S-types are abundant in the northern part (mainly in the **Bellenden Ker** and **Tinaroo Batholiths**). The granites forming the southern part of Dunk Island and adjacent Bedarra Island are significantly older than the late Carboniferous–early Permian granites of the nearby Tully and northern Ingham Batholiths. Results of recent isotopic dating indicate the granites of these offshore islands are Visean (~335Ma).

The Miocene–Holocene? **Atherton Subprovince** consists mainly of lava flows, with subordinate pyroclastic and minor lacustrine and fluviatile deposits. The subprovince is characterised by a range of volcano types and landforms, including lava shields, composite cones, cinder cones, and maars (at least six). Most of the volcanic rocks are moderately undersaturated. Hawaiite, *ne*-hawaiite, alkali basalt, and basanite are common rock types.

There are 170 known mineral occurrences, mines, and prospects in the Innisfail Sheet area. Most of these are located in five historic gold fields. The main mineral commodities are gold, tin, tungsten, and base metals. Deposits of limestone/marble, manganese ore, and mineral and silica sands have also been located. Some gemstones have been recovered, mainly from alluvial gold and cassiterite workings. Land access is a problem for exploration companies. More than 50% of the sheet area is classified as sterile or constrained land. Various restrictions regarding access and sampling are enforced in these areas.

Keywords: regional geology; stratigraphy; metamorphic geology; igneous geology; structural geology; economic geology; Barnard Province; Hodgkinson Province; Kennedy Province; Atherton Subprovince; Neoproterozoic; Cambrian; Ordovician; Devonian; Carboniferous; Permian; Triassic; Tertiary; Quaternary; Innisfail; Queensland; **SE55–6**.

INTRODUCTION

R.J. Bultitude

The regional geological field work in the Innisfail[1] 1:250 000 Sheet area was carried out during two 6-week periods, in 1992 and in 1994, by groups of three and two GSQ[2] geologists, respectively (Bultitude & Garrad, 1997). The mineral deposits were also investigated in 1994, by another group from GSQ (Garrad & Rees, 1995). In addition, the Barnard Province rocks and Cowley Ophiolite Complex are currently being studied by S. Wegner. Some of the results of his work have been incorporated on the map and in this report.

Much of the sheet area is either covered in dense tropical rainforest or is extensively cultivated (particularly the coastal plains). Outcrops away from the coast are generally sparse and deeply weathered, especially in the coastal plains and on the Atherton Tableland. The granitic and felsic volcanic rocks forming the mountainous country west of the coast or the coastal plains are well exposed locally, mainly in stream beds.

The investigation benefited significantly from previous studies of parts of the Barnard and Hodgkinson Provinces by researchers at James Cook University of North Queensland (*e.g.* Richards, 1977; Jones, 1978; Rubenach, 1978; Hammond & others, 1986).

Location and access

The sheet area extends from the coast and offshore islands to the Atherton Tableland in the west (Figure 1). Tully, Innisfail, Babinda, Gordonvale, Malanda, and Millaa Millaa are the main population and supply centres in the sheet area, which also contains numerous smaller settlements and resorts — particularly along the coast.

The area is connected to Cairns, to the north, and with cities to the south by the Bruce Highway and by the North Coast Railway, both of which traverse the coastal plains. The Gillies and Palmerston Highways link the coastal lowlands with the Atherton Tableland to the west. There is a dense network of roads on the coastal plains and the Atherton Tableland. The mountainous rainforest country, mainly in the central and south-western parts of the sheet area, is very difficult to traverse. Forestry roads and tracks formerly enabled access to parts of these ranges. Most are no longer maintained since the inclusion, in 1988, of the ranges in the World Heritage-listed Wet Tropical Rainforests Reserve.

More than 50% of INNISFAIL is classified as sterile or constrained land (*e.g.* national parks, forestry reserves, Wet Tropical Rainforests Reserve, water catchment reserves, the Great Barrier Reef Marine Park, Department of Defence training areas, and Aboriginal land), with varying restrictions regarding access and sampling. The Yarrabah Community, for example, would not allow the GSQ field parties to traverse Aboriginal land in the north-eastern part of the sheet area.

Industries

The pattern of human activities in the sheet area is closely related to physiography (Figure 2). Sugar cane growing, mainly on the coastal plains is the main primary industry. Several large mills (at Gordonvale, Babinda, South Johnstone, Mourilyan and Tully) process the sugar cane.

Bulk raw sugar is transported by ships to refineries from the storage facility at Mourilyan Harbour, the deep-water port. The sheet area also produces significant amounts of fruit (mainly bananas and paw paws) and vegetables, grown mainly on the fertile, basalt-derived soils of the coastal lowlands. To the west, the Atherton Tableland is the centre of a diverse range of agricultural pursuits, the main ones being dairy farming and small crops (such as maize, potatoes and peanuts). There are also some tea, avocado, macadamia nut, and sugar cane plantations in the Malanda area and, in the case of tea, on the eastern slopes of the escarpment (at Nerada). Beef cattle are raised on the poorer country and country which is too steep, too rough or too rocky for cropping. The rainforest country was, until fairly recently, a major source of timber in the region.

Mining activities in the sheet area have been relatively minor, although rich finds in the hinterland were responsible, either directly or indirectly, for European settlement and early development of most of north Queensland. The discovery of the Palmer River Gold Field in 1873, the Hodgkinson Gold Field in 1876, and the rich tin deposits of the Herberton–Irvinebank–Mount Garnet area in the early 1880s resulted in a large influx of people to the general region. Many of these turned to other occupations

1 1:250 000 sheet areas hereon shown in capitals

2 Geological Survey of Queensland

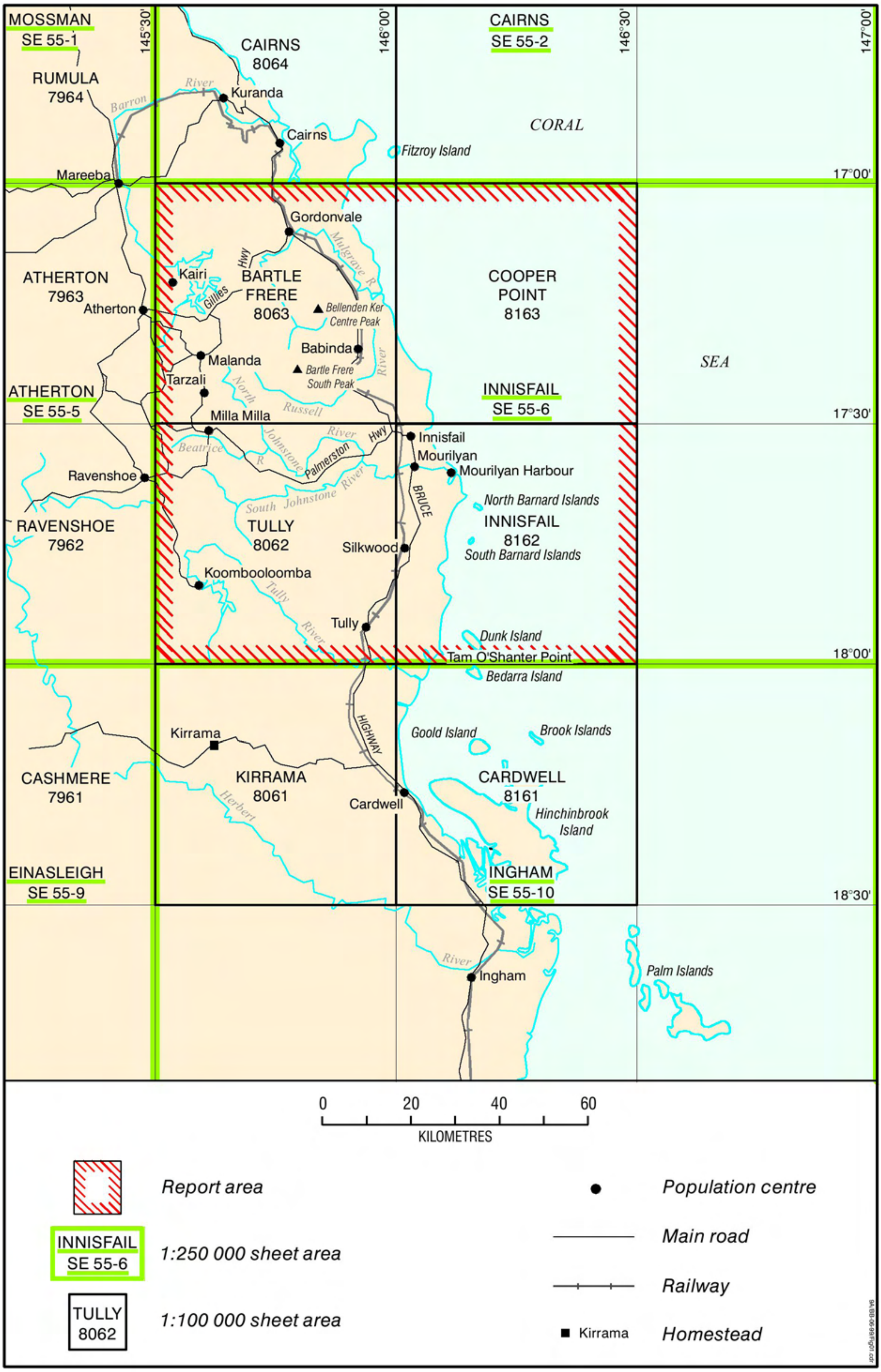

Figure 1. Locality map.

(mainly farming) as the ores petered out, or for other reasons, contributing significantly to the settlement of this part of north Queensland. Ports were established along the coast to service the mining fields.

Tourism is the industry with the most potential for growth in the foreseeable future. The proximity of the Great Barrier Reef to the coast, the tropical climate, and the numerous and diverse scenic attractions have resulted in an ever increasing influx of tourists, from both within Australia and overseas. The rapidly developing regional centre of Cairns, with an international airport and numerous tourist facilities, is located only ~80km north of Innisfail by road.

Early history and previous geological investigations

An account of the early history of the region and a summary of geological investigations up to 1960 have been presented by de Keyser & Lucas (1968) and Bultitude & Garrad (1997). Mining and mineral exploration activity in the sheet area have been summarised by Garrad & Rees (1995). The development of the Cardwell–Tully district has been narrated by Jones (1961); that of the Eacham Shire in the eastern part of the Atherton Tableland by publications of the Eacham Historical Society.

The first known European explorer to sail along the east coast of Australia was Lieutenant (later Captain) James Cook, in 1770. In early June of that year Cook, in HM Bark *Endeavour*, was off the north Queensland coast. The ship passed Dunk Island, at the northern end of Rockingham Bay, at about noon on 8th June and by early morning of the next day it had reached the Frankland Islands (both were named by Cook). Cook also included Fitzroy Island (in adjoining CAIRNS) in the Frankland Islands group (Wharton, 1893).

Between 1815 and 1870 several Royal Navy surveys were conducted along the north Queensland coast, generally with scientific observers aboard. The first European to explore the hinterland of the sheet area was Edmund Kennedy during his ill-fated expedition of 1848 from Rockingham Bay (near Cardwell, in adjacent INGHAM) to the top of Cape York Peninsula (Beale, 1970a,b).

The earliest detailed observations in INNISFAIL were made by R.A. Johnstone. Johnstone was sent to the Herbert River area in the mid 1860s as Sub-Inspector of Police, to provide protection to people in the areas being opened up in the north of the state — there being no settlement at that time between Cardwell and Thursday Island. He had a keen interest in exploration, natural history, the Aborigines and, just as importantly, kept a personal record of his observations (Johnstone-Need, 1984).

Johnstone was a member of the North-East Coast Exploring Expedition of 1873. The expedition, lead by G.E. Dalrymple, was sponsored by the Queensland Government after the discovery, by Johnstone in 1872, of "...a fine river, with rich soil and dense scrubs upon its banks..." a few kilometres north of the Moresby River (Johnstone-Need, 1984, page 129).

Many of the geographical features in INNISFAIL were examined and named during this expedition. Dalrymple named the river which sparked the expedition after Johnstone. Johnstone (Johnstone-Need, 1984) briefly described the geology and vegetation of Dunk Island, Clump Point, the South and North Barnard Islands, the Frankland Islands, and the adjacent mainland. He noted "...micaceous schist, with quartz veins and some galena..." on one of the islands of the North Barnard group (Johnstone-Need, 1984, page 128). High Island was reported to consist of "...granite, schist, quartz, hornblende, and mica" (Johnstone-Need, 1984, page 165). Tourmaline was also reported. Quartz veins, one reportedly containing manganese and iron ores, were found in the hills bordering the entrance to Mourilyan Harbour. Outcrops of mica schist, slate and talc schist were reported in the banks of the South Johnstone River a short distance upstream of its junction with the North Johnstone River (Johnstone-Need, 1984).

The glowing report on the Johnstone River area by Dalrymple, who recognised its suitability for growing sugar cane, and a boom in sugar prices prompted T.H. Fitzgerald to inspect the area in 1879, guided by Johnstone. Fitzgerald is credited as the founder of Innisfail. He had been involved in the sugar industry in the Mackay district for many years. The firm Fitzgerald & Co. was formed in 1880 and ~10 420 hectares (25 760 acres) were taken up on the Johnstone River. The first sugar cane was planted in 1880 and the first crushings were in 1881. Originally Cardwell supplied the new settlement with all essential supplies. The enterprise became firmly established and eventually a surveyed town, named Geraldton, was laid out. The town was subsequently renamed Innisfail (in 1887).

The 1879 sugar boom also resulted in another venture to develop the coastal lands of the Tully and Murray Rivers (in southern INNISFAIL and adjoining INGHAM). In that year James Tyson came to Cardwell to investigate possible areas for the cultivation of sugar cane. Again, it was Sub-Inspector Johnstone who escorted Tyson over the lands of the Tully and Murray Rivers. Tyson and two others took up three ~2075-hectare (5120-acre) blocks on the Tully River and land was cleared for planting in 1882 (Jones, 1961). Tyson soon lost interest in growing sugar cane but retained his properties for raising cattle. Nevertheless, the land on the Tully was readily selected by men seeking to profit from Tyson's renowned eye for a shrewd investment.

Following his widely publicised (and successful) search for a railway route to the tablelands from the vicinity of Cairns (in June 1882), the renowned north Queensland prospector and explorer Christie Palmerston was engaged by the Johnstone Divisional Board to find a practical route from Geraldton (Innisfail) to the mining settlement of Herberton (in adjacent ATHERTON to the west) — preferably one suitable for any subsequently planned railway between the two centres. The track previously pioneered (1–25 May, 1882) by Sub-Inspector Douglas between Herberton and Mourilyan Harbour was very steep in places. Palmerston left Geraldton on 1 November 1882 and reached Herberton twelve days later (Savage, 1989). He began the return journey on 21 December and, by following a slightly different route, arrived at Geraldton after 10 days. The modern-day Palmerston Highway essentially follows these routes between Innisfail and Millaa Millaa. During these trips Palmerston named the Beatrice River.

Palmerston subsequently undertook three prospecting journeys, each of about one month's duration, in the latter half of 1886, in the upper Russell River area. During these forays he discovered the Russell River Gold Field and climbed Bartle Frere (25–26 October), the first known European to make the ascent.

European settlement of the area around Malanda (current population ~1500) commenced in 1907 (Tranter, 1995a) and in the Millaa Millaa district in 1910 (Hanley, 1988). Gold prospectors and timber men looking for red cedar had been travelling through the region for the previous 20 years or so. As these early settlers began clearing the blocks of rainforest allocated to them, the lifestyle of the original Aboriginal inhabitants, who had lived essentially in harmony with their environment for thousands of years was irrevocably changed.

The coming of the railway to Malanda and the formation of the Eacham Shire Council in 1910 were important early events (Ray & Ray, 1995; Tranter, 1995b). The railway was eventually extended to Millaa Millaa in 1921 (Hanley, 1988). Other key events included the formation of the co-operative to control the dairying industry on the Atherton Tableland in 1912, the opening of the Malanda (in 1921) and Millaa Millaa (in 1930) butter factories, and the coming of the Australian Army in 1942 (which stimulated the development of the fresh milk industry; Stewart, 1995). With the coming of the railway the magnificent rainforest cabinet timbers became available to southern and overseas markets and several sawmills were constructed to process the timber. However, by the mid 1960s the railway to Millaa Millaa had closed (in 1964) and the timber industry began its final decline. In recent years most of the mills used mainly timber cut under licence from Queensland Government Forestry Reserves. When these reserves of Crown Land rainforests were placed on the World Heritage Register in 1988 most sawmills on the Atherton Tableland were forced to close.

Climate

The sheet area has a tropical climate. The coastal plains and, in particular, the mountainous country to the west receive some of, if not the highest, average annual rainfalls recorded in mainland Australia. The average annual rainfall at Innisfail is ~3650mm (Royal Australian Survey Corps, 1989a), and at Millaa Millaa ~2670mm (Hanley, 1988). The relatively wet conditions which characterise much of the coastal belt are directly influenced by the close proximity of the high (up to 1622m) ranges to the west. Rainfall on the summits of these mountains (which include Bartle Frere South Peak and Bellenden Ker Centre Peak, the highest and second highest peaks in Queensland, respectively) is significantly greater than on the coast, but decreases markedly westwards to ~1260mm at Kairi (on the western shores of Lake Tinaroo; Royal Australian Survey Corps, 1989b) due to a rain-shadow effect. The rainfall is seasonal, the wettest months generally being January to March and the driest June to October. Rainfall variability tends to increase with distance westwards from the coastal ranges. Some rainfall is not uncommon in any month, particularly in the coastal belt. The Tully–Babinda area averages slightly more than 100mm even in the driest month.

Temperatures remain relatively high throughout the year. The mean minimum temperature ranges from ~15°C in July to ~24°C in January, February and March at Innisfail on the coastal plains; the mean maximum from ~24°C in June and July to ~30°C in December and January (Royal Australian Survey Corps, 1989a). In contrast, Kairi, in the north-west of the sheet area and at an elevation of >700m, has a mean minimum temperature range from ~11°C in July to ~28°C in November, December and January (Royal Australian Survey Corps, 1989b). The combination of high rainfall and high temperatures in the coastal belt commonly results in oppressively humid conditions during the summer months.

Physiography
(mainly after de Keyser, 1964)

The main physiographic elements in the sheet area are shown in Figure 2. The **Atherton Tableland**, the most widespread element, extends over a broad area around Malanda, in the north-west. The average altitude of the Atherton Tableland ranges from ~800m in the

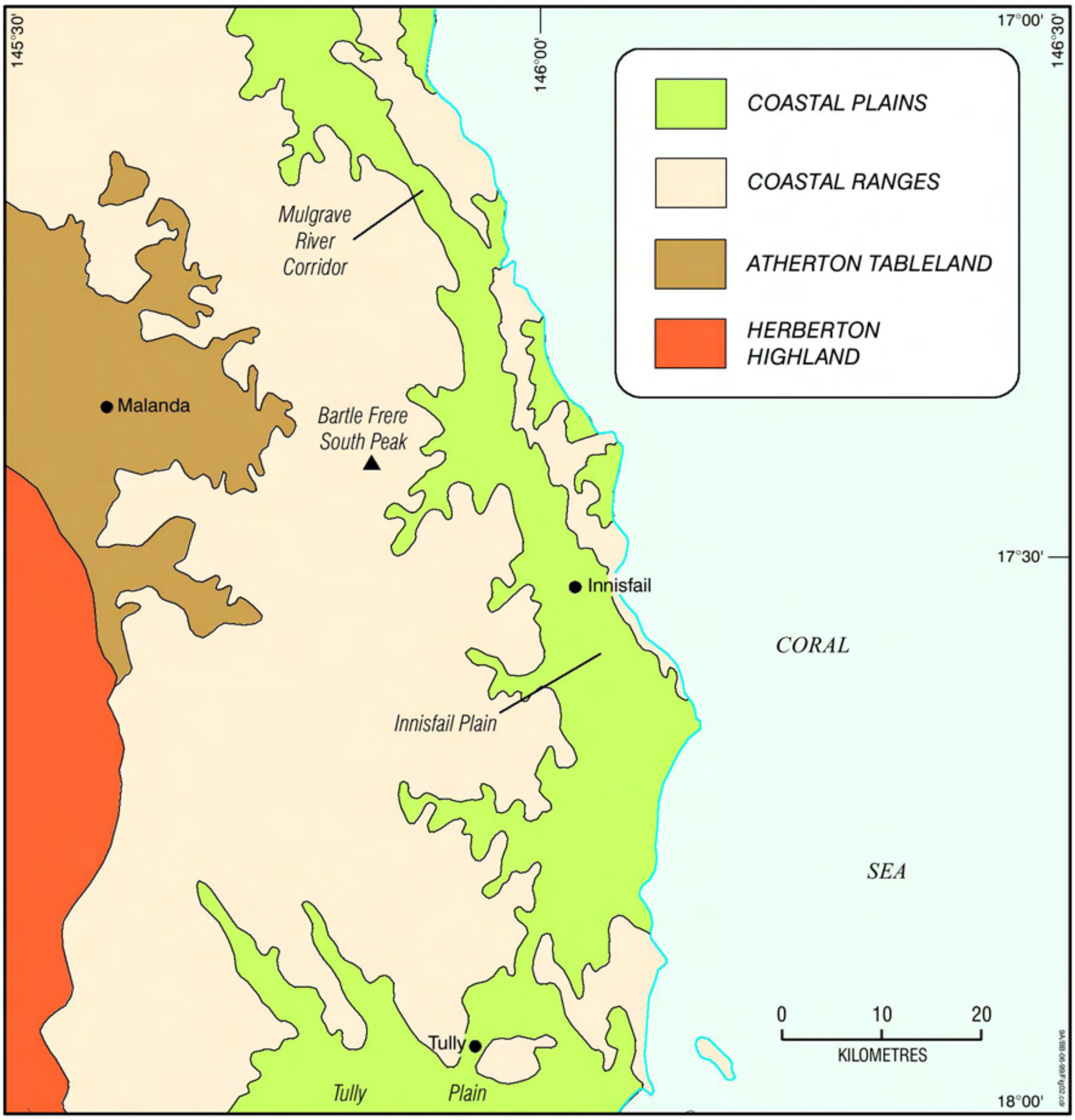

Figure 2. Physiographic sketch map, Innisfail 1:250 000 Sheet area.

south to ~720m in the north (Royal Australian Survey Corps, 1989b). Most of the central and northern parts of the tableland are covered by late Cainozoic basalt flows which filled depressions in the old land surface. As a result the topography now ranges from flat in the north (Plate 1) to undulating in the central part. The country is much more densely incised and hilly in the south (especially south of Millaa Millaa; Plate 2). Several prominent hills and mountains, such as the Seven Sisters (Plate 1), Mount Quincan (see Plate 27) and Mount Father Clancy represent extinct (to dormant?) volcanic centres. The eastern edge of the tableland is marked by a prominent escarpment, up to ~400m high.

The **Herberton Highland** (Best, 1962) forms rugged, mountainous country rising above the Atherton Tableland in the far central-west of the sheet area. The highland attains a maximum elevation of 1207m (at Mount Hugh Nelson; Royal Australian Survey Corps, 1969), 6km west of Millaa Millaa. It consists mainly of silicic volcanic rocks of the Glen Gordon Volcanics.

The **Coastal Ranges** form an irregular, northerly trending zone of rugged, rainforest-covered country (Plate 3) east of the Atherton Tableland, and adjacent to the coast. They are characterised by deeply incised valleys and steep to precipitous mountain sides. Swiftly flowing streams with numerous cascades, rapids and small waterfalls characterise the zone (Plates 4, 5). Bartle Frere South Peak (1622m) and Bellenden Ker Centre Peak (1561m) are the highest mountains in Queensland. Much of the zone is occupied by granite massifs of the Lamb, Bellenden Ker, Walter Hill, Malbon Thompson, and Graham Ranges. These granites are much more resistant to erosion than the enclosing metasedimentary rocks of the Hodgkinson Formation. Differential erosion has been marked. Subsequent valleys formed around the margins of the granite mountains. Some of these valleys were subsequently partly filled with basalt in the late

Cainozoic — the upper Mulgrave River, the Russell River, Cochable Creek, and Downey Creek being good examples.

The coastal ranges may have marked the position of the former divide between streams draining into the Pacific Ocean, to the east, and those emptying into the Gulf of Carpentaria, to the west. River captures and stream reversals following uplift, block faulting, and/or downwarping combined with extensive volcanic activity on the Atherton Tableland in the late Cainozoic may have shifted the divide farther west. Virtually the entire Innisfail 1:250 000 Sheet area now drains into the Pacific Ocean.

Much of the eastern part of the sheet area consists of **Coastal Plains** which have been subdivided into the Mulgrave River Corridor (Jardine, 1925), the Innisfail Plain (Sussmilch, 1938), and the Tully Plain (Sussmilch, 1938). These are separated from one another either by ranges (*e.g.* near Tully) or by thin sequences of Cainozoic basalt (*e.g.* between the North Johnstone and Russell Rivers). The coastal plains consist of low, flat to undulating surfaces of thick alluvium (maximum thickness >30m) and, near the coast, swampy lagoonal deposits and old beach sands.

Terminology

In this work 'arenite' is used as a general name for consolidated sedimentary rocks consisting mainly of sand-sized grains irrespective of composition. Terms describing metamorphic facies are as defined by Turner & Verhoogen (1960). The term 'concordant' is used to describe contacts between strata displaying parallelism of bedding or structure where a hiatus cannot be recognised but may exist (Bates & Jackson, 1980). The term 'migmatite' is used to describe a composite (mixed) rock consisting of igneous or igneous-looking and metamorphic components which are generally distinguishable megascopically (Bates & Jackson, 1980); injection of magma, *in situ* melting, or both, may have taken place.

Silica (SiO_2) content was used to classify the late Palaeozoic volcanic rocks. Analyses were first recalculated to 100% on a volatile-free basis and the following subdivisions were used:

- basalt - $\leq$53% SiO_2
- low-silica andesite - >53% SiO_2 $\leq$57% SiO_2
- high-silica andesite - >57% SiO_2 $\leq$63% SiO_2
- dacite - >63% SiO_2 $\leq$67% SiO_2
- rhyodacite - >67% SiO_2 $\leq$70% SiO_2
- rhyolite - >70% SiO_2

The standard Wentworth size classification and rock terms (Wentworth, 1922; in Pettijohn, 1957, page 19) were used to subdivide and describe the clastic sedimentary rocks, unless otherwise indicated. The following grainsize classification, based on the average size of groundmass grains, was used for the granitic rocks:

- fine grained - <1mm,
- medium grained - 1–5mm, and
- coarse grained - >5mm.

The AGSO geological timescale (Jones, 1995) was used to assign isotopically dated igneous rocks to periods and epochs.

Province terminology follows that recently proposed by Draper & others (1997).

Chemical analyses

Most of the chemical analyses used to generate the variation diagrams shown in subsequent parts of this report were determined either at the Government Chemical Laboratory, Queensland Department of Health, or at the Department of Geology, The Australian National University, Canberra, using mainly XRF techniques. Analyses of the Mission Beach Granite Complex supplied by S. Wegner were determined at James Cook University of North Queensland also using mainly XRF techniques.

Acknowledgments

Ian Rees (formerly of the Department of Mines and Energy) provided valuable assistance with the field work in 1994. Dick England (consulting petrologist, Townsville), and Brett Davis (formerly of the Department of Earth Sciences, James Cook University of North Queensland, Townsville) are gratefully acknowledged for constructive discussions on mineralogical and structural aspects of some of the rocks of the Barnard Metamorphics. P.J. Stephenson (formerly of the Department of Earth Sciences, James Cook University of North Queensland, Townsville) supplied isotopic ages of seven Cainozoic basaltic rocks from INNISFAIL. Emeritus Professor B.W. Chappell (Geology Department, The Australian National University) provided many of the chemical analyses of the granitic rocks. The assistance of I.P. Rienks (GSQ) is also acknowledged for providing analyses of rocks from the Ingham Batholith (in INGHAM) and the Glen Gordon Volcanics (in ATHERTON).

STRATIGRAPHY

R.J. Bultitude, S. Wegner, P.J.T. Donchak & C.M. Fanning

Seven lithological groups are represented in INNISFAIL (Figure 3), namely (from postulated oldest to youngest):

- metamorphic rocks of the Neoproterozoic–Cambrian? **Barnard Province** (Barnard Metamorphics and Babalangee Amphibolite),
- ultramafic–mafic rocks of the **Cowley Ophiolite Complex** (Neoproterozoic?),
- extensively deformed, early and late Ordovician granites (Tam O'Shanter Granite and Mission Beach Granite Complex) of the **Macrossan Province**,
- middle Palaeozoic metasedimentary and intercalated metavolcanic rocks of the **Hodgkinson Province** (Hodgkinson Formation),
- Carboniferous–Permian granites and volcanic rocks of the **Kennedy Province**,
- Tertiary and Quaternary basaltic rocks of the **Atherton Subprovince**, and
- Tertiary and Quaternary **sediments.**

The relationships between the main rock units in the sheet area are summarised in Figure 4.

BARNARD PROVINCE

Barnard Metamorphics

The Barnard Metamorphics crop out in the coastal area, between Tam O'Shanter Point and High Island (Frankland Islands group). Scattered outcrops of migmatitic gneiss farther north (in adjacent CAIRNS) along the coast are probably also part of the Barnard Metamorphics. The first systematic investigation of the rocks was undertaken by a joint BMR[3]–GSQ field party in 1962 (de Keyser, 1964, 1965; de Keyser & Lucas, 1968). De Keyser (1964, 1965) interpreted the Barnard Metamorphics as higher grade equivalents of the Barron River Metamorphics. The latter are currently interpreted as Hodgkinson Formation rocks which have been metamorphosed to the greenschist facies (de Keyser, 1965; de Keyser & Lucas, 1968; Bultitude & others, 1990).

The Barnard Metamorphics, prior to the BMR–GSQ survey, were regarded as probable Precambrian basement upon which the sediments of the Hodgkinson Province were deposited (Bryan & Jones, 1946; Jones & Jones, 1956). Differences in metamorphic grade were used to distinguish two units — the relatively high (amphibolite)-grade rocks forming the Barnard Metamorphics, and the lower (greenschist)-grade rocks the Barron River Metamorphics (now Hodgkinson Formation). This somewhat arbitrary subdivision resulted in a complex interfingering distribution of the two units because of variations in metamorphic grade now known to exist in the Barnard Metamorphics.

The results of recent investigations by GSQ and researchers at James Cook University (*e.g.* Richards, 1977; Jones, 1978; Rubenach, 1978; Hammond & others, 1986) indicate the Barnard Metamorphics are significantly older than the nearby Hodgkinson Formation. Furthermore, the two units are separated by a major shear zone (the Russell–Mulgrave Shear Zone of Hammond & others, 1986) and associated faults.

Rock types

The unit consists mainly of meta-arenite, quartzite, phyllite, 'greenstone', chlorite schist, muscovite–chlorite and biotite–muscovite schist, and subordinate granitic gneiss and migmatitic gneiss (Table 1). Other rock types recorded include hornblende granulite (Bultitude & others, 1996b), massive amphibolite, garnet-bearing amphibolite (*e.g.* at GR 948018, on High Island, Cooper Point 1:100 000 Sheet area) characterised by well-developed gneissic layering, metagabbro, metamorphosed ultramafic rocks, and talc-rich rocks.

The 'greenstone' lenses and layers probably represent several rock types. Well-bedded 'greenstone' forms conspicuous outcrops along the coast in the Etty Bay area.

Rare lenses of talc-rich rocks of uncertain origin have been found on High Island, at Mourilyan Harbour (e.g. at GR 072535, Innisfail 1:100 000 Sheet area), south of Bramston Point (Richards, 1977), and on Kent Island (North Barnard Islands).

3 Bureau of Mineral Resources (BMR); now Australian Geological Survey Organisation (AGSO)

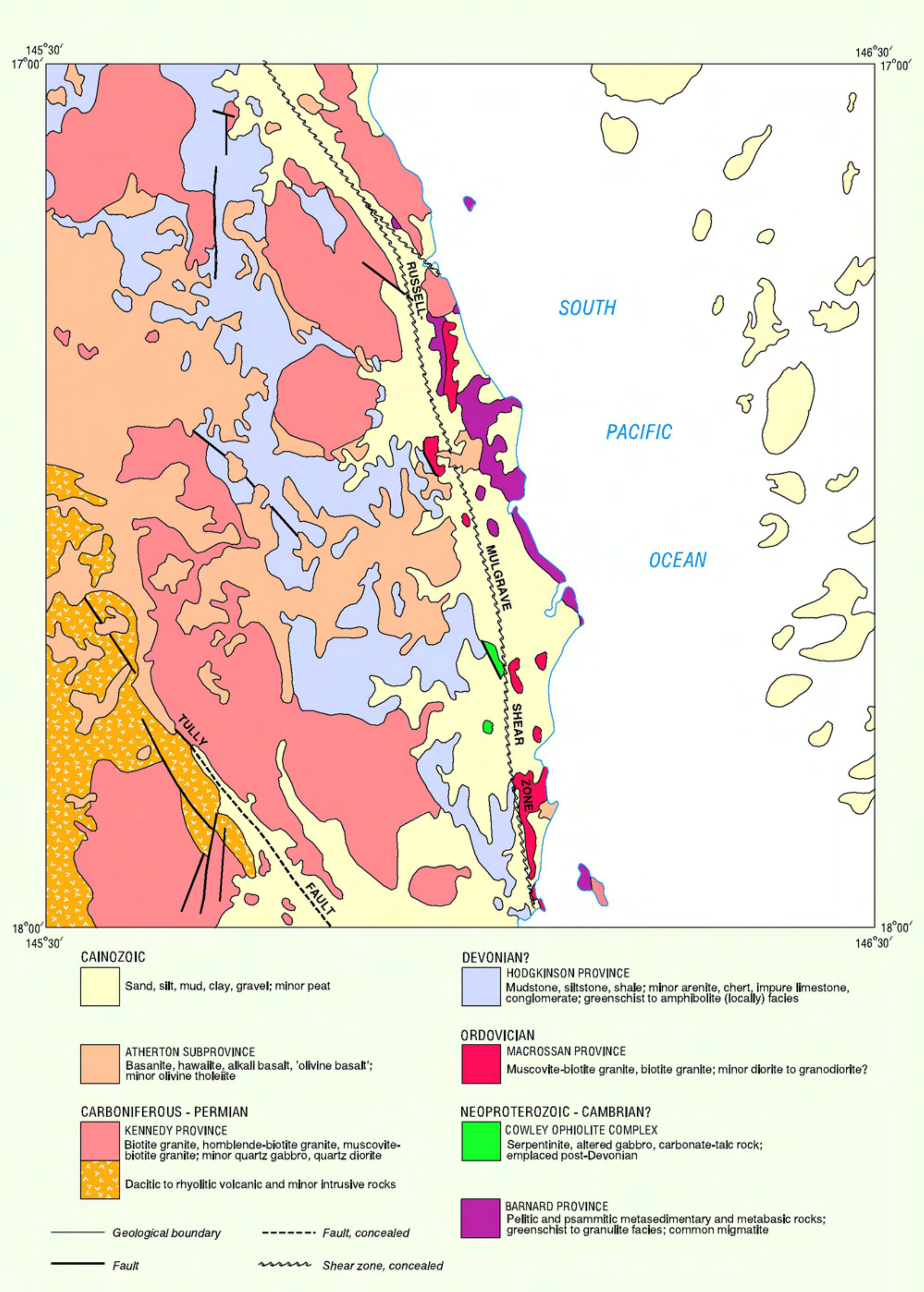

Figure 3. Main rock and structural units, Innisfail 1:250 000 Sheet area.

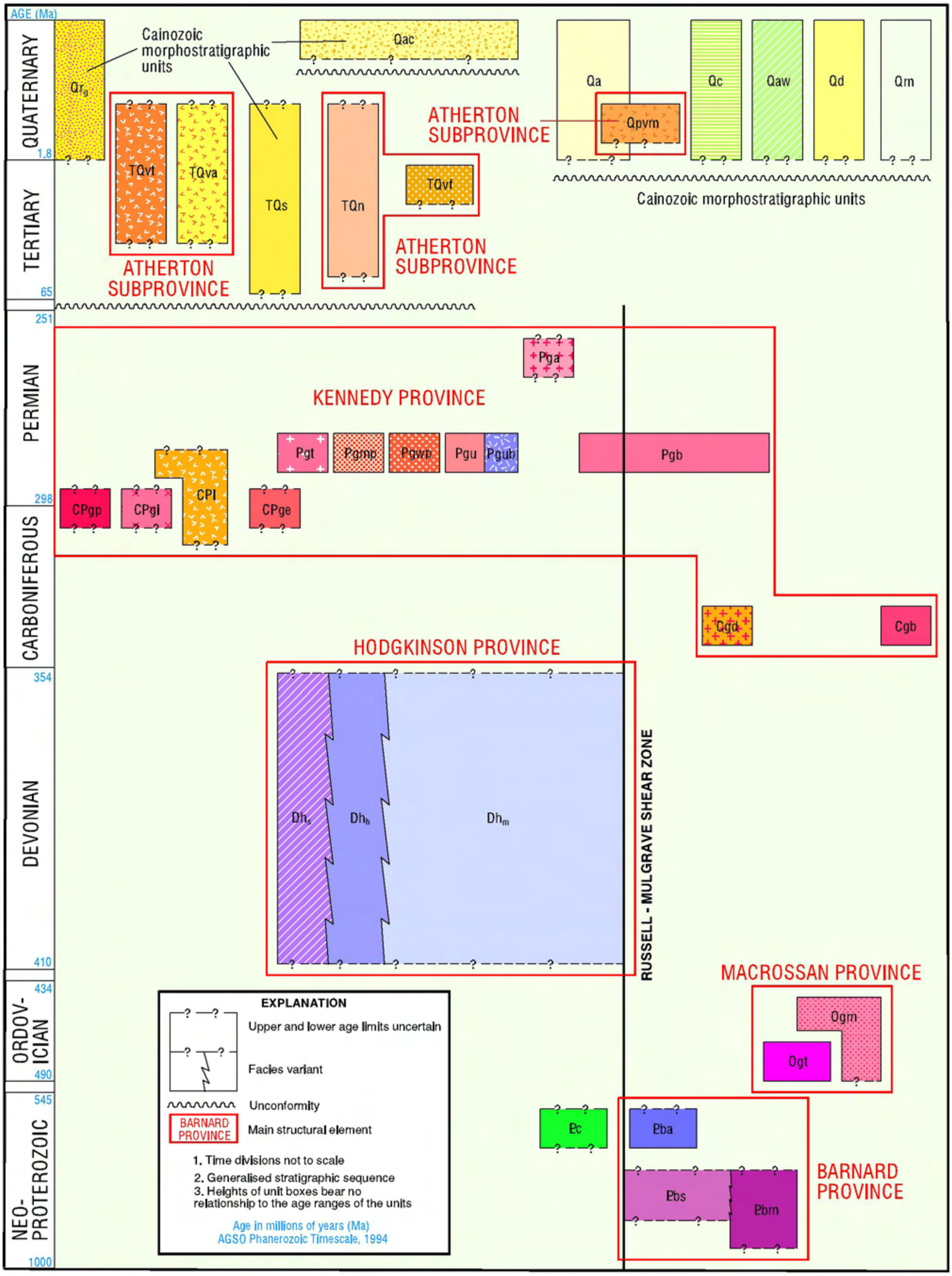

Figure 4. Schematic rock relationship diagram.

Low-grade metamorphic rocks

Much of the Barnard Metamorphics consists of greenschist facies **meta-arenite**, **quartzite, muscovite–chlorite** and **biotite–muscovite schist**, and **phyllite** (*e.g.* along the coast between Bramston Beach and Mourilyan Harbour, and on Dunk Island; Plates 6, 7). Pelitic layers in these rocks typically contain numerous discontinuous, mainly bed-parallel, siliceous laminae and quartz veinlets, as well as scattered quartz fragments (interpreted as disrupted quartz veins). Rubenach (1978) also reported that mineral assemblages typical of the chlorite zone predominate in the rocks exposed at Mourilyan Harbour and Etty Bay — whereas slightly higher grade rocks (biotite zone) are present in the Bramston Beach area. He noted, for example, that the headland at Mourilyan Harbour consists mainly of muscovite–chlorite schist, phyllite, and quartzite.

Low (greenschist) -grade quartz–muscovite schist is also a common rock type on Kent Island (North Barnard group). In addition, the assemblage there contains lenses of talc-rich rocks and thin layers (~15–20cm thick) of dark green, fine-grained 'greenstone' consisting virtually entirely of chlorite.

High-grade metamorphic rocks

Relatively high (middle to upper amphibolite and, locally, granulite)-grade rocks (mainly **migmatitic biotite gneiss**) are also present in parts of the unit. These high-grade rocks are mainly confined to the Frankland Islands (Plate 8), to a small area near the south-western end of the Malbon Thompson Range, and to a zone adjacent to the contact with the Dunk Island Granite (on Dunk Island — note that most of the metamorphic rocks on Dunk Island are greenschist facies and form part of the informal subunit Pbs, rather than subunit Pbm as shown on the geological map). Mineral assemblages (*e.g.* the presence of sillimanite rather than kyanite, together with andalusite even in the highest grade rocks) and the irregular distribution of the high-grade rocks imply they formed locally in zones where relatively high temperatures (as well as low pressures) prevailed — *e.g.* adjacent to granite plutons, either exposed (*e.g.* Dunk Island) or unexposed (*e.g.* Frankland Islands). The gneisses of the Frankland Islands are cut by relatively scarce, thin (<2m thick) dykes and rare small pods of granite (Plate 9), of unknown age. At least some of this granite may represent partial melts produced during the high-grade metamorphism(s).

The high-grade pelitic and psammopelitic rocks locally contain K-feldspar and porphyroblasts of unaltered to only slightly altered cordierite, andalusite and sillimanite (*e.g.* on the Frankland Islands and near the south-western end of the Malbon Thompson Range). The porphyroblasts are commonly 2–3cm long and, locally coarser (*e.g.* andalusite porphyroblasts at Cooper Point). Coarse andalusite is intergrown with, and replaced by, coarse sillimanite (both minerals up to ~5cm long) in the gneissic rocks of Russell Island (Frankland Islands group), as well as elsewhere (Plate 10). Such a relationship is commonly found in prograde metamorphic assemblages. The gneisses of the Frankland Islands, as well as those adjacent to the contact with the Dunk Island Granite (Dunk Island) and those on the south-western side of the Malbon Thompson Range, are migmatitic (Plates 11, 12). The migmatitic gneisses of Dunk Island contain K-feldspar, andalusite, muscovite, cordierite (altered), and fibrolite. The above mineral assemblages and textures are commonly found in low pressure–high temperature, regional metamorphic belts, as well as in some contact metamorphic aureoles.

Garnet is common in some high-grade rocks, and rare staurolite has also been found in (cordierite–) andalusite schist at Cooper Point. Scattered grains of tourmaline and myrmekitic intergrowths between quartz and plagioclase are also present in some of the gneisses on High Island.

Amphibolite is scarce in the Barnard Metamorphics. Fine-grained, garnet-bearing amphibolite forms a minor part of the assemblage (*e.g.* north of Bramston Beach, at ~GR 935879, Bartle Frere 1:100 000 Sheet area). The amphibolite contains abundant greenish brown to pale brown hornblende and scattered, small (~0.5mm–1mm across), euhedral to subhedral garnet poikiloblasts, as well as minor muscovite. Reddish brown biotite is a prominent accessory mineral. The amphibolite is interlayered with biotite–muscovite schist containing andalusite porphyroblasts.

Garnet-bearing amphibolite, ranging from massive to banded also crops out on High Island (Frankland Islands group; Plate 13). Elsewhere, numerous large blocks of massive amphibolite have been erupted from the Cainozoic basaltic volcano on Stephens Island (South Barnard Islands group). The Tam O'Shanter Granite and Mission Beach Granite Complex contain large inclusions of amphibolite.

Scattered outcrops of previously unreported mafic (SiO_2 = ~47%) **hornblende granulite** (locally containing metamorphic olivine) were found on the south-western side of the Malbon Thompson Range (~GR 849996, Bartle Frere 1:100 000 Sheet area) by R.J. Bultitude during the recent survey. The range consists mainly of Bellenden Ker Granite. The mafic rocks are interlayered with migmatitic andalusite–cordierite–sillimanite–K-feldspar-bearing biotite gneiss (Plate 14).

Table 1: Summary of stratigraphy — Innisfail 1:250 000 Sheet area

Unit	Type area	Distribution (Area)	Rock types
Qac		beds of Little Mulgrave and Mulgrave Rivers and Behana Creek ($\sim33km^2$)	sand, silt, mud, gravel
Qm		offshore coral reefs and shoals ($\sim66km^2$)	sand, silt, mud, and gravel, coral-reef rock
Qa		mainly in the coastal plains which form a north-trending belt extending into adjacent sheet areas to north and south ($\sim1328km^2$)	sand, gravel, silt, clay, mud; local coarse cobble and boulder deposits
Qc		only delineated in far north of sheet area ($\sim9km^2$)	sand, silt, mud, clay; minor gravel, gravelly clay
Qaw		adjacent to coast ($\sim41km^2$)	humic silt, mud, clay, sand
Qd		mainly adjacent to coast, but extending up to ~10km inland east of Mourilyan ($\sim79km^2$)	quartzose to lithic sublabile sand; minor silt, clay, peat
Qr_g		small area in far south-west of sheet area ($\sim0.5km^2$)	sand, gravel, silt
Meringa Basalt	southern flank of Green Hill (GR 733150, Bartle Frere 1:100 000 Sheet area; Willmott & others, 1988)	Green Hill (~120m high) and a small elliptical rise at Meringa ($\sim7km^2$)	olivine basalt lava, basaltic scoria and agglutinate
Adler Hill Basalt	eastern side of Adler Hill (GR 426152, Bartle Frere 1:100 000 Sheet area; Willmott & others, 1988)	small area west of Emerald Creek, in far north-west of sheet area ($\sim5km^2$)	vesicular to massive basalt lava; minor basaltic scoria
Twidler Hill Basalt	Tichum Creek quarry, in adjacent CAIRNS (Willmott & others, 1988)	small, elongate area on eastern side of Emerald Creek, in far north-west of sheet area ($\sim5km^2$)	vesicular to massive olivine basalt lava; minor basaltic scoria
The Fisheries Basalt	gully west of the Mulgrave River, near The Fisheries (GR 636997, Bartle Frere 1:100 000 Sheet area; Willmott & others, 1988)	valley of the Mulgrave River; outcrops in valley of North Babinda Creek also tentatively assigned to unit ($\sim36km^2$)	vesicular to massive olivine basalt lava; minor dark grey travertine
Atherton Basalt		mainly in central part of sheet area, in a zone extending from Stephens Island, in the east, to beyond the western boundary of sheet area ($\sim1315km^2$)	mainly hawaiite, *ne*-hawaiite, alkali basalt, basanite; minor olivine tholeiite, shale, sandstone, lignite, oil-shale, poorly consolidated conglomerate (mainly at base)
TQs		flat country along Emerald Creek and its tributaries, in north-western corner of sheet area; small area west of the Kennedy Highway, in central part of sheet area ($\sim12km^2$)	quartzose sand, ferruginous quartz sand; minor clay, silt, mud, gravel, 'ironstone' nodules; poorly consolidated
Ingham Granite Complex		northerly trending batholith, in south-western corner of sheet area ($\sim317km^2$)	mainly pale pink, fine to medium-grained, even-grained, leucocratic biotite granite

Age	Relationships	Comments
Quaternary; probably mainly Holocene	unconformable on older units	active stream channel deposits
Quaternary		coral reef and subtidal and mud-bank deposits; not examined during the recent survey
Quaternary		mainly alluvial and minor colluvial deposits; maximum thickness of >35m in coastal plains and swamps
Quaternary		mainly older alluvium
Quaternary		swamp deposits
Quaternary; (Pleistocene–Holocene)		mainy beach-ridge and dune deposits
Quaternary	interfingers with, and overlain by Qa	granite-derived residual and colluvial deposits
986 000 B.P. (K–Ar)	interbedded with Qa	basalt erupted from the well-preserved, asymmetrical cone forming Green Hill, and possibly from a deeply eroded centre in the Meringa area (Willmott & others, 1988); lava flows are very deeply weathered; drill holes indicate presence of basalt in subsurface between Green Hill and Meringa
Pliocene–Pleistocene	unconformable on Hodgkinson Formation rocks; interbedded with TQs	Adler Hill, the eruptive centre, is a steep-sided dumbbell-shaped, double cone consisting of vesicular and massive basalt as well as pyroclastic (scoria) deposits (Willmott & others, 1988)
Pliocene–Pleistocene	unconformable on Hodgkinson Formation rocks; interbedded with TQs	Twiddler Hill, the eruptive centre, consists of a well-preserved, symmetrical double cone of coarse, bouldery scoria (Willmott & others, 1988)
Pliocene–Pleistocene	unconformably overlies Hodgkinson Formation, Bellenden Ker Granite, Bartle Frere Granite	several flat-lying lava flows, with a maximum combined thickness of ~50m; possibly erupted from several vents, including at least one (Gillies Crater) on the Atherton Tableland (Willmott & others, 1988); lava flows contain small ultramafic nodules; travertine deposits, up to ~10m thick have been mined as a source of agricultural lime
Miocene–Holocene?	unconformably overlies Barnard Metamorphics, Mission Beach Granite Complex, Hodgkinson Formation, Glen Gordon Volcanics, Tinaroo Granite, Tully Granite Complex, Bartle Frere Granite	mainly lava flows and minor pyroclastic (scoria) deposits; thickness depends on topography of pre-basalt land surface; range of volcanic landforms preserved; basal sediments contain significant amounts of alluvial gold and cassiterite in places (*e.g.* the deep-lead deposits of the Russell River Gold Field)
Tertiary–Quaternary	unconformable on Hodgkinson Formation rocks; sediments in far north-west interfinger with Twiddler Hill and Adler Hill? Basalts	flat lying, with a maximum thickness of ~20m; commonly mottled grey and reddish brown; sediments in far north-west deposited in a fluviatile environment, mainly from a granitic source (Willmott & others, 1988); incorrectly described as mainly residual deposits on map legend
late Carboniferous–early Permian	relationship with the Glen Gordon Volcanics uncertain (contact not seen); tentatively interpreted to post-date the volcanics	extends into INGHAM to the south; disseminated molybdenite relatively common in the Koombooloomba area; may be source of alluvial gold deposits in same area; part of the I-type Ingham Supersuite of Garrad & Bultitude (1999)

Table 1: Summary of stratigraphy — Innisfail 1:250 000 Sheet area (continued)

Unit	Type area	Distribution (Area)	Rock types
Tully Granite Complex		north-westerly to northerly trending batholith in the Tully–Tarzali area (~800km^2)	mainly biotite monzogranite, hornblende–biotite monzogranite to granodiorite, biotite–hornblende granodiorite, tonalite, diorite; minor quartz gabbro
Bartle Frere Granite	Josephine Falls (~GR 788722, Bartle Frere 1:100 000 Sheet area)	circular batholith centred on Bartle Frere, at the southern end of the Bellenden Ker Range (~134km^2)	pale grey to white, medium-grained, slightly to moderately porphyritic hornblende–biotite monzogranite and biotite granite; with minor tourmaline (locally), traces of ilmenite, allanite, biotite-rich clots (to ~2cm) and inclusions (to ~40cm) of biotite-rich gneiss
Walshs Pyramid Granite	eastern flank of Walshs Pyramid	ovoid stock with a north-westerly elongation, centred on Walshs Pyramid at the northern end of the Bellenden Ker Range (~11km^2)	buff to brown or white to pale grey, medium-grained, even-grained to locally slightly porphyritic, leucocratic (tourmaline–muscovite–) biotite syenogranite
Bellenden Ker Granite	two type areas designated by Willmott & others (1988): 1) base of Kearneys Falls (GR 704937, Bartle Frere 1:100 000 Sheet area), and 2) at Fishery Falls (GR 802989, Bartle Frere 1:100 000 Sheet area)	ovoid, north-westerly-trending batholith in northern part of sheet area (~358km^2)	white to pale grey, or brown (altered), coarsely and highly porphyritic/megacrystic (tourmaline–) muscovite–biotite monzogranite to granodiorite?; minor medium to coarse-grained, even-grained to slightly porphyritic, leucocratic (garnet–altered cordierite?–tourmaline–) muscovite–biotite granite and biotite–muscovite granite
Mount Peter Granite	Sandy Creek	north-trending elliptical pluton on the eastern flank of the Isley Hills (~4km^2)	fine to medium-grained, even-grained biotite monzogranite; with mafic inclusions to ~20cm
Tinaroo Granite	Davies Creek (~GR 474197, Bartle Frere 1:100 000 Sheet area; Willmott & others, 1988)	irregular northerly trending ovoid area forming the Lamb Range (~274km^2)	white to pale grey, medium-grained, porphyritic biotite monzogranite; with euhedral–subhedral feldspar phenocrysts to ~3cm and traces of garnet
Unit CPgp		small area on western boundary of sheet area (<0.5km^2)	pale pink to pale grey, or cream, fine to coarse-grained, porphyritic to even-grained biotite granite; extensively altered
Emerald Creek Microgranite	Douglas Creek	irregular, north-trending stock in north-western corner of sheet area (~23km^2)	white to pale grey, and brown, fine to coarse-grained, even-grained to slightly porphyritic, muscovite–biotite granite; pegmatite zones common; traces of garnet
Glen Gordon Volcanics	Glen Gordon (in ATHERTON; de Keyser & Lucas, 1968)	north-trending belt in far west of sheet area (~450km^2)	rhyolitic to dacitic ignimbrite and lava; minor volcanic breccia, andesite

Age	Relationships	Comments
286±4Ma (SHRIMP)	intrudes Hodgkinson Formation rocks and Glen Gordon Volcanics; cut by hornblende basalt/dolerite dykes (Permian?); unconformably overlain by Atherton Basalt	mafic units relatively common compared to the Ingham Batholith to the south; part of the I-type Ingham Supersuite of Garrad & Bultitude (1999); titanite and ilmenite relatively common accessory minerals (not in same sample)
Permian	intrudes Hodgkinson Formation rocks; unconformably overlain by Cainozoic basalt tentatively correlated with The Fisheries Basalt	unit is relatively undeformed compared to the nearby Bellenden Ker Granite; main granite is cut by dykes and small pods of fine to medium-grained, even-grained, leucocratic (hornblende–) biotite monzogranite, locally containing miarolitic cavities
early Permian	intrudes Hodgkinson Formation rocks	contains scattered biotite-rich clots and tourmaline-rich aggregates (up to ~2cm across), and granophyric intergrowths of quartz and K-feldspar; extensively deformed
280±4 Ma (SHRIMP)	intrudes Hodgkinson Formation rocks; unconformably overlain by The Fisheries Basalt (late Cainozoic)	composite unit forming a large batholith; foliated and intensely sheared in places; cut by the Russell–Mulgrave Shear Zone and associated faults; K–Ar ages of ~233Ma–246Ma (Richards & others, 1966) probably relate to the shearing event(s); tourmaline-rich aggregates (up to ~4cm across) common in the felsic units; contains large inclusions (up to ~25m long and 3m wide) of gneiss, granite, and microgranite south of Bramston Point, on eastern side of the Graham Range
early Permian?	intrudes Hodgkinson Formation rocks	not examined during the recent survey; western margin possibly faulted; high-grade, regional-contact metamorphic rocks similar to those west of the Tinaroo Batholith developed locally (Willmott & others, 1988)
early Permian	intrudes Hodgkinson Formation rocks and Emerald Creek Microgranite	composite unit according to Rubenach & Bell (1988); moderately well-developed foliation in marginal zones; similar to Whypalla Supersuite granites but is more primitive isotopically (Champion, 1991; Champion & Bultitude, 1994)
early Permian?	unconformably overlain by Atherton Basalt	forms much more extensive unit in adjacent Atherton 1:100 000 Sheet area (Clarke, 1995), where it is mapped as Cattle Camp Granite (Bultitude & others, 1999); not examined during recent survey
uncertain; most probably mid–late Carboniferous or early Permian	intrudes Hodgkinson Formation; cut by Tinaroo Granite and dykes of muscovite–biotite granite	composite unit (Rubenach & Bell, 1988); locally foliated; characterised by diffuse contact zone, up to ~300m wide, containing upper amphibolite-grade rocks; distinct geochemically from granites of the Tinaroo and Whypalla Supersuites
late Carboniferous–early Permian	intruded by Tully Granite Complex; unconformably overlain by Atherton Basalt; relationship with Ingham Granite Complex uncertain	very poorly exposed in most places; unit contains I- and A-type rocks, of probable mid–late Carboniferous and early Permian age, respectively; Wellman (1997) identified two discrete cauldron subsidence structures in the unit

Table 1: Summary of stratigraphy — Innisfail 1:250 000 Sheet area (continued)

Unit	Type area	Distribution (Area)	Rock types
Bedarra Granite	Bedarra Island, (around GR 099100, Cardwell 1:100 000 Sheet area, in INGHAM)	Bedarra Island (<1km^2)	white to pale grey, medium to coarse-grained, porphyritic biotite granite
Dunk Island Granite	north-eastern side of Dunk Island (from ~GR 106165 north to contact with Barnard Metamorphics, Innisfail 1:100 000 Sheet area)	southern part of Dunk Island (~3km^2)	pale grey, white, or brown, medium to coarse-grained, even-grained to porphyritic biotite granite
Hodgkinson Formation	Hodgkinson Gold Field (in MOSSMAN; de Keyser & Lucas, 1968)	NNW trending belt, mainly west of the Bruce Highway; extends from northern part of Rockingham Bay (in far south) into adjacent sheet areas to north and west (~955km^2)	mudstone, siltstone, slate, phyllite, schist; minor arenite, quartzite, limestone, marble, conglomeratic arenite, chert, 'greenstone', schist, amphibolite, calc-silicate gneiss
Mission Beach Granite Complex	north of Ninney Point (at GR 051295, Innisfail 1:100 000 Sheet area)	scattered outcrops from South Mission Beach to Russell River area, and on Timana Island (~45km^2)	mainly medium-grained, even-grained biotite granite, with rare garnet xenocrysts; minor granodiorite–diorite?; inclusions of country rocks common
Tam O'Shanter Granite	Tam O'Shanter Point	Tam O'Shanter Point (<1km^2)	medium-grained, even-grained to slightly porphyritic (altered cordierite?–) muscovite–biotite granite; with numerous inclusions of biotite gneiss and quartz
Cowley Ophiolite Complex	ridge west of Bruce Highway, Cowley	elongate belt mainly west of Bruce Highway at Cowley; small pod south-east of Silkwood (~3km^2)	serpentinite, talc schist, (talc–) tremolite schist, (tremolite–) chlorite schist, talc–magnesite rock; minor altered peridotite, gabbro, and basalt (as dykes)
Babalangee Amphibolite	Graham Range, ~6km east of Babinda (de Keyser & Lucas, 1968)	north-trending belt east of Babinda (~10km^2)	amphibolite
Barnard Metamorphics	North Barnard Islands, ~22km south-east of Innisfail (de Keyser & Lucas, 1968)	east of the Russell–Mulgrave Shear Zone, from High Island south to Dunk Island (~79km^2)	meta-arenite, quartzite, phyllite, 'greenstone', chlorite schist, mica schist, biotite gneiss, migmatitic gneiss; minor amphibolite, hornblende granulite; rare talc-rich and ultramafic rocks

Age	Relationships	Comments
early Carboniferous (Visean)	contacts with enclosing rocks not exposed	contains inclusions of biotite granite (to ~1m), biotite-rich metasedimentary rocks (to ~10cm), and biotite-rich clots (to ~4cm); unit much more extensive in adjoining INGHAM
336±5 Ma (SHRIMP)	intrudes Barnard Metamorphics	more than one pluton present; locally with a well-developed foliation; contains inclusions (to ~2m) of mainly migmatitic biotite gneiss, microdiorite?, biotite granite
Devonian?	faulted against Barnard Metamorphics and Mission Beach Granite Complex; intruded by early Permian granites of the Kennedy Province; unconformably overlain by late Cainozoic basalts of the Atherton Subprovince	thickness unknown; unfossiliferous; metamorphosed mainly to lower greenschist grade; upper amphibolite-grade rocks present in aureole of Tinaroo Batholith and possibly, locally, adjacent to Mount Peter Granite; finer grained siliciclastic rocks commonly carbonaceous; only one major foliation recognised in most outcrops — this probably represents a composite fabric
early?–late Ordovician; granite which intrudes Tam O'Shanter Granite has yielded a U–Pb SHRIMP age of 463±7 Ma	intrudes metasedimentary rocks of the Barnard Metamorphics, and Tam O'Shanter Granite; faulted against Hodgkinson Formation rocks	weakly to intensely foliated, and commonly extensively recrystallised; mafic units extensively altered; consists of several informal units (Garrad & Bultitude, 1999); extensively weathered away from coast; contains inclusions of migmatitic gneiss, amphibolite
486±10 Ma U–Pb zircon (SHRIMP)	intrudes metasedimentary rocks of the Barnard Metamorphics; cut by pod of biotite granite (Mission Beach Granite Complex) which has yielded a SHRIMP age of 463±7 Ma	inclusions up to ~5m (most <10cm) of mainly migmatitic gneiss, amphibolite, and quartz; extensively deformed and recrystallised with a well-developed gneissic foliation; plagioclase compositions in the oligoclase range (~An_{14}–An_{23}); similar chemically to Whypalla Supersuite granites and to Ordovician granites of the Ravenswood Batholith, Charters Towers region
Neoproterozoic?	tectonically emplaced into Hodgkinson Formation rocks and Barnard Metamorphics?	forms fault-bounded lenses; may have been tectonically emplaced during the Permian–Triassic Hunter–Bowen Orogeny
Neoproterozoic?	intruded by Mission Beach Granite Complex and Bellenden Ker Granite	poorly exposed; contacts with Barnard Metamorphics not found; may represent part of an ophiolite complex
Neoproterozoic–Cambrian?	faulted against Hodgkinson Formation rocks; cut by Tam O'Shanter, Dunk Island, and Bellenden Ker Granites, and Mission Beach Granite Complex	three major, regional deformations recognised; in addition, rocks on Dunk Island show a well-developed fabric related to the emplacement of the Visean Dunk Island Granite; several other local? events have also been reported; rocks on Dunk Island belong mainly to informal subunit Ᵽbs rather than Ᵽbm as shown on the accompanying geological map

Table 2: Mineral assemblages and compositions in interlayered hornblende granulite and felsic gneiss on the south-western side of the Malbon Thompson Range (GR 849996, Bartle Frere 1:100 000 Sheet area)

Sample No.	Mineralogy[4]	Comments
BB1959	plagioclase (An_{89}–An_{78}), orthopyroxene (mg-ratio[5] = 51–53), brown hornblende, ilmenite, apatite, biotite, quartz, cummingtonite, pyrrhotite?, sericite	abundant brown hornblende; orthopyroxene commonly forms coarse, highly irregular, poikilitic grains (Plates 15,16)
BB1959C1	plagioclase (An_{100}–An_{90}), clinopyroxene (mg-ratio = 66–69), brown hornblende, ilmenite, quartz, biotite (rare), titanite, chlorite	alternating, thin, irregular felsic and mafic-rich lenses; significant grain size variations between some lenses; triple-point type junctions between grains common in some lenses; clinopyroxene locally forms coarse, irregular grains
BB1959E	plagioclase (An_{100}–An_{96}), olivine (mg-ratio = 54–57), orthopyroxene (mg-ratio = 66–67), brown hornblende, ilmenite, hercynite?, apatite, chlorite	grains of anorthite common; abundant brown hornblende; orthopyroxene commonly forms large, poikilitic grains; other thin sections from same hand specimen contain clinopyroxene instead of orthopyroxene and cummingtonite instead of brown hornblende; olivine grains commonly partly altered
BB1959A	quartz, plagioclase (~An_{50}–An_{33}), microcline, sillimanite, andalusite, cordierite, biotite, muscovite (mainly secondary), ilmenite, spinel (hercynite?, with ~4% Zn), monazite, apatite, zircon, garnet	felsic gneiss (psammopelite) interlayered with hornblende granulite; abundant unaltered or only slightly altered cordierite (Plate 14); sillimanite forms coarse, tabular grains as well as needles of fibrolite and 'inclusions' in cordierite; spinel (hercynite?) locally abundant, as small grains; monazites have yielded a U–Pb (SHRIMP[6]) age of 268±4Ma

The mafic rocks are compositionally banded on all scales. Some samples examined contain orthopyroxene + brown hornblende ± minor olivine, whereas in other samples the mafic minerals are mainly clinopyroxene + brown hornblende ± minor olivine (*e.g.* Table 2). Orthopyroxene generally forms coarse (up to ~2cm), highly irregular and poikilitic grains (Plates 15, 16).

On a much finer scale, most thin sections show thin, irregular, alternating mafic-rich and plagioclase-rich laminae/lenses. Green to black spinel (hercynite?) and cummingtonite are common accessory minerals. Traces of graphite are present in some quartz–plagioclase veinlets, whereas pyrrhotite, chalcopyrite and pentlandite? are present in others. Grains of chalcopyrite are also relatively common in some laminae. A noteworthy feature of the hornblende granulites is the presence of highly calcic plagioclase, analysed grains ranging in composition from An_{78} to An_{100} (Table 2). The opaque oxide is ilmenite rather than magnetite, indicating formation under reducing conditions.

Migmatitic quartzofeldspathic gneiss associated with the hornblende granulites contains abundant sillimanite — as coarse, tabular grains and aggregates of fine acicular grains (fibrolite) — and unaltered cordierite (Plate 14), as well as relict andalusite. Biotite grains are a conspicuous bright red-brown colour, typical of those produced under reducing conditions. Green spinel (hercynite?) is also a common accessory mineral in some of these rocks, but is scarce in the more quartz-rich layers. The folded, thin layering preserved in some samples may represent highly modified, relict bedding.

Granitic rocks in the Barnard Metamorphics

The Barnard Metamorphics are locally cut by dykes and pods (rare) of granite of uncertain age and origin (*e.g.* Plates 7, 9). At least some of these granites may have been produced by partial melting of the country rocks during high-grade metamorphism. The dykes on High Island consist mainly of medium-grained to locally pegmatitic muscovite–biotite granite (containing amphibolite inclusions up to ~50cm across in

4 Mineral compositions determined using the Cameca electron microprobe at the Australian National University, by electron-dispersive spectrometry (EDS)

5 mg-ratio=100(MgO/40.32)/(MgO/40.32 + FeO*/71.85), where FeO* = total Fe as FeO

6 SHRIMP = sensitive high-resolution ion microprobe — a joint Research School of Earth Sciences–AGSO facility at The Australian National University, Canberra, ACT

places), and rare (garnet–tourmaline–) muscovite pegmatite. The gneissic rocks of Russell and Normanby Islands are cut by scattered dykes and rare pods of pale grey to pale brownish grey biotite microgranite, containing angular inclusions, up to ~20cm across, of migmatitic biotite gneiss (Plate 9). The granitic rocks are foliated and partly to extensively recrystallised.

The low (chlorite)-grade metamorphic rocks on Kent Island are also cut by dykes (up to ~30cm thick) of deformed, leucocratic tourmaline–muscovite granite. The adjacent schists commonly contain traces of tourmaline. These dykes post-date an older generation of extensively altered, foliated granitic dykes.

Similarly, the gneissic rocks of Mound Island are cut by scattered dykes (<1m thick) of pale brown, medium-grained, even-grained muscovite leucogranite. The muscovite grains are extensively deformed and most quartz grains have recrystallised to finer grained aggregates.

Chemical characteristics

Whole-rock geochemical data for the Barnard Metamorphics indicate a wide range in compositions, from metabasite to quartzose meta-arenite, and quartzite. Most samples analysed are metamorphosed pelites and psammopelites, with SiO_2 contents between 60% and 75% and Al_2O_3 contents between 12% and 20%. The average CIA[7] (Nesbitt & Young, 1982) for these metasedimentary rocks is ~65, indicating only minor weathering of the source rocks and derived sediments.

The siliciclastic metasedimentary rocks of the Barnard Metamorphics are distinct from most of those analysed from the nearby Hodgkinson Province (Figure 5). The latter, particularly the arenites, generally have mineralogical and chemical characteristics (*e.g.* relatively high SiO_2 and Na_2O and low Al_2O_3, Sc, and Th contents and low CIA) indicating they were derived mainly from rapidly eroded, unweathered quartzofeldspathic sources. In contrast, basic source rocks made a significant contribution to the protolith of the Barnard Metamorphics.

Bhatia & Crook (1986) used trace-element abundances in greywackes from several eastern Australian Palaeozoic sequences to determine the provenance and tectonic setting of the various rock assemblages. Using discriminants such as Th, U, B, Rb, Pb, and Zr contents, and Zr/Th, Ni/Co, and V/Ni ratios, the metapelites and psammopelites of the Barnard Metamorphics mainly plot in the field delineated by Bhatia & Crook for rocks derived from active (Andean-type) continental margins. Nb, Y, La, and Ce contents tend to be anomalously high in the Barnard Metamorphics, but they are closer to those for rocks from active continental margins than any other tectonic setting. In contrast, Sc, V, Cr, Co, Ni, Cu, and Zn contents are significantly higher and correlate more closely with those in sediments deposited in island arc settings.

Structure

The Barnard Metamorphics are complexly deformed. Three major, ***regional*** deformational events were recognised during the GSQ investigation (Donchak, 1997). Several other, possibly local events have also been reported (*e.g.* Richards, 1977; Jones, 1978; Hammond & others, 1986; Donchak, 1997). Richards, for example, recognised two relatively weak events (b^8D_4, bD_5)[9] in the Mulgrave River area and on High Island. In addition, the high (upper amphibolite) -grade aureole rocks on Dunk Island preserve a well-developed fabric apparently related to the emplacement of the Visean granites forming the southern half of the island (*e.g.* Donchak, 1997). S. Wegner is currently investigating the structure of the Barnard Metamorphics.

First major deformation (bD_1). The first regional deformation (bD_1) produced a finely differentiated mylonitic fabric in the upper greenschist and higher grade rocks (Hammond & others, 1986) and a bed-parallel slaty cleavage in the lower grade meta-arenites (Donchak, 1997). The well-developed gneissic layering in the high-grade rocks was probably also produced during this deformation, as well as some migmatitic rocks. Migmatitic gneiss inclusions in the Tam O'Shanter Granite are commonly oriented so that the foliation (bS_1) is at high angles to the pervasive foliation (bS_2) in the granite (see Plate 20). The bD_1 deformational event, therefore, occurred prior to or during the emplacement of the early Ordovician Tam O'Shanter Granite. It probably pre-dates the oldest deformation (middle Ordovician?) recorded in the Hodgkinson Province (Bultitude & others, 1996a).

7 CIA = chemical index of alteration = $100Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)$, where CaO* = amount of CaO in silicate minerals

8 b refers to deformational events and tectonic fabrics in the Barnard and Macrossan Provinces

9 Structural terminology after Bell & Duncan (1978):
D = deformation, L = lineation, S = surface/foliation, F = fold, M = metamorphism,
$_2$ = second deformation event, ^{1} = first surface or lineation deformed;
e.g. F_2^1 = folding of a first generation foliation by a second generation deformation

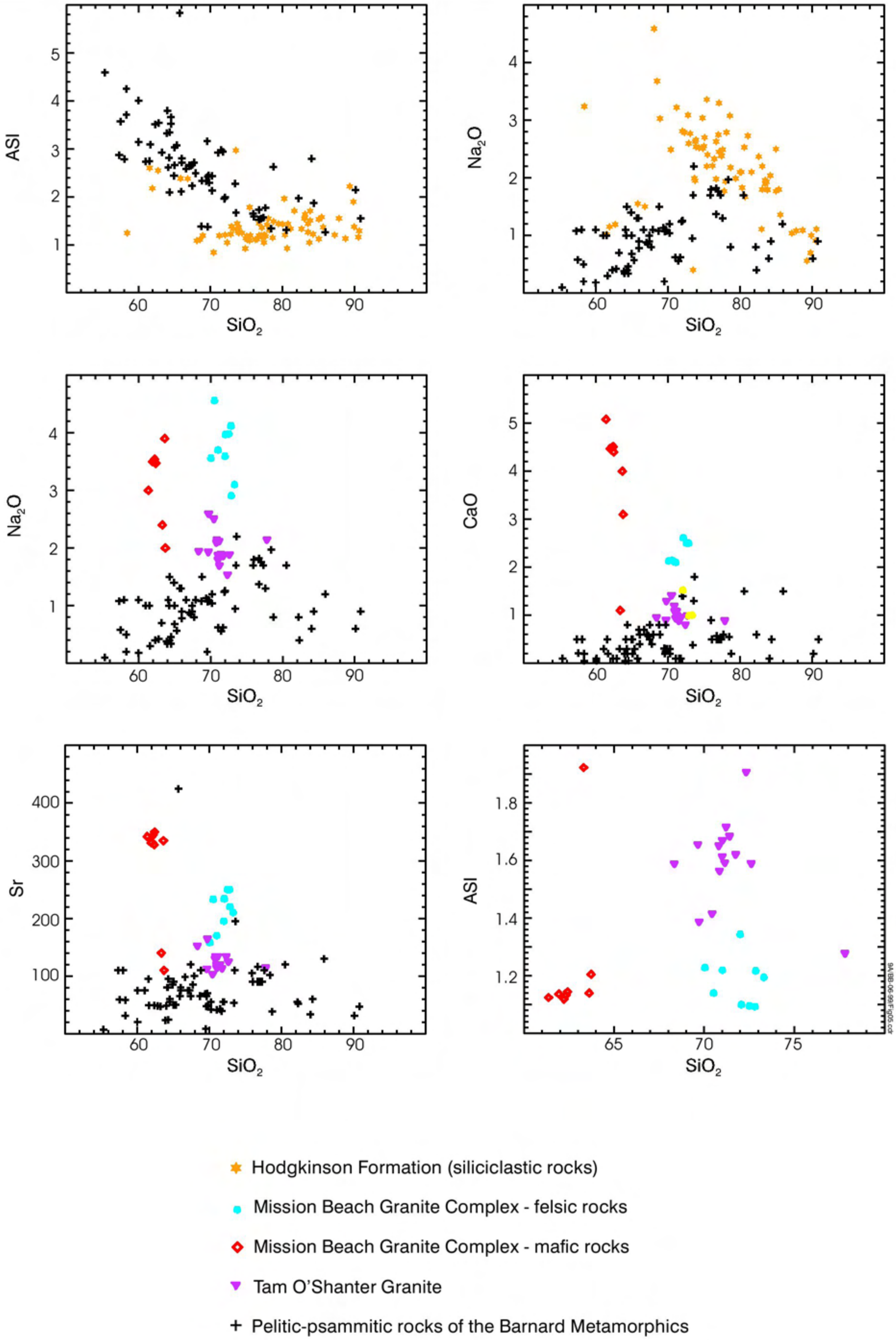

Figure 5. ASI, Na_2O, CaO, and Sr versus SiO_2 plots for the pelitic and psammitic rocks of the Barnard Metamorphics. Also shown for comparison are analyses of rocks from the Hodgkinson Formation (siliciclastic rocks only), Mission Beach Granite Complex, and Tam O'Shanter Granite. Major oxides are in weight per cent (wt%), trace elements in parts per million (ppm).

Second major deformation (bD_2). The second major regional deformational event (bD_2) extensively transposed the bS_1 gneissic fabric in the high-grade rocks (Donchak, 1997). In the lower grade parts of the assemblage, bD_2 produced an intense bed-parallel schistosity (bS_2) in pelitic layers and a spaced crenulation cleavage locally in adjacent meta-arenites (*e.g.* at Etty Bay; Donchak, 1997). The main foliation in most outcrops is bS_2. Granites of the Mission Beach Granite Complex were deformed during the same event. The data imply a maximum age of late Ordovician (~460Ma — indicated by the SHRIMP age yielded by one of the granites of the complex) for bD_2.

Third major deformation (bD_3). The third major regional deformation (bD_3) produced widespread crenulations and mesoscopic folds, particularly in the lower grade rocks in the Bramston Beach–Mourilyan Harbour area. A steeply dipping to subvertical crenulation cleavage (bS_3) is commonly present in these relatively well-bedded pelitic–psammitic rocks (Donchak, 1997). In contrast, bS_3 is only weakly developed in the relatively coarse-grained, high-grade gneissic rocks of the Mission Beach area and the Frankland Islands, being defined by local new platy mineral (mainly mica) growth (Donchak, 1997). In the south, mesoscopic bF_3^2 folds have been reported in relatively high-grade rocks (schist, gneiss, migmatite) at Bingal Bay (Rubenach, 1978).

The bD_3 deformation was a relatively young event (or events), and formed part of the Hunter–Bowen Orogeny. The Hunter–Bowen Orogeny was a major tectonic episode, which affected much of eastern Australia in the Permian–Triassic (Fergusson, 1991; Henderson & others, 1993). The bD_3 event intensely deformed early Permian (~280Ma–285Ma) granites of the Bellenden Ker Batholith.

The ***Russell–Mulgrave Shear Zone*** was one of the main zones of dislocation/shearing in the sheet area during the orogeny. The trace of the shear zone is only approximately located for much of its length, mainly because of poor exposures. The shear zone may anastomose in places, and it may consist, at least locally, of an imbricate stack of several fault slices. Any of these possibilities may explain the juxtaposition of rocks mapped as Mission Beach Granite Complex and Hodgkinson Formation (contact faulted) north-west of Innisfail, and west of the trace of the Russell–Mulgrave Shear Zone as shown on the geological map.

Furthermore, the Russell–Mulgrave Shear Zone was probably only one of several major faults, which were active in the sheet area during the Hunter–Bowen Orogeny. Intensely deformed granite in the summit area of Bellenden Ker Centre Peak, for example, probably marks the location of another shear zone (unmapped). There is also a major shear zone in the Bramston Point area.

Dunk Island aureole deformational event

Significant thermal metamorphism (upper amphibolite grade) and deformation (bD_a) of the country rocks in the contact zone accompanied emplacement of the Dunk Island Granite. The contact zone is very well exposed on the north-eastern side of the island. Quartzofeldspathic laminae in country rocks adjacent to the granite contact show evidence of melting and mobilisation (Donchak, 1997), leading to the formation of migmatites (Plate 11). Small-scale folds (bF_a) also developed in the contact rocks during granite emplacement, which locally involved injection of leucosomes (quartzofeldspathic 'melt') along bF_a axial planes (Donchak, 1997). The bS_a foliation extends for up to ~0.5m into the adjacent granite in places. The main part of the granite pluton, however, transects bF_a folds and is mainly unfoliated.

Donchak (1997) interpreted the high-grade thermal metamorphism and deformation of the contact rocks to have resulted from the forceful emplacement of the Dunk Island Granite. The granite may have been emplaced in pulses, each successive pulse reaching higher levels in the deforming country-rock carapace.

A sample of granite from the south-western side of Dunk Island has yielded an isotopic age of 336±5Ma. Assuming all the components of the composite Dunk Island Granite were emplaced essentially at the same time, the high-grade thermal metamorphism and deformation of the adjacent country rocks must have also occurred in the Visean. However, overprinting relationships between bS_a and the younger, approximately co-planar bS_3 foliation have not been detected.

The development of migmatitic gneiss adjacent to contacts with the Dunk Island Granite in the Visean may have significant implications regarding the age of formation of similar migmatitic rocks elsewhere in the Barnard Metamorphics. In particular, those in the Frankland Islands and towards the south-western end of the Malbon Thompson Range (but see below). However, granites of this age have not been identified at the latter two localities.

Age of the high-grade metamorphism in rocks near the south-western end of the Malbon Thompson Range

The high-grade metamorphic rocks exposed towards the south-western end of the Malbon Thompson Range and on the Frankland Islands may represent the exposed parts of a fault block, or blocks, of older basement rocks. These rocks may have originated at a sig-

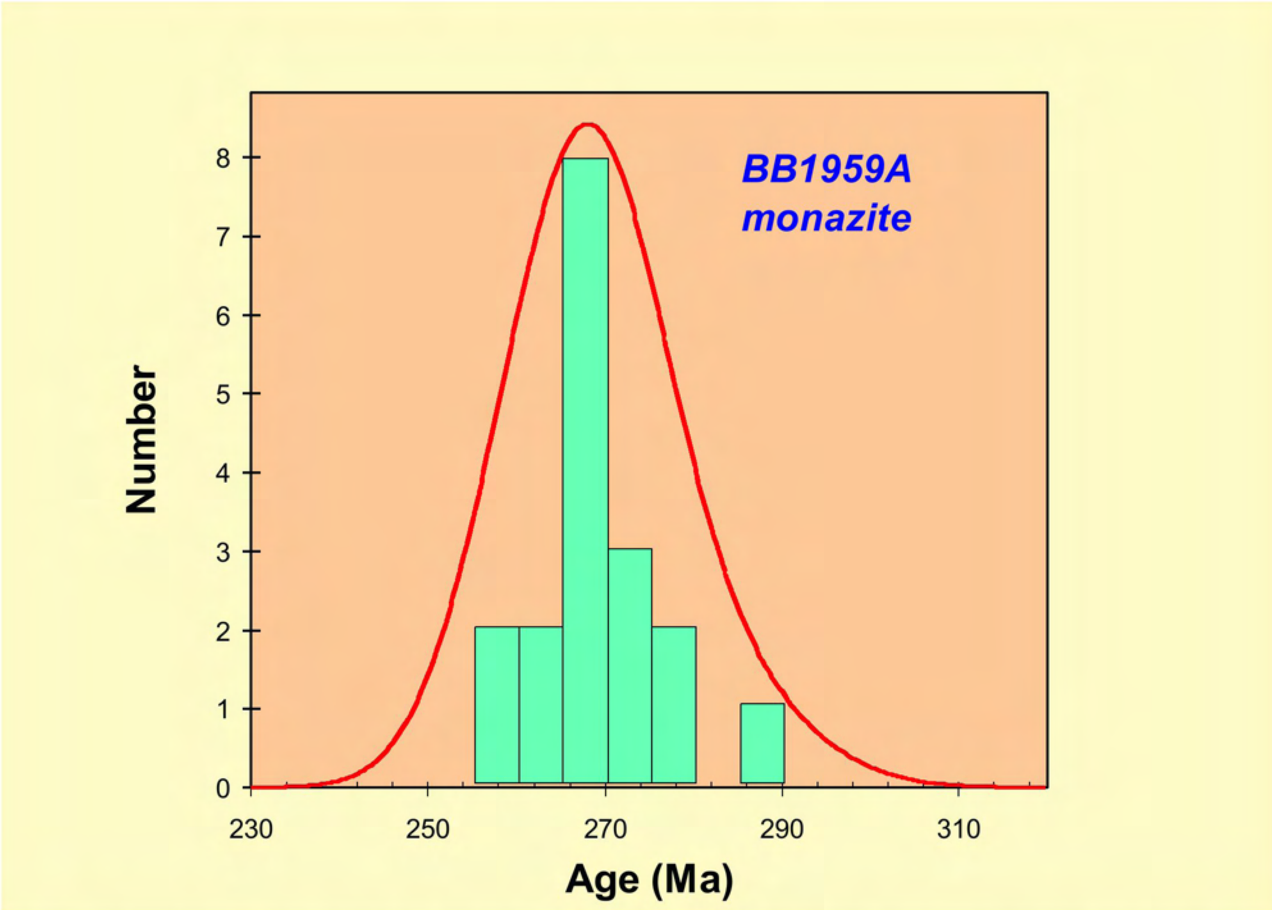

Figure 6. Frequency plot of $^{206}Pb/^{238}U$ ages yielded by SHRIMP analyses of monazites from migmatitic gneiss (BB1959A) exposed near the south-western end of the Malbon Thompson Range (GR 849996, Bartle Frere 1:100 000 Sheet area).

nificantly greater depth in the crust than the lower grade rocks of the formation exposed farther south. Alternatively, the high-grade rocks may have resulted from relatively localised elevated temperatures associated, for example, with granite emplacement. Mancktelow (1974, 1982) and Rubenach & Bell (1988) postulated that upper amphibolite-grade rocks in adjoining ATHERTON, adjacent to the Tinaroo Batholith developed in response to the emplacement of that batholith.

In an attempt to resolve the age of the high-grade metamorphic event, at least in the Malbon Thompson area, monazites were separated from a sample of migmatitic gneiss (at GR 849996, Bartle Frere 1:100 000 Sheet area). The gneiss is interlayered with hornblende granulite near the south-western end of the Malbon Thompson Range.

Unlike zircons, monazites typically recrystallise at upper amphibolite grades and the isotopic 'clock' is consequently reset (*e.g.* Williams, 1998). Dating monazites from the migmatitic gneiss, therefore, should determine the timing of the last high-grade metamorphic event to affect these rocks.

The monazites separated from the gneiss are mainly subhedral to anhedral (angular) with no evidence of abraded detrital grain shapes or zoning (Plate 17). Most also contain small inclusions. The monazites, therefore, have typical metamorphic morphologies and are interpreted as representing new grains, which formed during a high-grade metamorphic event. The U–Pb (SHRIMP) isotopic data indicate the age of monazite formation to be 268±4Ma (Figure 6). No isotopic evidence for the presence of relict, inherited monazite was found.

The results, therefore, do not confirm (or necessarily refute) the model favoured by R.J. Bultitude in earlier reports (*e.g.* Bultitude & Garrad, 1997; Garrad & Bultitude, 1999) — namely, that the high-grade metamorphic rocks represent a relatively old, deep-seated assemblage, which had been uplifted by vertical movements on major faults during the Hunter–Bowen Orogeny. Rather, they imply the high-grade metamorphic effects (or at least the latest) were associated with the emplacement of the nearby Bellenden Ker Batholith. Whether or not this metamorphism overprinted a significantly older high-grade metamorphic assemblage has not been determined. S. Wegner is currently investigating the problem.

Other possible 'basement' assemblages

Rocks (delineated as Dh_s) exposed in the aureole of the Tinaroo Batholith, in the north-western part of INNISFAIL (and adjoining ATHERTON), form an anomalously wide, high-grade (up to upper amphibolite grade) zone. Mancktelow (1974, 1982) interpreted these rocks to form a regional metamorphic aureole. Biotite-bearing slate and phyllite on the outer fringes of the aureole grade into schist, which extends up to ~6km (west of the Emerald Creek Microgranite) from granite contacts (Mancktelow, 1974, 1982; Donchak & Bultitude, 1994, 1998). The schistose rocks contain andalusite, staurolite and garnet (almandine) porphyroblasts. In several places the pelitic rocks within ~10m of the contact with the Emerald Creek Microgranite are represented by gneisses containing quartz, plagioclase, K-feldspar, andalusite, biotite, muscovite and sillimanite (fibrolite). Staurolite and garnet are preserved as relict cores in andalusite porphyroblasts (Rubenach & Bell, 1988). Lenses of calc-silicate gneiss (commonly containing minor scheelite; Mancktelow, 1982) and amphibolite are present locally.

The presence of upper amphibolite grade rocks adjacent to contacts with the Emerald Creek Microgranite and the broad zone of schistose rocks west of the contact contrast markedly with the relatively narrow (andalusite–cordierite) hornfels zones developed around most of the other plutons in the eastern Hodgkinson Province. The nearby, younger Tinaroo Granite, for example, is mainly enclosed by a relatively narrow contact metamorphic aureole containing andalusite and cordierite, and a zone up to ~200m wide containing biotite porphyroblasts (Rubenach & Bell, 1988). Rubenach & Bell (1988) concluded that the Emerald Creek Microgranite provided the heat for the main metamorphic event (which attained upper amphibolite grade). Subsequently, most of the Emerald Creek Microgranite presumably must have been stoped away during the emplacement of the Tinaroo Granite.

Mancktelow (1974, 1982) postulated the extensive zone of relatively high-grade rocks resulted from either deformation of the metasedimentary rocks (of the Hodgkinson Formation) during the forceful emplacement of the Tinaroo Batholith, or from an increased response to the regional stresses in an area of higher heat flow and consequently higher rock ductility. He noted that the Tinaroo Batholith has shallowly dipping contacts with the adjacent country rocks in places and that it also contains large roof pendants — the relatively high heat flow and resultant broad aureole, therefore, possibly reflecting the presence of granite at shallow depths.

According to Hammond & others (1986; also see Rubenach & Bell, 1988) the rocks surrounding the Tinaroo Batholith, as well as elsewhere in the eastern Hodgkinson Province, are characterised by a distinctive mylonitic foliation which is not present in nearby lower grade rocks of the Hodgkinson Formation. Hammond & others, therefore, proposed that these rocks form part of an older assemblage (of probable early Palaeozoic age) and that the mylonitic fabric was imposed prior to the deposition of the Hodgkinson Formation sediments. Hammond & others correlated the assemblage with the Barnard Metamorphics, which have a similar mylonitic fabric.

Discussion

Structural studies and the results of recent SHRIMP dating of two granites in the Barnard Metamorphics indicate the enclosing supracrustal metamorphic rocks are older than early Ordovician. The supracrustal rocks of the Barnard Metamorphics, therefore, are significantly older than the adjacent Hodgkinson Formation (most probably Devonian) and are probably significantly older than all the units in the Hodgkinson Province.

The available data, therefore, are consistent with the interpretation of the Barnard Metamorphics as an uplifted 'basement' assemblage on the south-eastern margin of the Hodgkinson Province. There are no doubt other models which can accommodate the data. One possible alternative explanation is that the Barnard Metamorphics (and the enclosed Ordovician granites) represent an allocthonous terrane. This terrane may have been displaced from farther south by sinistral, strike-slip faulting in the mid–late Palaeozoic. Ordovician granites, for example, are relatively abundant in the Charters Towers region. Subsequent vertical movements on the Russell–Mulgrave Shear Zone and associated faults during the Hunter–Bowen Orogeny then virtually obliterated the horizontal fabrics developed during the earlier faulting.

The depositional environment for the metasedimentary rocks of the unit is uncertain. Subsequent deformations and metamorphic events have obliterated most of the primary sedimentary structures. The common presence of interlayered 'greenstone' bands may indicate an extensional setting, possibly on or near a passive continental margin. A similar setting has been postulated for the Anakie Metamorphics (Withnall & others, 1995), possible correlatives farther south.

The metasedimentary rocks of the Barnard Metamorphics are probably mainly Neoproterozoic–Cambrian?. Scattered outcrops of metamorphic rocks of uncertain, but possibly similar age have been mapped farther south in the Charters Towers and Townsville regions (*e.g.* the Running River, Argentine, Cape

River — part, and Charters Towers Metamorphics). These rocks may represent remnants of formerly more extensive assemblages, which were extensively disrupted, overlain by younger Palaeozoic sequences (mainly in the Hodgkinson and Broken River Provinces) and extensively intruded by Palaeozoic granites. The units may also be at least partly coeval with the more extensive Anakie Metamorphics of the Emerald–Clermont region. The Barnard Metamorphics, therefore, may represent the northernmost outcrops of an orogen, which extended along much of eastern Australia (and possibly other Gondwanaland continents) in the Neoproterozoic–Cambrian.

Babalangee Amphibolite

The Babalangee Amphibolite (de Keyser, 1964) crops out over ~10km^2, in the Russell River–Wyvuri Swamp area, east of Babinda. The unit is very poorly exposed and contacts with the nearby Barnard Metamorphics have not been found. The Babalangee Amphibolite pre-dates and has been metasomatised by the Bellenden Ker Granite forming the Graham Range. It typically contains ~75% hornblende, ~23% plagioclase (calcic andesine), and 1–2% titanite, apatite, epidote/clinozoisite and sulphide(s) (de Keyser & Lucas, 1968). The fabric ranges from massive to schistose. The amphibolite has been affected by the Permian–Triassic bD_3 deformation. It is cut by north-westerly trending shear zones and is commonly extensively deformed, foliated (Plate 18) and variably recrystallised and altered (de Keyser & Lucas, 1968).

The massive, relatively uniform character of the amphibolite away from shear zones implies it probably represents a basic intrusion (or several basic intrusions).

The Babalangee Amphibolite has yielded a K–Ar age (corrected) of 642Ma (Richards & others, 1966). The significance of this age is uncertain. Richards & others (1966) postulated the age was likely to be anomalously old because of the probable presence of extraneous argon. It was not regarded as significant by later workers (*e.g.* de Keyser, 1965). However, the age is consistent with recent age and Nd-isotopic data obtained from Ordovician granites in the nearby Barnard Metamorphics. These indicate the supracrustal rocks of the Barnard Metamorphics are older than early Ordovician (~485Ma) and are most probably Neoproterozoic–Cambrian? (Champion, 1991; Champion & Bultitude, 1994).

COWLEY OPHIOLITE COMPLEX

There are relatively extensive outcrops of mafic–ultramafic rocks in the Cowley area. Farther south, serpentinite has been quarried ~3.5km south-east of Silkwood (at ~GR 976366, Innisfail 1:100 000 Sheet area) to supply large blocks for headland protection in the Bingal Bay area. The ultramafic complex at Cowley consists of metamorphosed serpentinite, talc schist, (talc–) tremolite schist, (tremolite–) chlorite schist, and talc–magnesite rocks (containing relict peridotite kernels), as well as some gabbro, and basaltic or andesitic dykes (Jones, 1978; Rubenach, 1978). Talc and chlorite schists crop out in road cuttings, but surface float of serpentinised peridotite, altered gabbro and basaltic rocks have been reported at the base of the ridge formed of the complex (Rubenach, 1978). Rubenach (1978) postulated the assemblage may represent part of an ophiolite assemblage.

Jones (1978) reported the following minerals in the metamorphosed ultramafic rocks in the Cowley area — talc, tremolite, chlorite, magnesite, antigorite, plagioclase (altered), clinozoisite (mainly after plagioclase), pyroxene (altered), magnetite, ilmenite, and titanite.

The mafic–ultramafic complex near Cowley forms a north-trending ridge on the western side of the Bruce Highway. It was included in the Barron River Metamorphics by Jones (1978). However, the complex was tectonically emplaced and probably has no direct relationship to either the Hodgkinson Formation or the Barnard Metamorphics.

Small pods or lenses of metamorphosed ultramafic rocks also crop out on Dunk Island and islands of the North Barnard group (Rubenach, 1978; Jones, 1978). They have not been delineated as separate units but have been included in the Barnard Metamorphics. Those on Dunk Island contain relict olivine.

The ultramafic complexes were probably emplaced during the Permian–Triassic Hunter–Bowen Orogeny. Their age of formation is unknown.

MACROSSAN PROVINCE

Tam O'Shanter Granite and Mission Beach Granite Complex

The Barnard Metamorphics are extensively intruded by Ordovician granite, particularly in the South Mission Beach–Tam O'Shanter Point area (Plate 19). The extents of most individual plutons could not be delineated because of the very poor exposures away from the coast. Isotopic dates recently yielded by two of the granites constrain the minimum age of the enclosing country rocks and, together with the geochemical data, have assisted in placing the Barnard Metamorphics in a regional context.

Mineralogical and chemical characteristics

The S-type ***Tam O'Shanter Granite*** forms extensive pavements and massive outcrops at Tam O'Shanter Point. Similar granite (S-type) exposed near the southern end of South Mission Beach is shown as part of the ***Mission Beach Granite Complex*** on the accompanying 1:250 000-scale geological map. Outcrops of S-type granite at the northern end of Narragon Beach are too small to show on the map and have been included with the Barnard Metamorphics. Elsewhere, the granites have been mainly delineated as Mission Beach Granite Complex.

The S-type granites contain large flakes of biotite (commonly extensively recrystallised) and muscovite (generally <biotite), rare aggregates consisting mainly of fine mica (possibly representing altered cordierite grains), numerous biotite-rich lenses (up to ~3cm long) and inclusions of quartz (up to ~15cm) and biotite gneiss and amphibolite (up to ~1m; Plates 20 and 21). These inclusions are scattered throughout the outcrops.

Some of the felsic I-type? granites of the Mission Beach Granite Complex are distinguished from the felsic S-type granites by more equigranular habits, a relative abundance of plagioclase, a relative scarcity of muscovite, apatite, and inclusions (especially quartz), and the interstitial habit of the biotite grains. They also contain rare garnet grains, the origin of which is uncertain. The garnets form relict grains surrounded by prominent reaction rims, consisting mainly of biotite and muscovite. They may have been derived from garnet-bearing country rocks.

Mafic I-type? granites of the complex are characterised by relatively high concentrations of mafic minerals and relatively low quartz abundances. Those examined south of Garners Beach and on Timana Island (GR 087114, Innisfail 1:100 000 Sheet area) appear to form small pods and lenses.

The granites pre-date bD_2 and are extensively deformed and recrystallised.

Age

U–Pb zircon (SHRIMP) dating of felsic S- and I?-type granites of the Tam O'Shanter Granite and Mission Beach Granite Complex has yielded emplacement ages of 486±10Ma and 463±7Ma (Bultitude & others, 1996b; Bultitude & Garrad, 1997; Garrad & Bultitude, 1999; early and late Ordovician, using the AGSO timescale; Jones, 1995), respectively. The results are consistent with the field relationships. The zircons separated from the two samples contain numerous inherited cores. One core from the felsic I-type? yielded Archaean ages (~3000Ma and ~3300Ma). Inherited cores which yielded ages between ~950Ma and 1200Ma are relatively common in the sample from the Mission Beach Granite Complex. In contrast, the sample of Tam O'Shanter Granite contains inherited cores which yielded ages of ~2000Ma, ~1200Ma, and ~565Ma.

The age yielded by the felsic I-type? granite overlaps with the 455±5Ma SHRIMP age yielded by a dacite clast in late Ordovician (Ashgill) conglomerate (the Mountain Creek Conglomerate; Bultitude & others, 1993) of the Hodgkinson Province. The conglomerate crops out adjacent to the Palmerville Fault in the north-west (Figure 7) — probable early Ordovician rocks (Mulgrave Formation) also crop out in this area (Bultitude & others, 1993). A similar SHRIMP age (465±21Ma) has also been obtained from a silicic igneous clast from a conglomerate lens (in the Devonian Hodgkinson Formation) in the far north-east of the province (Figure 7; Garrad & Bultitude, 1999).

Geochemistry

Most of the granites analysed form three reasonably tight, discrete groups on most chemical variation diagrams (Figure 8), despite being extensively deformed and recrystallised. The felsic S-type granites have relatively high TiO_2, FeO*, K_2O, Ce and Rb contents, as well as ASI[10]s and Rb/Sr ratios, and low Na_2O and total alkalies compared with the felsic I-type? granites of similar SiO_2 content (Figure 8). The mafic I-type? granites are characterised by relatively low SiO_2 contents (~62%).

The analysed granites are characterised by Sr-depleted, Y-undepleted signatures similar to those shown by the Ordovician granites of the Ravenswood Batholith (Hutton & Crouch 1993). Such signatures are generally attributed to the presence of residual plagioclase in the source regions of the magmas, implying the magmas were generated above the amphibolite–eclogite transition zone.

The relatively high ASI values yielded by many samples may indicate some Na, K, and possibly Ca were removed during deformation, metamorphism and recrystallisation of the granites. An alternative explanation is that most (all?) of the analysed granites are S-types. Most analysed samples of mafic I-type? granites have ASIs of between 1.1–1.2 (Figure 8). An exception is the diorite collected from Timana Island which has an anomalously high ASI (>1.9), even for an S-type. The felsic I-types? have similar ASI values of between ~1.09–1.24. However, it is the felsic S-type granites (mainly Tam O'Shanter Granite) which have exceptionally high ASIs — ranging from 1.58–1.72 in 7 out of 8 samples (Figure 8). Such a rela-

10 ASI = Aluminium Saturation Index = $(Al_2O_3/101.94)/(CaO/56.08 - P_2O_5/42.59 + Na_2O/61.98 + K_2O/94.2)$

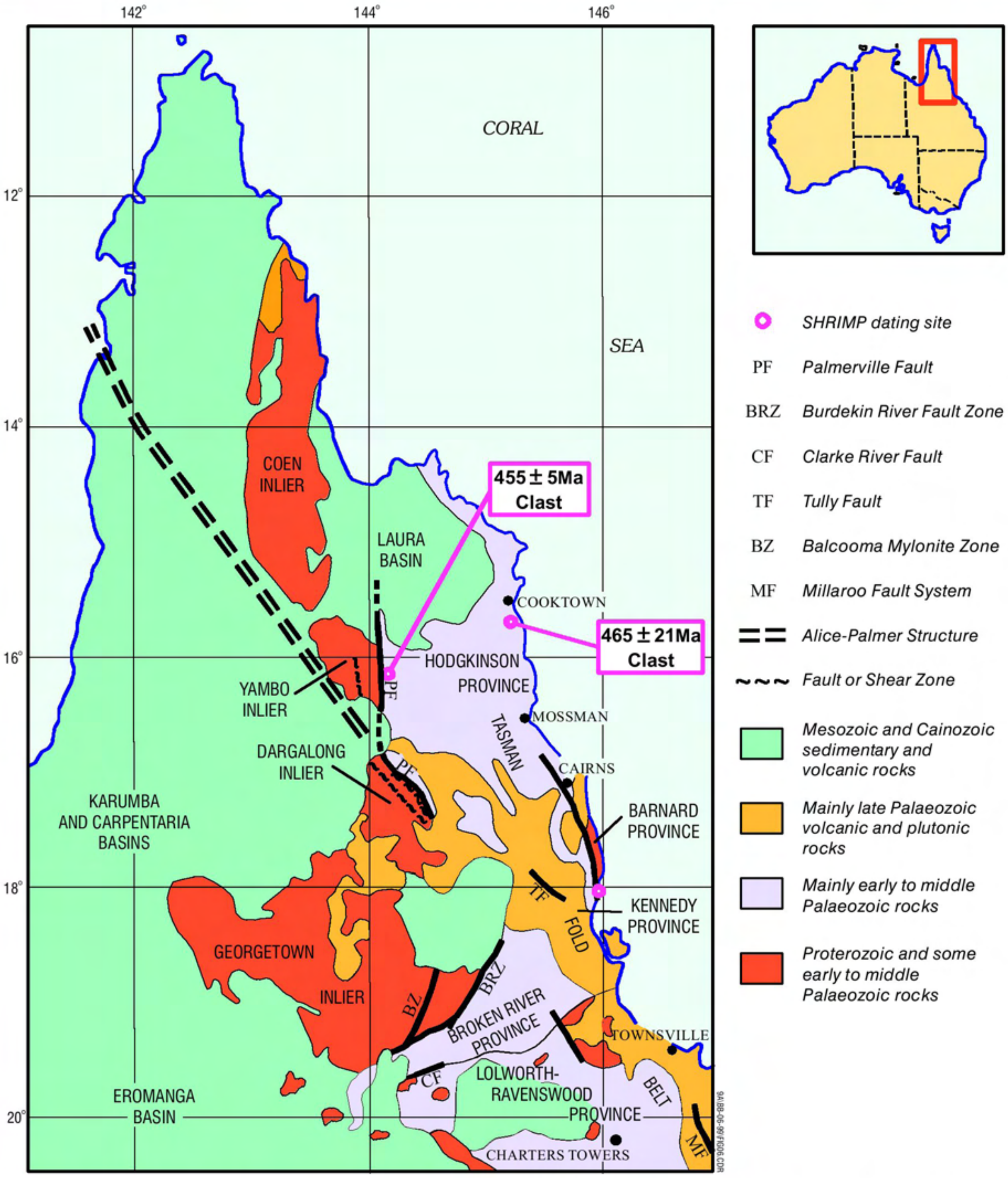

Figure 7. Distribution of main rock units in north Queensland, showing the locations of sites in the Barnard and Hodgkinson Provinces where Ordovician U–Pb zircon (SHRIMP) isotopic ages have been obtained.

tively small range of ASI values would appear to be unlikely if there had been extensive open-system alteration of the granites, particularly as the samples were collected from a relatively large area.

Comparisons between the S-type granites and the Barnard Metamorphics

The analysed samples of S-type granite (mainly from the Tam O'Shanter Granite) are chemically distinct from most of the supracrustal rocks of the Barnard Metamorphics. The latter are generally characterised by lower CaO, Na_2O, and Sr, and higher or similar K_2O and Th contents, as well as higher ASIs and Rb/Sr and Ga/Al ratios (Figure 8). However, migmatitic gneiss in the Mission Beach area is closely associated spatially with lenses of foliated granite implying there may be a genetic relationship between some of the granites and the Barnard Metamorphics.

Discussion

The Ordovician granites in the Barnard Metamorphics are the most northerly known igneous rocks of that age in eastern Australia. The most extensive outcrops of early Palaeozoic rocks in north Queensland are in the Charters Towers region. Recent SHRIMP dating indicates the Ordovician granites of

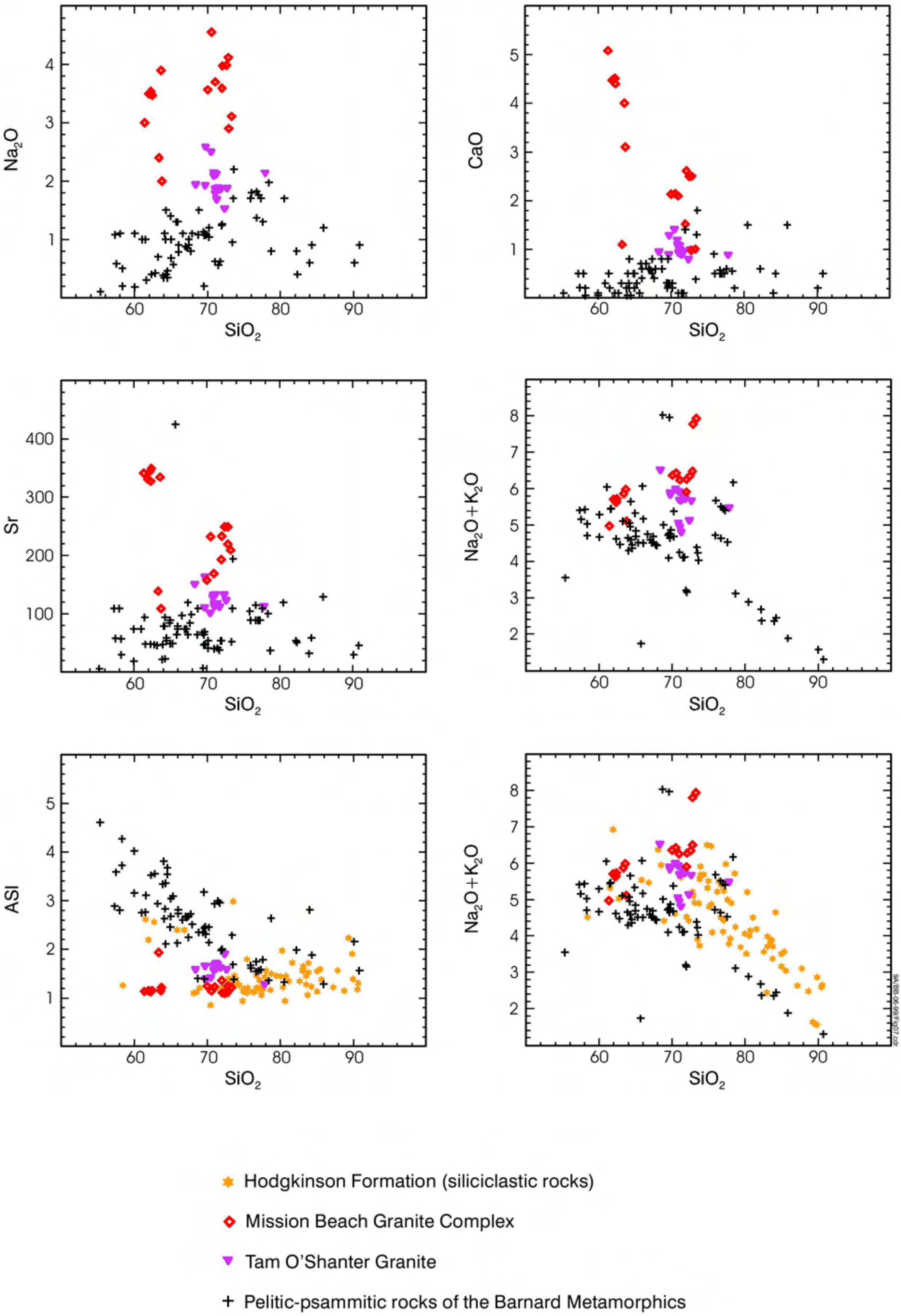

Figure 8. Chemical variation diagrams highlighting differences between Ordovician granites of the Macrossan Province and the enclosing pelitic–psammitic rocks of the Barnard Metamorphics. Major oxides are in weight per cent, trace elements in parts per million.

that region were emplaced in two main episodes (Rienks, 1991; Hutton & Crouch, 1993; Hutton & others, 1994), namely between:

- ~480Ma– ~490Ma, and
- ~460Ma– ~470Ma.

The dated granites from the Barnard Metamorphics fit neatly into these two groups.

The data, therefore, imply either:

1) significant magmatic activity occurred in INNISFAIL, as well as the Charters Towers region in the early and late Ordovician, or
2) the Barnard Province was located farther south in the Ordovician, and was subsequently displaced northwards by major strike-slip faulting. Movements on the Russell–Mulgrave Shear Zone and associated faults during the compressional Hunter–Bowen Orogeny subsequently obliterated indicators of the predominantly horizontal displacement (see subsequent section on 'Granites of the Bellenden Ker Batholith').

HODGKINSON PROVINCE

Hodgkinson Formation

Whitehouse (1930, page 27) originally named rocks mapped as part of the Hodgkinson Formation in INNISFAIL and CAIRNS the "Barron River Series". Whitehouse examined exposures in the Barron River gorge (in adjoining CAIRNS to the north). The name was subsequently amended to 'Barron River metamorphics' on the 1953 edition of the Geology of Queensland map (Hill, 1953). The earlier interpretation of Jensen (1923), who correlated these rocks with those exposed farther to the north-west in the Hodgkinson and Palmer River Gold Fields, was also ignored by many subsequent workers (*e.g.* Hill, 1951; Brooks, 1960, White, 1961). The Barron River Metamorphics were widely thought to be older than the predominantly Devonian Hodgkinson Formation. Following the major regional surveys in the late 1950s–early 1960s by joint BMR–GSQ parties de Keyser (1965) concluded that the Barron River Metamorphics were the more highly metamorphosed equivalents of the Hodgkinson Formation to the west and north-west. However, Hammond & others (1986) reported that the rocks of the Barron River Metamorphics were characterised by a distinctive mylonitic fabric not found in the lower grade Hodgkinson Formation rocks. Consequently, they supported the interpretation of earlier workers.

Rock types

Deep-water, turbidity-current deposits dominate the very extensive Hodgkinson Formation. Fine-grained rock types predominate in INNISFAIL. They consist mainly of metamudstone, metasiltstone, slate, phyllite, and schist. The rocks are commonly carbonaceous. Minor rock types include meta-arenite, quartzite, impure limestone, marble, conglomerate, conglomeratic arenite, chert (commonly thin bedded), 'greenstone', amphibolite and calc-silicate gneiss (also see Jones, 1978). Most of the high-grade metamorphic rocks are located in the aureole of the Tinaroo Batholith. Primary sedimentary structures are generally very poorly preserved, because of the extensive deformation and recrystallisation.

The phyllitic and schistose rocks consist of mainly quartz, and minor plagioclase, K-feldspar, muscovite, sericite, graphite, ilmenite, and detrital tourmaline (Jones, 1978). The widespread presence of minor to trace amounts of carbonaceous matter (mainly pyrobitumen in the least metamorphosed rocks), particularly in the finer grained rocks, indicates the siliciclastic sediments of the Hodgkinson Formation were deposited mainly under reducing conditions. Much of the originally disseminated carbonaceous matter was mobilised during subsequent deformations.

The metamorphic grade, excluding the aureoles of granitic intrusions, appears to be lower greenschist, although mineral assemblages in the rocks of INNISFAIL have not been studied in detail. Willmott & others (1988) noted that rare 'greenstone' lenses in the formation farther north (in CAIRNS) consist of plagioclase, chlorite, epidote and opaque minerals, consistent with greenschist facies metamorphism.

Age

The Hodgkinson Formation is sparsely fossiliferous. No diagnostic fossils have been recovered from the unit in INNISFAIL — or for that matter, from most of the eastern Hodgkinson Province. Conodonts from rare limestone lenses and from clasts in conglomeratic units (mainly in the central part of the province to the north-west of INNISFAIL) indicate an age range from early Devonian (Lochkovian), or possibly late Silurian, to late Devonian (Famennian; Cranfield & Hegarty, 1989; Halfpenny & Hegarty, 1991; Donchak & others, 1992; Domagala & others, 1993).

The Hodgkinson Formation is also intruded by several plutons of Mount Formartine Granite in adjoining CAIRNS. A sample from one of these plutons recently yielded a U–Pb zircon (SHRIMP) age of 357±6Ma (Zucchetto & others, 1998, 1999), thereby constrain-ing the upper age limit of the formation in the east to pre-late Famennian.

Structure

Only one major regional foliation has been recognised in the Hodgkinson Formation of INNISFAIL — a pervasive, steeply dipping, north-westerly trending slaty cleavage (Donchak, 1997). This fabric is axial plane to the few mesoscopic folds found in the unit. Donchak (1997) argued it most probably developed during the Permian–Triassic Hunter–Bowen Orogeny. However, the presence locally (*e.g.* in the Mena Creek and El Arish areas) of a well-developed, overprinting crenulation implies the main foliation may have formed during an earlier deformational event. In most places the foliation detected has the same orientation and morphology as foliations in the central parts of the Hodgkinson Province, farther to the north-west (Bultitude & Donchak, 1992; Bultitude & others, 1993). These latter fabrics pre-date or are contemporaneous with late Carboniferous–early Permian granite emplacement (*e.g.* Davis, 1993, 1994). The foliation displayed by most of the Hodgkinson Formation rocks of INNISFAIL, therefore, may be a composite one, produced by re-use or reactivation (in the sense of Bell, 1986) of older fabrics in the formation (Donchak, 1997). The relationship between the deformational history of the Hodgkinson Formation in INNISFAIL and the adjacent Barnard Metamorphics has yet to be convincingly determined.

Hornfels zones

The Hodgkinson Formation has been intruded by several late Palaeozoic granite plutons, which have produced poorly to well-defined contact metamorphic aureoles. Typical effects are induration and recrystallisation in arenite units and the development of (cordierite–) andalusite–quartz–mica hornfels in mudstone units adjacent to the contacts. Most aureoles are <~1.5km wide.

Discussion

The tectonic setting for the Hodgkinson Province remains uncertain. Most interpretations of the evolution of the northern Tasman Orogenic Zone involve the presence of a consuming plate margin for much of the Palaeozoic (*e.g.* Coney & others, 1990). However, there is no general agreement as to the location of the volcanic arc(s) and subduction zone(s) with respect to the Hodgkinson Province.

Most previous workers (*e.g.* Arnold, 1975; Cooper & others, 1975; Henderson, 1980) interpreted the Hodgkinson Province succession as having accumulated in a fore-arc–accretionary prism setting located to the east of an active continental magmatic arc. In contrast, Fawckner (1981) postulated that the tholeiitic rather than calc-alkaline character of the basic lavas (which are widespread throughout the province), and the overall scarcity of penecontemporaneous intermediate to silicic volcanic detritus, indicated a model involving the development of a rifted continental margin (*i.e.* overall extension rather than compression).

The results of recent investigations of the Hodgkinson Province by GSQ geologists favour an extensional rather than a compressional regime for the evolution of the Hodgkinson Province (Bultitude & others, 1996a; Garrad & Bultitude, 1999). Whether a rifted continental margin as suggested by Fawckner (1981) is a more appropriate setting than a back-arc basin depends essentially on whether the locally abundant volcanic detritus in the north-eastern part of the province, as well as minor amounts elsewhere, was derived from a nearby contemporaneous magmatic arc or from an older volcanic assemblage.

KENNEDY PROVINCE

The Carboniferous–Permian igneous rocks of INNISFAIL form part of a major late Palaeozoic post-orogenic igneous province, previously termed the Coastal Ranges Igneous Province by Stephenson & Griffin (1976), and the North Queensland Volcanic and Plutonic Province by Day & others (1983). They also form part of the more recently defined Townsville–Mornington Island Igneous Belt of Wellman & others (1994).

Dunk Island and Bedarra Granites

The Bedarra granite belt comprises the chain of islands, extending from Dunk Island in the north to the Brook Islands in the south-east (Bultitude & Garrad, 1997; Garrad & Bultitude, 1999). Most of the granites are located in adjoining INGHAM, to the south — only the Dunk Island Granite and the northern end of the Bedarra Granite (Plate 22) crop out in INNISFAIL. These were previously mapped as part of the Tully Granite Complex (de Keyser, 1964). However, the granites of the Bedarra belt are distinct from most of those on the nearby mainland. Hornblende and titanite, for example, have not been detected in the Dunk Island and Bedarra Granites. In contrast, granites containing hornblende and primary titanite are common on the nearby Tully Granite Complex on the mainland. Informal subdivisions of the granites of the belt are listed in Garrad & Bultitude (1999, appendix 1).

Age

The Bedarra belt granites were previously regarded as being of similar age to the late Carboniferous–early

Permian granites of the Tully and northern Ingham Batholiths (*e.g.* de Keyser, 1964; de Keyser & others, 1965). However, the results of recent isotopic dating indicate at least some of the granites of the belt are significantly older (Visean). Granites from Dunk Island (at the northern end of the belt) and North Island (Brook Islands group; at the southern end of the belt, in INGHAM) have recently yielded U–Pb zircon (SHRIMP) ages of 336±5Ma and 335±6Ma, respectively. The granites of the Bedarra belt, therefore, are of similar age to the Kallanda Granite (330±4Ma) and Clemant Microgranite (337±6Ma) (Gunther, 1993; Gunther & Withnall, 1995) of the Kangaroo Hills Mineral Field (in south-western INGHAM).

Mineralogy and geochemistry

Biotite is the dominant mafic mineral. Ilmenite is the main opaque mineral, indicating the granites of the Bedarra belt were generated under reducing (low fO_2) conditions. Granite exposed on the south-western side of Dunk Island (GR 123132, Innisfail 1:100 000 Sheet area) also contains traces of late-stage, interstitial tourmaline.

The few chemical analyses of the Dunk Island and Bedarra Granites currently available indicate they are felsic (SiO_2>68%), unfractionated (Rb<200ppm), and peraluminous. The absence of significant Ba and Sr depletion in the samples is also consistent with the lack of extensive feldspar fractionation — in contrast to granites of similar age in the Kangaroo Hills Mineral Field (Figure 9).

Most of the granites of the Bedarra belt and those of the Kangaroo Hills Mineral Field (I-type Oweenie Supersuite) define coherent trends on most variation diagrams (*e.g.* Figure 9), implying derivation by similar processes, from sources of similar composition.

One of the most significant differences between the granites of the Bedarra belt and the Kangaroo Hills Mineral Field are the significantly higher ASIs (~1.13–1.21) of the Dunk Island Granite samples. Elevated ASIs can result from alteration involving partial removal of one or more of the relatively mobile elements, Na, K, and Ca. However, field observations and thin section studies indicate the Dunk Island Granite is not extensively altered.

Furthermore, biotites analysed from samples of Dunk Island Granite plot with those from S-type granites of the Hodgkinson Province on a total Al versus mg-ratio diagram (Figure 10). Biotites analysed from other granites in the Bedarra belt plot either on the boundary between the fields defined by the I- and S-type supersuites of the eastern Hodgkinson Province or slightly in the S-type field. However, their total Al contents are significantly lower than those in biotites analysed from the Dunk Island Granite (Figure 10).

In contrast, CaO abundances in the samples of Dunk Island Granite, with the possible exception of some of those on the south-western side of the island appear to be too high for the unit to be a typical S-type. Most of the samples plot on the same trends as those defined by more felsic granites of the belt (*e.g.* Figure 9). The latter are interpreted to be I-types. Consequently, the Dunk Island Granite is also tentatively interpreted to be an I-type.

A sample of foliated granite from a boulder on the south-western side of Dunk Island (at GR 123132, Innisfail 1:100 000 Sheet area; informally referred to as the Tapp-Ana granite by Garrad & Bultitude, 1999) is much more felsic than the other granite samples analysed from the island. This granite is characterised by relatively high SiO_2, K_2O, and low CaO, P_2O_5, Ce, La, Sr, and Zr contents. Its relationship to the other granites on the island is unknown. However, dykes of similar garnet-bearing felsic granite cut the main Dunk Island Granite at GR 117143 (Innisfail 1:100 000 Sheet area.

Glen Gordon Volcanics

The belt of predominantly silicic volcanic rocks extending discontinuously from north-west of Ravenshoe (in ATHERTON) south-south-east to the Running River area (in southern INGHAM) was formerly mapped mainly as Glen Gordon Volcanics (Best, 1962; de Keyser, 1964; de Keyser & others, 1965; Branch, 1966). There was no general agreement among the early investigators regarding the age and extent of the unit. Best (1962) separated the volcanic rocks in the Sunday Creek area (south-eastern corner of ATHERTON) as the Sunday Creek Volcanics, of inferred Carboniferous age, from similar rocks of probable Permian age to the north (Glen Gordon Volcanics). Branch (1966) extended the range of the Sunday Creek Volcanics, which he interpreted to be unconformably overlain by the Glen Gordon Volcanics of probable middle–late Carboniferous age. In contrast, de Keyser (1964) and de Keyser & others (1965) mapped contiguous volcanic units in adjacent INNISFAIL and INGHAM as Glen Gordon Volcanics which they regarded to have been most probably erupted between the middle Carboniferous and early Permian. Blake (1972) concurred with the conclusions of de Keyser (1964) and de Keyser & others (1965) and included the Sunday Creek Volcanics of Best (1962) and Branch (1966) in the Glen Gordon Volcanics. Blake interpreted the unit to be most probably late Carboniferous.

The term 'Glen Gordon Volcanics' in this report is applied to the sequence of volcanic rocks, which crop

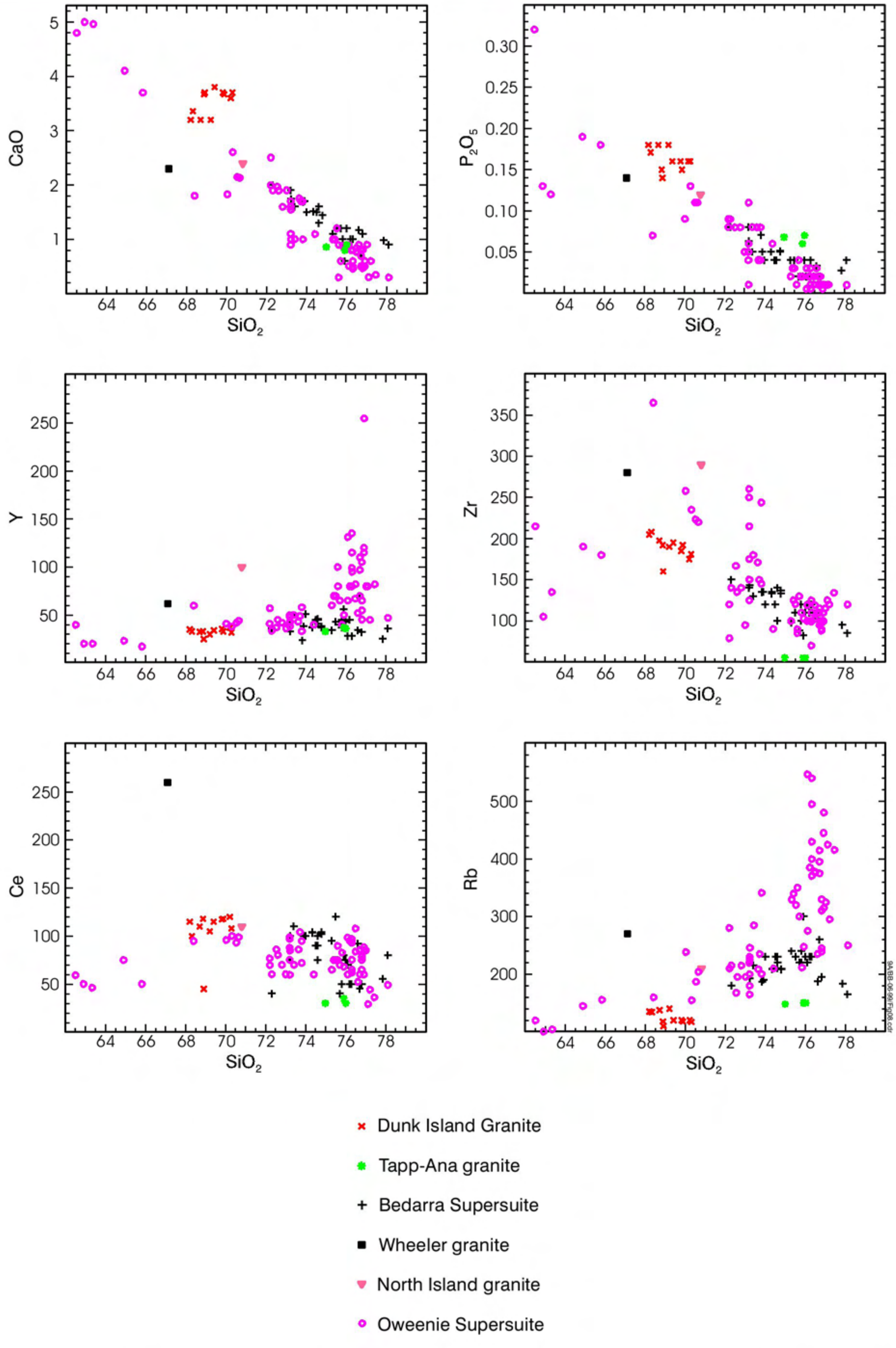

Figure 9. Chemical variation diagrams for the Bedarra granite belt. Only the Dunk Island Granite, Tapp-Ana granite (informal unit), and northernmost part of the Bedarra Granite crop out in the Innisfail 1:250 000 Sheet area. The remaining units in the belt, most of the Bedarra Granite, and the Oweenie Supersuite granites are exposed in the adjacent Ingham 1:250 000 Sheet area. Major oxides are in weight per cent, trace elements in parts per million.

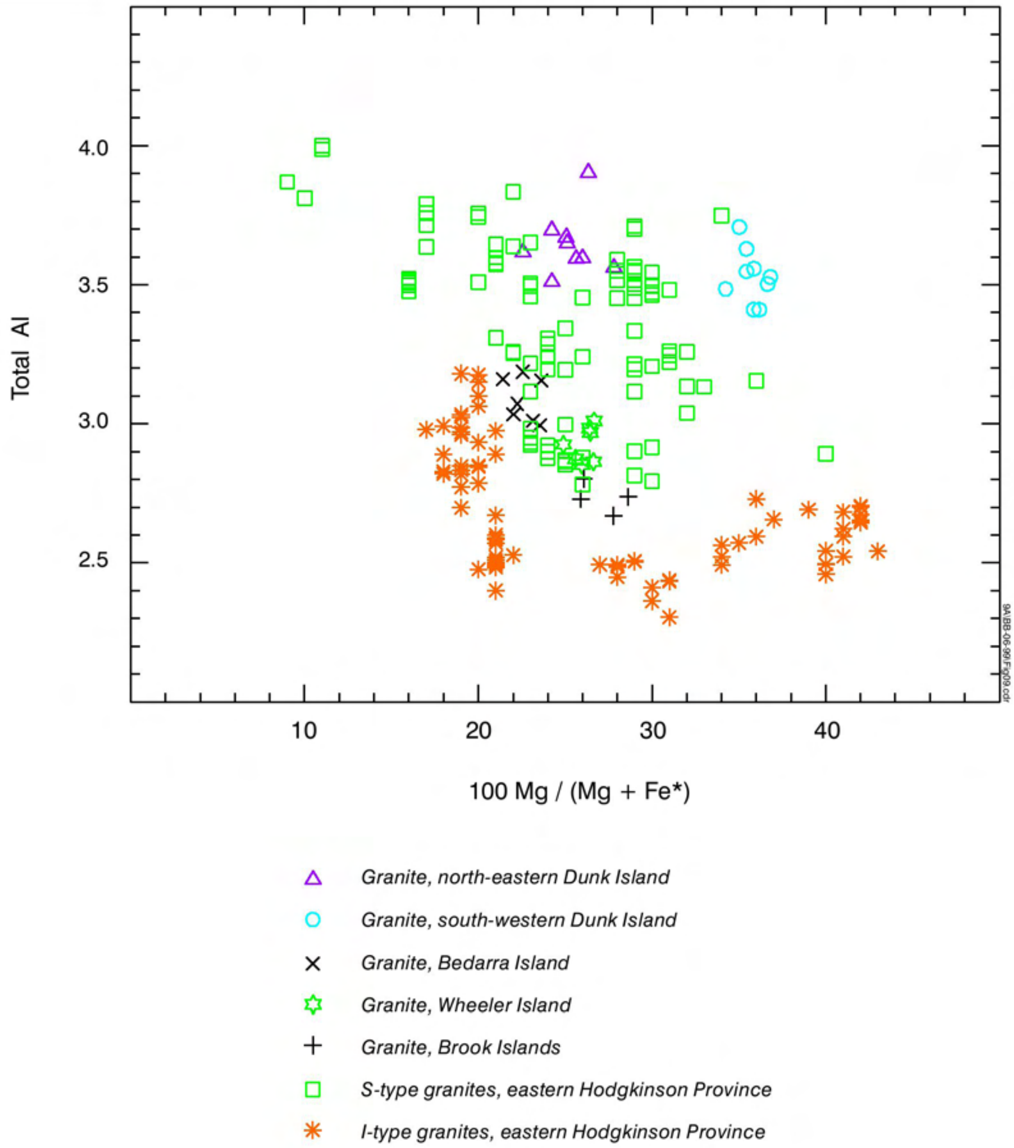

Figure 10. Total Al versus mg-ratio for biotites from selected granites of the Bedarra belt and I- and S-type granites of the eastern Hodgkinson Province.

out north of Kirrama homestead (in the north-western corner of INGHAM), along the south-western boundary of INNISFAIL. The unit is generally densely vegetated and poorly exposed.

The Glen Gordon Volcanics (reported maximum thickness >600m) consist mainly of rhyolitic to rhyodacitic ignimbrite and lava, and subordinate dacite, andesite and volcanic breccia (de Keyser, 1965). Wellman (1997) identified two discrete cauldron subsidence structures in the Glen Gordon Volcanics, based on interpretation of aeromagnetic anomalies.

Age

Granites of the O'Briens Creek Supersuite intrude the lower part of the Glen Gordon Volcanics (in ATHERTON). The latter have yielded Rb–Sr isotopic ages mainly in the 300Ma–315Ma range (Black & others, 1978; Johnston & Black, 1986). However, the presence locally of silicic volcanic rocks with A-type affinities implies the unit contains rocks of probable early Permian age. Silicic volcanic rocks with A-type affinities have been recorded in most of the major late Palaeozoic volcanic units in this part of north Queensland (including the Wallaman Falls, Galloway, and Nychum Volcanics, and the Featherbed, Newcastle Range, and Scardons Volcanic Groups). All those, which have been isotopically dated using modern techniques, have yielded Permian ages. The Glen Gordon Volcanics, therefore, most probably range in age from late Carboniferous to early Permian.

Geochemistry

The analysed samples (many from outcrops in adjoining ATHERTON) from the Glen Gordon Volcanics range in composition from andesite to rhyolite (Figure 11). Those with >~78% SiO_2 probably reflect the effects of post-eruption devitrification and alteration. About half of the analysed samples plot in the A-type

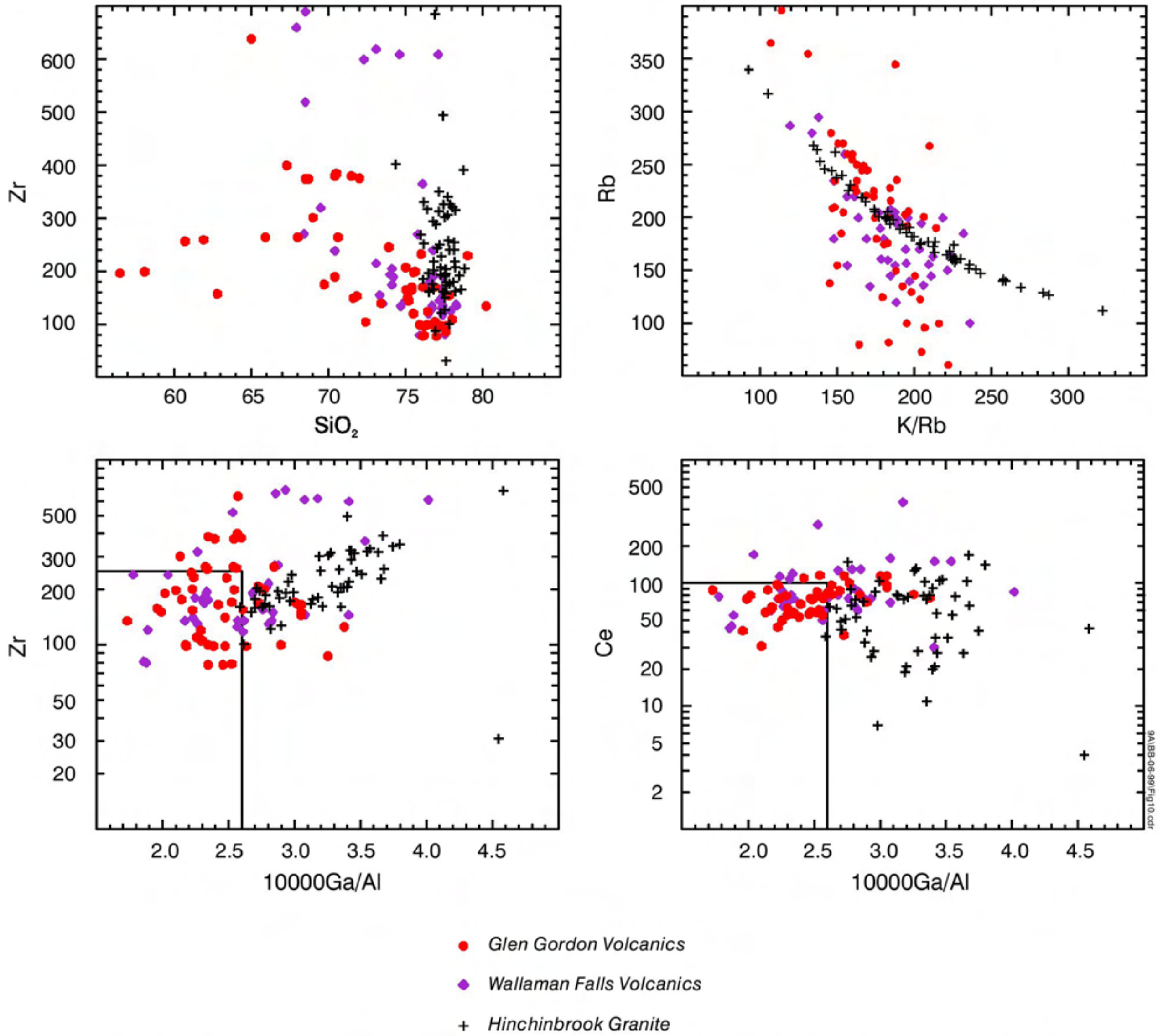

Figure 11. Zr versus SiO_2, Rb versus K/Rb, and Zr and Ce versus Ga/Al plots for the Glen Gordon Volcanics. Some of the samples analysed are from the adjacent Atherton 1:250 000 Sheet area, to the west. Also shown for comparison are the Wallaman Falls Volcanics and A-type Hinchinbrook Granite, which crop out in the adjacent Ingham 1:250 000 Sheet area, to the south. Trace elements are in parts per million (ppm), SiO_2 in weight percent (wt%). The rectangular boxes in two of the plots enclose the fields of I-, S- and M-type granites selected by Whalen & others (1987).

field (Figure 11), with the A-type Hinchinbrook Granite of INGHAM (Stephenson & others, 1992), on the discrimination diagrams of Whalen & others (1987). The A-types are characterised by relatively high Ga/Al ratios, as well as elevated FeO*, Ce, Ga, La, Pb, Zn, and Zr contents.

Most of the constituent subunits in the formation are unfractionated. K/Rb ratios, for example, remain more or less constant in rocks containing between ~50% and ~75% SiO_2. Some subunits with higher SiO_2 contents show a trend of decreasing K/Rb ratios, consistent with some feldspar fractionation.

Discussion

The Glen Gordon Volcanics apparently evolved in a similar manner to the Featherbed Volcanic Group. The Featherbed Volcanic Group is a very extensive volcanic succession to the west and north-west of the sheet area (in nearby ATHERTON and MOSSMAN) containing both early Permian silicic volcanic rocks with A-type affinities and older (late Carboniferous) I-type volcanic rocks (Mackenzie, 1997; Garrad & Bultitude, 1999). Most of the A-types were erupted (at ~280Ma–290Ma) after extensive volcanic activity in and adjacent to the Featherbed Cauldron complex in the late Carboniferous (at ~300Ma–313Ma; Mackenzie, 1997). The available data imply the volcanic activity, which produced the Glen Gordon Volcanics, commenced earlier than that which produced the Featherbed Volcanic Group.

Granites of the Tinaroo Batholith

Several granites in the southern part of the eastern Hodgkinson Province previously mapped or described as part of the Mareeba Granite (de Keyser &

Lucas, 1968; Sheraton & Labonne, 1974, 1978) are chemically or isotopically distinct (Champion, 1991; Champion & Bultitude, 1994). Those forming the Tinaroo Batholith have been delineated as the Tinaroo Granite (Tinaroo Supersuite) and Emerald Creek Microgranite (Emerald Creek Supersuite) — both composite units according to Rubenach & Bell (1988). These units have been described previously by Willmott & others (1988), Bultitude & Champion (1992) and Champion & Bultitude (1994).

Emerald Creek Microgranite

The Emerald Creek Microgranite crops out in the south-western part of the Tinaroo Batholith and contains biotite and muscovite in roughly equal amounts.

The contact between the microgranite and enclosing metasedimentary rocks (mapped as part of the Hodgkinson Formation) is reported to be shallowly dipping (Mancktelow, 1974, 1982). According to Mancktelow the shallow dip resulted in the development of a diffuse contact zone, up to ~300m wide, containing high (upper amphibolite) -grade regional-type metamorphic rocks.

The age of the Emerald Creek Microgranite is uncertain. An imprecise U–Pb zircon (SHRIMP) age of ~320Ma was obtained on a sample of the microgranite.

Despite mineralogical similarities, the Emerald Creek Microgranite is geochemically distinct compared with units of similar SiO_2 contents in the Tinaroo and Whypalla Supersuites (Champion, 1991; Champion & Bultitude, 1994). The Emerald Creek Microgranite, for example, is characterised by relatively high CaO and MgO contents and mg-ratios, and low K_2O and Y contents.

Tinaroo Granite

The Tinaroo Granite (Willmott & others, 1988) forms densely vegetated, rough, mountainous country in the far north-west of the sheet area. Samples of the granite have yielded K–Ar biotite and muscovite ages (corrected for spike and calibration errors) ranging from 268Ma to 283Ma and Rb–Sr ages in the range from 253Ma to 285Ma (most calculated using assumed initial $^{87}Sr/^{86}Sr$ ratios in the range 0.710–0.715; Richards & others, 1966; Black, 1978, 1980; Champion, 1991). The majority are in the 270Ma–280Ma range. They indicate the unit is most probably early Permian. The relatively young K–Ar and Rb–Sr dates may represent reset ages which resulted during subsequent deformation(s) in the region during the Hunter–Bowen Orogeny.

The Tinaroo Granite (the only member of the Tinaroo Supersuite of Champion, 1991, and Champion & Bultitude, 1994) has similar mineralogical, petrographic and geochemical characteristics to units in the Whypalla Supersuite and possibly should be included in that supersuite. However, despite these similarities, the unit is distinct isotopically. The Tinaroo Granite is characterised by a primitive ε_{Nd} value (-2.01, at 280Ma) compared with members of the Whypalla Supersuite (-3.85– -6.43, at 280Ma; Champion, 1991; Champion & Bultitude, 1994). Consequently, the unit has been assigned to a separate supersuite.

Mount Peter Granite
(after Willmott & others, 1988)

The Mount Peter Granite was not examined during the recent survey. The granite has an elliptical shape and forms steep, forested country on the eastern flank of the Isley Hills.

Willmott & others (1988) noted that massive fine-grained arenites and argillites (of the Hodgkinson Formation) west of Yatee and in the Mount Peter area have apparently undergone a regional-contact type of metamorphism similar to that found around parts of the Tinaroo Batholith. The rocks have been extensively converted to andalusite schist and spotted schist.

The age of the granite is uncertain. It is considered to be most probably early Permian. According to Willmott & others (1988) the granite is lithologically similar to the early Permian Tinaroo Granite to the west.

Granites of the Bellenden Ker Batholith

Units (including the I-type Bartle Frere Granite) forming the Bellenden Ker Batholith (see Willmott & others, 1988; Bultitude & Champion, 1992, for discussions on the usage of this term) had been mapped as part of the Mareeba Granite by de Keyser (1964) and de Keyser & Lucas (1968). Willmott & others (1988) subsequently mapped the northern half of the batholith and delineated the very extensive Bellenden Ker Granite as well as several unnamed, informal units.

Bellenden Ker and Walshs Pyramid Granites

Most of the Bellenden Ker, Malbon Thompson, and Graham Ranges consist of the Bellenden Ker Granite (Willmott & others, 1988). The unit comprises mainly variably and commonly extensively deformed (mylonitic), highly megacrystic, biotite-rich granite to granodiorite?. These granitic rocks had previously been referred to as the Mulgrave River Granite

(Rubenach, 1978) and the Mulgrave River Granite Complex (Richards, 1977), but no type areas or sections were defined.

The **Bellenden Ker Granite** is a heterogenous unit possibly consisting of several discrete plutons. Intensely foliated (mylonitic), megacrystic, biotite-rich monzogranite–granodiorite? exposed at Bramston Point (GR 912924, Cooper Point 1:100 000 Sheet area), for example, is distinctly more biotite rich than granite exposed at Bellenden Ker Centre Peak. It is distinguished chemically by relatively high P_2O_5 and V and low SiO_2 (<68%) contents (Figure 12). Similarly, megacrystic granite forming the Malbon Thompson (southern part) and Graham Ranges is relatively rich in biotite and enclaves, at least locally. Granite exposed on the flanks of the Bellenden Ker Range (*e.g.* at Kearneys Falls, The Boulders, and on the outskirts of Babinda) is also relatively mafic.

Scattered pods of finer grained, more even-grained, felsic (garnet–altered cordierite?–tourmaline–muscovite–) biotite granite and biotite–muscovite granite are common around the margins of the pluton(s) of megacrystic granite, particularly in the northern part of the Bellenden Ker Range (*e.g.* in the Clamshell Falls area), at Walshs Pyramid, at Palmer Point, and at the north-western end of the Graham Range (*e.g.* at GR 885941, Bartle Frere 1:100 000 Sheet area). The granite at Palmer Point had been included in the Yarrabah granite (informal unit) by Richards (1977). Walshs Pyramid consists of medium-grained, even-grained to only slightly porphyritic (tourmaline–muscovite–) biotite syenogranite (**Walshs Pyramid Granite**) which is more highly fractionated and biotite poor than the type Bellenden Ker Granite. Most, probably all, of these intrusions post-date the type (megacrystic) Bellenden Ker Granite but their ages and extents have not been established. All of the units, except for the Walshs Pyramid Granite, are currently included in the Bellenden Ker Granite.

Tourmaline is a widespread late-stage mineral in the Bellenden Ker and Walshs Pyramid Granites. K-feldspar megacrysts in intensely deformed granite forming the summit area of Bellenden Ker Centre Peak are partly replaced by tourmaline. Tourmaline-rich aggregates (up to 10cm across) are also common.

The Bellenden Ker Granite contains inclusions of 'diorite', biotite-rich gneiss, biotite granite (*sensu lato)*, microgranite (*sensu lato)*, and hornfelsed country rocks. Inclusions are very common in granite exposed on the eastern side of the Graham Range (*e.g.* at GR 912924, Bartle Frere 1:100 000 Sheet area), where some of the gneiss enclaves are up to ~25m long and 3m wide (most are <1m long). The inclusions and enclosing granite in this area are intensely deformed. Smaller inclusions (up to ~50cm; most <15cm) of mainly biotite-rich metasedimentary gneiss are also locally abundant in granite exposed on the western flanks of the range (*e.g.* at GR 891893, Bartle Frere 1:100 000 Sheet area).

The Bellenden Ker Granite with all its components resembles granites of the Whypalla Supersuite, which form extensive outcrops in the eastern Hodgkinson Province farther north — and like the latter it contains few, if any, diagnostic minerals to indicate whether the constituent plutons are S- or I-types. The presence locally of rare aggregates (clots) of fine white mica possibly after cordierite, the presence of sparse garnet and interstitial apatite, the local abundance of tourmaline, and their peraluminous character are interpreted to indicate the Bellenden Ker and Walshs Pyramid Granites are S-types.

Supporting evidence is also provided by the Al contents of the biotites. Al concentrations in biotites of the Bellenden Ker Granite are similar to or higher than those in biotites (with similar mg-ratio) in S-type granites of the Whypalla and Cooktown Supersuites (Figure 13). They are significantly greater than the Al concentrations in biotites (of comparable mg-ratio) from I-type granites of the eastern Hodgkinson Province.

Deformation

Deformational effects in the Bellenden Ker Granite range from slight to very extensive. A mylonitic foliation with prominent 'S' and 'C' planes is well developed in the summit area (*e.g.* at GR 786913, Bartle Frere 1:100 000 Sheet area; Plate 23) and eastern side (*e.g.* at Fishery Falls and Babinda; Plates 24, 25) of the Bellenden Ker Range and on the eastern (*e.g.* at GR 912924, Bartle Frere 1:100 000 Sheet area; Plate 26) and western (*e.g.* at GR 891893, Bartle Frere 1:100 000 Sheet area) flanks of the Graham Range. The Bellenden Ker Range is bounded to the east by the Russell–Mulgrave Shear Zone. Kinematic indicators in deformed granite west of the shear zone, such as the orientations of porphyroclasts, stretching lineations and 'S–C'[11] planes, indicate a dominant east-block-up sense of movement (also see Donchak, 1997).

Intensely tectonised granite in the Bramston Point area has a similar deformational fabric. However, the orientations of the stretching lineations imply a significant sinistral shear component and a west-block-up movement sense (Donchak, 1997; this study). The deformation fabrics in this area may be re-

11 'S–C' planes are the asymmetric fabrics typically developed in mylonites;
'S' = schistosity plane, 'C' = cisaillement (or shear plane); after Berthé & others (1979)

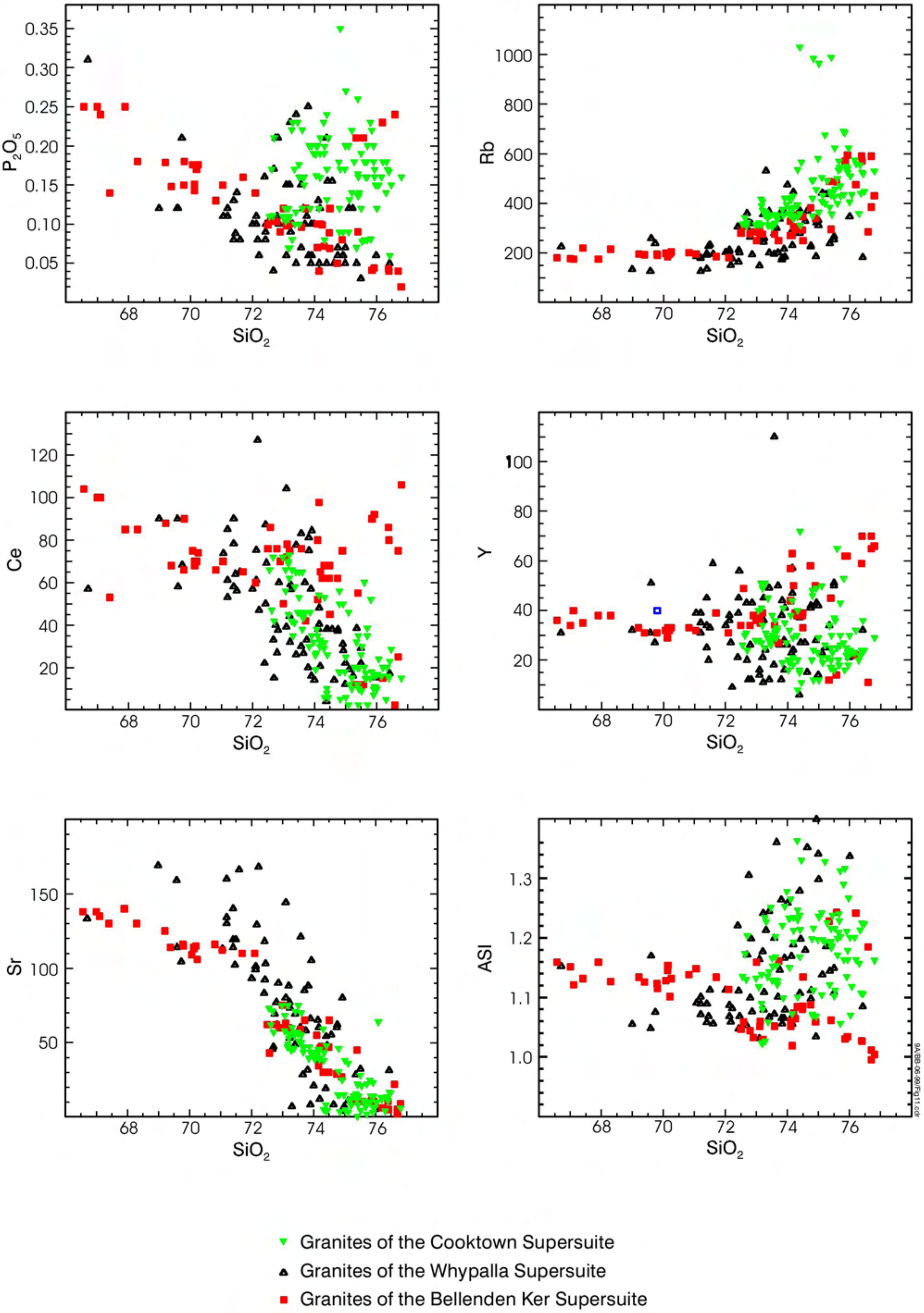

Figure 12. P_2O_5 (wt%), Rb, Ce, Y, Sr, (ppm) and ASI versus SiO_2 (wt%) plots for the granites of the Bellenden Ker Supersuite. Also shown for comparison are granites of the S-type Cooktown and Whypalla Supersuites of the eastern Hodgkinson Province.

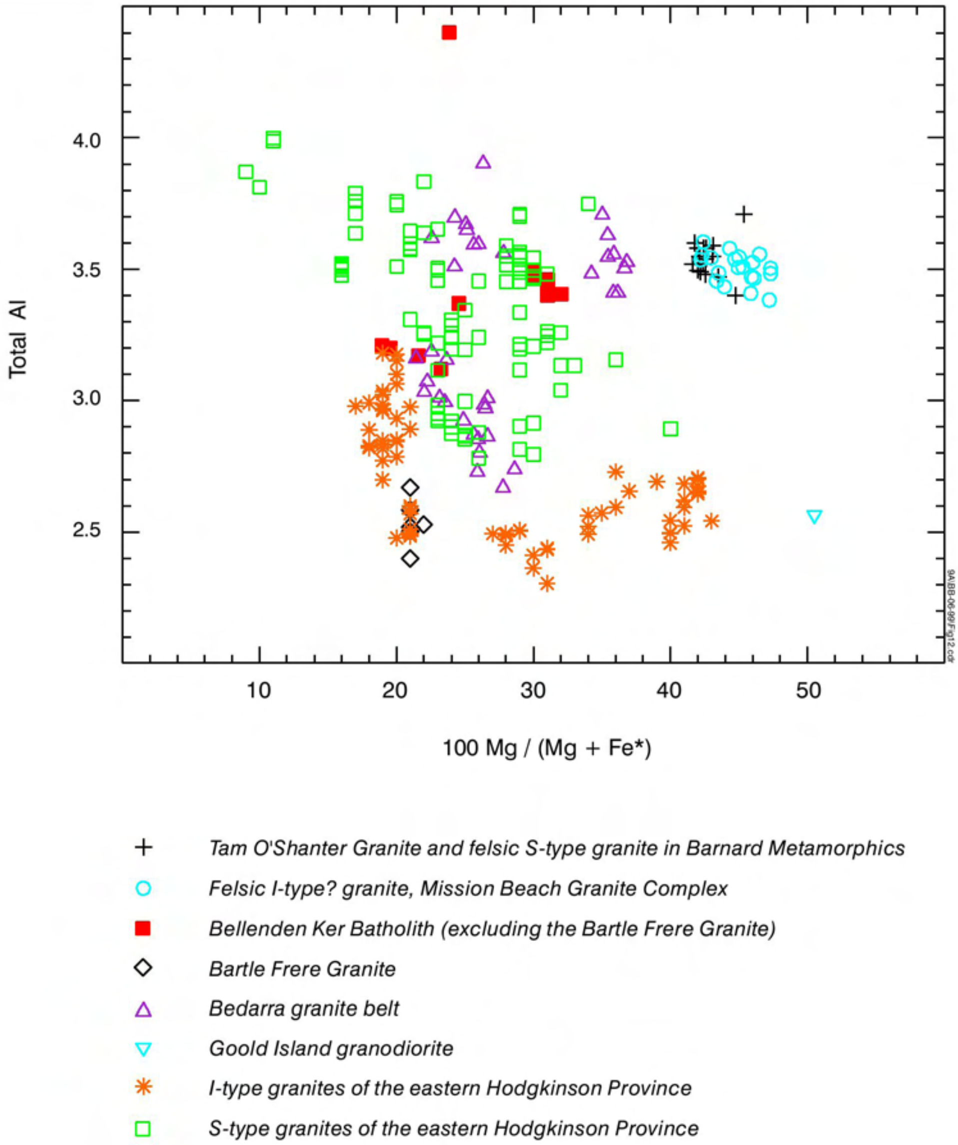

Figure 13. Plot of total Al versus mg-ratio for biotites in selected granites of the Innisfail 1:250 000 Sheet area. Analyses of biotites from S-type and I-type granites of the eastern Hodgkinson Province and from granites in the adjacent Ingham 1:250 000 Sheet area are also shown for comparison.

lated to the presence nearby of a major north-westerly striking shear zone (a splay of the Russell–Mulgrave Shear Zone or, possibly the main component of the Russell–Mulgrave Shear Zone). The postulated shear zone separates high-grade rocks of the Barnard Metamorphics on the Frankland Islands and adjacent mainland from lower grade rocks to the south and south-west.

Age

A sample of coarsely megacrystic granite (from GR 799817, Bartle Frere 1:100 000 Sheet area) similar to the type Bellenden Ker Granite at Kearneys Falls has yielded a U–Pb zircon (SHRIMP) age of 280±4Ma (Bultitude & Champion, 1992). K–Ar ages (corrected) of 238Ma and 251Ma had been previously obtained on samples of Bellenden Ker Granite (Richards & others, 1966). These dates are similar to those yielded by samples of extensively deformed granites from elsewhere in the eastern Hodgkinson Province (Bultitude & Champion, 1992). They are interpreted as reset ages (*cf.* Willmott & others, 1988).

Geochemistry

The granites of the Bellenden Ker Batholith — except for the I-type Bartle Frere Granite — have been assigned to the ***Bellenden Ker Supersuite*** (Garrad & Bultitude, 1999).

Rb contents (and Rb/Sr and Rb/Ba ratios) remain more or less constant in rocks containing <~72% SiO_2 (Figure 12). These parameters increase significantly in rocks with higher SiO_2 contents, and Ba and Sr show marked depletions (*e.g.* Figure 12). These trends are consistent with feldspar fractionation having played a prominent role in the evolution of the more felsic granites of the supersuite.

The most fractionated unit is Walshs Pyramid Granite, west of Gordonvale. This granite contains ~600ppm Rb, ~30ppm Ba, and ~5–10ppm Sr (Figure 12). The very low Sr and Ba contents may indicate the pluton has undergone subsolidus hydrothermal alteration. Alternatively, the partition coefficients for Sr and Ba in plagioclase may increase significantly in albite-rich compositions (*e.g.* Blundy & Wood, 1991), thereby accounting for the very low Sr and Ba contents of the highly fractionated Walshs Pyramid Granite.

Relatively high TiO_2, K_2O, and V, and low Al_2O_3, CaO, Na_2O, Ba, and Sr contents distinguish the Bellenden Ker Supersuite granites from the Whypalla Supersuite granites of about the same age. In addition, ASIs and elements such as La, Ce, and Y display contrasting trends on Harker-type variation diagrams (*e.g.* Figure 12).

Bartle Frere Granite

The Bartle Frere Granite forms a prominent, rugged mountain at the southern end of the Bellenden Ker Range. It was formerly mapped as part of the Mareeba Granite (de Keyser, 1964; de Keyser & Lucas, 1968), but is mineralogically and chemically distinct. The Bartle Frere Granite contains minor hornblende (<biotite) and traces of primary titanite, allanite and ilmenite; it is therefore classified as a reduced I-type. It is the sole unit of the ***Bartle Frere Supersuite*** of Bultitude & Champion (1992).

Dykes and pods of fractionated, finer grained leucogranite cut the Bartle Frere Granite. At least some of the leucogranites contain traces of hornblende, as well as minor biotite and, locally, small miarolitic cavities.

Age

A sample of little deformed granite from the Bartle Frere Granite has yielded a Rb–Sr age of 264±4Ma. The significance of this apparently anomalously young date is uncertain. The date is currently regarded as probably spurious, particularly in view of the anomalously high $^{87}Sr/^{86}Sr$ initial ratio (0.771) reported.

Granites of the Tully Batholith

The Tully Batholith is made up of the Tully Granite Complex (de Keyser, 1964). The batholith has a north-westerly to northerly elongation similar to that of the nearby Ingham Batholith to the south-west.

Biotite monzogranite, hornblende–biotite monzogranite to granodiorite, biotite–hornblende granodiorite, tonalite, and diorite are well represented in the complex. The complex also contains minor gabbro.

The range of compositions, textures, and magnetic susceptibilities imply numerous plutons are present. The relatively low magnetic susceptibilities measured on most outcrops examined are consistent with the observation that ilmenite is the principal opaque oxide in many plutons.

The granites are I-types, based on the common presence of hornblende, traces of primary titanite locally, and geochemical characteristics.

Age

A sample of tonalite from the Tully Granite Complex (cutting on the Palmerston Highway, east of the Beatrice River, at GR 603567, Tully 1:100 000 Sheet area) has yielded a U–Pb zircon (SHRIMP) age of 286±4Ma. Consequently, the complex is shown as early Permian on the 1:250 000-scale geological map. Richards & others (1966) had previously obtained seven K–Ar mineral ages (corrected) ranging from 273Ma to 302Ma from rocks in the complex. The available data, therefore, imply some of the rocks of the Tully Granite Complex may have been emplaced in the very late Carboniferous.

Dykes

The Tully Granite Complex is locally cut by dykes (up to ~4m thick) of basalt and dolerite containing numerous euhedral to subhedral laths, up to ~1.5cm long, of plagioclase and brown to brownish green hornblende. The hornblende phenocrysts are mainly unaltered, in contrast to the extensively altered character of the plagioclase phenocrysts and the very fine-grained groundmass. The best exposures of these dykes found during the survey were in the wall of a quarry on the northern flank of Mount Mackay (at GR 917177, Tully 1:100 000 Sheet area). The age of the dykes is uncertain. They are tentatively regarded as Permian.

Chemical characteristics

The Tully Granite Complex has an extended compositional range from gabbro to moderately fractionated granite (Figure 14). The rocks define typical I-type geochemical trends. They are characterised by decreasing abundances of TiO_2, FeO*, MgO, CaO, Sr, Ga, and Zr, and increasing K_2O, Rb, U, and Nb with increasing SiO_2 (*e.g.* Figure 14). Pb and Th contents increase and P_2O_5 contents decrease with increasing SiO_2, whereas Ce, La, Y and Zr concentrations show little change in most samples (Figure 14). ASIs increase slightly in the granites with increasing SiO_2 (Figure 14). The complex shows a trend towards fractionated compositions (with Rb>300ppm; Figure 14).

Granites of the northern Ingham Batholith

Only the very northern part of the Ingham Batholith extends into INNISFAIL, where the granites were delineated as unnamed unit Pzg (de Keyser, 1964). Pale pink, fine to medium-grained, even-grained leucogranite crops out over extensive areas in the Koombooloomba area (in south-western INNISFAIL). The leucogranite contains rare biotite and disseminated molybdenite in places. It may also have been the source of alluvial gold deposits (*e.g.* at Culpa) in local watercourses. Garrad & Bultitude (1999) have assigned the granites to the Ingham Granite Complex.

Age

None of the granites of the complex in INNISFAIL have been isotopically dated. The three K–Ar biotite ages (corrected) obtained from the northern part of the Ingham Batholith in adjoining INGHAM range from 296Ma to 299Ma (Richards & others, 1966). They overlap with the SHRIMP age of 301±6Ma recently obtained from a granite on Goold Island (at GR 131900, Cardwell 1:100 000 Sheet area). In contrast, results of recent SHRIMP dating of a granite from north-west of Ingham (at GR 612904, Kirrama 1:100 000 Sheet area) have yielded an age of 282±4Ma. The available data, therefore, imply the granitic rocks of the Ingham Batholith were emplaced in the late Carboniferous–early Permian.

Mafic rocks of High Island

Scattered boulders of medium-grained metadolerite are present on the north-western coast of High Island (Frankland Islands group; at ~GR 940029, Cooper Point 1:100 000 Sheet area). The unit is too small to be shown on the 1:250 000-scale geological map. The original mafic minerals in the metadolerite have been completely replaced by pale green actinolite. However, the relict doleritic texture is preserved by the plagioclase laths, which are randomly oriented. Rare relict plagioclase phenocrysts are also present.

The metadolerite contrasts markedly with amphibolite found interlayered with the gneisses near the southern end of the island (at ~GR 948017, Cooper Point 1:100 000 Sheet area). The latter is much finer grained and characterised by a well-developed granoblastic texture. The amphibolite forms a lens, ~1m thick, in the biotite gneiss assemblage. It consists mainly of green to brownish green hornblende and calcic plagioclase. Quartz, opaque oxide and biotite are the main accessory minerals.

The metadolerite is, therefore, interpreted to be significantly younger than the amphibolite. It may conceivably be the same age (Permian?) as the hornblende dolerite–basalt dykes described below.

Southland gabbro (informal name)

Medium to coarse-grained, slightly porphyritic hornblende metagabbro intrudes biotite–chlorite–muscovite schist of the Barnard Metamorphics north of Bramston Beach (at ~GR 934881, Bartle Frere 1:100 000 Sheet area), on the mainland. Richards (1977) informally referred to this unit as the Southland gabbro. The metagabbro forms a net-veined complex with the Bellenden Ker Granite in the same area. The unit has not been delineated on the Innisfail 1:250 000-scale geological map.

An igneous (intergranular) texture is well preserved in the metagabbro despite the presence of a poorly developed foliation in places. Relict grains of plagioclase and clinopyroxene are common. The pale to bright reddish brown hornblende grains are characterised by abundant very fine-grained exsolution lamellae and rounded grains of opaque oxide (ilmenite?). They are mainly pseudomorphs and partial replacements of clinopyroxene grains; relict cores of clinopyroxene are locally common. Very pale green amphibole (tremolite–actinolite), chlorite, epidote/clinozoisite, muscovite/sericite, and secondary titanite are relatively common.

The metagabbro is most probably about the same age (early Permian) as the granite with which it is closely associated in places. It is cut by thin quartz veins, which are truncated by irregular dykes of highly porphyritic granite similar to the nearby Bellenden Ker Granite. The metagabbro is also cut in places by irregular lenses of medium-grained, biotite-rich granodiorite? locally containing rounded inclusions of metagabbro up to ~75cm across. The granodiorite? lenses are also cut by dykes of highly porphyritic granite.

Dykes

Several dykes were found during the recent field work. Not surprisingly, most are located along the coast or on the offshore islands — *i.e.* in areas of good exposure. There are undoubtedly many more dykes in the sheet area, but the majority, particularly the mafic dykes, are poorly exposed as a result of deep weathering and the dense vegetation cover.

The dykes examined are typically simple and form vertical or sub-vertical tabular bodies ranging from ~1m to ~4m in thickness.

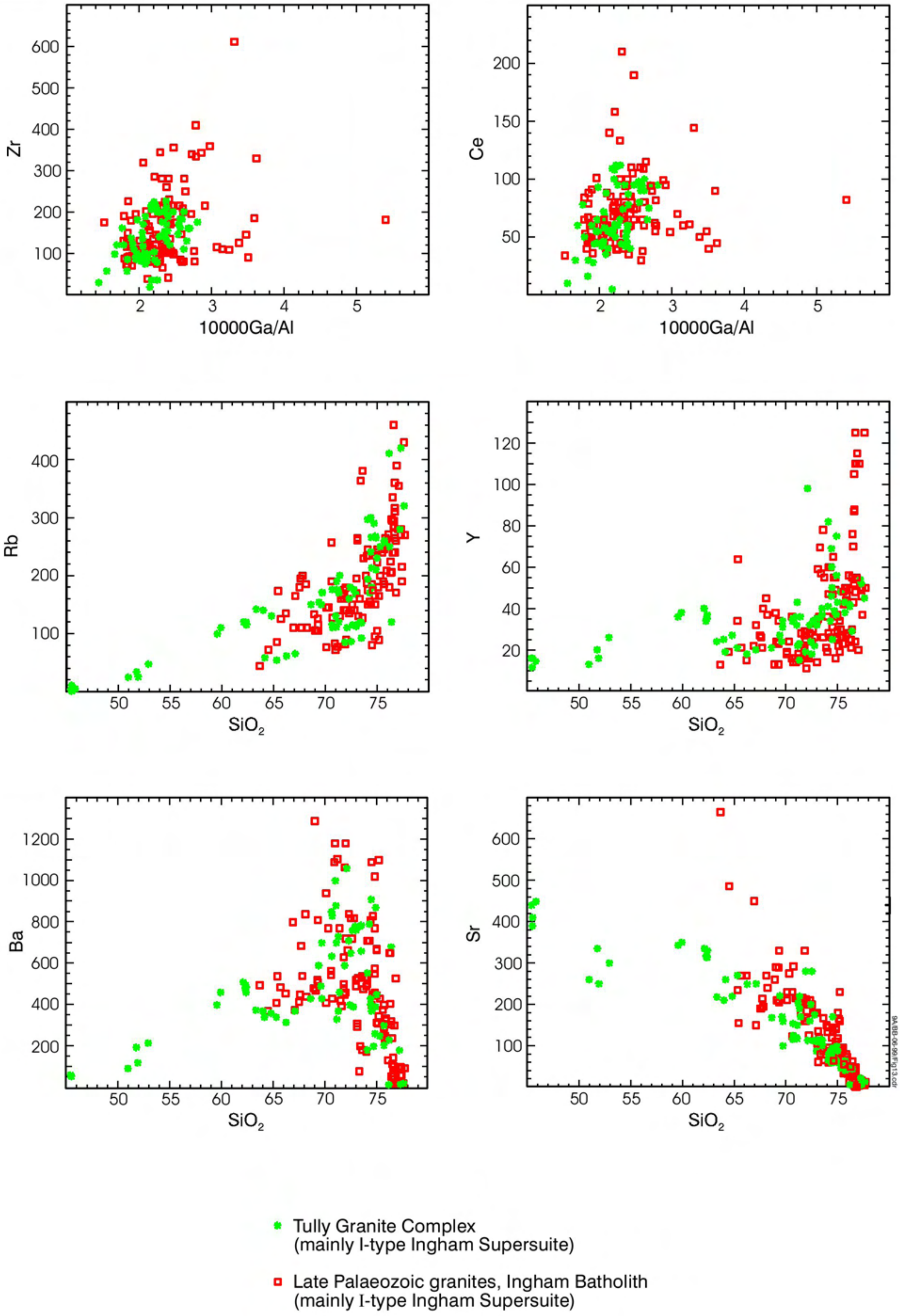

Figure 14. Zr, Ce, Rb, Y, Ba, and Sr (ppm) versus SiO_2 (wt%) plots for the late Palaeozoic granites of the Tully and northern Ingham Batholiths. Most of the samples analysed from the Ingham Batholith are from the adjacent Ingham 1:250 000 Sheet area.

None of the dykes has been isotopically dated. However, the extended range of compositions, orientations and mineralogical diversity shown by the mafic dykes imply several episodes of emplacement, from several distinct sources. The olivine-bearing basalts and dolerites, for example, are probably related to the widespread late Cainozoic volcanic activity in the region.

Dykes in the Glen Gordon Volcanics

A few dykes of highly and very coarsely porphyritic rhyolite which intrude the Glen Gordon Volcanics (at GR 472030, and GR 476077, Tully 1:100 000 Sheet area) were examined during the survey. The dykes contain euhedral to subhedral phenocrysts of (in descending order of abundance) quartz, K-feldspar, plagioclase, and biotite. K-feldspar phenocrysts tend to be the largest (up to ~2cm long). Quartz phenocrysts are commonly embayed. Scarce, small, euhedral, zoned zircon grains are also generally present. The groundmass in the dykes consists of a very fine-grained quartzofeldspathic mesostasis.

The dykes are variably altered. Biotite phenocrysts are generally at least partly replaced by chlorite. Epidote is the other common secondary mineral (mainly as a partial replacement of feldspars and biotite), although it is locally very rare or absent.

The dykes probably represent high-level, comagmatic intrusions, genetically related to the nearby extrusive rocks of the Glen Gordon Volcanics.

Porphyritic hornblende basalt–dolerite dykes

Several dykes of massive to slightly vesicular, fine to medium-grained, highly porphyritic to even-grained hornblende basalt–dolerite cut the Barnard Metamorphics (*e.g.* at GR 051268 — northern end of Narragon Beach; Innisfail 1:100 000 Sheet area) and the Tully Granite Complex (*e.g.* at GR 917177 — quarry on the northern flank of Mount Mackay; Tully 1:100 000 Sheet area). Two dykes examined in the South Mission Beach and Narragon Beach areas have east or south-south-east trends, and range from ~1m to ~4m in thickness.

The dykes are slightly to extensively altered. They are holocrystalline and most are characterised by the presence of numerous tabular laths and small phenocrysts of greenish brown to brown hornblende. The dyke which cuts the Tully Granite Complex on the northern flank of Mount Mackay contains numerous hornblende phenocrysts up to ~1.5cm long. The hornblende in these dykes, unlike most of the other primary minerals (in particular, plagioclase), is unaltered or only very slightly altered. Calcic plagioclase (extensively altered) is the other main mineral present, mainly as groundmass laths but locally also as euhedral–subhedral phenocrysts. Minor, accessory, and secondary minerals include (not all present in every thin section) quartz, opaque oxide, actinolite, cummingtonite?, chlorite, epidote, sericite, and calcite.

Clinopyroxene phenocrysts and groundmass grains are common in some dykes (*e.g.* the dyke at Narragon Beach). The dyke at Narragon Beach also contains scattered inclusions (up to 10cm across) of country rocks, in marginal zones. A dyke at the southern end of South Mission Beach (GR 036144, Innisfail 1:100 000 Sheet area) contains abundant pale green actinolite (after clinopyroxene?), reddish brown secondary biotite, and rare enclaves of sillimanite-bearing gneiss.

De Keyser (1965) reported the presence of scattered mafic dykes, similar to those described above, in a belt extending from Dunk Island to Cochable Creek. These dykes were also reported to have easterly to south-easterly trends and to cut the Barnard Metamorphics, Hodgkinson Formation, and Tully Granite Complex.

The dykes are unmetamorphosed, and were probably emplaced in the Permian.

Olivine basalt dykes

The pyroclastic deposits forming Stephens Island are cut by several dykes (ranging from ~0.5m to ~2m in thickness) of porphyritic olivine basalt. These dykes are distinct from those described above in several aspects, namely:

- they are not significantly altered,
- they contain numerous phenocrysts of olivine and clinopyroxene, as well as groundmass grains of clinopyroxene, and
- they do not contain hornblende.

The dykes may represent feeders to the nearby basaltic lava flows (late Cainozoic) on Sisters Island and King Reef. They are vertical, trend in east-south-east to south-south-east directions, and generally show a gradation, from chilled margins of very fine-grained, massive basalt, through variable-width, intermediate zones of slightly to moderately vesicular basalt, into more massive, coarser grained basalt in the central parts.

ATHERTON SUBPROVINCE OF THE EASTERN AUSTRALIAN CAINOZOIC IGNEOUS PROVINCE

The Miocene–Holocene? Atherton Subprovince has also been referred to as the Atherton Basalt Province (Best, 1960; de Keyser & Lucas, 1968; Denmead, 1971), the Quincan Province (Morgan, 1968), and the Atherton Province (Stephenson & others, 1980; Stephenson, 1989). It extends from Stephens and Sisters Islands (South Barnard group), off the coast, to west of INNISFAIL. The subprovince has an area of ~1800km^2, and covers extensive areas of the Atherton Tableland. More than fifty eruptive centres have been identified so far (*e.g.* Stephenson, 1989). Many of these are located in INNISFAIL — mainly on the Atherton Tableland, but several are in the coastal lowlands. Most investigators have included the products from all these centres in the Atherton Basalt. Willmott & others (1988) defined some discrete areas of basalt in the northern and north-eastern parts of INNISFAIL as separate formations.

Topography

The Atherton Subprovince is characterised by broad lava plains on the Atherton Tableland, which is abruptly terminated in the east by a steep escarpment. Some flows were erupted from volcanic centres on the Atherton Tableland and descended the coastal scarp (up to ~400m high) into the valleys of the Mulgrave and Russell Rivers (Denmead, 1971; Stephenson & others, 1980; Whitehead & McDougall, 1991). Basalt lava from a small volcano ~1km south of Malaan flowed down Cochable Creek to reach the Tully River gorge (Stephenson & others, 1980).

Stephenson & others (1980) also postulated basaltic lavas flowed from the Atherton Tableland down the ancestral Johnstone River. The gorges of the South and North Johnstone Rivers west of Innisfail flank a ridge, which provides relatively easy access to the Atherton Tableland. The ridge consists mainly of basaltic lava flows, which filled a deep gorge in the former Johnstone River (Stephenson & Griffin, 1976). An apparently younger infilling, more than 300m thick, of basalt in a former gorge of the North Johnstone River is well exposed in the narrow ridge extending west from the Douglas Creek junction (Stephenson & others, 1980). No time breaks or flow units have been recognised in this North Johnstone basaltic sequence, implying the gorge was filled in one major eruptive episode (Stephenson & others, 1980). These extensive gorge-filling lava flows backed up into some side tributaries of the present South Johnstone River — especially Downey Creek where at least three successive flows have been recognised (Stephenson & others, 1980). Some of these lava flows filling the ancestral Johnstone River and its tributaries were reportedly erupted from the large shield volcano ~15km south-south-east of Millaa Millaa, but the source of the North Johnstone River infilling is uncertain.

Basalts from the shield volcano centred on Lamins Hill (GR 623781, Bartle Frere 1:100 000 Sheet area) are present on the saddle between the headwaters of the Russell and West Mulgrave Rivers (Whitehead & McDougall, 1991). The gorges cut by these two rivers separate the Bartle Frere massif from the Atherton Tableland to the west. Basalts from Lamins Hill volcano are also present in the valley of the Russell River (where they are at least 36m thick; Whitehead & McDougall, 1991) and on the tableland above it to the west, where they form the edge of the escarpment. The infilling of the upper parts of the ancestral Russell River resulted in the readjustment of the river's profile and the westward migration of the Russell River valley from its original position, now occupied by basalt, to its present position on the western edge of the flows.

Volcanic landforms

A range of volcano types are preserved in INNISFAIL, including lava shields (*e.g.* Malanda Volcano), composite cones (*e.g.* Mount Weerimba, Adler Hill), cinder cones, and maars. The lava shields include several large examples. The one located ~12km south-west of Malanda has flanks, which extend more than 10km from the eruptive centre (Stephenson & others, 1980). Most of the shield volcanoes are extensively weathered and deeply eroded. One of the most reliable ways of detecting them is by examining aerial photographs and topographic maps for areas characterised by radial drainage patterns.

There are numerous cinder cones, the most prominent example being Mount Quincan, 3.5km south of Yungaburra. Pin Gin Hill is a thickly vegetated and deeply weathered scoria cone ~10km west-south-west of Innisfail (de Keyser & Lucas, 1968). Breadcrust bombs and fragments of scoriaceous olivine basalt have been reported from the flanks of the cone (de Keyser & Lucas, 1968).

The Atherton Subprovince contains several maars. They include Lakes Eacham, Barrine and Euramoo, Bromfield Swamp, and Lynch's Crater (GR 603793, Bartle Frere 1:100 000 Sheet area). The maars are relatively young features and have a reported age range from ~200 000 years B.P. to ~10 000 years B.P. (Stephenson, 1989). Several contain sediments recording significant vegetation changes over the last 200 000 years or so (*e.g.* Kershaw, 1970, 1971, 1974).

Stephens Island

Stephens Island, in the South Barnard group, represents an offshore volcano (Jones, 1978). It is an eroded pyroclastic cone characterised by excellent exposures in wave-cut platforms and bordering sea cliffs. Some beds have internal structures indicative of deposition by base surges, although marine fragments, such as coral, have not been identified.

The very well-exposed pyroclastic deposits (of mainly coarse to fine tuff, lapilli tuff, volcanic breccia, and scoria) on Stephens Island contain numerous angular fragments of metamorphic rocks (mainly biotite–muscovite schist, biotite gneiss and amphibolite) and quartz (up to ~30cm). Amphibolite is by far the most abundant exotic rock type represented in the fragments. The amphibolite fragments also tend to be the largest; exceptional examples are up to ~3m across (most <1m). Basaltic scoria ranging between ~5mm and 10mm in diameter is very common in some layers. Some of these relatively coarse layers contain scattered larger blocks of basalt, up to ~50cm across. Bombs, some containing cores (up to ~10cm across) of ultramafic rocks, are relatively scarce, and are most common in the deposits on the southern side of the island. One spindle bomb was found during the recent survey.

The pyroclastic deposits are poorly sorted, but are well bedded (mainly thin to medium beds). They show normal and reverse graded bedding, cross-bedding (including low-angle cross-bedding characteristic of surge deposits), cut and fill structures, impact structures, and erosional discontinuities (also see Jones, 1978). Low-angle cross beds are common. The deposits are cut by several olivine-bearing basaltic dykes (ranging from ~50cm to 2m thick; see previous section), possibly representing feeders for nearby lava flows on adjacent Sisters Island and several reefs farther south.

Green Hill

Green Hill (Danes, 1912; Hedley, 1925; Denmead, 1971; Muller & Henry, 1982; Willmott & others, 1988) is a well-preserved, asymmetric, grass- and scrub-covered cone ~105m high, located ~6km north-east of Gordonvale. It consists mainly of basaltic scoria and ash, lapilli tuff, and agglutinate. Scoriaceous basaltic bombs are common. Basaltic lava flows were also erupted from the vent.

Mount Quincan

Mount Quincan cone (GR 490860, Bartle Frere 1:100 000 Sheet area; Jack & Etheridge, 1892; Danes, 1912; Jardine, 1925; Best, 1960; Denmead, 1971) is located ~4km south of Yungaburra and rises to a height of 215m above the surrounding land surface. The cone has a crater, which partly fills with water after heavy rain. The cone is characterised by markedly asymmetrical flanks, which are significantly higher on the north-western side than on the south-eastern side. The north-western rim of the crater is ~60m higher than the south-eastern rim (Plate 27). The prevailing winds during the eruptions which produced the cinder cone were from the south-east, resulting in most of the pyroclastic debris being deposited downwind of the crater (*i.e.* on the north-western side of the crater; also see Jack & Etheridge, 1892).

The pyroclastic deposits forming the cone consist mainly of winnowed basaltic cinders/scoria (Plate 28). They also contain numerous peridotite and lherzolite nodules and rare titaniferous pargasite megacrysts (Stephenson & Griffin, 1976). The crater is circular in outline, ~0.8km across, and contains a swamp ~0.5km in diameter. This swamp contains ~10m of predominantly organic detritus (Kershaw, 1971). Palynological studies (Kershaw, 1971) indicate sclerophyll woodland dominated in the region from at least 9700 B.P.– ~7000 B.P. Subsequently, higher temperatures, possibly combined with increased rainfall, encouraged the return of rainforest species. At ~2000 B.P. a decrease in rainfall allowed a partial return to sclerophyll forest (Kershaw, 1971).

Seven Sisters

The Seven Sisters (see Plate 1) are a group of conspicuous cones, ~45m–60m high, located 3km north of Mount Quincan. None of the cones has a preserved crater. The cones consist of weathered scoria and basalt boulders. Bombs, some with cores of ultramafic rocks, and scattered peridotite nodules are present in scoria deposits on the flanks of the southern cones (also see de Keyser & Lucas, 1968).

Lynch's Crater

This crater (GR 603796, Bartle Frere 1:100 000 Sheet area; Jardine, 1925), located south of Fiske Road, ~10km east of Malanda, has an elliptical outline (~0.8km x ~0.4km). The crater is ~48m deep and has a flat marshy floor (Plate 29). The inner walls dip at ~25° but no outer slopes are observed, because the crater developed as an oval pit on a broad basalt swell that has been partly dissected. Scattered boulders of grey vesicular basalt are present on the inner slopes of the crater. De Keyser & Lucas (1968) also reported boulders of schist up to ~30cm long. The crater wall has been breached (Plate 29) on the southern side by a stream, which flows into the North Johnstone River. The marshy floor of the crater contains at least 20m of lacustrine sediments and peat deposits which provide a pollen record extrapolated to extend beyond ~60 000 B.P. (Kershaw, 1974, 1976). The peat deposits are mined (Gro-fast lease; M.L. 4 317; Plate 29), 2022t being extracted in the 1995–96 financial year. The peat is used for horticultural purposes.

Gillies Crater

This volcanic structure is a breached crater adjacent to the Gillies Highway (~GR 615953, Bartle Frere 1:100 000 Sheet area; Denmead, 1971). Outcrops are rare because of the dense rainforest. Well-bedded scoria, ash, and lapilli tuff are exposed in a quarry on the outer lip of the crater. These pyroclastic deposits contain clasts of shale, schist and other country rocks, as well as peridotite and lherzolite nodules, and rare mafic granulite fragments (de Keyser & Lucas, 1968).

Bromfield Swamp

Bromfield Swamp is the largest maar in the Atherton Subprovince, with a diameter of ~1.6km and a depth of ~45m–60m (Jardine, 1925; Denmead, 1971; Kershaw, 1975). It is breached on its eastern side by a stream, which forms the headwaters of the North Johnstone River. The deposits forming the rim of the maar are deeply weathered and obscured by thick soil cover. Rare boulders of massive basalt have been found on the inner slopes. The crater is geomorphologically more mature (and therefore probably older) than the Mount Quincan cone and Euramoo maar (Kershaw, 1975).

Lakes Eacham and Barrine

Lakes Eacham and Barrine are probably the best-known maars on the Atherton Tableland. Both are deep, flat-floored vents surrounded by rims of pyroclastic deposits. The rims have outer slopes of ~15° (Jardine, 1925) and inner slopes averaging ~30° but as steep as 75° in places (Timms, 1976). Lake Barrine has an embayment on its north-eastern side from which the headwaters of Toohey Creek (a tributary of the Mulgrave River) emanate. The ring wall of the Barrine maar consists of interbedded fine to medium-grained lapilli tuff and ash containing blocks of amphibolite and schist up to 0.6m across (Jardine, 1925). At Lake Eacham the ring wall consists of scoria, lapilli tuff and ash, which is extremely soft and crumbly. These pyroclastic deposits contain clasts of decomposed basaltic lava and blocks of granite and schist (Jardine, 1925), as well as nodules of peridotite and lherzolite.

Lake Euramoo

Timms (1976) described, in detail, the dumb-bell-shaped, double explosion crater forming Lake Euramoo, the northernmost maar identified on the Atherton Tableland. Lake Euramoo has a closed catchment (*i.e.* it is not drained by a creek), so there is a seasonal fluctuation (of ~2m–3m in an average year) in the level of the lake. It is unique (for the Atherton Tableland) in that rather than being more or less circular, it has an outline similar to that of a dumbbell. The dual craters probably resulted when uprising gas-charged magma came into contact with subsurface water at two closely spaced localities, resulting in what has been termed a double 'explosion'. The north-north-east elongation of the depression occupied by Lake Euramoo indicates the magma moved upwards along a fault with that orientation.

Kershaw (1970) reported a pollen record from ~10 000 B.P. to the present day in the sediments of Lake Euramoo.

Lake Newell

Lake Newell (~GR 598995, Bartle Frere 1:100 000 Sheet area) is considered by some investigators to be a maar-type structure. It forms a depression surrounded by dense rainforest. There is no obvious ring wall to the structure although poorly exposed, deeply weathered pyroclastic detritus has been found in the general vicinity of the depression. During the wet season the structure is occupied by a shallow lake, which dries out during dry periods.

Flow Fronts

The fronts of individual lava flows are preserved at two locations on that part of the Atherton Tableland in INNISFAIL. One example is 5km south-west of Yungaburra (GR 452869, Bartle Frere 1:100 000 Sheet area) adjacent to Leslie Creek. The second is ~1km south-west of Yungaburra near the junction of the Gillies Highway and the Malanda–Yungaburra road (GR 485893, Bartle Frere 1:100 000 Sheet area). These flow fronts form terraces up to 3m high. They consist of vesicular olivine basalt which crops out as rounded boulders in red soil. No primary flow structures are preserved. The flows are thought to represent the final eruptive products of the Atherton Basalt in the Yungaburra–Malanda area.

Basal sediments

The volcanic rocks of the Atherton Subprovince overlie poorly exposed, deeply weathered Tertiary lacustrine and fluviatile sedimentary rocks and alluvium in many places south and east of Malanda (*e.g.* near the head of the North Johnstone River; de Keyser & Lucas, 1968). Stephenson & others (1980) reported outcrops at the North Johnstone River 6km east of Malanda, in the Jaggan–Tarzali area, and in the bank of West Butcher Creek (at the end of Lud Road) ~12km north-east of Malanda. The main rock types are shale and sandstone, but some thin beds of waxy to dull black lignite and thicker beds of low-grade oil

Table 3: K–Ar ages of some basalts from the Innisfail 1:250 000 Sheet area (data for first 7 samples — AT53 to Paronella — supplied by P.J. Stephenson, Department of Earth Sciences, James Cook University of North Queensland, Townsville, written communication, 1996)

Sample number	Age (Ma)	Grid reference	Comments
AT53	1.24	700526	from near K tree, south of Palmerston Highway (Tully 1:100 000 Sheet area)
IF29	1.635	582594	from Campbells Hill (Beatrice River cone), south-west of Palmerston Highway (Tully 1:100 000 Sheet area)
IGO1	1.61	750512	from near Montrosa, northern side of the Palmerston Highway (Tully 1:100 000 Sheet area)
IGO4	0.645	758560	unnamed volcano at head of Bora Creek (Tully 1:100 000 Sheet area)
IGO7	0.803	866540	eastern flank of unnamed volcano, ~6.5km west of South Johnstone (Tully 1:100 000 Sheet area)
IGO8	0.767	956705	unnamed volcano, ~4km north-north-east of Daradgee (Cooper Point 1:100 000 Sheet area)
Paronella	3.39 3.35	891477	waterfall on Mena Creek, (Paronella Park, Mena Creek; Tully 1:100 000 Sheet area)
DA1	0.986±0.025	731158	Green Hill, ~6km north-east of Gordonvale (Bartle Frere, 1:100 000 Sheet area)

shale have been reported in West Butcher Creek (Stephenson & others, 1980). The oil shale contains well-preserved dicolyledonous leaf impressions and plant pollens (Kershaw & Sluiter, 1982). Kershaw & Sluiter concluded that the sequence most probably formed in the Pliocene or early Pleistocene (between ~5Ma and 1Ma).

Rock types

The volcanic rocks include lava flows and coarse to fine-grained pyroclastic deposits. They are generally deeply weathered and the lava flows are commonly difficult to distinguish from the pyroclastic deposits. The lavas range from massive to highly vesicular or amygdaloidal. Columnar jointing is very common in the massive parts of relative thick lava flows (also see Willmott, 1980a). Good exposures can be observed at the many waterfalls (*e.g.* Millaa Millaa Falls, Tchupala Falls; Plates 30, 31) for which the eastern part of the Atherton Tableland is renowned. The lava flow forming King Reef, off the coast, also displays crude columnar jointing in places (Jones, 1978). Spheroidal weathering is well developed in the massive basalt at Clump Point (also see Isbell & others, 1976).

Some of the lava flows contain small (generally <5cm across), scattered ultramafic inclusions. The presence of these inclusions indicates an upper mantle origin for the parent magmas and rapid ascent from the zone of partial melting to the surface. Localities where numerous xenoliths have been found include Lakes Eacham and Barrine, Mount Quincan, and Gillies Crater. Host rocks are mainly stratified scoria — for example, the Mount Quincan basanite (Plate 28). Mantle-derived peridotite inclusions up to ~30cm across dominate in the basanite. Inclusions of pyroxenite (several types), as well as scarce granulite and schist have also been reported (de Keyser & Lucas, 1968; Stephenson, 1989). Pyroxene, amphibole, spinel, and anorthoclase form megacrysts (Stephenson, 1989).

Age

Basalts from the Lamins Hill volcano range in age from 1.4Ma (in the valley of the Russell River) to 0.9Ma (on the upper slopes of the volcano; Whitehead & McDougall, 1991). There are also several small, relatively young volcanoes and lava fields in the coastal belt, east of the Atherton Tableland. These include Green Hill (0.986Ma; Muller & Henry, 1982) near Gordonvale, and three dated volcanoes in the Innisfail district ranging from 0.803Ma–0.645Ma (Table 3). The Malanda cone is the oldest eruptive centre dated in the subprovince (3.1Ma and 2.9Ma; Stephenson, 1989).

Composition

Stephenson (1989) reported the basaltic rocks of the Atherton Subprovince to range in composition from basanite to tholeiitic basalt. Most rocks are moderately undersaturated. Hawaiite, *ne*-hawaiite, alkali basalt and basanite are the most common rock types represented in the Innisfail 1:250 000 Sheet area, using the classification scheme of Johnson & Duggan (1989) and an adjusted Fe^{++}/Fe (total) ratio of 0.8. A few samples (from GR 937732 and GR 642757, Bartle

Frere 1:100 000 Sheet area; GR 938701, Cooper Point 1:100 000 Sheet area; and GR 6230545, Tully 1:100 000 Sheet area) contain more than 10% normative hypersthene and are *ol*-tholeiitic basalts. None of the samples analysed contain normative quartz.

Ewart (1989) noted that the mafic Cainozoic magmas of north Queensland have been less modified by fractional crystallisation processes than many of those elsewhere in eastern Australia, the trends apparently being controlled by augite fractionation.

Twiddler Hill Basalt
(after Willmott & others, 1988)

The Twiddler Hill Basalt was described by Fardon & de Keyser (1964) as a thin valley-fill sequence. The eruptive centre forming Twiddler Hill (GR 441181 Bartle Frere 1:100 000 Sheet area) consists of a well-preserved, symmetrical double cone of coarse bouldery scoria. It is surrounded by relatively low plains, which formed on poorly exposed vesicular basalt. The lava flows appear to have been erupted towards the end of the volcanic activity.

The basaltic lavas and ejecta erupted from Twiddler Hill covered the Pliocene–Pleistocene sediments of Emerald Creek. Emerald Creek was infilled by basalt lava flows for ~7km — between Twiddler Hill and the ancient junction of Emerald and Davies Creeks (near the present-day junction of Tichum and Davies Creeks, in CAIRNS).

Adler Hill Basalt
(mainly after Willmott & others, 1988)

Best (1960) reported minor basalt flows in a tributary of Emerald Creek and concluded that they had originated from an eruptive centre (Adler Hill), in the far north-west of the sheet area. These volcanic rocks are most probably Pliocene–Pleistocene.

The Adler Hill Basalt crops out over a dumb-bell-shaped area in which the most prominent feature is the composite double cone forming Adler Hill. The northern cone is symmetrical, higher and better preserved than the southern one; both are partly eroded and consist of interlayered vesicular and massive basalt as well as scoria (cinder) deposits. Away from the vents, the flows are poorly exposed and deeply weathered.

Vesicular and massive basalt is exposed on the eastern and south-eastern flanks of Adler Hill. The basalt is dark grey, fine grained and contains phenocrysts of olivine (generally partly altered to iddingsite) and subordinate augite in a groundmass of opaque oxide and plagioclase.

At the time of the eruption of the lavas, the eruptive centre was located in a small valley eroded in rocks of the Hodgkinson Formation. The lavas filled the valley and flowed north-west towards Emerald Creek. Differential erosion has subsequently resulted in the formation of an inverted topography.

The Fisheries Basalt
(after Willmott & others, 1988)

Willmott & others (1988) assigned the lava flows, which were erupted from several centres and flowed along the beds of the upper Mulgrave and Little Mulgrave Rivers, to The Fisheries Basalt. Three flows have been recognised near The Fisheries (at GR 636997, Bartle Frere 1:100 000 Sheet area). However, in most places the number of lava flows in the unit is very difficult to determine because of the deep weathering, poor outcrop and extensive erosion. Individual flows are up to ~10m thick.

The major eruptive centre appears to have been an asymmetrical breached cone (at GR 665014, Bartle Frere 1:100 000 Sheet area), east of The Fisheries (Willmott & others, 1988). Two other possible vents were described by Cohen (1975) near the junction of the Mulgrave and Little Mulgrave Rivers. Basaltic lava flows temporarily dammed the Mulgrave River north of the postulated major vent. As a result lava flowed back up the Mulgrave River valley to near the junction of the East and West Mulgrave Rivers (Plate 32), and also up the Little Mulgrave River valley. Basaltic lavas erupted from volcanoes on the Atherton Tableland — in particular, from the Gillies Crater (~GR 615953, Bartle Frere 1:100 000 Sheet area) — may have contributed to this unit by descending the ~400m-high scarp into the Mulgrave River valley via Toohey Creek and possibly Christmas Creek (Denmead, 1971; but also see Willmott & others, 1988). Subsequent erosion and down-cutting by the streams have left remnants of the flows perched on valley walls.

The lavas contain phenocrysts of olivine and minor augite, as well as small ultramafic nodules. Amygdales are typically infilled by zeolite, yellow-green 'chlorite', chalcedony and rare calcite. Vertical columnar jointing is common. Pyroclastic debris is lacking, indicating most eruptions were characterised by the relatively quiet effusion of lava (Cohen, 1975). Spheroidal weathering is well developed in places.

Deposits of pale to dark grey, porous travertine in the Little Mulgrave River area have been described by Reid (1926), Whitehouse (1926), Connah (1958a,b) and Willmott (1980b). The travertine appears to have accumulated in freshwater bogs, which formed on the basaltic terrain between eruptions (Willmott & others, 1988). The deposits are estimated to be up to

~10m thick. They have been mined in the past, as a source of lime for agricultural purposes.

The Fisheries Basalt has yielded a K–Ar isotopic age of 2.2Ma (Whitehead & McDougall, 1991). The extensive dissection of the lavas by the Mulgrave River is consistent with the 34m/million years incision rate reported by Whitehead & McDougall (1991).

Meringa Basalt
(after Willmott & others, 1988)

The Meringa Basalt was erupted from the volcanic centre forming Green Hill (GR 731154, ~6km north-north-east of Gordonvale, Bartle Frere 1:100 000 Sheet area) and possibly from a deeply eroded centre in the Meringa area (~6km south-west of Green Hill). The basalts of the unit are deeply weathered and have produced thick mantles of dark red to red-brown soil. The well-preserved asymmetrical cone forming Green Hill consists mainly of basaltic scoria and agglutinate. The higher porosity and permeability of these rocks relative to the more massive basalt has assisted in the preservation of the cone.

Basalt lava (agglutinate?), bombs and blocks on the southern flank of Green Hill are massive to scoriaceous, fine grained, and porphyritic. The more massive varieties are relatively fresh. The basalt contains small phenocrysts of olivine (generally partly replaced by iddingsite) and subordinate augite; it also appears to contain inclusions of basaltic fragments or ejecta distinguished by finer grainsize and less altered olivine microphenocrysts.

The Green Hill vent is the most obvious source for the Meringa Basalt, but a subsidiary vent may be present near Meringa. A hole drilled in this area intersected 57m of basalt from the surface (drill hole 101; Muller, 1978). In contrast, the thickness of basalt intersected in holes drilled between Meringa and Green Hill did not exceed 20m; and the basalt is buried by alluvium. Hence it is unlikely that basalt lavas from Green Hill could have been solely responsible for the formation of the relatively thick sequence and elevated basalt country in the Meringa area. Subsequent erosion has virtually completely removed all traces of this postulated subsidiary vent, the area being marked by a low rise with dark red to red-brown soils.

Alluvial deposits of postulated Pleistocene age are unconformably overlain by the Meringa Basalt. Local erosion of the basalt and subsequent sediment deposition by the ancestral Mulgrave River has buried a large part of the unit. The overlying sediments attain a maximum thickness of ~35m (Muller, 1978). Volcanism appears to have been restricted to one period of activity — no other flows interlayered with these sediments were intersected in holes drilled in the Mulgrave River valley (Muller, 1978).

The Mulgrave River and possibly also the Russell River appear to have formerly flowed into Trinity Inlet (north of INNISFAIL), and it was previously thought that their diversion southwards was caused by the eruptions from Green Hill (Jack, 1888; Hedley, 1925), or by slight magmatic updoming (de Keyser, 1964). However, the subsurface information obtained by Muller (1978) indicates the basaltic lavas from the vent are buried by substantial thicknesses of alluvium. Muller, therefore, considered the deflection of the Mulgrave River (and, by inference, the Russell River) was a later event.

CAINOZOIC SEDIMENTS

(mainly after de Keyser, 1964)

Alluvial and colluvial deposits (**Qa**), of mainly late Cainozoic age, cover extensive areas of the coastal plain, and much smaller areas on the Atherton Tableland, to the west (Figure 2, Table 1). Willmott & others (1988) have described the deposits in the northern part of the sheet area in some detail. Residual dark brown to reddish brown soils, of varying depths, are extensively developed on basaltic lava flows of the Atherton Basalt (*e.g.* Plate 1). However, in most places because of the distinctive soil and soil colour, the underlying basalt is depicted on the geological map.

Alluvial deposits consist of sand, gravel, silt , clay and mud. Many of the larger streams have cut deep channels in their alluvial fans where they debouche onto the coastal plains. De Keyser (1964) reported three alluvial terraces preserved adjacent to the Mulgrave River, south of Gordonvale.

Fossil beach- and dune-sand deposits (**Qd**) are scattered along the coast. Beach-ridge deposits are most extensively developed south-east of Mourilyan, where they extend up to ~10km inland. Former strand lines are clearly visible on aerial photographs in this area. Many of the beach deposits were originally sand spits and bars behind which former lagoons have silted up. They are characterised by a northwards migration pattern with time, due to the influence of long-shore currents caused by the prevailing south-easterly winds.

Aeolian dunes of probable late Pleistocene–Holocene age are also preserved along the coast. The older dunes have a degraded appearance in comparison with the Holocene parabolic dunes, and are much higher. Soil horizons are commonly well developed on the older dunes. The dunes presumably developed in response to strong prevailing south-easterly winds.

These winds have reworked an abundant supply of sand, by blowing out pre-existing beach ridges.

Significant deposits of silt and mud are present in several places along the coast, where they mark the positions of former lagoons separated from the open sea by projecting sand spits and barriers. Those at the mouths of the larger rivers grade into tidal flats interwoven with a network of tidal channels fringed with mangroves.

Fluviatile alluvium of the coastal plains probably interfingers with brackish and littoral–marine sediments — mangrove fragments, for example, have been found in cores from holes drilled in the Gordonvale area (de Keyser, 1964). Coastal swamps gradually merge with fluviatile swamps in the Tully Plain; they probably also extended farther inland prior to the most recent emergence recognised by many investigators.

A deposit (<10m thick) of travertine is exposed in the valley of the Little Mulgrave River, ~13m above the level of the present stream bed (de Keyser, 1964; Willmott & others, 1988). The travertine, which contains fossil plant fragments and some gastropods, was probably deposited in a freshwater lake, which formed by the damming of the Mulgrave River valley, by infilling late Cainozoic basalt lava flows.

ECONOMIC GEOLOGY

P.D. Garrad

INTRODUCTION

The following account is a summary of the mineral deposits in INNISFAIL. It is based on more detailed studies by Garrad & Rees (1995).

There are 170 known mineral occurrences, mines and prospects in INNISFAIL (Figure 15). The principal commodities are gold, tin, tungsten and base metals. Deposits of limestone/marble, manganese ore, and mineral and silica sands have also been located but are of relatively minor importance. Some gemstones have also been recovered, mainly from alluvial gold and tin workings.

The total recorded gold production from 1879 to 1990 is 1842.797kg (extracted from ARDMs[12] for 1879–1990; also see Figure 16). Most of the mining activity occurred prior to 1908 (with a recorded production of 1332.732kg), the period from 1908 to 1965 accounting for most of the remaining production. The actual amount of gold recovered was probably significantly more than the above total because the amount of alluvial gold (which occurs in most of the major deposits) was commonly understated in the early ARDMs or not recorded.

The major centres of historic mining were the Russell River (includes the Russell Extended), Mulgrave, Mount Peter Provisional and Jordan Gold Fields (Figure 15). The Kraft Creek, Tinaroo and Five Mile Creek areas were also mined extensively. The Kraft Creek area was also referred to informally as the Bartle Frere Gold Field. There was also some small-scale mining at other scattered locations, but there are few records.

The gold in the Mulgrave Gold Field, Russell River Gold Field, Kraft Creek area and Mount Peter Provisional Gold Field is in narrow, discontinuous, structurally-controlled, north-westerly trending quartz reefs hosted by the Hodgkinson Formation (Figure 17). Erosion of the reefs produced the alluvial deposits in these areas. The primary gold mineralisation is considered to be of mesothermal slate-belt type. The mineralising fluids were probably produced by dewatering/devolatilisation of the sedimentary pile during regional metamorphism — the gold being scavenged from the sedimentary rocks to be channelled into dilational sites such as faults or shear zones. Gold precipitation from these fertile fluids was probably due to wallrock interactions or decreases in pressure and/or temperature.

The Russell River Gold Field contains extensive deep lead deposits which have produced most of the gold in INNISFAIL. These deep leads were deposited within Tertiary drainage systems, the gold probably being derived from erosion of gold–quartz veins similar to those in the Mulgrave Gold Field.

Mineralisation in the Jordan Gold Field is related to narrow quartz veinlets and associated alteration zones hosted by biotite granite. The deep weathering of this granite produced extensive eluvial and alluvial deposits which were worked principally prior to 1907.

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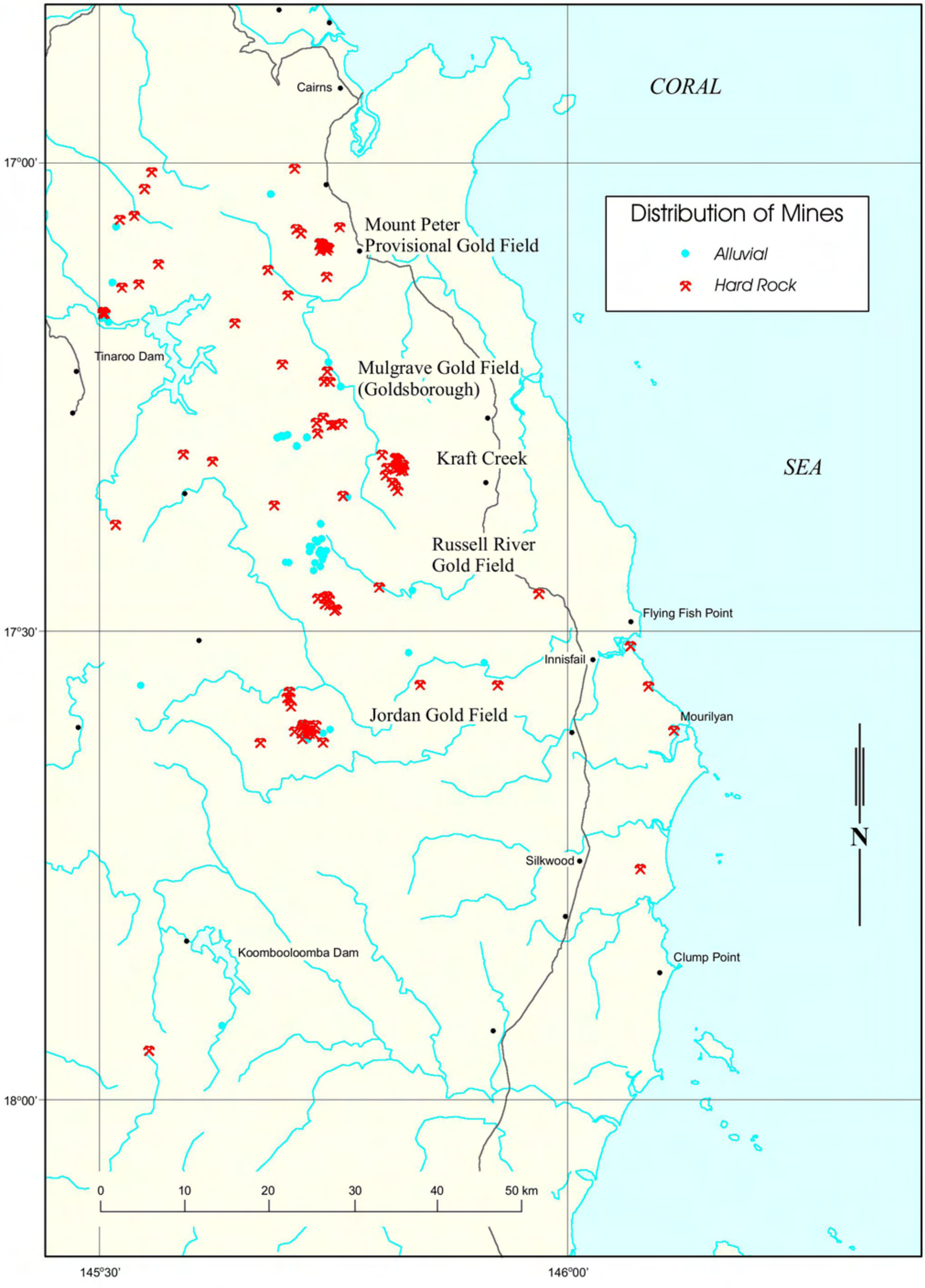

Figure 15. Distribution of the main, worked mineral deposits and gold fields in the Innisfail Sheet area.

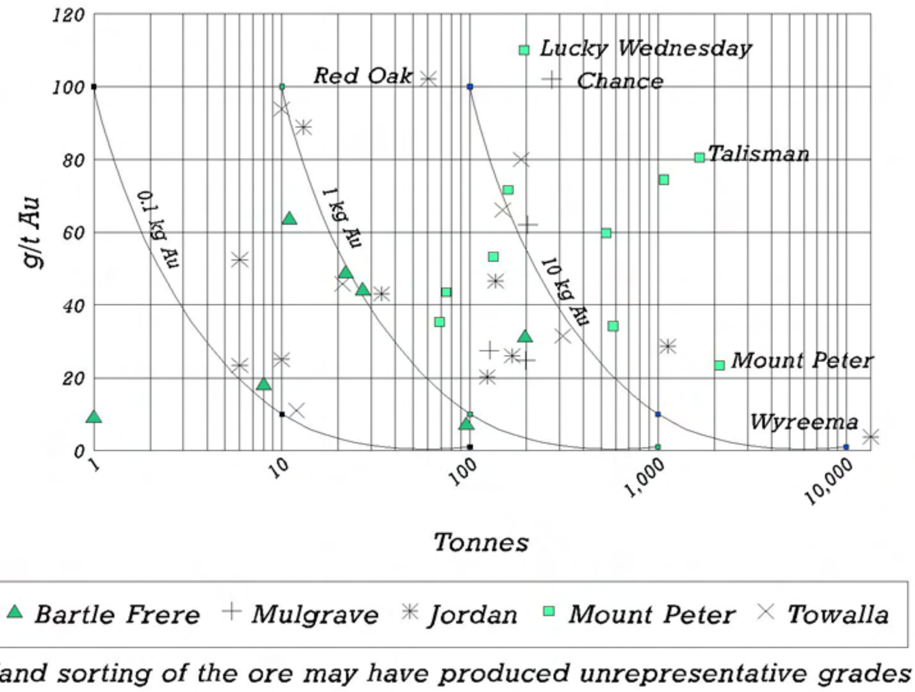

Figure 16. Recorded production from the main gold mines in the Innisfail Sheet area.

GOLD

Jordan Gold Field

History

The Jordan Gold Field (which includes the 'Johnstone diggings') was proclaimed on 18 March 1896 and covers the area between the Beatrice and South Johnstone Rivers. The total recorded production for this gold field from both lode and alluvial sources is 401.045kg of gold, obtained between 1898 and 1981 (ARDMs 1898–1981; Figure 16). Reef gold production amounted to 158.498kg. The mining activity in the 'Johnstone diggings' was short-lived because of low gold grades in the alluvium.

The gold in the area around Jordan Creek (where most of the gold mineralisation occurs) was discovered by two prospectors, McNeil and Donaldson, during 1897–98 (Dempsey, 1980). Both lode and alluvial mining were reported in the 1899 ARDM. The main workings were concentrated around Henrietta and Jordan Creeks (tributaries of the North Johnstone River) where several batteries were erected in about 1900. Initially, the easily mined alluvial deposits were worked, with most of the gold recovered before 1903. Activity on the field declined as the alluvial and lode resources decreased in quantity and grade, and the field was virtually abandoned by 1918. The Wyreema mine was the only lode mine operating from 1904 to 1918.

Mining activity resumed in 1931, with both lode and alluvial operations concentrated around the Wyreema mine and in the Little Beatrice River area. This activity ceased in 1943 and the field was abandoned until 1949 when small-scale mining recommenced at several of the old workings. This low level of activity continued until the late 1980s when most of the area was included in the World Heritage-listed Wet Tropical Rainforests Reserve.

The Johnstone River was investigated for its large-scale dredging potential in 1923 and 1926 but on both occasions the project was considered uneconomic. In 1946 the Coccoolah Island reach of the Johnstone River was reappraised and dredging operations commenced. These operations continued with mixed success until 1950.

Ball (1901) had reported men working in the Little Beatrice River area for alluvial gold (with poor results) as early as the early 1900s. A few rubies have also been found in these deposits. Most of the alluvial mining was confined to the creek beds (Morton, 1934). This area has also been worked on a small to medium scale for lode gold from 1932, the principal mines being Red Oak, Miyee and Red Hill group.

Geology

The Jordan Gold Field contains several auriferous quartz veins which cut decomposed granite of the Tully Granite Complex. The Wyreema mine is the major working in the area, with numerous collapsed and filled in shafts and adits. The reefs in the Jordan Gold

Field are generally small and discontinuous. The gold occurs in splay and stockwork veins, and in thin quartz stringers throughout the decomposed granite. The decomposed nature of the granite encouraged sluicing operations as the main mining method for extracting the gold.

Several small lode mining operations attempted to work the larger quartz veins in the granite. These reefs generally strike north-east and dip ~70° to the north-west — i.e. perpendicular to the dominantly north-westerly trends of most of the smaller reefs in the area (Figure 17). The reefs are commonly very irregular and disrupted by faults. The gangue minerals, arsenopyrite and pyrite, form rounded aggregates (clots) in massive white quartz. The gold is spatially associated with the pyrite and occurs in irregular shoots. Extensive alteration of the granite occurred adjacent to some of the reefs, producing auriferous zones up to 3m wide (Morton, 1934). At the Douglas Creek workings biotite granite is cut by numerous pyrite-rich veinlets with associated chlorite–epidote (propylitic) alteration. Farther north, in the Mountain Goat workings, disseminated pyrite and arsenopyrite are present in chloritised and silicified biotite granite; this mineralisation may constitute the auriferous zones noted by Morton (1934). The old underground workings appear to have been concentrated on pyrite–arsenopyrite-bearing quartz veins which cut the granite, whereas the sluicing operations appear to have exploited the associated auriferous alteration zones.

The granite hosting the mineralisation in this region is a titanite-rich oxidised I-type which is a strong indicator for associated gold mineralisation (Blevin & Chappell, 1992). Overlying the granite is basalt of the Atherton Subprovince. Deep lead deposits have been located below these basalts but are uncommon and not extensive.

The alluvial/eluvial gold is derived from the numerous thin quartz veins which cut the deeply weathered biotite granite of the area. Nuggets up to 186g have been found associated with floaters of rich gossany quartz (Morton, 1934). Garnet, tourmaline, topaz, zircon, sapphire and ruby are also present in the alluvial deposits; a white metallic mineral, possibly osmiridium, has also been reported (Ball, 1901). The garnets are relatively large and deep red, whereas the sapphires and rubies are generally small (less than a carat; Ball, 1913; Morton, 1934).

The sapphires and rubies have probably been derived from the basaltic volcanic rocks overlying the granite. A possible origin for the garnet, topaz and zircon is the erosion of either the granite or fine-grained quartz porphyry (porphyritic microgranite?) dykes, similar to those intersected in the Boulder mine workings

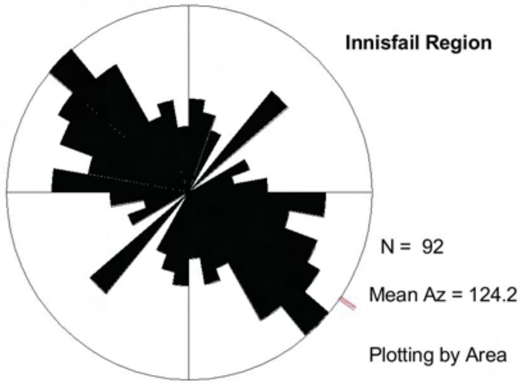

Figure 17. Rose plot of the orientations of mineralised quartz veins measured in the Innisfail Sheet area. Note the west-north-westerly to north-westerly trends of most of the veins, more or less parallel to the dominant regional fabric in the enclosing country rocks.

(Ball, 1901). The dykes were reported to contain these minerals. Unconfirmed outcrops of garnet–augite–chromite bearing rocks (reportedly similar to kimberlite) in the Jordan Creek area may also be contributing material to the locally-derived sediments.

Mount Peter Provisional Gold Field

History

The Mount Peter Provisional Gold Field is located in Sawmill Pocket, in the ranges behind Edmonton. Traces of alluvial gold were known to occur in gullies around Mount Peter but early prospectors had failed to find the source. This was until Peter Petersen, a local farmer, unearthed specimens of coarse-grained gold in quartz while ploughing his fields on Wright Creek. He concluded that the gold was being shed from the nearby hills. Prospecting of these hills resulted in the discovery of the Mount Peter reef in 1913. Other reefs were discovered soon after and the Mount Peter Provisional Gold Field was proclaimed two years later, on 16 July 1915.

The gold field is very steep and rugged with dense scrub, making prospecting very difficult. The rough nature of the area possibly accounts for the relatively late discovery of the field, considering its proximity to settled country. O'Cavanagh (1950) compiled a comprehensive summary of the history of the field, but some dates and production figures do not correlate with other information sources. The total recorded production for the Mount Peter Provisional Gold Field is 313.734kg of gold (ARDMs for 1899–1951).

The major reefs in the gold field are Mount Peter, Talisman, Golden Crown and Specimen Hill. All these reefs have been worked under a variety of names. The Talisman reef yielded the most gold (one third of the field's total production) and contains the deepest workings. The Specimen Hill reef had the highest grades (up to >124g/t Au; Reid, 1931a). However, the lode was of limited extent and the mineralisation patchy. Consequently, it was only worked intermittently, commonly for poor yields.

Initially ore won from the various reefs was crushed by a five-head battery erected near the Mount Peter mine. With increasing depths more sulphide-rich ores were extracted. These were transported to the State Smelters at Chillagoe for treatment. Ore was also treated at the Venus battery in Charters Towers, because the Mount Peter battery was inefficient and commonly not operational. The high cost of transporting these ores to distant treatment facilities resulted in only the high-grade deposits being economic. High ore processing costs hampered mining operations throughout the life of the field. The construction of smaller, privately owned batteries on the field proved unsuccessful because they were handicapped by an absence of reliable water supplies or the shortage of capital to maintain the machinery in good working order.

The first recorded gold production was in 1915 and by 1973 313.734kg had been produced from 5890.492t of ore (ARDMs for 1915–1973; O'Cavanagh, 1950). The average grade of the ore was 53g/t Au. This anomalously high grade largely resulted from the selective mining of the richer veins and hand sorting of the ore.

Mining occurred in three main periods, namely from:

- 1915 to 1925 when the Talisman, Specimen Hill and Easter Monday mines were the major producers; 79.04kg of gold were produced during this period,
- 1931 to 1943 (the main period of activity), when 161.31kg of gold were extracted, principally from the Talisman, Lucky Wednesday and Golden Crown; activity ceased in 1943 mainly due to World War 2 and the resultant shortage of labour, and
- 1946 to the 1970s; this phase of mining was dominated by small operations concentrated on the old workings around the Talisman and a new deposit called the Lady Lyn.

Geology

Three main gold-bearing quartz reef systems have been worked in this gold field since 1915. These are the Talisman, Specimen Hill and Mount Peter lodes. The host rocks consist of meta-arenite/quartzite and pelitic schist of the Hodgkinson Formation — a small marble lens is also located in the area. The reefs are irregular in strike and commonly anastomose. The gold occurs in widely spaced narrow shoots (splay veins) where it is mainly present either as discrete visible specks of high fineness or associated with arsenopyrite (Denmead, 1947). Apart from the Talisman, which maintained its size at depth, the lodes have limited vertical extents, pinching out at depth. The veins are generally narrow and ribbon textured — the ribbons being defined by numerous host-rock fragments. The larger veins contain ribbon quartz, stylolites and clear quartz veinlets. These veins also show evidence of incremental quartz deposition. The ribbon texture may be present on both vein margins or may be restricted to one side only of a large buck quartz vein. Other types of gold-bearing ore are buck quartz, complexly brecciated quartz and fractured quartz.

Arsenopyrite commonly occurs in these ribbons as a partial replacement of the host-rock fragments. Denmead (1947) also noted the presence of pyrite and chalcopyrite in restricted narrow bands within quartz veins — galena was also found during the recent field inspection. The presence of sulphides in the quartz veins commonly indicated zones of higher gold grades.

The ribbon quartz is considered to have formed from a crack-seal process as defined by Ramsay (1980). Native gold is commonly associated with the ribbon quartz in which it occurs as specks/blebs along the ribbon surfaces. Coarse gold also commonly occurs within massive white quartz. The white massive quartz generally had lower gold content and mining, consequently, tended to focus on the ribbon quartz.

Two possible sources for the mineralising fluids have been proposed, namely:

- a metamorphic source (after Phillips & Powell, 1992), or
- a nearby, unexposed granite pluton (Cohen, 1988).

The metamorphic process involves dewatering/devolatilisation of the sediment pile during regional metamorphism, the resultant fluids being channelled to dilational sites in fault/shear zones (Phillips & Powell, 1992).

Cohen (1988, page 28) proposed that "a granitic intrusive has domed the overlying strata...and has been the generator for the introduction of gold bearing fluids into the overlying strata". He recognised three sets of veins at Mount Peter, namely:

- veins which parallel bedding planes and cut the slaty cleavage,

- veins which parallel the slaty cleavage and cut across bedding, and
- veins which are at right angles to the slaty cleavage and also cut across bedding.

Only veins of the first group contain gold. The orientations (most have north-westerly trends; Figure 18) and distribution of these veins (parallel to bedding) were considered to be the result of certain rock types (namely greywacke or meta-arenite) being more susceptible to fracturing, particularly along bedding planes, than the interlayered finer grained sedimentary rocks. No drilling was carried out to determine the presence or otherwise of a granitic source or a stratigraphic control.

The observation by Cohen (1988) that the gold is associated with bed-parallel veins is consistent with the orientations of the mineralised veins in the Mulgrave Gold Field (where they were informally referred to as 'contact veins'). However, textural and other characteristics of the latter are consistent with their being slate-belt-type veins rather than of igneous origin.

Mulgrave Gold Field (Goldsborough)

History

Very little has been recorded about the workings in this gold field other than brief descriptions in ARDMs and reports by Jack (1893), McConnell & Carver (1984, 1985), and McConnell (1985). The paucity of information is mainly due to the small size of the field and the inaccessibility of the mines even when they were operating. The mountainous terrain and the inclusion of the area in the World Heritage-listed Wet Tropical Rainforests Reserve has also deterred exploration company activity in the area.

Alluvial gold was first found in the Mulgrave River in October 1879 (Dempsey, 1980), and the gold field was proclaimed on 1 July 1880. The field encompasses a large tract of mountainous country along the Mulgrave River. There were three principal mining centres, namely:

- Goldsborough (Lower Camp or Fanning Town),
- Top Camp (Upper Mulgrave), and
- Kraft Creek, informally called the Bartle Frere Gold Field (described separately).

The total recorded gold production from 1879 to 1942 (from both reef and alluvial sources) is 206.126kg (130.012kg of alluvial gold and 76.115kg of lode gold; ARDMs for 1879–1942).

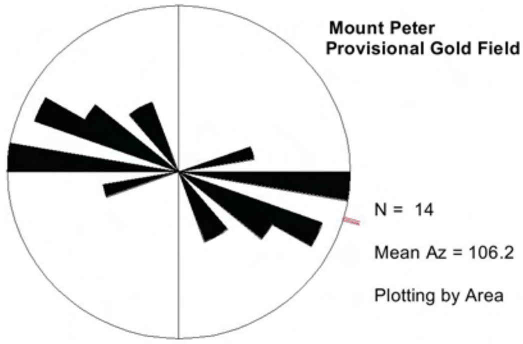

Figure 18. Rose plot of the orientations of quartz reefs mined in the Mount Peter Provisional Gold Field.

The Goldsborough area, referred to by early writers as Lower Camp or Fanning Town, is located on the western bank of the Mulgrave River at its junction with Toohey Creek. In 1880, a Cairns syndicate installed the first mining plant on the field, called the General Roberts Mill, at Goldsborough. This consisted of a twelve-horsepower portable engine and a five-head battery.

In the Goldsborough area, the Chance lode (Plate 33) was considered "the most premier reef on the field" (ARDM for 1884, page 25). To treat this ore a 7m-diameter water wheel was erected in 1885 at Goldsborough to drive a five-head battery, 100m from the Golden Crown mine (ARDM for 1885, page 29). This plant was referred to as the Golden Crown Company's machine in the ARDM of 1888 (page 32). The Chance mine was worked until 1891 when it was abandoned. The mine re-opened in 1922 under the name of 'Goldsborough'. A five-head battery was constructed in 1924 with a tram line from the workings to the mill. The mines in this area were worked on tribute until the 1930s.

The area referred to as 'Upper Camp' is located ~7km south of Goldsborough, in rugged country between Butcher and Machinery Creeks. The Upper Camp area was first mentioned in the ARDM of 1881. By 1888 the area had two stores, a mine owner's house, and several shacks and tents.

The Upper Camp area contains mainly hard-rock mines, the Walter Hodgson and Orient-Mowbray being the largest. The reefs in this area are larger and better defined than those in the Goldsborough area, farther north.

The first battery in the area, called the Mowbray Mill, was erected in 1882 and consisted of a ten-horsepower stationary engine with a five-head stamper (the mill was later referred to as the Mount Orient battery; ARDM for 1888, page 32). This battery was situated on Toohey Creek below the Orient-Mowbray mine. The ore was transported down the steep slope by a rail-bucket system. These operations were abandoned in 1897 because of poor grades.

The Walter Hodgson was the longest operating mine in the Mulgrave Gold Field. The reef was discovered in 1887 by W. Delinen and by 1895 a ten-head battery, driven by a water wheel, had been constructed on Butcher Creek to treat the ore. The reef was worked via several adits to a depth of 90m, the ore being transported to the battery via a tramline and rail-bucket system.

The Mulgrave River has been worked intermittently for alluvial gold since the 1870s. In 1896 a cyanide plant was erected on Butcher Creek to treat the fine gold from the sandy reaches of the river. This venture failed due to the presence of numerous large boulders in the alluvium. In 1899, the Mulgrave River was investigated for its dredging potential (ARDM for 1899, page 86), despite the scepticism of dredging experts. The project was unsuccessful and was abandoned by 1901. In 1931, an Authority to Prospect was granted to Oriomo Explorations Ltd, over the Mulgrave River from the junction with Butcher Creek downstream for ~12km. Test pits in the river bed yielded poor gold grades and the area was again abandoned.

The main production of alluvial gold from the Mulgrave Gold Field was in the area adjoining the Russell River Gold Field, particularly in the Swipers Flat area. In 1890, a small gold rush occurred to an area 11km north of the old Russell diggings and ~2km outside the Russell River Gold Field (probably the Swipers Flat area). Nuggets weighing 722g and 429g were obtained from this area. Both of these nuggets reportedly were not very waterworn and were thought to have been derived from an old river channel located near the creek flat (ARDM for 1890, page 34). Specimens up to 155g were also recovered from the creek. All had some host rock attached, implying a nearby reef source (ARDM for 1890, page 34). The area was not mentioned in the ARDMs again until 1910 when it was prospected for a lode gold source. In 1934, the area was hydraulically sluiced but no production figures were reported.

Geology

The gold-bearing quartz reefs mined in this district are hosted by graphitic schist and meta-arenite of the Hodgkinson Formation. The reefs are both concordant with and cut the dominant foliation in the enclosing country rocks. The mineralised quartz veins are consistently associated with graphitic schist. They occur along the contact between graphitic schist and meta-arenite in the Chance and Sheila mines

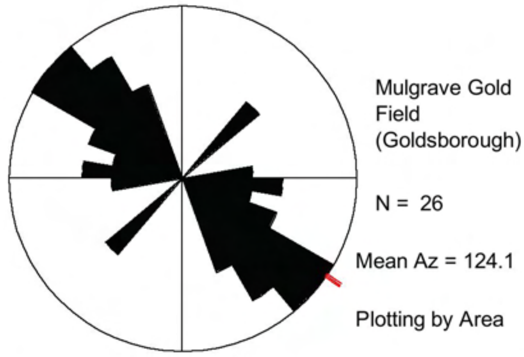

Figure 19. Rose plot of trends of quartz reefs in the Mulgrave Gold Field (Goldsborough).

(Goldsborough). Most of the mineralised veins have a north-westerly strike (Figure 19).

The mineralised reefs in the area consist of ribbon quartz, commonly with associated massive white crystalline quartz. Host-rock inclusions in the ribbon quartz consist of stylolitised graphitic schist, which is commonly partly to extensively replaced by fine pyrite and arsenopyrite — galena has also been reported (Reid, 1931b). The gold occurs as aggregates (patches) of mainly coarse, visible grains associated with these inclusions in the ribbon quartz.

Reid (1931b) considered the presence of "granites and quartz-porphyries" (page 397) in the slopes of Mount Mac as indicating a magmatic source for the quartz and gold mineralisation. However, the results of a recent field inspection and a study of the literature imply metamorphic processes were more likely to have been responsible for the generation of the auriferous quartz reefs. In particular, the quartz reefs:

- are localised along the boundary between graphitic schist and meta-arenite,
- display widespread ribbon textures,
- are characterised by inclusions and selvedges of graphitic schist, implying incremental quartz deposition, and
- have rare infill textures in the bands of relatively massive white quartz which are locally interlayered with the ribbon (thinly laminated) quartz.

These features appear to indicate a crack-seal model of ribbon/laminated vein formation (Ramsay, 1980) to be the most appropriate. The lithological control on some of the reefs implies the graphitic schists were involved in the concentration and precipitation of the gold. The presence of massive crystalline quartz displaying infill textures was possibly due to periodic increases in the hydrostatic pressure — such increases resulting in the generation of enlarged open spaces favourable for crystal growth and the formation of the relatively thick bands of white quartz.

Kraft Creek area (Bartle Frere Gold Field)

History

Gold in the Kraft Creek area (Figure 15), also informally called the Bartle Frere Gold Field (although it is not a gazetted gold field but part of the Mulgrave Gold Field), was discovered in about 1931 by W. Kraft and S. Wilkie (Tramp, 1937). These two prospectors found alluvial gold in the Mulgrave River and traced it upstream as far as the Kraft Creek area. The gold was eventually found (in 1936) to be shedding from quartz reefs located on the northern slopes of the Bartle Frere massif. The discovery attracted considerable attention, and more than 100 leases were pegged by the middle of 1937 over the ten main reefs and alluvial/eluvial deposits. The inaccessibility of the area and the steep country severely hampered mining operations.

The total recorded gold production from the Kraft Creek area was 14.052kg according to the ARDMs for 1937–1942. However, McConnell (1984) reported an unsourced total production figure of 16.174kg. The gold was produced in a single burst of activity from 1937 to 1942 and represented the total yield from the Mulgrave Gold Field for this period. The main method of working was hand-picking quartz float in the creeks and hillsides within the area of the original discovery. True reef deposits are rare, and most quartz outcrops when mined were found to be large boulders (commonly ranging from 1t to 4t) in a deep soil mantle. The Mount Morgan Development Company investigated two of the most promising reefs (Key of the Hills and Krawil) during 1937 and 1938 by driving adits into both reefs. The results were disappointing and the workings were abandoned.

Initially, the ore was transported by horse to Babinda and then forwarded to the State Smelters at Chillagoe, a costly exercise which attests to the rich nature of the ore. In 1939, a five-head battery was erected at the Krawil Extended mine to treat quartz float from Kraft Creek. In the same year, two three-head batteries were erected; one at the Hicroft mine and the other downstream from the Golden Horseshoe mine. A single-head battery was also erected at the Divided mine. These batteries operated for only short periods, and the area was abandoned in the 1940s.

Accounts of the history of the area and the conditions endured by the prospectors can be found in Tramp (1937), Whitty (1937), Roberts (1978, 1985), and Jago (1985).

Geology

The Kraft Creek area contains gold-bearing quartz reefs hosted by the Hodgkinson Formation. These reefs range in width from several centimetres to >3m. The strike of the reefs parallels that of the pervasive cleavage in the host rocks. The rocks marginal to the veins commonly contain thin quartz stringers but no extensive stockworks.

The gold is associated with sulphides and also occurs as discrete, commonly coarse, visible grains. The sulphides which include pyrite, arsenopyrite, marcasite, galena and sphalerite occur as aggregates (clots) in the coarsely crystalline quartz. Arsenopyrite and pyrite are also disseminated throughout the quartz. Most lode-mining operations concentrated on the sulphide ores as these reportedly contained the highest gold grades (between 31g/t and 186g/t; Murdoch, 1981). As noted above, most of these mines were not in true lode deposits. Rather, the gold was obtained mainly from quartz float (which formed boulders up to ~1.5m across) in Kraft Creek and the adjacent steep banks. The source of these boulders was not found during the recent survey. Examination of the quartz float yielded several samples containing disseminated visible gold associated with sulphide-rich clots in massive crystalline quartz.

Inspection of the reef exposed in the Krawil workings and reports about the deposits indicate they consist of ribbon quartz, the ribbons being defined mainly by inclusions of graphitic country rocks. These reefs are similar to those in the Mount Peter, Towalla and Mulgrave areas. In contrast, the auriferous float in the creek contains fewer graphitic inclusions (ribbons) and is commonly gossany, and may have a different source.

Russell River Gold Field

Introduction

The area (Figure 15) was initially referred to as the Russell River Gold Field but was commonly shortened to Russell Gold Field in the Annual Reports of the Department of Mines (ARDMs). The gold field was worked intermittently between 1887 and 1959, 680.409kg of gold and possibly as much as 100t of cassiterite concentrate being produced (ARDMs for 1891–1959; Hughes, 1971). The main period of production was between 1891 and 1901, when 586.323kg of gold were reportedly extracted (ARDMs for 1891–1901). This figure is too low because of the practice of not tabulating alluvial production figures in the early ARDMs and the lack of regulatory bodies during this period to monitor production. In contrast, Dempsey (1980) reported 3000kg of gold to have been produced from the Astronomer mine (the largest in the field) alone, whereas de Keyser (1964) reported an estimated production of 833kg of gold for the entire field.

Alluvial gold in deep-lead deposits was the primary target (Plate 34). The alluvium also contained cassiterite which was extracted as a by-product. Minute flakes of platinum have also been found in the gold-bearing alluvium in the Coopa, Coopooroo and Wairambar workings (Jack, 1888). Reef mining has also occurred at scattered locations, principally in the Towalla area.

History

The following account of the discovery of the Russell River Gold Field and the early history of the field has been summarised from the following sources:

- a 1985 publication by the Eacham Historical Society entitled 'Christie Palmerston: Explorer of the Rain Forest', and

- ARDMs for the period 1891–1901.

Following unsuccessful prospecting for gold along the South Johnstone River in the mid-1880s, the renowned explorer Christie Palmerston and a colleague, Svenson, decided to investigate the area north of the North Johnstone River. On reaching the Russell River, in August 1886, they discovered encouraging traces of gold, probably in the China Bend area. Proceeding upstream they prospected as far as Wairambah Creek where the best prospects were found. On 16 August they returned to Geraldton (now Innisfail) because their supplies had run out. On a second visit to the area, Palmerston (without Svenson) met Clarke and Joss (an old colleague) at the 'Johnstone diggings'. After telling them of his find, Palmerston provided one of his aboriginal guides to lead the prospectors to his discovery. Clarke and Joss prospected the area but moved into Coopooroo Creek where most of the deep leads are located (subsequently referred to as the Boonjie Terraces). On his return in late 1886 Palmerston worked the area around Wairambah Creek until both parties decided to peg their claims and notify the authorities.

Subsequently most of the basalt escarpment was prospected by other miners who rushed to the area, in 1887. The gold field was proclaimed in September 1887. In 1890 two smaller rushes occurred to the field; these were in the Five-Mile and Nine-Mile areas. These rushes were short lived, the deep-leads being of limited extent.

The principal method of working the deep leads was by tunnelling below the decomposed basalt capping and following the buried, auriferous alluvium. This method was eventually replaced by larger sluicing operations. The water for these operations was channelled to the area along races totalling ~64km in length. Faces of up to ~20m high were worked using this method (Plate 34).

Throughout the life of the field the sluicing operations suffered from periodic shortages of water, which hindered continuous operations. This lack of a permanent water supply probably shortened the life of the field as the alluvial deposits were generally low grade and only economic when worked on a large scale.

Geology

The auriferous deep-lead deposits in this area are in alluvium which was deposited during the Tertiary. The alluvium is overlain by up to ~60m (average ~15m) of basaltic lava flows. The flows are commonly deeply weathered. The alluvium appears to occur at different elevations, implying a complex system of channels and terraces below the basalts.

The grade of the alluvium ranges markedly, an average of 4.5g Au and 1.78kg Sn per cubic metre having been reported (Spectrum Resources, 1988). The gold is probably derived from thin quartz veins in the Hodgkinson Formation. The presence of gold-bearing reefs, which cut the Hodgkinson Formation in the Towalla area supports this theory.

Langton (1974) considered the cassiterite in the alluvium to have been derived from arenite beds in the Hodgkinson Formation. Emery & Noakes (1968) had previously reported that the median distance from the primary source at which economic placer cassiterite deposits are likely to form is ~8km. This would locate the source of the cassiterite in the Russell River deep-lead deposits in the Malanda area, because the late Tertiary drainage in that area was from west to east. The presence of a granite-hosted tungsten deposit containing traces of tin (< 0.1%) near Peeramon (within the likely source area) implies the presence of cassiterite-bearing granites in the area. Erosion during the Tertiary of these stanniferous granites and auriferous quartz veins hosted by the Hodgkinson Formation metasedimentary rocks are the most probable modes of formation of the cassiterite and gold-bearing Russell River deep-lead deposits.

Russell Extended Gold Field (Towalla)

History

The reef-gold deposits of the Towalla area were first mentioned in 1892 by the local Mining Warden. Their location has been referred to either as the Russell Extended Gold Field or Towalla area. After 1907, the area was incorporated into the Russell River Gold Field. The total recorded gold production for this area is 155.328kg, which were obtained between 1889 and 1907 (ARDMs for 1889–1907). Lode-gold deposits contributed 137.685kg, and alluvial gold made up the remaining 17.663kg.

The earliest recorded production from this area was in 1889 when 9.5kg of alluvial gold were recovered (ARDM for 1889). It was not until 1893 when a rush occurred to the area that the main period of gold production started. The first claims worked in 1893 were the Coral Queen and the Victory, which operated a small, two-head battery driven by a water wheel. This battery, called the Phoenix Mill, originally used wooden stampers. These were subsequently replaced by iron stampers.

By 1894, another two batteries were operating in the field — a three-head battery at the Towalla King Claim and the New Years Gift Mill. The latter was a five-head battery powered by a water wheel and was located in a steep gully. The New Years Gift Mill was the only one operating by 1897.

The Rose and Shamrock and Towalla King reefs are the largest in the field, ranging from 0.15m to 0.6m in width. The other reefs worked averaged <10cm in width and were of limited extent. Mining operations in this area were intermittent and short-lived, because the auriferous quartz reefs are narrow and discontinuous (both along strike and down dip) — in contrast to the claims of some early miners that the reefs became wider and richer with depth (ARDM for 1895, page 107). The creeks and gullies of the area were also worked for alluvial gold.

The small size of most deposits and the rough, inaccessible, and densely vegetated character of the area resulted in the departure of most of the prospectors by 1898. Mining activity had ceased in the area by 1900. In 1941, the Python mine commenced processing ore from the extensive underground workings at Towalla. Silver mineralisation is also present in this reef, 1.6kg being obtained from 110t of ore in 1942. Operations ceased in 1943 due to a shortage of manpower as a result of World War 2. The field was never reopened.

Geology

The mineralisation in the Towalla area is identical to that in the Mount Peter Provisional and Mulgrave Gold Fields, the gold being concentrated in extensively stylolitised and ribbon-textured quartz veins. The ribbons in the quartz veins consist mainly of schistose graphitic material; some detached selvedges of graphitic schist are also present. Pyrite and arsenopyrite are associated with both the graphitic selvedges and the ribbons. Most of the veins have north-westerly trends (Figure 20).

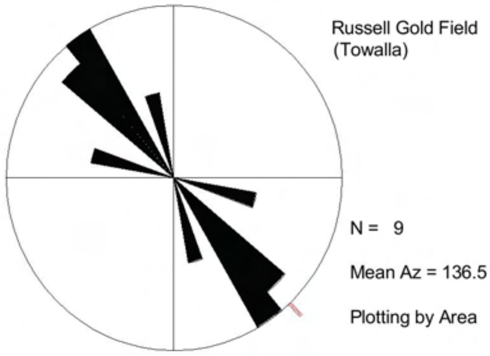

Figure 20. Rose plot of trends of quartz reefs mined in the Towalla area of the Russell Gold Field.

Visible gold was found in samples of ribbon quartz from the Python workings during the recent survey. However, this gold was not associated with sulphides or with the stylolitised ribbons and graphitic selvedges, unlike the gold mineralisation in the Mount Peter Provisional and Mulgrave Gold Fields.

Other small gold deposits

Small-scale mining has also taken place at the Culpa diggings, Freshwater Creek, Rocky Creek and in the Eubenangee area.

Culpa diggings

The Culpa diggings are located on gold-bearing alluvial terraces along Culpa Creek, a tributary of the Tully River, upstream of Koombooloomba Dam. This area was first mentioned in the ARDM for 1894 (page 83) when "a few ounces were also brought in from the Tully...". No other information has been found except the gold production figures in the ARDMs for 1897–1905. These figures were commonly included with those for the Tate Gold Field in the Chillagoe district. The total recorded production for the two areas is 86.155kg of alluvial gold, most of which was probably from the Tate Gold Field.

The alluvial gold in Culpa Creek is flaky and fine, and is thought to have been derived from reworking of alluvial terraces adjacent to the creek (Garth, 1968). The presence of high-level granite (of the Ingham Granite Complex) containing disseminated molybdenite and of locally derived alluvial gold may indicate the presence of a pluton-hosted gold-mineral system analogous to the Timbarra deposit of northern New South Wales (Mustard & others, 1998). More detailed mapping and geochemical studies would better define the mineral potential of this area.

Freshwater Creek

Alluvial gold has been reported from the headwaters of Freshwater Creek, several kilometres west of Edmonton. The area was the focus of a small gold rush prior to 1919 (Jensen, 1919). The Freshwater Creek Diggings were mentioned in the ARDM for 1891 (page 79) as "being almost abandoned", implying the alluvial mining occurred some time prior to 1891. Little information is recorded for this area and its location in rugged country of the Lamb Range prevented a field inspection during the recent survey.

The alluvial gold in the headwaters of Freshwater Creek is probably derived from erosion of small auriferous quartz veins which cut the Hodgkinson Formation. The veins probably have a similar origin as those in the Mount Peter Provisional Gold Field.

Eubenangee

Alluvial gold was found on Portion 12, Parish of Glady, in the Eubenangee area, in 1924 (ARDM for 1924). The resultant flurry of activity was short-lived, the area being abandoned by 1926. The recorded gold production for this period was 3.389kg. The area was worked again, from 1931 to 1937, the operations concentrating mainly on several small reefs. These efforts had only limited success.

The gold obtained in the Eubenangee area was from both reef and alluvial deposits. Reid (1931c) considered the lode deposits to be quartz veins of magmatic origin. The veins are 0.05m–0.15m wide and trend north-east. Reid examined six gold specimens from the area. One contained ~778g Au; another smooth and water-worn specimen contained intergrown quartz and native gold, implying the presence of a reef. All specimens were recovered from the soil mantle overlying bedrock of granite.

MOLYBDENUM

Disseminated molybdenum mineralisation was found by Noranda Australia Ltd at the Summit Hill prospect (GR 468149; Tully 1:100 000 Sheet area), as a result of a search for Climax-type deposits (Climie, 1973). Similar but more extensive mineralisation is present farther south at the Biok, Yamanie and Yuccabine prospects. Windows in the Glen Gordon Volcanics have exposed the roof zones of granitic intrusions hosting disseminated and stringer mineralisation. Associated mild chloritic alteration is present in both rock units adjacent to the contacts.

TIN AND TUNGSTEN

Tinaroo area

History

The Tinaroo area contains numerous small deposits principally mined for tin, tungsten and gold. Sub-economic molybdenum and copper mineralisation is also present in places. The area forms part of the Tinaroo Mineral Field which extends west into adjoining ATHERTON. Local pastoralist, John Atherton, discovered alluvial cassiterite in Tinaroo Creek, in 1878 (see Dash & others, 1991). Soon after this discovery the area was being worked by several miners. Ninety-five tonnes of cassiterite concentrate were produced in 1879 (ARDM for 1879, page 21). Gold was also recovered from the stanniferous alluvium. However, the only recorded gold production was 4.665kg in 1879 (ARDM for 1879, page 21).

The alluvial cassiterite is concentrated along Tinaroo, Douglas, Black Rock and Deception Creeks and their tributaries. Black Rock Creek has been extensively reworked in recent times.

Small-scale hard-rock mining has occurred in scattered locations throughout the area, the Glen Atherton (GR 449054; Bartle Frere 1:100 000 Sheet area) and Robson's (also called United — GR 408021; Bartle Frere 1:100 000 Sheet area) mines being the largest workings. The Glen Atherton mine was first mentioned by Ball (1911) and originally worked for tin. However, tungsten became more abundant as mining proceeded and was the principal commodity produced. No other information has been found about the history of this deposit. Robson's mine is located on the northern bank of the Barron River (Saint-Smith, 1916; Jensen, 1920). The workings are concentrated on thin quartz veins, which cut the Tinaroo Granite. The veins contain mainly tin and tungsten mineralisation, as well as traces of copper and molybdenum minerals.

Geology

The tin–tungsten mineralisation of the Tinaroo area is mainly restricted to the margins of the Tinaroo Batholith. Most mineralisation is associated with quartz veins, pegmatite dykes, and greisen zones in the Emerald Creek Microgranite, along the contacts between the Emerald Creek Microgranite and Tinaroo Granite, or in the Tinaroo Granite. Mancktelow (1982) studied this area and also noted the presence of scheelite in a 0.5km–1km-wide zone around part of the Tinaroo Granite. The scheelite is associated with calc-silicates mapped as part of the Hodgkinson Formation.

The mineralisation consists mainly of cassiterite, wolframite and scheelite. These minerals occur in massive to crystalline, milky quartz veins which commonly also contain disseminated pyrite, chalcopyrite, arsenopyrite and molybdenite. The veins are up to 1.2m thick and generally trend in a north-easterly direction. They cut both the Emerald Creek Microgranite and the Tinaroo Granite. The tin–tungsten-bearing quartz veins are commonly overprinted and cut by quartz–tourmaline veins up to 5cm thick, containing open space infillings of coarse, radiating tourmaline crystals. Small blebs of molybdenite are commonly associated with the tourmaline. The molybdenum mineralisation appears to post-date the Sn–W mineralisation and to be related to discrete, boron-rich fluids. Support for this hypothesis is given by the scheelite from the Tinaroo area which has a bright sky-blue fluorescence, indicative of a low molybdenum content (Greenwood, 1943).

Mancktelow (1982) considered the tungsten mineralisation in the aureole of the Tinaroo Batholith to be granite-derived and to have resulted from broad-scale infiltration metasomatism. In this model, tungsten-bearing fluids emanating from the Tinaroo Batholith flushed lime-rich lenses in the Hodgkinson Formation or were concentrated along preferred flow paths. The tungsten within the fluids either reacted with the lime-rich lenses to form scheelite or was precipitated in these flow paths during cooling, thereby producing the vein deposits.

Mancktelow (1982) noted the anomaly of low-molybdenum scheelite associated with molybdenite in the quartz-vein deposits. He postulated that the low-molybdenum scheelite formed in the calc-silicates in a reducing environment (low fO_2 and high fS_2), the molybdenum being dispersed to concentrate in the vein-style deposits. It should be noted that low-molybdenum scheelite occurs not only in the calc-silicates but also in vein-style deposits with molybdenite. Considering the vein relationships described above, it is probable that the tungsten and molybdenum mineralisation is either the result of precipitation from discrete, unrelated fluids or from the evolution of fluids derived from the same hydrothermal system — the latter is the more likely.

Mineralisation in the Glen Atherton workings appears to be localised at the intersection of a north-west trending lineament with easterly and southerly-trending lineaments, implying the deposit is structurally controlled.

The drainage channels of the Tinaroo area have been extensively worked for cassiterite. The disposition of the workings implies the cassiterite has been derived mainly from weathering of the Emerald Creek Microgranite (Willmott & others, 1988). The small quantities of gold found in the stanniferous alluvium are considered to be derived either from erosion of quartz veins in the granite or from reworked Tertiary sediments, or both.

MANGANESE

History

Manganese ores have been mined from two small deposits in INNISFAIL. Mount Martin, the larger deposit, is located ~3km north-west of Edmonton and was worked intermittently from the 1900s to the 1940s. The operations were small-scale, and only ~1117t of 40–50% manganese ore were produced. The Weekend Stunt was worked intermittently prior to 1919. The deposits were again worked in the 1940s but poor grades and the discontinuous character of the lodes made operations uneconomic.

Geology

All the known manganese deposits are hosted by metasedimentary rocks of the Hodgkinson Formation, and are located in the north-eastern part of INNISFAIL. The deposits are thought to be stratiform, except for Mount Martin. The ore-body at Mount Martin forms an irregular lens which dips at approximately right angles to the enclosing schist. The origin of this deposit is unknown (Jensen, 1941).

Most stratiform manganese deposits can be classified into one of two main groups — (1) non-volcanogenic, or (2) volcanogenic–sedimentary, depending on the source of their contained manganese. The manganese deposits in the Hodgkinson Province are probably volcanogenic–sedimentary, because of their common association with chert (of exhalite origin?). Most of these stratiform deposits have zones of secondary manganese enrichment which were the foci of mining activity.

INDUSTRIAL MINERALS

A deposit of recrystallised limestone (ML 32, Birthday) was mined in the Mount Peter area from 1960 to 1963. The operation (by North Queensland Marble Pty Ltd) produced 203t of crushed lime which was spread on the nearby cane fields. The marble potential of this deposit was also investigated during the 1960s but no production has been reported. Agricultural lime has been mined from two earthy limestone deposits in the valley of the Little Mulgrave River. These deposits were called Little Mulgrave No. 1 (ML 40) and Little Mulgrave No. 2 (ML 40). More than 3000t of lime were produced from these deposits for agricultural use between 1962 and 1971.

Clay was mined locally for the Silkwood brickworks from 1952 to 1975. During this period 17 100t of clay was extracted and made into bricks for use in the region. These operations were virtually continuous except for name changes to the company operating the brickworks.

GEMSTONES

Garnet, topaz, zircon, sapphire and ruby have been reported in alluvial deposits of the Jordon Gold Field. Although it is unlikely that significant concentrations of gemstones exist in the sheet area, small alluvial deposits amenable to small-scale, hand-mining techniques may be present.

Diamonds have been recovered from alluvium of the Russell River deep leads, the Little Beatrice River and the headwaters of the Mulgrave River. These diamonds are small to very small (generally <1 carat), the largest observed being ~5 carats (A.D.C. Robertson, Department of Mines and Energy, personal communication, 1994). Reconnaissance geochemical prospecting for diamonds took place over much of the sheet area during the mid-1980s. No diamonds or indications of kimberlitic rocks were found. However, a recently unconfirmed report (by a local prospector) of garnet–augite–chromite-bearing rocks in the Jordan Creek area may indicate the presence locally of potential source rocks in the sheet area.

SILICA SAND

The Mourilyan silica sand deposit, located south-east of Innisfail, extends for 22km along the coastal plain. This deposit consists of an inner and outer beach-ridge–barrier complex. The inner barrier is Pleistocene and is covered, in places, by low, degraded, transgressive dunes. The transgressive dune system contains indicated reserves of 10 739 500t of >99% silica to a depth of 0.5m (Cooper, 1993). The Inarlinga Defense Reserve extends over part of the outer Holocene barrier.

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Plate 1. Flat-lying country developed on extensively weathered basaltic lava flows of the Atherton Subprovince, with the prominent cinder (scoria) cones of the Seven Sisters in the distance. The basalts have yielded very fertile soils which have been cultivated for ~ 100 years. Main road between Atherton and Yungaburra.

Plate 2. Extensively dissected and hilly country formed on the Atherton Basalt, southern part of the Atherton Tableland. Note the steep-sided, rainforest-covered Bartle Frere massif in the distance rising well above the level of the tableland. View from Millaa Millaa Lookout, south of Millaa Millaa, towards the north-east.

Plate 3. The rugged, rainforest-covered Bellenden Ker Range from the Mulgrave River, near the junction with the Russell River.

Plate 4. Kearneys Falls, on the western flank of the Bellenden Ker Range.

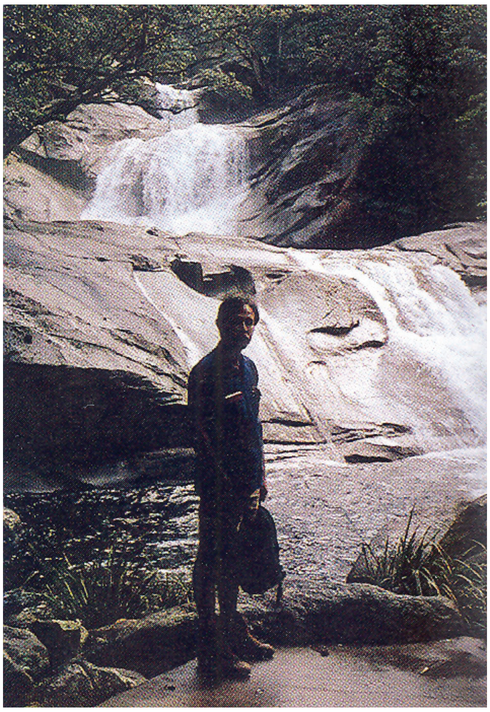

Plate 5. Josephine Falls on the south-eastern flank of the Bartle Frere massif.

Plate 6. Thin to medium-bedded meta-arenite and metamudstone, Barnard Metamorphics, northern end of Narragon Beach.

Plate 7. Interlayered meta-arenite and metamudstone cut by dyke of felsic S-type granite, Barnard Metamorphics. Northern end of Narragon Beach.

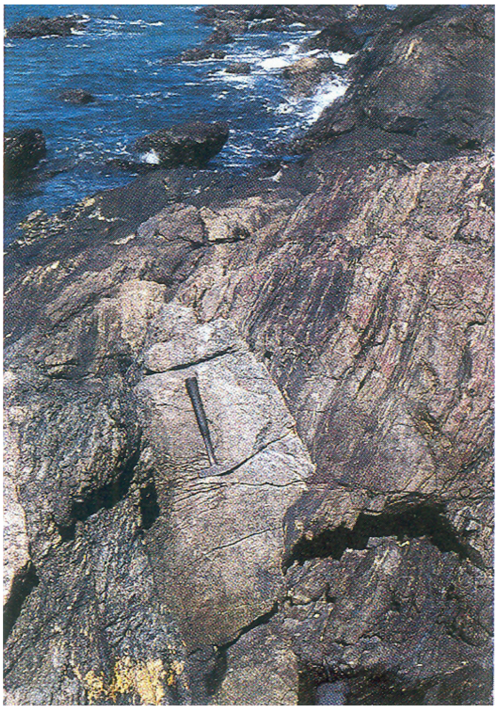

Plate 8. Migmatitic biotite gneiss of the Barnard Metamorphics forming prominent, massive outcrops. North-eastern end of Normanby Island, Frankland Islands group.

Plate 9. Relatively thick dyke of foliated, fine-grained biotite granite, which cuts biotite gneiss of the Barnard Metamorphics. Northern end of Russell Island, Frankland Islands group. Note the enclaves of migmatitic gneiss.

Plate 10. Coarse andalusite intergrown with (and partly replaced by?) coarse sillimanite, in migmatitic biotite gneiss of the Barnard Metamorphics. North-western end of High Island (GR 940030, Cooper Point 1:100 000 Sheet area). Cross-polarised light; magnification x16.

Plate 11. Massive migmatitic biotite gneiss, Barnard Metamorphics. North-western end of High Island (GR 940030, Cooper Point 1:100 000 Sheet area).

Plate 12. Migmatitic biotite gneiss, Barnard Metamorphics. Adjacent to contact with Dunk Island Granite, north-eastern side of Dunk Island (GR 105165, Innisfail 1:100 000 Sheet area). The gneiss at this locality is characterised by well-developed banding, in contrast to the gneiss on High Island (Plate 11).

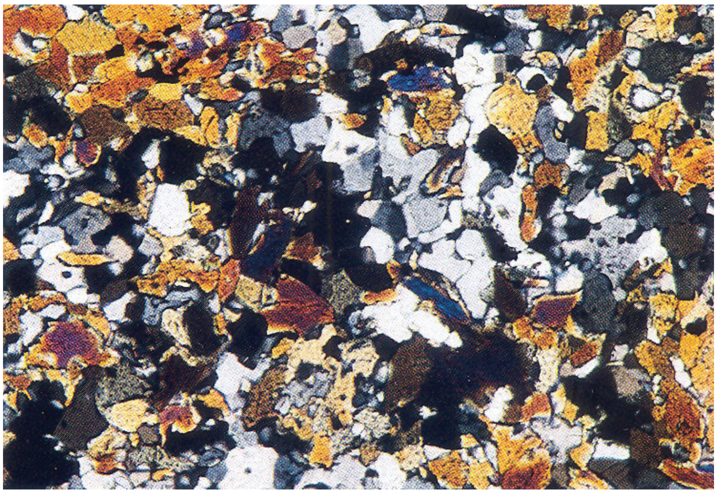

Plate 13. Fine-grained amphibolite, Barnard Metamorphics. Southern side of High Island (GR 948017, Cooper Point 1:100 000 Sheet area). Cross-polarised light; magnification x63.

Plate 14. Coarse cordierite grain (with inclusions of spinel and biotite), in migmatitic biotite gneiss (BB1959A), Barnard Metamorphics. Near the south-western end of the Malbon Thompson Range (GR 849996, Bartle Frere 1:100 000 Sheet area). Cross-polarised light; magnification x16.

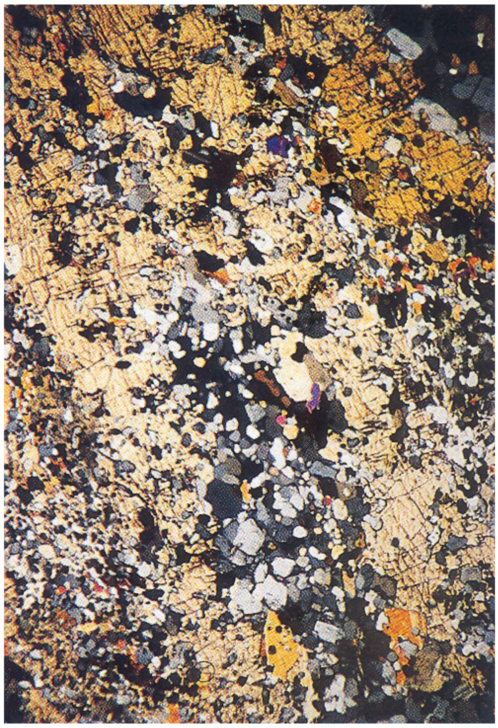

Plate 15. Coarse poikiloblastic orthopyroxene grain in hornblende granulite (BB1959), Barnard Metamorphics. South-western end of the Malbon Thompson Range (GR 849996, Bartle Frere 1:100 000 Sheet area). Cross-polarised light; magnification x16.

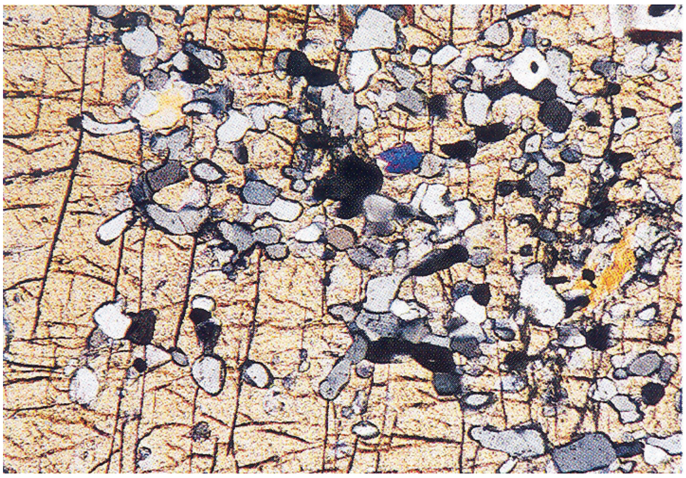

Plate 16. Close-up of coarse poikiloblastic orthopyroxene grain in hornblende granulite (BB1959). Near the south-western end of the Malbon Thompson Range (GR 849996, Bartle Frere 1:100 000 Sheet area). Cross-polarised light; magnification x63.

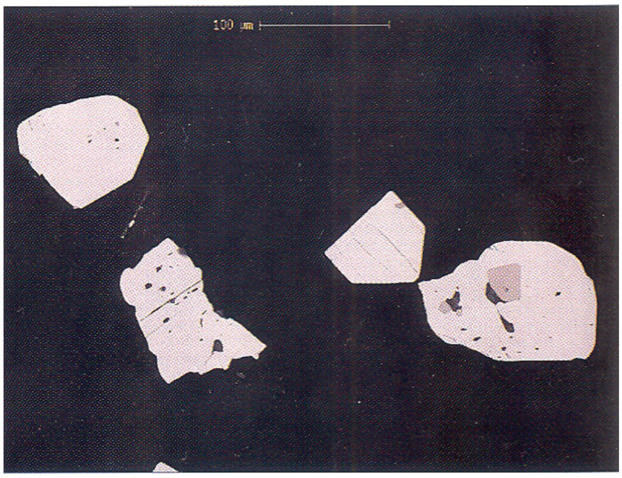

Plate 17. Backscattered scanning electron microscope image of monazite grains separated from sample BB1959A (migmatitic gneiss near the south-western end of the Malbon Thompson Range). Note the subhedral to angular grain shapes and the presence of inclusions.

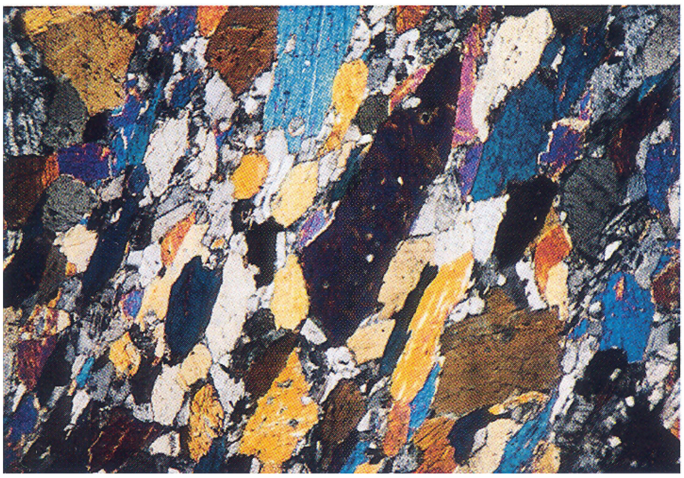

Plate 18. Foliated amphibolite, Babalangee Amphibolite. Graham Range (GR 904854, Bartle Frere 1:100 000 Sheet area). Hornblende and plagioclase are the main minerals. Cross-polarised light; magnification x16.

Plate 19. Contact between S-type granite of the Mission Beach Granite Complex and biotite-rich migmatitic gneiss of the Barnard Metamorphics. Southern end of South Mission Beach (GR 037144, Innisfail 1:100 000 Sheet area). Photograph by I.D. Rees.

Plate 20. *Enclave of migmatitic biotite gneiss in S-type granite of the Mission Beach Granite Complex. Southern end of South Mission Beach (GR 037144, Innisfail 1:100 000 Sheet area). Note the marked angular discordance between the dominant foliation in the gneiss and the foliation in the granite (trend indicated by orientation of clutch pencil), implying the country rocks were deformed and metamorphosed prior to or during the emplacement of the granite.*

Plate 21. Tam O'Shanter Granite with large enclave of biotite-rich gneiss. Tam O'Shanter Point (GR 047128, Innisfail 1:100 000 Sheet area).

Plate 22. Extensive pavements and boulders of Bedarra Granite, northern end of Bedarra Island (GR 099010, Innisfail 1:100 000 Sheet area).

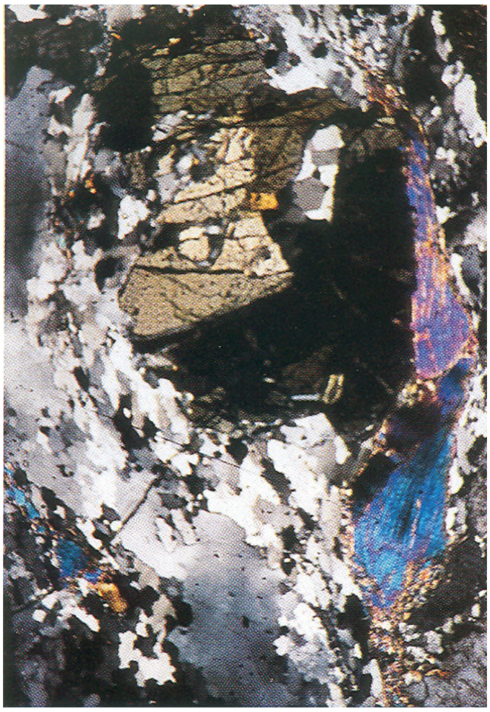

Plate 23. Extensively deformed Bellenden Ker Granite, with relict tourmaline, muscovite 'fish', and ribbon quartz. Summit area of Bellenden Ker Centre Peak (GR 786913, Bartle Frere 1:100 000 Sheet area). Crossed polarisers; magnification x16.

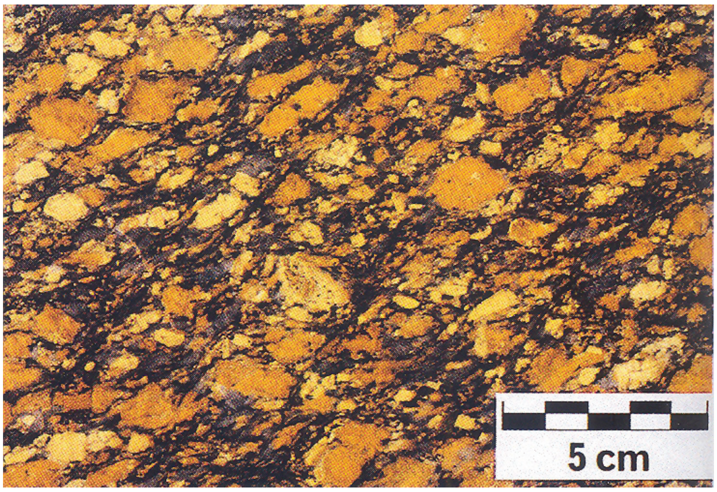

Plate 24. Stained slab of extensively deformed Bellenden Ker Granite, with well-developed 'S' and 'C' planes. The granite contains numerous K-feldspar phenocrysts/megacrysts (yellow), as well as scattered plagioclase phenocrysts (white). Whaleback on eastern side of the Bruce Highway, ~1km north of Fishery Falls township (GR 807008, Bartle Frere 1:100 000 Sheet area).

Plate 25. Extensively deformed Bellenden Ker Granite, with biotite 'fish', and ribbon quartz. Outskirts of Babinda (GR 849822, Bartle Frere 1:100 000 Sheet area). Crossed polarisers; magnification x16.

Plate 26. Intensely deformed, highly porphyritic/megacrystic biotite granite, with prominent 'S' and 'C' planes. Bellenden Ker Granite, south-east of Bramston Point (GR 931898, Bartle Frere 1:100 000 Sheet area).

Plate 27. Mount Quincan cone, viewed from the east (Peeramon Road, GR 502865, Bartle Frere 1:100 000 Sheet area).

Plate 28. Quarry in stratified scoria, northern flank of Mount Quincan. Note the numerous blocks of mainly peridotite and lherzolite in the deposits.

Plate 29. Lynch's Crater viewed from the north. Note the breach in the crater wall to the south and the flat, marshy floor of the crater. The crater contains peat deposits, which support a small-scale mining venture.

Plate 30. Millaa Millaa Falls on Theresa Creek, about 2km north of Millaa Millaa. The creek is flowing over a thick basalt flow with well-developed columnar jointing.

Plate 31. Tchupala Falls on Henrietta Creek, Palmerston National Park.

Plate 32. Basalt lava flow, probably forming part of the Fisheries Basalt. Bed of the East Mulgrave River upstream of the junction with the West Mulgrave River, western flank of the Bellenden Ker Range. The dense vegetation on the riverbanks is typical of that on much of the coastal ranges and environs.

Plate 33. *Steeply dipping quartz vein of the Chance lode, exposed in wall of an abandoned shaft, Goldsborough.*

Plate 34. Abandoned deep-lead working. Upper Russell River (Boonjie) area (GR 661735, Bartle Frere 1:100 000 Sheet area). Deeply weathered Cainozoic sediments are overlain by a relatively thick (~ 30m), columnar jointed basalt lava flow. The deposits were worked mainly by hydraulic sluicing.

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Copies of this publication are available from the Department of Mines and Energy, Level 5, 61 Mary Street, PO Box 194, Brisbane, Qld 4001. For further information contact the Geological Information HOTLINE, Ph: 07 3006 4666 or email: geological_info@dme.qld.gov.au.

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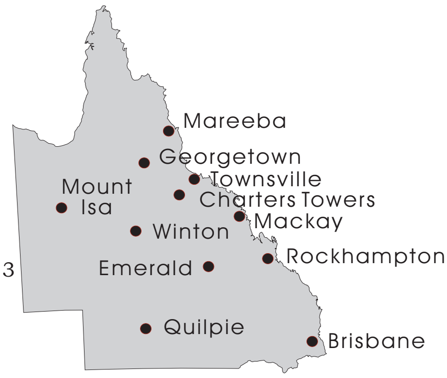

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