GEOLOGY AND MINERALISATION OF THE TEXAS REGION, SOUTH-EASTERN QUEENSLAND

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SUMMARY

This report describes the geology, mining history, and mineralisation of rock units in the Queensland portion of ALLORA (and western part of WARWICK), INGLEWOOD, TEXAS (and north-eastern part of ASHFORD), and STANTHORPE (and western part of DRAKE) 1:100 000 map sheets which cover the bulk of the Texas region in south-eastern Queensland. The area forms part of the Woolomin and Silverwood Provinces within the central part of the New England Orogen (NEO). The Woolomin Province comprises Palaeozoic rocks of the Texas and Silver Spur Subprovinces, as well as igneous rocks of the Stanthorpe Batholith. The Silverwood Province contains the constituent formations of the Silverwood Group, a ?Cambrian to Devonian package of island arc volcanic and sedimentary rocks. These rocks together with the accretionary wedge rocks of the Texas beds (belonging to the Texas Subprovince of the Woolomin Province) were accreted to the craton margin during Late Devonian to Late Carboniferous Andean-style subduction at the eastern margin of the Australian continents. The Texas beds sediments are rich in felsic volcanic detritus derived from the active magmatic arc to the west.

During the Late Carboniferous, the tectonic setting changed from a purely convergent plate margin to a combination of transform faulting and subduction. The site of subduction moved to the east. The rocks of the now inactive accretionary wedge were folded into a large double oroclinal structure, the western portion of which forms the Texas Megafold. Back-arc extension and also possibly orocline-related transtension produced a number of Early Permian basins of the Silver Spur Subprovince, developed on the older deformed accretionary wedge. Immature diamictite-rich volcaniclastic sediments and minor felsic volcanics were deposited in these basins. During this time a felsic pluton the (Bullaganang Granite) was intruded into the core of the Texas Megafold, followed later in the Early Permian by intrusion of the Greymare Granodiorite.

After the period of Early Permian sedimentation, the region was affected by uplift, faulting and local folding related to the first phase of the episodic Hunter–Bowen Orogeny. This uplift was succeeded by post-orogenic Late Permian mainly felsic volcanism, and sedimentation (concentrated mainly across the border in New South Wales) produced a range of rock packages assigned to the Wandsworth Province. The volcanism was accompanied by the emplacement of numerous co-magmatic granitic plutons ranging from small stocks to large composite batholiths. The latter continued to be intruded until the Early Triassic as dominantly hornblende-bearing I-type plutons assigned to the New England Batholith. The most extensive bodies of granite occur in the Stanthorpe area, where they are mapped as the Ruby Creek Granite, the Ballandean Granite, and variants of the Stanthorpe Granite. With the exception of the Ballandean Granite these granites are post-orogenic leucogranites. The Ruby Creek Granite is considered to be the source of most of the tin-tungsten-molybdenum mineralisation in the area. The extent of this pluton is difficult to map throughout the area.

Large volumes of quartz-rich sand were derived from the uplifted and unroofed granitic rocks in the Latest Triassic to Middle Jurassic and were deposited by an extensive stream network to form the basal units of the Clarence–Moreton and Surat basin. Tertiary deep weathering and concentration of heavy minerals in stream channel alluvium resulted in the formation of rich alluvial cassiterite deposits.

Mineralisation in the Texas region in Queensland includes tin, tungsten, arsenic, molybdenum, bismuth, gold, silver, copper, lead, zinc and manganese. Limestone, marble, building stone, and gemstone deposits also occur in the area. Tin was the main commodity mined in the Stanthorpe area. Alluvial cassiterite deposits in the Stanthorpe area and minor lode deposits at Sundown, Mineral Hill and Sugarloaf have produced 56 537t of cassiterite concentrates since 1872. The entire arsenic production of Queensland (2290.5t of arsenic oxide and 2150t of arsenic concentrates) came from the State Arsenic Mine at Jibbinbar and from mines in the Sundown area.

The first gold deposits in Queensland were discovered in the south-east of Warwick in 1852 and further productive reef and alluvial fields were established west of the town. The main period of production was from the late 1800s to early 1900s, but sporadic small-scale activity continued on these fields until 1998.

Some notable base metal deposits were also developed in the region, the most important of which was the Silver Spur Mine, discovered east of Texas in 1890. The mine was worked most intensively from 1892–1914, with some sporadic production until 1976. Total production was 68t of silver, 1950t of lead, 690t of zinc, and 140kg of gold.

Sporadic mining of manganiferous jasperoidal bodies in the Texas beds has occurred since the late 1800s. Most of the major manganese mines (War Effort, Mount Fuller and Mount Devine) are located on INGLEWOOD, although some small deposits (Mount Gammie, The Glen) also occur to the east on ALLORA.

Mineral deposit types in the study area include: epithermal to mesothermal reef gold, strata-bound manganese and late stage alteration-related magnetite accumulations in the Texas beds; tin, tungsten, molybdenum, arsenic and base metal deposits related to the Ruby Creek Granite; strata-bound and shear-hosted base metal sulphide deposits in Early Permian units; and alluvial/ eluvial placer deposits.

Mineral exploration since 1966 has been mainly for large tonnage, low-grade tin deposits, alluvial tin deposits, and precious metal-base metal sulphide deposits and industrial minerals such as building stone. Significant, but subeconomic, discoveries include sheeted Sn vein systems in the Sundown and Sugarloaf areas.

Sheeted vein systems offer the best potential for hard rock tin deposit discoveries. Palaeogravels of probable Tertiary age have potential as sources of alluvial tin. Permian sedimentary and volcanic units are targets for precious and base metals.

Keywords. Regional geology; tectonics; mineralisation; ore genesis; mining history; mineral exploration; resource potential; tin; tungsten; arsenic; molybdenum; silver; copper; lead; zinc; bismuth; gold; manganese; limestone; building stone; gemstones; Risdon Stud Formation; Connolly Volcanics; Bald Hill Formation; Ormoral Volcanics; Bromley Hills Formation; Texas beds; Bondonga beds; Pikedale beds; Terrica beds; Alum Rock Conglomerate; Silver Spur beds; Wallangarra Volcanics; Dundee Rhyodacite; Stanthorpe Granite; Ruby Creek Granite; New England Orogen; Woolomin Province; Silverwood Province; Devonian; Carboniferous; Permian; Triassic; Tertiary Queensland/Stanthorpe; Queensland/Drake; Queensland/Warwick; Queensland/Texas; Queensland/Inglewood; Queensland/Ashford; Queensland/Allora; SH 56-02 9240; SH 56-02 9340, SH-02 9341; SH 56-02 9241; SH 56-01 9141, SH 56-01 9140; SH 56-01 9139.

INTRODUCTION

The Texas region encompasses a range of geological environments whose historical mineral production indicates potential for the development of future mineral resources. The region is also an important grazing centre (mainly for sheep as well as some cattle) and an important producer of agricultural produce including grapes, olives, stone fruit and grain products. Sundown and Girraween National Parks (south of Stanthorpe) attract significant numbers of tourists to the region.

The Geological Survey of Queensland carried out the current survey between 1999 and 2004, with the aim of producing a base dataset for mineral exploration and landuse purposes. This study also includes work done by one of the authors (D. Purdy) as part of an MSc project. Most of the chemical analyses plotted on variation diagrams in following sections are of samples collected by Bultitude as part of the recent AMIRA P515 project.

Airborne radiometric and magnetic geophysical surveys as well as air-photo coverages were extensively used to re-interpret the geology of the area, combined with field checking of selected areas. The new mapping updates the earlier 1:250 000 scale government mapping of the area conducted in 1968.

The current survey also included mineral occurrence (MINOCC) mapping of the Allora 1:100 000 Sheet area to complement earlier MINOCC mapping of the surrounding Stanthorpe, Texas, Ashford and Inglewood 1:100 000 Sheet areas conducted between 1989 and 1992. Sections on mineralisation are mostly restricted to the Queensland part of the project area, and exclude New South Wales occurrences. Grid references cited in the text refer to Map Grid of Australia, zone 56 coordinates (based on the GDA94 datum).

LOCATION AND ACCESS

The Texas Region straddles the New South Wales–Queensland border south-west of Brisbane, and covers the area of the ALLORA, INGLEWOOD, TEXAS, and STANTHORPE 1:100 000 map sheets. The major population centres are Warwick in the north-east (on ALLORA), linked to Stanthorpe in the south-east (on STANTHORPE) by the New England Highway, and to Inglewood in the west (on INGLEWOOD) by the Cunningham Highway.

The small town of Texas (on TEXAS) is the major centre in the south-west of the region and is linked by a major sealed road to Inglewood and by a network of lower standard sealed roads to Stanthorpe. Access throughout the region is generally good via an extensive network of sealed and unsealed roads as well as numerous station tracks.

PHYSIOGRAPHY

The region forms the crest and flanks of the Great Dividing and Herries Ranges and exhibits landforms ranging from rugged mountains to gently undulating hills and plains. The greatest elevations occur in the south-east on STANTHORPE, where granite massifs and volcanic outcrops typically stand several hundred metres above mature sandy flats. Resistant rock types within the Palaeozoic units north and west of Stanthorpe (mainly cherts and siliceous arenites) form bed-parallel ridges which locally form rugged country.

An expansive area of indurated Palaeozoic rocks in the Sundown area also forms a rugged plateau incised by the Severn River and other tributaries of the Dumaresq River. The western and north-eastern parts of the region (on TEXAS/ INGLEWOOD and ALLORA/WARWICK respectively) exhibit more mature landscapes defined by flat-lying Mesozoic and younger deposits which are drained by the Dumaresq–Macintyre River and Condamine River systems respectively.

PREVIOUS INVESTIGATIONS

Numerous brief geological reports dating back as far as 1869, and covering small parts of the area and individual mineral deposits, are found in the literature. Aplin (1869a,b,c,d) was the first to describe the mines on the Talgai, Thanes Creek, Canal Creek and Lucky Valley Goldfields. Archibald (1888) described the major gold mines of the Warwick district, including the Mountain Maid, Malakoff, Perseverance, Lady Caroline, Lucky Valley, Glenelg, Queen, Gladstone, Big Chum, Big Hill, Queenslander, Taylor, and Prince of Wales mines.

The first general report on the regional geology and mineralisation of the Stanthorpe district was by Skertchly (1898). This work was updated by Saint-Smith (1914a).

Richards & Bryan (1923, 1924) conducted further studies, concentrating mainly on the Silverwood area south-east of Warwick. Knowledge of the Drake area in New South Wales was successively built up by Andrews (1908) and Voisey (1936, 1939). Lucas (1957, 1958, 1960a,b,c) mapped the Palaeozoic rocks west of the New England Batholith. Simmonds (1958), McDonagh (1962), Robertson (1964), Phillips (1966), Oxley (1972), Berg (1973), Butler (1974), McLean (1976), Sorby (1976), Forster (1991) and Cohen (1991) carried out Honours and Ph.D. mapping projects in the area. Van Noord (1999b) carried out a Ph.D. project covering the Silverwood area and his results have been largely incorporated into the current mapping.

The Bureau of Mineral Resources and the Geological Survey of Queensland mapped the area in 1968 (Olgers, 1974; Olgers & others, 1974; Robertson, 1974). The geology of the area was updated as part of the Moreton Geology Map (Whitaker & Green, 1980).

Thomson (1976) reported on the geology and mineralisation of the Drake 1:100 000 Sheet area. Denaro (1989) has reported on mineralisation in the Inglewood, Texas and Ashford 1:100 000 Sheet areas. Production data for mines in the Stanthorpe area were compiled by Denaro (1992a), and mineralisation in the Stanthorpe–Texas area has been described by by Denaro (1992b). Denaro & Burrows (1992) described mineral occurrences on the Stanthorpe and Drake 1:100 000 Sheet areas.

REGIONAL SETTING

The major Palaeozoic rock units of the Texas region form part of the New England Orogen (NEO), a north-trending fold belt running along much of the eastern margin of the Australian craton (see Figure 1). The exposed parts of the orogen within the study area encompass three major structural entities — the Silverwood and Woolomin Provinces (comprising the Silverwood Group, and Texas and Silver Spur Subprovinces; see Figures 2 and 59), and the Wandsworth Province (comprising Late Permian volcanics with some sediments). Extensive areas of Early Permian to Triassic plutonic rocks belonging to the New England Batholith intrude the rocks of the Woolomin and Silverwood Provinces. The Palaeozoic rocks and plutonics are unconformably overlain by Mesozoic continental sediments of the Clarence–Moreton and Surat basins (see Figure 2). Tertiary volcanics of the Lamington–Main Range Province and Tertiary to Quaternary morphostratigraphic units.

The Woolomin and Silverwood Provinces consist of variably-deformed marine sediments and volcanics ranging in age from ?Cambrian to early Permian. Lithic greywacke and argillite are the dominant rock types, together with less abundant chert, minor mafic volcanics and scattered limestone bodies. These rocks formed in various marine settings east of the Australian craton, but were ultimately accreted to the continental margin during Devonian–Carboniferous plate convergence. The resultant subduction complex was flanked to the west by a coeval belt of forearc rocks assigned to the Yarrol–Tamworth Province, which is not exposed in the study area (see Figure 2). When subduction ceased along this margin in the Late Carboniferous the accretionary wedge rocks of the Texas Subprovince (as well as the forearc Yarrol–Tamworth Province rocks) were folded into a large double orocline. Sedimentation and calc-alkaline volcanism resumed in the Early Permian and volcanic and volcaniclastic rocks of the Silver Spur Subprovince were deposited in fault-bounded, extensional or pull-apart basins superimposed on the deformed accretionary wedge rocks.

Permian and Triassic calc-alkaline volcanics and granitoids post-date the deformed assemblages. The undeformed granitoids comprise Early Permian to Middle Triassic I-type granites of the New England Batholith. Some of the I-type intrusives are highly fractionated leucocratic granites which are the major mineralising systems within the map sheet area. The Stanthorpe Granite and Ruby Creek Granite are post-orogenic leucogranites which form a large batholith in the centre of the study area. The Ruby Creek Granite is considered to be the source of most of the mineralisation in the Stanthorpe area.

Late Permian silicic volcanics, with some associated sediments (the Wandsworth Volcanic Group of the Wandsworth Province), occur as a small area in the

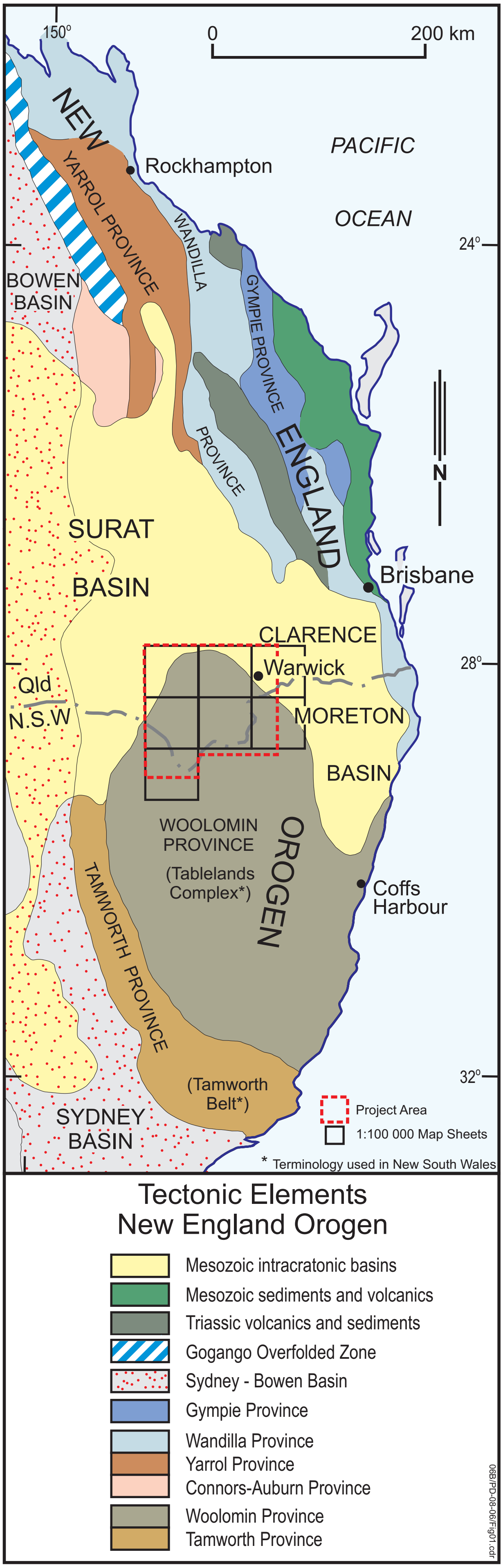

Figure 1. Tectonic elements of the New England Orogen, eastern Australia

far south-east of STANTHORPE but are much more extensive across the border in New South Wales. They include ignimbrites, lavas and subvolcanic intrusives preserved as eroded remnants of volcanic cauldrons and ignimbrite sheets. These volcanics are typically intruded by granitoids. Late Permian volcanic remnants also occur south-east of Warwick. Subsequent to Late Permian magmatic activity, the NEO became a tectonically stable landmass, with the Woolomin and Silverwood Provinces forming a mountainous upland into the Mesozoic.

Formation of the Mesozoic Clarence–Moreton Basin commenced in the latest Triassic (Wells & O'Brien, 1994), and deposition extended to the Early Cretaceous (McElroy, 1962, 1969). The basinfill comprises >7000m of fluvial sediments, with minor volcanics at the base.

In the Tertiary, continental volcanics and coarse continental sediments were deposited. The volcanics were sourced from shield volcanoes (Ewart, Stevens & Ross, 1987) located to the east of the study area (the Mount Warning and Focal Peak shield volcanoes). Very minor subvolcanic rhyolite occurs in the north-east of region.

Alluvial events recorded in stream valley landforms have been mapped as morphostratigraphic units, rather than lithostratigraphic units.

Mineral deposit types in the Queensland part of the study area include mesothermal and epithermal vein gold and stratabound manganese accumulations in the Texas beds and tin, tungsten, molybdenum, arsenic and base metal deposits related to emplacement of the Ruby Creek Granite.

The major structural groupings and their constituent rock units in the Texas region are described in more detail below.

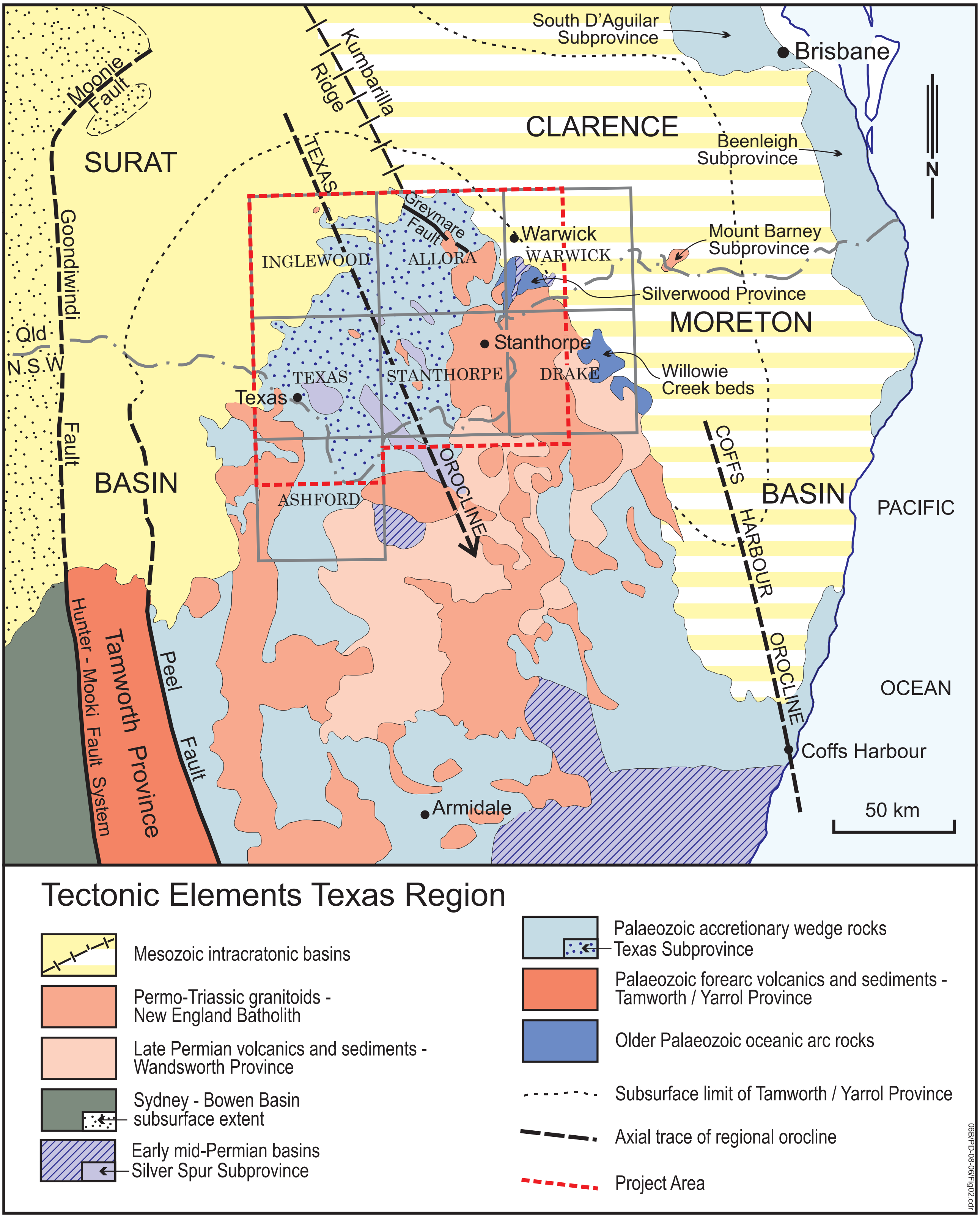

Figure 2. Tectonic elements of the Queensland–New South Wales border region

STRATIGRAPHY

PALAEOZOIC ROCKS

SILVERWOOD PROVINCE

The Silverwood Province comprises the various formations of the Silverwood Group, which are present only in the Warwick area, although equivalents and informal unit subdivisions are recognised to the north and south of this area. The distribution of the various units of the Silverwood Group is shown in Figure 3, based largely on the work of Van Noord (1999b).

Silverwood Group (*SDs, SDs$_m$*)

The Silverwood Group (**SDs**) represents a mixed package of marine volcaniclastic, clastic and volcanic rocks exposed as a roughly triangular block covering around 100km^2, mainly between Warwick and the New South Wales border. The unit extends as small outcrops into New South Wales where it is truncated and metamorphosed by a series of later granitoid masses. In the Bakers Hill area south-east of Maryland, a small mass of fine grained metadolerite and metabasalt has been mapped as subunit **SDs$_m$**. Further south into New South Wales, the sequence is again exposed as the Willowie Creek beds (see Figure 2), which van Noord (1999a) has recently confirmed as being equivalent to the Silverwood Group. Olgers & others (1974) divided the Silverwood Group into three formations, the Risdon Stud Formation (base), the Connolly Volcanics and the Rosenthal Creek Formation (top). In Queensland, the Silverwood Group corresponds to the Keinjan Terrane of Flood & Aitchison (1988). The group is thought to represent a long complex history of sedimentation, mainly in an island arc setting (Marsden, 1972; Fergusson, 1982; Van Noord, 1999a). Van Noord postulated a thickness of ~10km for the Silverwood Group, but this figure probably results from some structural thickening of the unit. Early Devonian marine macrofossils have been described from the unit (Richards & Bryan, 1924; Hill, 1940, 1942; Strusz *in* Olgers, 1974; Wass & Dennis, 1977) although Wass & Dennis (1977) also recorded Late Ordovician bryozoans from limestone clasts in diamictite. Early Devonian conodonts faunas were also described by Telford (1972) and Mawson in Van Noord (1999b). Radiolaria have also been found at numerous localities throughout the unit, but proved to be too poorly preserved to allow identification (Van Noord, 1999b).

Van Noord (1999a) revised the subdivisions of Olgers & others (1974) and retained the Risdon Stud Formation and much of the Connolly Volcanics, but subdivided the remaining outcrop areas into the Bald Hill Formation overlain by the Ormoral Volcanics at the base with the Bromley Hills Formation forming the uppermost unit. Unconformities exist at the base of the Bromley Hills and Bald Hill Formations, but these are interpreted to represent geologically insignificant time breaks during the protracted evolution of a tectonically unstable volcanic arc environment. As a result, the group status of the rock package is maintained here. The following unit descriptions are largely derived from Van Noord (1999a).

Risdon Stud Formation (*Sri*)

The Risdon Stud Formation (**Sri**) is the westernmost unit and comprises silicified, fine grained cherty pyroclastic andesitic crystal-lithic tuffs, interbedded with subordinate thin to medium bedded, fine-grained silicified turbidites with a total thickness of ~2500m (Van Noord, 1999b). The formation was probably deposited at some distance from an active volcanic arc in a slope-apron setting within a marginal basin, at depths of 1200–2000m. The unit is unfossiliferous, apart from poorly preserved radiolaria. As the unit lies conformably below the Connolly Volcanics, which in turn lie below the dated Bald Hill Formation, the Risdon Stud Formation is at least older than Early Devonian. Based on sedimentation rates of comparable sequences, Van Noord (1999a) suggests a late Early Cambrian to middle or late Silurian age range for the formation. However, the age range is almost certainly significantly less due to structural repetition within the sequence, and we have assigned a Silurian age to the unit.

Connolly Volcanics (*SDc*)

The Connolly Volcanics (**SDc**) overlie the Risdon Stud Formation and comprise a volcanic-rich lower sequence and more clastic-dominated upper sequence with a total thickness of ~2430m (Van Noord, 1999b). The lower sequence consists of submarine pyroclastics and lavas (and associated intrusive dolerites), which are of low-K tholeiitic basaltic to locally dacitic composition deposited in an intra-arc basin environment (Van Noord, 1999a). The upper sequence is dominated by thin-bedded turbidites, with scattered coarse conglomeratic horizons and limestone lenses. This sequence is rich in primary volcaniclastic debris derived by subaerial erosion of an intermediate volcanic arc some distance away. Pyroclastic facies and sediment geochemistry suggest depths of deposition ranging from 1200–2000m.

The age of the Connolly Volcanics is uncertain as it contains no recoverable fossils, apart from poorly preserved radiolaria. The unit is older than the overlying Emsian Bald Hill Formation and Van Noord (1999a) suggests a Middle or late Silurian to

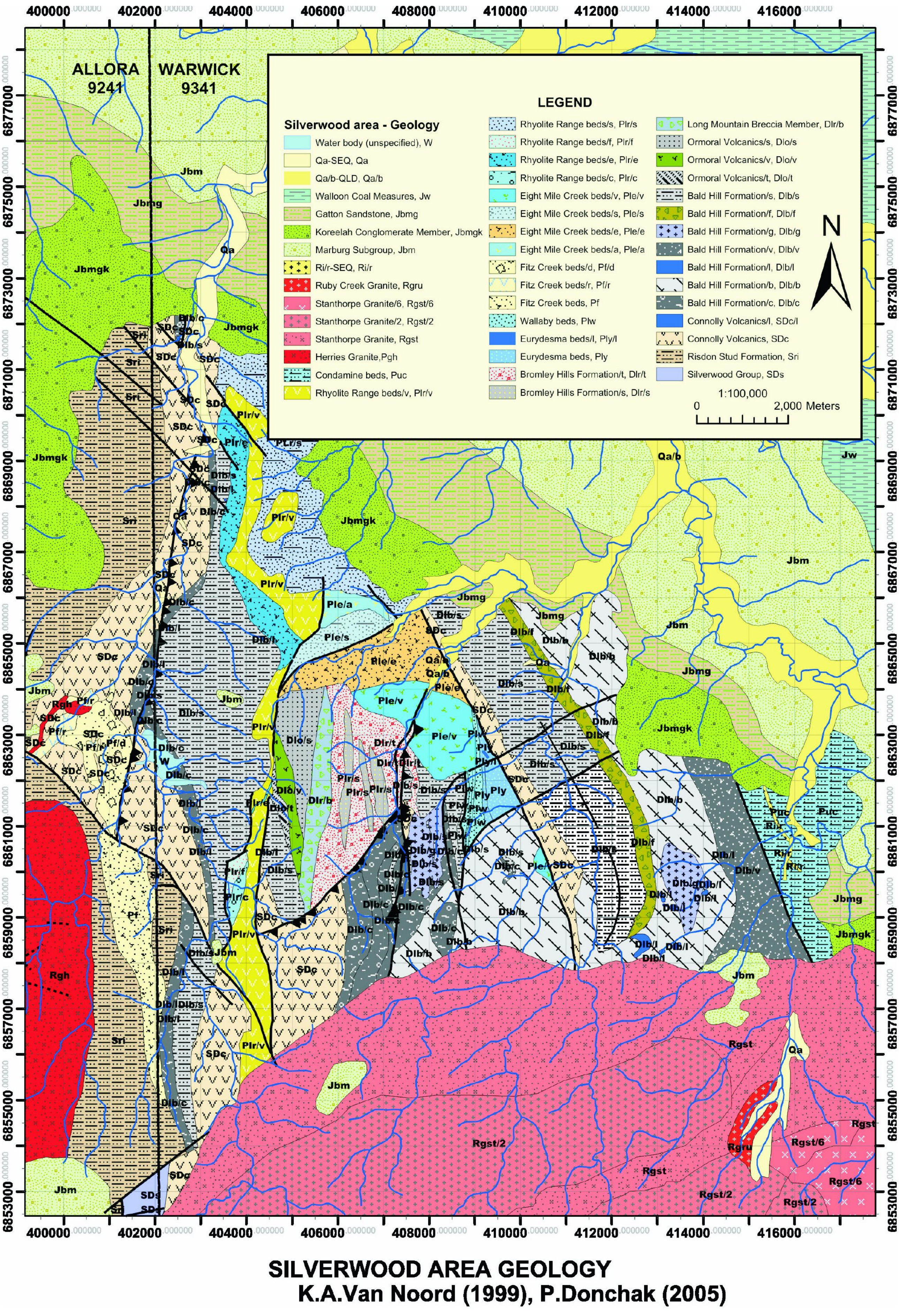

Figure 3. Silverwood area geology

Click for more detailed figure

Early Devonian age range based on inferred rates of deposition for comparable sequences. However, we consider this to be an unreliable estimate due to probable structural thickening of the unit, and suggest a Late Silurian to Early Devonian age for the Connolly Volcanics.

Bald Hill Formation

(Dlb_c, Dlb_v, Dlb_s,Dlb_b, Dlb_g, Dlb_f, Dlb_l)

The **Bald Hill Formation** is the most extensive unit of the group, occupying over half the outcrop area and has a total thickness of ~2450m (Van Noord,1999b). In most places, this unit is separated from the Connolly Volcanics by an unconformity, which is considered by Van Noord (1999b) to represent a geologically insignificant time-break. The unit has been subdivided into three major packages of rocks. The basal package (subunit $\mathbf{Dlb_c}$) is characterised by polymictic para-conglomerate and breccia containing large olistostromal blocks of thin-bedded turbidite, chert, mafic volcanics and limestone derived from older sequences of the Silverwood Group. These rocks exhibit exceptional textural and compositional variation along strike, and represent coarse debris flow deposits produced during a period of uplift and shelf-edge failure.

The overlying package of rocks is dominated by largely syn-depositional sills and locally emergent cryptodomes of low-K tholeiitic basalt and basaltic andesite together with some peperites, volcaniclastic deposits (including hyaloclastites and debris flows) and limited lava flows. Four lithological subdivisions of this sequence have been recognised (subunits $\mathbf{Dlb_v}$; $\mathbf{Dlb_b}$, $\mathbf{Dlb_g}$; $\mathbf{Dlb_f}$). Subunit $\mathbf{Dlb_v}$ comprises a variety of metabasite bodies, peperites and associated volcaniclastic deposits. $\mathbf{Dlb_b}$ is dominated by metabasite sills and hypabyssal intrusions ranging from basalt to dolerite or gabbro, as well as some lavas. Small limestone bodies within the sequence have been separated out as subunit $\mathbf{Dlb_l}$. A large medium to coarse grained metagabbro sill — the Kelvin Falls Sill — has been delineated as subunit $\mathbf{Dlb_g}$. The sill is thought to represent a partly emergent cryptodome. Draped over these intrusive dominated sequences is a series of basaltic hydroclastic debris flow deposits mapped as subunit $\mathbf{Dlb_f}$.

The third lithological package within the Bald Hill Formation (subunit $\mathbf{Dlb_s}$) is characterised by a series of thin-medium bedded mud/sand turbidites and some chert, showing abundant evidence of soft-sediment deformation (including sedimentary melange) probably resulting from widespread slope instability. The upper part of this slumped sequence contains large olistoliths of chert, volcanic rocks and limestone derived from older components of the Silverwood Group. The deposits within this sequence have a much lower volcaniclastic component than similar rock types in the underlying formations, indicating a more distal relationship to any contemporaneous volcanic arc.

Coral faunas retrieved from limestone lenses and clasts constrain the age of the formation to between Pragian and Emsian (Jell, 1988). Conodont faunas from the limestones and enclosing sediments further refine the age of the unit to Early Emsian (Telford, 1972; Van Noord, 1999b). Late Ordovician bryozoans have been recorded from limestone clasts in conglomerates south-west of Rokeby (Wass & Dennis, 1977), indicating erosion of an older emergent sequence now no longer exposed.

Ormoral Volcanics

(Dlo_v, Dlo_t, Dlo_s)

The **Ormoral Volcanics** form a volcanic wedge that conformably overlies the Bald Hill Formation in the central part of the outcrop area. These rocks are characterised by low-K tholeiitic submarine extrusive rocks and also contain some hypabyssal rocks with a range of compositions including dolerite, anorthosite, basalt, basaltic andesite and andesite of backarc basin affinity. The extrusive rocks include pillow lavas, hyaloclastites and peperites that contain sporadic interbeds of proximal epiclastic high-density turbidites. The latter are particularly common in the lower part of the unit. A series of lapilli breccias and associated tuffaceous sediments is present toward the base of the unit sourced from nearby emergent andesitic to dacitic/rhyolitic volcanoes. The lavas and associated metabasites have been subdivided as subunit $\mathbf{Dlo_v}$, while the volcaniclastic turbidite/peperite sequences have been mapped as subunit $\mathbf{Dlo_t}$. Thick amalgamated volcaniclastic arenite sequences have been mapped as subunit $\mathbf{Dlo_s}$.

The unit attains a maximum thickness of ~620m and is interpreted to have been deposited in a deep marine intra-arc basin at depths ranging from 1700–3100m. No macrofossils or microfossils have been recovered from the unit, but the sequence is interpreted to have rapidly succeeded the Bald Hill Formation, indicating an early Middle Devonian age (Van Noord, 1999b).

Bromley Hills Formation

(Dlr_s,Dlr_t, Dlr_b)

The **Bromley Hills Formation** is exposed in the centre of the outcrop area, where it overlies the Bald Hill Formation and Ormoral Volcanics with an angular unconformity along its western border, and is faulted against the Bald Hill Formation and Connolly Volcanics along its southern margin. The Eight Mile Creek beds unconformably overlie the unit along its northern border. The formation has a total thickness of ~1720m.

The unit is characterised by sand-rich volcaniclastic turbidites containing detritus mainly of basic to acid low-K to calc-alkaline composition, sourced from an adjacent intra-oceanic island arc. In addition to the volcaniclastic detritus, carbonate-coated grains and ooid fragments sourced from a nearby shelf form an important minor component of the sediments.

The basal part of the Bromley Hills Formation is the **Long Mountain Breccia Member** (subunit **Dlr**$_\mathbf{b}$) — a 350m-thick sequence of polymictic megabreccia, capped by 60m of cross-stratified pebbly arenite. The megabreccia contains fragments of basaltic to andesitic composition as well as various types of clastic sedimentary blocks, and is thought to represent a debris flow deposit initiated by catastrophic collapse along the margins of a stratovolcano. The overlying part of the formation contains two lithological associations, subunits **Dlr**$_\mathbf{s}$ and **Dlr**$_\mathbf{t}$. The latter is typified by thin-bedded arenite/mudstone turbidites punctuated by gravel-rich bands and debris-flow deposits, while the former is dominated by very thick-bedded amalgamated coarse sandy turbidites. The thin-bedded turbidites have higher sand/mud ratios and thicker sand beds than similar rocks in the Risdon Stud and Bald Hill Formations. These turbidite sequences are thought to form part of a sand-rich point-source submarine fan system.

No fossils (other than radiolaria which could not be extracted) have been found within the unit, so the age of the sequence remains uncertain. On the basis of similarities with the upper parts of the nearby Texas beds (the presence of ooids and carbonate fragments), Van Noord (1999b) suggested a broadly corresponding age — Middle Devonian to early Carboniferous for this unit. However, we consider the formation to be largely older than the Texas beds, probably Middle to Late Devonian.

The Silverwood Group is probably equivalent to elements of the Gamilaroi terrane exposed to the south along the Peel Fault in New South Wales. The latter contains a number of sequences ranging in age from Cambrian to Devonian thought to have developed in an intra-oceanic arc rift environment similar to that postulated for the Silverwood Group (Offler & Gamble, 2002).

WOOLOMIN PROVINCE

Texas Subprovince

Texas beds

(*Ctx, Ctx, Ctx*$_j$*, Ctx*$_v$*, Ctx*$_l$*, Ctx*$_m$*, Ctx*$_{cg}$*, Ctx*$_w$)

The Texas beds (**Ctx**) form the most extensive unit in the Texas region, covering the eastern margin of the Goondiwindi 1:250 000 Sheet and the bulk of the adjoining Warwick 1:250 000 Sheet. The unit was originally defined by Olgers & others (1974), and has been more recently subdivided by Fergusson & Flood (1984) into four tectono-stratigraphic subunits (Ct1 to Ct4) on the basis of relative abundances of contained lithologies. Major north-west-trending fault networks were used to separate these lithological zonations. However, the current survey has shown that only the northernmost clastic sequence differs lithologically to any significant degree from clastics to the south, and as such has been mapped as subunit **Ctx**$_\mathbf{m}$ (equivalent to subunit Ct1 of Fergusson & Flood, 1984).

Figure 4. Folded, thin to medium bedded turbidites of the Texas beds; MGA 373600 6832800

The current subdivisions show that the Texas beds form a sequence of volcaniclastic turbidites (lithic arenite and mudstone) (units **Ctx** and **Ctx**$_\mathbf{m}$) with minor chert/argillite and/or jasper/argillite (mapped as **Ctx**$_\mathbf{c}$ and **Ctx**$_\mathbf{j}$ respectively), altered mafic volcanics (mapped as **Ctx**$_\mathbf{v}$) and limestone (mapped as **Ctx**$_\mathbf{l}$). The mafic volcanic rocks within the formation are mostly basaltic in composition, and often occur in association with manganiferous jasperoidal rocks. The Texas beds turbidites commonly comprise rhythmically interlayered volcaniclastic arenite and mudstone (see Figure 4), although the sequence shows continuous variation towards either thick amalgamated arenite-dominated or pelite dominated end-members. The pelitic component ranges from phyllite to slate. The well-bedded arenites commonly show grading and locally display ripple cross-lamination (especially in thin to medium beds). Arenites throughout the Texas beds typically consist of silicic volcaniclastic detritus with <10% matrix (see Figures 5 and 6). Lithic sedimentary grains and granules (including some mafic fragments and rare granitic grains) are locally common in coarser lithologies. Radiolarian chert grains are a minor lithic component in some arenites (see Figure 7).

Subunit **Ctx**$_\mathbf{m}$ occurs north-east of the Greymare Fault (see Figure 2) and is characterised by

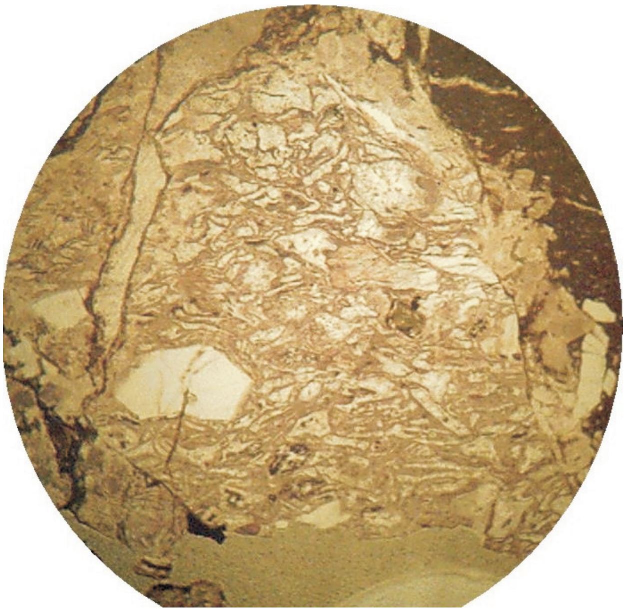

Figure 5. Welded ignimbrite grain in Texas beds arenite; field of view 1mm; MGA 368446 6850920

Figure 6. Shard-rich, siliceous tuff grain in Texas beds arenite; field of view 5mm; MGA 363569 6827510

relatively continuous bed-parallel linear aeromagnetic responses, contrasting with more subdued or sporadically high magnetic response shown by the rest of the unit. The sequence comprises thin to thick-bedded turbidites, including massive fine to medium-grained arenite, massive to thin-bedded cream to bluish-grey chert with phyllitic mudstone interlayers, and meta-basalt lava and some tuff. The linear magnetic character may reflect the presence of numerous thin bands of mafic lava and/or poorly exposed igneous sills, as well as magnetite alteration of chert/jasper beds (e.g. at MGA 364706 6898488).

The clastic rocks of subunit **Ctx$_m$** consist largely of felsic volcaniclastic detritus similar to most of the Texas beds. However, some of the thinner-bedded siltstone sequences north of Pratten (Figure 8) are locally rich in glass shards as well as what appear to be fine bands rich in spherules of uncertain origin (see Figures 9 and 10). The spherules may represent impact-related microtektites or glass microbeads produced by lava fountaining. These beds also locally contain collapsed radiolarian tests (Figure 11). Independent radiolarian dating at this site indicates a probable Visean age for this part of the sequence (at MGA 380206 6894288; sample site UNE L 1914 — Aitchison & Flood, 1990a). Abundant ooliths have been reported from the sequence west of Carondale homestead, (P. Flood, personal communication, 2002), but no further occurrences were found during the current survey. Subunit **Ctx$_m$** is strongly tectonised with a bedding-parallel slaty cleavage common throughout the clastic rocks. An anastomosing melange-style fabric is widespread in argillite-rich sequences which contain dismembered thin to medium beds of more competent material such as chert or siltstone enclosed in a scaly mudstone matrix.

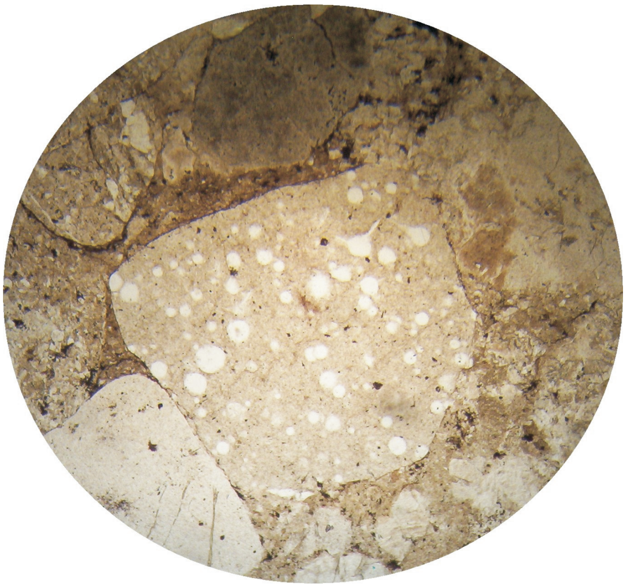

Figure 7. Radiolarian chert grain in Texas beds arenite; field of view 5mm; MGA 363569 6827510

Figure 8: Thin-bedded siliceous siltstone and mudstone within subunit Ctx$_m$ north of Pratten; MGA 380206 6894288

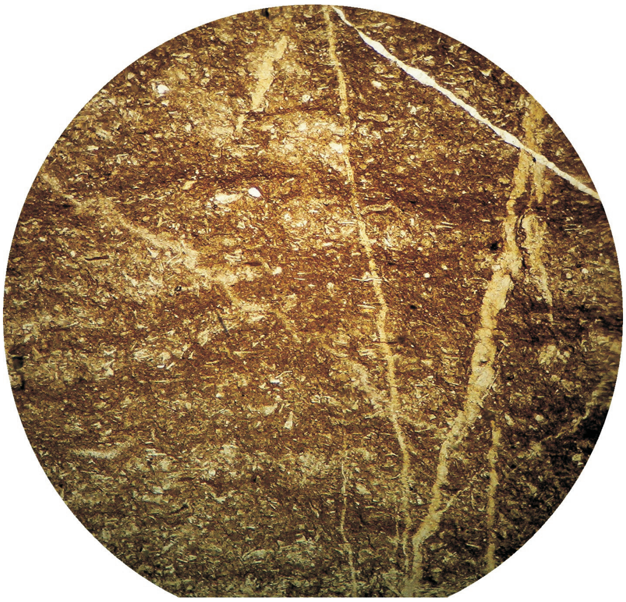

Figure 9. Tuffaceous siltstone from Texas beds, north of Pratten; glass shards scattered throughout matrix; field of view 5mm; MGA 380206 6894288

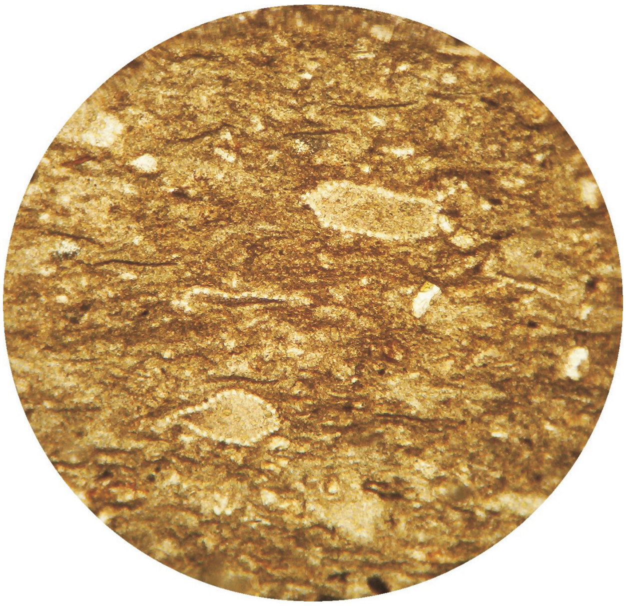

Figure 11. Collapsed radiolarian tests in tuffaceous siliceous siltstone of the Texas beds north of Pratten; field of view 1.5mm; MGA 380206 6894288

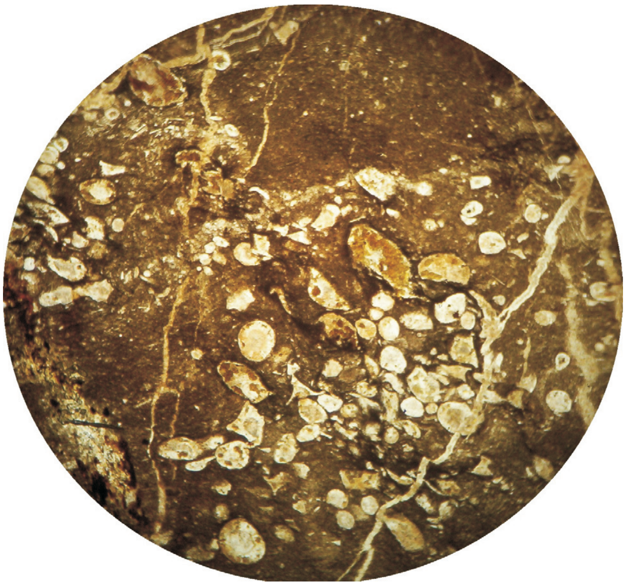

Figure 10. Unidentified spherules forming bands in tuffaceous siliceous siltstone of the Texas beds north of Pratten; field of view 5mm; MGA 380206 6894288

The undivided Texas beds (**Ctx**) immediately south-west of the Greymare Fault are equivalent to *subunit Ct2* of Flood & Fergusson (1984). This part of the sequence is dominated by turbidites of Mutti & Ricci Lucchi (1972) facies C and D, as well as some thick amalgamated arenite beds of facies A and B. This area also contains a few meta-basalt horizons. Chert, jasper, mafic lava (greenstone) and associated limestone horizons become more common within the greywacke/argillite sequence forming an arcuate, 20km-wide zone in the centre of the outcrop area (equating to *subunit Ct3* of Flood & Fergusson,1984).

The southernmost part of the Texas beds between Ballandean and Texas is roughly equivalent to *subunit Ct4* of Flood & Fergusson (1984). The sequence here is dominated by an arenite/massive blue-grey argillite sequence with very few greenstone/jasper associations. In the Sundown area, massive, strongly jointed, dark grey, silicified, medium to fine grained or locally gritty arenite predominates, along with some massive argillite — all with sedimentary structures and textures obliterated by extensive contact metamorphism presumably related to unexposed intrusions at depth. To the west of Sundown National Park similar rocks types occur, together with sporadic intervals of medium to thin bedded turbidite. The sequence here is less jointed and indurated, and displays better preserved bedding features.

The ***chert and jasper-rich sequences*** within the Texas beds have been mapped out as subunits **Ctx$_c$** and **Ctx$_j$**, respectively. The two lithological units commonly grade into each other at outcrop scale and may have cream to greenish variants. These cherts and jaspers commonly display thin, lensoidal bedding, with the siliceous layers alternating with seams or thicker beds of pelitic material. Locally these units are massive, recrystallised and are manganiferous (*e.g.* at Mount Gammie and The Glen), especially within the jasper-dominated sequences. The cherts and jaspers contain radiolaria, which give almost the only age dating control of the unit outside the limestone-bearing areas. Many jaspers are intimately interlayered with basalt, and in general the jaspers are more common in parts of the sequence containing mafic volcanics. However, several jasper bodies have no known associated or nearby mafic horizons.

Mafic extrusives (and minor high level intrusive equivalents) have been mapped as subunit **Ctx$_v$,** with the largest bodies confined to the central part of the unit. These rocks are mostly basalts of alkalic affinity, and include pillow lava (Figure 12) and

Figure 12. Pillow basalt from within the Texas beds south of Greymare; MGA 372350 6875200

Figure 13. Scoriaceous basaltic tuff overlying Texas beds submarine basalt flows south of Greymare; MGA 372580 6875820

Figure 14. Vesicular basalt block in crystal-rich basaltic tuff; MGA 341925 6883241

epiclastic/pyroclastic deposits, and are locally intimately associated with thin-bedded jasper sequences and quartzite. The lavas vary from massive to strongly porphyritic, and the tuffaceous types are locally strongly foliated. The pyroclastic rocks include agglomerates and scoriaceous deposits (Figures 13, 14), interpreted to indicate relatively shallow water depths where the hydrostatic pressure was insufficient to prevent explosive eruptions.

Figure 15. *Symplectophyllum* sp rugose corals preserved within Texas beds limestone, Riverton Quarry — ASHFORD 1:100000 sheet; field of view is 10cm

Figure 16. Interlayered basalt-limestone within the Texas beds — Pike Creek; MGA 367456 6837308

The ***limestone*** occurrences (mapped as subunit **Ctx$_1$**) occur sporadically throughout the central and southern part of the unit, and range from pebbles in volcaniclastic conglomerate to large bodies up to a few kilometres in length. The most notable occurrences are in the Texas area (from Limevale south-east to Riverton) and near Gore at Cement Mills, where the limestone bodies are large enough to be commercially quarried. The limestones are mostly massive, recrystallised and poorly fossiliferous. Olgers & others (1974) reported the presence of sparse crinoids, corals, whole shells, shell fragments and oolites at some of the limestone localities (see Figure 15).

In many localities limestone is associated with basalt lava (Figure 16), with limestone/basalt breccias locally common near their contacts (*e.g.* South Pikedale homestead; see Figure 17). A discontinuous chain of basalt, jasper and limestone lenses trends north-west from South Pikedale homestead through Spring Creek to Cooinoo homestead before following the regional easterly strike in the Barongarook area, where a number of small limestone bodies have been reported by Siemon (1973). This limestone-basalt chain appears to be roughly confined to one stratigraphic horizon extending for over 30kms, and is thought to represent the remnants of an island chain or a seismic ridge.

Intraformational ***conglomerates*** occur at a few localities within the Texas beds (*e.g.* at MGA 326044 6880769 and MGA 351882 6872955). These typically contain a variety of angular to subrounded pebble to granule-sized clasts of mudstone, siltstone and arenite

Figure 17. Limestone-basalt breccia — Pikedale Homestead; MGA 369806 6832368

clasts (similar in composition to the enclosing Texas beds sequence), sparse rhyolitic volcanic fragments, and rare granitic, basaltic and radiolarian chert clasts. The felsic volcanic clasts display textures ranging from microporphyritic to fluidal to eutaxitic. The conglomeratic facies has been delineated as subunit **Ctx**$_{cg}$ 12km west-north-west of Mount Bodumba and 3km north of Gore on the Inglewood 1:100 000 Sheet. Conglomeratic greywackes 15km south-west of Warwick have also been mapped out as a discrete unit (**Ctx**$_{w}$) by Van Noord (1999b).

Alteration

Adjacent to granite intrusives in the Stanthorpe area (for example, at Jibbinbar Mountain, Red Rock and Mineral Hill), the metasedimentary rocks have been contact metamorphosed to spotted biotite hornfels; and calcareous beds have been metamorphosed and metasomatised to calc-silicate skarn and marble. Further north, adjacent to the eastern margin of the Herries Granite, a strong magnetic signature developed in a narrow belt of arenite, mudstone, chert and mafic volcanics within subunit **Ctx**$_{m}$ is attributed to local hornfelsing of the sequence. A different style of metasomatic? quartz-tourmaline alteration occurs in the Hunters Hill area and has been mapped as subunit **Ctx**$_{al}$. A prominent oval-shaped zone of potassic alteration a few kilometres across surrounds the Bullaganang Granite and nearby intrusives, forming an envelope around the Waroo and Ashton Valley copper-gold deposits.

At some locations the jasper/chert sequences exhibit disseminated or stratabound magnetite alteration (see Figure 18) which is intense enough to be visible on regional aeromagnetic images (*e.g.* MGA 354106 6878188). In some cases, massive magnetite quartzites have been formed (*e.g.* at MGA 372672 6876044). This style of alteration is most common in association with mafic volcanic/exhalite packages. The alteration may be analogous to hydrothermal magnetite alteration of radiolarian chert interbedded with basalt reported in the southern Coffs Harbour Block within Texas bed-equivalent turbidites (Korsch & Perkin, 1993).

Figure 18. Stratabound magnetite-jasper alteration adjacent to basalt lava within the Texas beds; MGA 354106 6878188

Structure

The Texas beds in Queensland form an arcuate, convex-northwards fold ~75km across. This structure forms part of a larger regional double orocline — the Texas–Coffs Harbour Megafold (see Figure 2). A steeply-dipping, roughly north-trending fracture cleavage which sporadically overprints bed-parallel structures is probably associated with the regional megafolding event. Dips are generally steep to vertical and beds are overturned in many places. Many lithological contacts within the Texas beds are faulted, and bedding parallel cleavage fabrics are widespread. The latter range from a slaty cleavage or strong fissility in argillite layers to an anastomosing melange-style fabric which is common in thin-bedded chert-arenite-argillite sequences. Bed-parallel mylonitic fabrics also occur within some thick arenite sequences (*e.g.* at MGA 356306 6873788). Deformation-induced, quartz-filled extension fractures are locally common in incompetent arenite beds in many parts of the region (*e.g.* in the Thanes Creek area on ALLORA; see Figure 19). On ALLORA, these fractures are commonly an expression of the regional north-south megafold-related cleavage, which cuts regional bedding trends at a low angle but refracts at high angles through individual incompetent arenite layers.

Figure 19. Quartz-filled extension fractures cutting incompetent arenite bed — Texas beds, Thanes Creek; MGA 372446 6875088

The Texas beds have been interpreted by Flood & Fergusson (1984) to be an imbricated stack of fault slices. The predominant overall younging direction is thought to be inward directed towards the central portion of the fold structure, whereas the younging direction within individual fault blocks is mainly outward directed. This younging arrangement is consistent with the model proposed by Karig & Sharman (1975) to explain the deformation style within thick accretionary wedge sequences of subduction complexes. Subsequent folding of this subduction complex has occurred about a north-north-west-trending axial plane with a near-vertical fold axis to form a z-shaped megafold or double orocline (the Texas–Coffs Harbour Megafold) within the New England Orogen (Murray & others, 1987). The Texas beds in the map area are interpreted to have originally had a meridional strike produced by accretion to the Australian craton margin above a west-dipping subduction zone. However, they have been subsequently rotated through 120° by the megafolding event.

Some of the major north-west-trending fault networks that cut through the unit subparallel to the strike of the beds may have initiated as west-verging backthrusts resulting from transpression during megafolding. Such a mechanism may explain the shallow, severely overturned dips that occur in places within the Texas beds (e.g at MGA 363206 6880088). Alternatively, the overturning may be related to extensional normal faulting. Several generations of kinks occur throughout the unit, probably related to post-megafolding fault movements. However, Lennox & Flood (1997) group these and other foliation styles together into a megafold related group.

They also document an east-west foliation that postdates both the Texas beds and overlying early Permian basins.

Regional geophysical images show that the megafold hinge area west of Terrica homestead is modified by open folding about an axial plane trending slightly west of north-west. No axial plane features are associated with this folding. Immediately south of this fold, anomalously shallow bedding geometries occur sporadically in the Texas beds (Figure 20) and complex remnants of overlying Permian sediments are preserved associated with interpreted reverse faulting (*e.g.* the Terrica Thrust). These structural features may be a result of compressional folding and reverse faulting in the core of the megafold produced by tangential longitudinal strain developed during the megafolding event. This model implies complementary extension within the outer arc of the megafold, which may explain radial extensional? faults visible in the Texas beds beneath cover rocks in regional aeromagnetic images (see Figure 21).

Figure 20. Shallow-dipping turbidite sequence in Texas beds south-west of Terrica homestead; MGA 353951 6841490

Alternatively, the complexity in the Terrica area may be related to a south-west-directed post-megafold shortening event or oblique compression along the north-west-tending Pikedale Fault system, and may be associated with the numerous kink folds found in places throughout the Texas beds. In a post-megafold scenario, these features may be inboard expressions of the regional crustal shortening experienced by much of the New England Orogen during the Hunter–Bowen Orogeny.

Age and Provenance

Most of the fossil ages reported from the Texas beds are from coral faunas preserved in limestone ranging from pebbles to large blocks. Carboniferous limestones were first reported from the unit by Ball (1923). Silurian to Devonian ages were later recorded by Lucas (1960a,b) from localities around Cement Mills and Cooinoo, as well as an early Carboniferous age from the Pikedale area. However, resampling of these and other sites throughout the region by Strusz (*in* Olgers & others, 1974) failed to duplicate the older ages, yielding only early Carboniferous (Visean) ages. A possible late Carboniferous brachiopod/bryozoan fauna site has been recorded from the turbidite sequence east of Terrica (sample TH417; Olgers & others,1974).

The difference in limestone fossil ages found during the Lucas study and the follow-up Strusz study of the area may indicate that the Carboniferous reefs

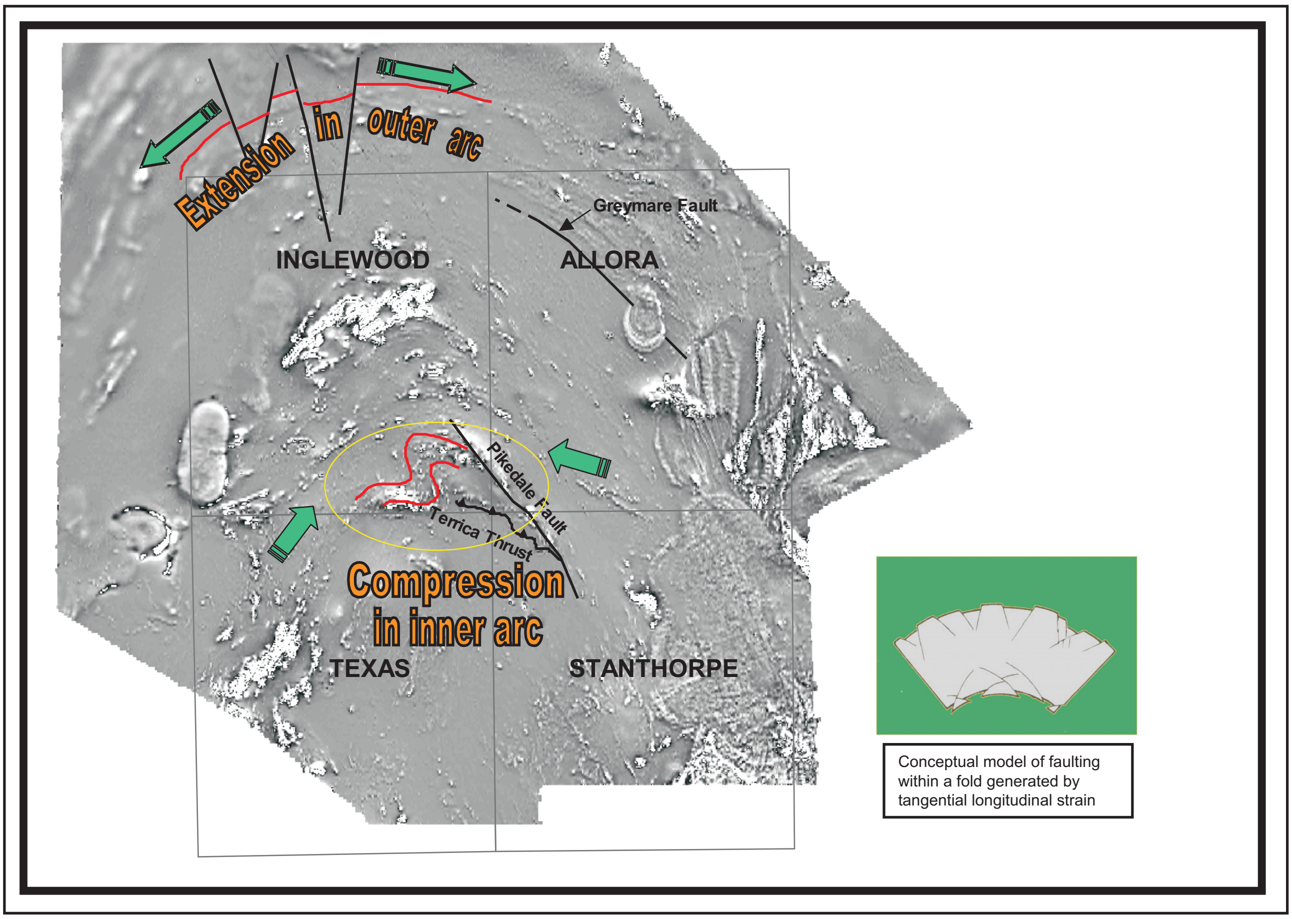

Figure 21. Structural features of the Texas Megafold interpreted to result from tangential longitudinal strain during folding

also incorporated older Silurian–Devonian limestone detritus. Alternatively, the original determinations (derived from fossils that are now missing) may have been unreliable, although Devonian *alveolites* corals were independently identified by Dorothy Hill, a widely recognised expert in the field (Cec Murray, personal communication). A Visean age for the cherts within the Texas beds has also been reported by Aitchison & Flood (1990a) based on radiolarian extracts from three localities. Simple subduction models applied to the Texas beds imply that gross structural packages within the unit become younger away from the core of the Texas Megafold. Thus subunit $\mathbf{Ctx_m}$ may represent the oldest part of the sequence.

Flood (personal communication,2002) suggests that the chert and limestone (and associated mafic lava) from which the fossil ages are derived were deposited in a deep ocean or seamount environment respectively, far from the site of subduction, requiring some 30Ma for transport from the site of deposition to the continental margin where they were structurally incorporated into the accreting turbidite pile. He thus interprets the turbidites of the Texas beds to be late Carboniferous in age, intercalated with early Carboniferous limestone, basic volcanic rocks and chert. However, this study has found primary arc-derived tuffs at one of the Visean radiolarian-bearing sample sites (UNE L 1914; Aitchison & Flood, 1990a) within the oldest subunit ($\mathbf{Ctx_m}$), implying reasonable proximity to the active arc. This sequence includes cherty layers probably belonging to the proximal Type II cherts described by Aitchison & Flood (1990b). We therefore consider the Visean radiolarian age to give a true indication of the turbidite age for subunit $\mathbf{Ctx_m}$.

Correlatives

The Visean age of parts of subunit $\mathbf{Ctx_m}$ combined with the local presence of detrital oolites in this unit provide a possible link between these rocks and inboard elements of the Carboniferous accretionary wedge rocks of the Wandilla Province of eastern coastal Queensland. Correlative formations of the Wandilla Province therefore include the Neranleigh–Fernvale beds in the Brisbane area and the Wandilla Formation in Central Queensland. The latter have been interpreted as slope deposits containing detrital oolites derived from numerous bodies of Tournaisian and Visean oolitic limestone developed within the adjacent unstable forearc basin of the Yarrol Province to the west. The presence of felsic tuff deposits within subunit $\mathbf{Ctx_m}$ also supports a provenance linkage with contemporaneous subduction-related arc volcanism occurring immediately to the west of the adjacent forearc sequence (represented by the Tamworth Belt in NSW and southern Queensland). The forearc rocks of the Tamworth Belt are considered to be equivalent to those of the Yarrol Province of central Queensland (Roberts & Engel, 1980).

Relationships

The Texas beds are unconformably overlain by or faulted against Early Permian sedimentary rocks of the Bondonga, Pikedale and Terrica beds, and unnamed units of this age that all occur as sporadic deformed basins remnants. The Texas beds are intruded by Permian–Early Triassic granitoids (e.g. the Stanthorpe Granite, Greymare Granodiorite, Herries Granite), by mafic dykes and by unnamed granitoids. They are unconformably overlain by largely undeformed rocks of the Middle–Late Permian Wandsworth Volcanic Group.

Geochemistry of basalts

The mafic volcanics range from ~40 to ~52wt% SiO_2 and are broadly classified as basalts to trachy-basalts according to a TAS classification scheme. However, they have variable MgO content (2.1–9.7wt%), relatively high LOI (ranging up to ~9wt%) and exhibit significant scatter on most major element variation diagrams, reflecting varying alteration/metamorphism. The basalts form tighter clusters on tectonic discrimination diagrams utilising relatively immobile high field strength elements (HFSE) and generally plot in within plate fields (Figure 22). They have variably enriched chondrite-normalised REE patterns (La_n/Yb_n = 2.4–8.8) consistent with an OIB origin (Figure 23a) and lack depletion of HFSEs commonly observed in supra-subduction zone environments (Figure 23b). In many cases, samples from widely distributed sites have very similar trace element compositions.

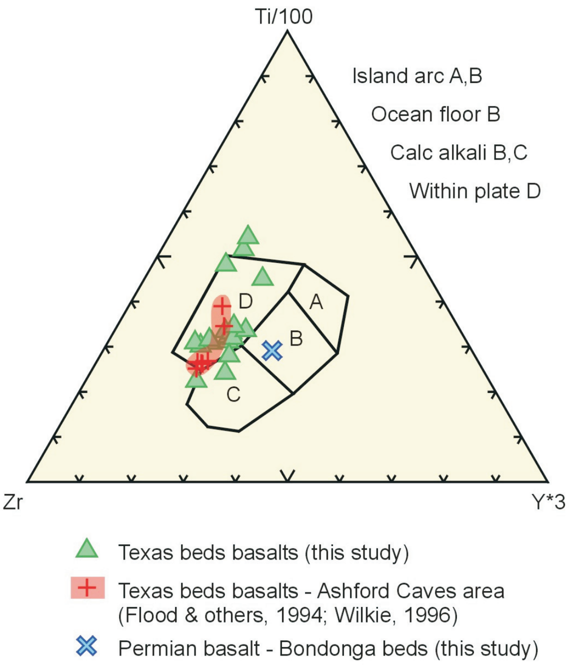

Figure 22. Tectonic discrimination diagram (Pearce & Cann, 1973) utilising high field strength elements. Texas basalts form clusters within or around the ‘within plate’ (ie. OIB) field. Permian basalt from the Bondonga beds is clearly different and plots in the ‘ocean floor’ (ie. MORB) field.

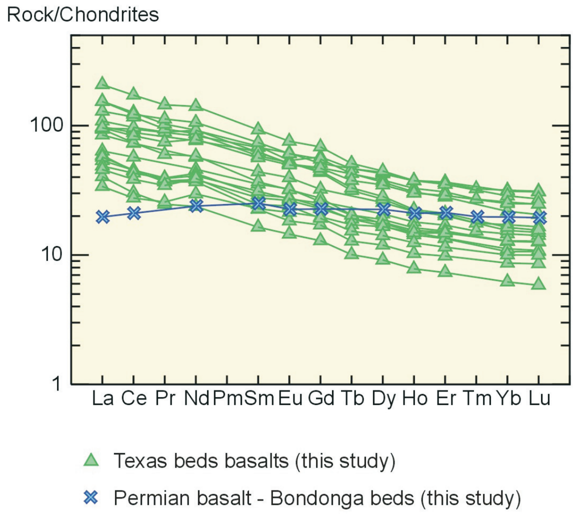

Figure 23a. Chondrite-normalised REE plot highlighting the variably enriched OIB-like patterns of basalts from the Texas beds and the flat, MORB-like pattern of Permian basalt from the Bondonga beds. Normalising values are from Sun & McDonough (1989).

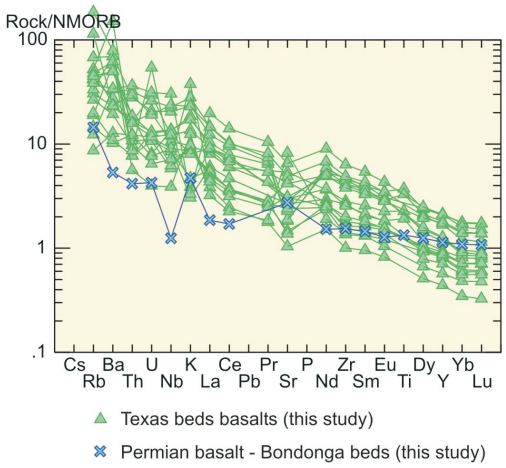

Figure 23b. NMORB-normalised trace element spidergram for Texas and Bondonga beds basalts. Texas beds basalts lack depletion of HFSEs (notably Nb) commonly observed in suprasubduction zone environments. Bondonga beds basalt and Texas beds basalts both exhibit significant scatter of trace element patterns for relatively mobile elements. Normalising values are from Sun & McDonough (1989).

Silver Spur Subprovince

The Silver Spur Subprovince consists of a number of Early Permian basin remnants developed on older deformed accretionary sequences of the Woolomin Province. The subprovince is named after one of the largest of these remnants, exposed to the north-east of Texas as the Silver Spur beds.

Silver Spur beds (*Psp*)

The Early Permian Silver Spur Beds (**Psp**) are dominated by steeply-dipping to vertical sequences of rhythmically interbedded mudstone and arenite. In most instances these are extremely difficult to distinguish from similar sediments in the Texas beds. The bedding thickness and sand:mud ratio within the Permian sequences can vary substantially. Fine-grained interbeds often show development of low-grade metamorphism and pencil cleavage that is absent from the coarser sandy horizons. Sandy horizons often exhibit internal lamination and are preferentially silicified. Pervasive silicification is particularly intense in the Twin Hills and Mount Gunyan areas where it may be associated with finely disseminated silver mineralisation.

Relatively thin (generally <20cm) pebble- to cobble-rich horizons are common within the sandy beds. These comprise rounded to well-rounded clasts, mostly >3cm in diameter, within a sandy matrix. Rare pebbles and cobbles also occur within muddy beds. Thicker (metre-scale) diamictite/conglomerate beds are also common throughout the mudstone and arenite sequences. These contain abundant, rounded to well-rounded clasts mostly >10cm in diameter in a muddy to sandy matrix. Fine- to medium-grained silicified clastic sediments are the most abundant clast type in both the diamictites/conglomerates and pebbly/cobbly arenites. Clasts of chert, quartzite, coarse-grained sediments, vesicular basalt, andesite, rhyolite and granite are less abundant. Early Permian marine macrofossils in the sediments are well documented (Olgers & others, 1974; Sorby, 1976) and poorly preserved brachiopod and bryozoan internal moulds were found at some locations (*e.g.*MGA 323891 6815177). Thin, discontinuous and deeply weathered limestone crops out ~1.2km north-west of Woodbine homestead (MGA 327310 6808946) and limestone breccia was intersected in drill holes at Tooliambi (Krosch, 1972). A thin (~25m) basaltic horizon is interbedded with mudstone and pebbly sandstone west of Woodbine homestead (MGA 325089 6809429).

In contrast to similar sediments in the surrounding Texas beds, the Silver Spur beds host mineralisation. Copper occurs at Tooliambi, copper lead and zinc occur at Texas Copper Mine, and silver occurs at Silver Spur, Twin Hills, Silver Crown and Silver King. These deposits fall into 3 separate but related mineralisation classes (Jupp, 1998).

Bondonga beds (*Pox, Pox$_l$*)

The Bondonga beds (**Pox**) occupy a linear, fault-bounded basin remnant extending north-west to south-east enclosed within the Texas beds. This belt of rocks extends northwards from the Mole Valley on the Grafton 1:250 000 map sheet in New South Wales. They comprise massive orthoconglomerate, paraconglomerate, lithic arenite and minor siltstone (Rose, 1960; Vickery, 1972; Brodie, 1983; Barnes, 1987). Bedding is poorly developed, and is subvertical, vertical or overturned. The rocks are probably folded, but have an open fracturing parallel to bedding, rather than a cleavage. Detailed mapping indicates that this Permian package of rocks comprises elongate lenses of conglomerate, arenite and siltstone (Brodie, 1983), suggestive of regional folding and imbrication. The informal unit Glenlyon beds of Denaro & Burrows (1992) contain Early Permian marine fossils and have been included in this unit. The sequence consists of conglomerate (containing pebbles and cobbles derived from the Texas beds), lithic arenite, pebbly lithic arenite, pebbly mudstone, and minor, poorly fossiliferous limestone (mapped as **Pox$_l$**). A relatively thin basalt horizon crops out along Glenlyon dam road north-west of Calm Downs homestead turnoff (MGA 353383 6804732). This basalt is interbedded with an arenite and mudstone sequence. It is slightly vesicular and has lobate and possible pillow textures. The basalt is weakly porphyritic and comprises sparse plagioclase phenocrysts in a highly altered groundmass dominated by fine plagioclase laths. It has a relatively flat (MORB-like) chondrite-normalised REE pattern ($La_n/Yb_n = 0.93$) (see Figure 23b).

The Bondonga beds in New South Wales contain Early Permian fossils (Rose, 1960; Vickery, 1972). Contacts with the enclosing Carboniferous Texas beds are probably faults or unconformable boundaries but they have not been observed.

Alum Rock Conglomerate (*Par*)

The Alum Rock Conglomerate (**Par**) was first mapped by Lucas (1958). It forms a narrow, north-west-trending outlier extending for ~20km within the Texas beds 30km north-west of Stanthorpe. The lower half of the sequence consists mainly of conglomerate, pebbly arenite, arenite, and minor siltstone, while the upper half consists of rhyolitic to locally dacitic breccia, tuff and some lava with minor calcareous arenite and limestone. The conglomerate is brownish in colour, thin to thick bedded, locally graded, and contains mainly siliceous pebbles (quartzite, rhyolite, chert, siliceous siltstone) derived from the underlying Texas beds basement (see Figure 24). The arenites range from lithic to volcaniclastic in composition, the latter containing felsic volcanic detritus (including monocrystalline quartz and feldspar grains) and minor local mafic volcanic detritus. The siltstone and arenite beds locally contain ferruginous concretions.

The eastern margin of the outlier unconformably overlies the Texas beds while the western margin is faulted. The moderate south-west dips of the unit shallow to ~20° against the fault, consistent with either west-over-east thrusting or east-block-down normal faulting. Brachiopod faunas recorded from the basal and upper parts of the section indicate an

Figure 24. Conglomerate and arenite near base of Alum Rock Conglomerate, north-west of Cooinda homestead; MGA 364514 6853512

Asselian to Sakmarian age for the unit (Roberts & others, 1996). Roberts & others (1996) report a mean zircon age of 291.3±2.8Ma for rhyolites lying stratigraphically between the two brachiopod faunas.

Terrica beds
(*Pt*)

The Terrica beds (**Pt**) were first mapped by Lucas (1959, 1960c). The unit is exposed as small partly fault-bound basin remnants, located 45km west-north-west of Stanthorpe. The unit comprises interbedded medium to thick bedded, poorly sorted lithic arenite, mudstone and siltstone, together with rare vitric tuff and conglomerate. The arenites are locally pebbly (Figure 25) Thick olive brown to black, locally bioturbated mudstone packages (Figure 26) and scattered diamictite lenses also occur in places south-east of Terrica. Lithic clasts in the arenites and conglomerates are largely derived from the underlying Texas beds. The finer grained lithologies locally contain abundant plant material. Lucas (1957) reported Permian fossils from the area. A fossil fauna similar to that in the Alum Rock Conglomerate has been reported from the Terrica rocks, although suggestive of a slightly younger age (D.J.C. Briggs in Lennox & Flood, 1997). The Terrica beds are unconformable on and faulted against the Texas beds (Olgers & Flood, 1970; Olgers & others, 1974).

Pikedale beds
(*Pk*)

The Pikedale beds (**Pk**) occur as a narrow north-north-west trending, partly fault-bound wedge of sediments located 30km west of Stanthorpe. The unit comprises lithic arenite, siltstone and mudstone, interlayered with sporadic discontinuous pebbly, conglomeratic lenses up to 5m thick, as well as local vitric tuff lenses 10cm–5m thick. The conglomerates are mainly matrix-supported and the dominant clast types are rhyolitic tuff, chert, and siliceous siltstone, together with scattered angular mudstone and other lithic fragments. Grading is rare and the conglomerates are generally interleaved with massive gritty arenites.

Figure 25. Basement pebbles contained within labile arenite of the Terrica beds, Treverton Creek , Terrica station; MGA 352774 6845153

Figure 26. Thick mudstone interval within Terrica beds, Terrica Station; MGA 353001 6845649

The Pikedale beds are less structurally complex than the underlying Texas beds, with open gently plunging folds and moderate to locally steep dips predominating. Contacts with the Texas beds basement are interpreted to be gently dipping unconformity surfaces or faults. Fossil wood and other plant remains have been reported from the Pikedale area (Olgers & others, 1974; Forster, 1991). The Permian age assigned to the sequence is based on the close similarity between these rocks and the Permian strata in other outliers in the area.

Eurydesma beds
(*Ply*, *Ply$_l$*)

The Eurydesma beds (**Ply**) are exposed over a few square kilometres around Rokeby homestead, 17km south-east of Warwick. The sequence is around 200m thick and consists of conglomerate, fine to medium grained lithic arenite, dark calcareous siltstone, and thin-bedded limestone (**Ply$_l$**) containing an Early Permian marine macrofossil assemblage. The unit is faulted against older basement rocks of the Silverwood Group and is overlain by the slightly younger Wallaby beds with a small angular unconformity (Olgers & others, 1974).

Wallaby beds
(*Plw*)

The Wallaby beds (**Plw**) are exposed over a few square kilometres north and west of Rokeby homestead, 17km south-south-east of Warwick. The unit is ~150m thick and consists of a lower sequence of conglomerate, lithic arenite, and siltstone overlain by an upper sequence of mainly ferruginous siltstone.

The unit unconformably overlies the slightly older Eurydesma beds with a small angular unconformity and is unconformably overlain by the slightly younger Eight Mile Creek beds. The unit is downfaulted against older basement rocks of the Silverwood Group.

Eight Mile Creek beds
(Ple_a, Ple_s, Ple_e, Ple_v)

The Eight Mile Creek beds (**Ple_a, Ple_s, Ple_e, Ple_v**) are exposed 15km south of Warwick as a small outlier occupying an area of around 8km^2. The unit was originally defined by Olgers & others (1974), and supported by the studies of Dennis (1974b). Van Noord (1999b) extended the boundaries of the unit into areas previously mapped as Connolly Volcanics. The lower half of the unit is dominantly sedimentary containing a variety of rock types including conglomerate, pebbly lithic arenite, well sorted lithic arenite, siltstone and mudstone. The conglomerate contains pebbles of chert, silicified arenite and basic to acid volcanics. Abundant Early Permian marine macrofossils occur within this sequence. The upper half of the unit consists predominantly of felsic to locally intermediate volcanic pyroclastic rocks (agglomerate, breccia and tuff) and lavas.

Van Noord (1999b) mapped a number of subdivisions within the unit — intermediate to acid volcanic sequences have been mapped as subunit **Ple_a**; siliciclastic sediments have been mapped as subunit **Ple_s**; silicic epiclastics, pyroclastics and flows have been mapped as subunit **Ple_e**; and basaltic andesitic to dacitic volcanics have been mapped as subunit **Ple_v**.

The Eight Mile Creek beds are unconformable on or faulted against units of the Silverwood Group and Wallaby beds, and are unconformably overlain by Jurassic units of the Marburg Subgroup.

Unnamed sedimentary rocks
(*Ps*)

Probable Early Permian conglomeratic sediments (**Ps**) also occur as a number of small outliers north and east of Mount Bullaganang (on TEXAS), and north of Mount You You, between Pike Creek and the Severn River, and in the Sundown area (on STANTHORPE). At the latter locality, lithic pebbly arenites with local conglomerate are interpreted to have been hornfelsed by unexposed Permo-Triassic granitoid intrusions.

WANDSWORTH PROVINCE

Wandsworth Group

The Wandsworth Province is dominated by Late Permian volcanic packages centred mainly in New South Wales (the Wandsworth Volcanic Group — Barnes & others, 1991). Volcanics and sediments of similar age south-east of Warwick in Queensland have also been assigned to the province.

Wallangarra Volcanics
($Pwar_l$, $Pwar_u$)

The Wallangarra Volcanics (**$Pwar_l$** , **$Pwar_u$**) crop out in the Queensland/NSW border area, mostly in the area immediately west of Wallangarra. They are well exposed in large road cuttings along the New England Highway between Ballandean and Wallangarra and form rough, mountainous terrain with abundant, hard, and blocky outcrop. Previous workers (Simmonds, 1958; Butler, 1974; Olgers & others, 1974; McLean, 1976; Godden, 1982; Barnes & others, 1991) describe the Wallangarra Volcanics as a 300–450m thick package of rhyolitic and rhyodacitic tuffs and lavas with possible epiclastic interbeds. Eutaxitic texture defined by flattened pumice lenticles indicates dips of approximately 20–30° with variable strikes. Dips as low as 10° have been observed in bedded tuffs (Olgers & others, 1974). The Wallangarra Volcanics unconformably overlie the Texas beds. They are intruded by the Stanthorpe Granite and possibly by the Undercliffe Falls Granite, and are locally unconformably overlain by the Dundee Rhyodacite.

Recent detailed work (Purdy, 2003) divided the Wallangarra Volcanics into two thick and relatively monotonous units deposited subaerially in an intracaldera environment. The units comprise a relatively ash-rich, moderately to intensely welded, rhyolitic ignimbrite >400m thick lower unit (**$Pwar_l$**) and a crystal-rich, strongly to intensely welded trachydacitic ignimbrite >300m thick upper unit (**$Pwar_u$**). These are separated by a thin (<50m) package of thinly bedded ignimbrite, air fall deposits, surge deposits and sediments.

Both ignimbrites contain medium-large plagioclase, alkali feldspar, embayed quartz and biotite phenocrysts as well as minor magnetite and ilmenite. The upper **$Pwar_u$** unit also contains minor hornblende and very minor pyroxenes in places. Lithic clasts, mostly comprising small fragments of glassy ignimbrite, range up to 30cm in diameter and are sparsely distributed throughout the Wallangarra Volcanics. Pumice clasts are abundant in both units but are particularly large (up to 25cm) and crystal-rich in the upper **$Pwar_u$** unit. Pervasive silicification is particularly intense adjacent to granitoid contacts and has destroyed original pyroclastic textures in these areas.

The Wallangarra Volcanics are high-K calc-alkalic in composition. They range from 65–79wt% SiO_2 and have moderately enriched REE patterns. The lower and upper units were deposited in rapid succession and may be related via fractional crystallisation. Together, these represent eruption of a large-volume silicic magma system.

On the basis of lithological similarity, Olgers & others (1974) correlated the Wallangarra Volcanics with the Upper Permian Drake Volcanics that crop out 40km east of Wallangarra. Godden (1982) correlated the Wallangarra Volcanics with the Emmaville Volcanics to the south. Stroud & others (1992) include the Wallangarra Volcanics in the Wandsworth Volcanic Group and consider them to be equivalent to the Emmaville Volcanics and younger than the Drake Volcanics.

Dundee Rhyodacite
(*Pwdr, Pwds, Pwdt, Pwdi*)

The Dundee Rhyodacite (**Pwdr, Pwds, Pwdt, Pwdi)** (Dundee Adamellite–Porphyrite of Shaw [1969] and Olgers & others [1974]) is a distinct and widespread, highly fragmented ignimbrite. It crops out as several separate but lithologically similar ‘masses’ throughout the Tenterfield–Dundee–Coombadjha area (Barnes & others, 1991) of northern New South Wales and southern Queensland. Larger ‘masses’ of the Dundee Rhyodacite are ovoid bodies, ~10–30km in diameter. Four of these ‘masses’ occur within the sheet area. The Tarban mass (**Pwdr**) is dominated by a rhyolitic ignimbrite with a distinctive micrograniticgroundmass. The Sunnyside, Tenterfield and Timbarra masses (**Pwds, Pwdt** and **Pwdi** respectively) consist mainly of rhyodacitic ignimbrite. The Timbarra mass is typically deeply weathered, and locally sheared and veined.

The ‘masses’ may represent ponded outflow remnants from the Coombadjha Volcanic Complex (in New South Wales), or individual focii of eruption and subsidence within a broader eruption-triggered collapse area (McPhie, 1986, 1988). In the vicinity of Wallangarra, the Dundee Rhyodacite unconformably overlies the Wallangarra Volcanics, forming relatively subdued topography comprising sparse dark grey/blue round, bouldery outcrops. It is crystal-rich and contains abundant fragments of plagioclase, deformed biotite, hornblende, pyroxene and quartz phenocrysts. The groundmass contains abundant, strongly welded glass shards.

The overall distribution of the Dundee Rhyodacite (considering significant erosion and possible original connectivity of separate outcrops), along with relatively homogeneous mineralogy, grainsize and componentry suggest that it represents an extremely voluminous unit, possibly comparable to some western USA or central Andean ‘monotonous intermediates’ (*e.g.* Fish Canyon Tuff, Lund Tuff, Cerro Galan ignimbrite).

The distinct lithological character of the Dundee Rhyodacite makes it a useful regional age marker. It is the youngest unit of the Wandsworth Volcanic Group and has recently yielded a U–Pb zircon age of 257.6±0.5Ma using laser-ablation inductively coupled plasma mass spectrometry (Belousova & others, 2006). Shaw (1994) had previously reported a Rb–Sr (biotite) age of ~248Ma for the emplacement of the unit, although the published radiometric ages vary somewhat (*cf.* Everden & Richards, 1962; Hensel & others, 1985; Shaw & Flood, 1993).

Other Mid–Late Permian rocks

Rhyolite Range beds
(*Plr_v, Plr_c, Plr_f, Plr_e, Plr_s*)

The Rhyolite Range beds were originally mapped by Olgers & others (1974) but redefined soon after by Dennis (1974a). Van Noord (1999b) modified the extent of the unit. The Rhyolite Range beds occur as a narrow elongate outlier exposed within the Silverwood Group 10km south of Warwick. They are over 1300m thick and consist predominantly of felsic volcanics, including spherulitic rhyolite sills (and flows?), agglomerate, crystal tuff, quartz-feldspar porphyry, and minor dacitic to andesitic lava, with a variable thickness of (~120–300m) of lithic arenite, pebbly arenite and siltstone at the base. The siltstone is locally calcareous and worm trails have been observed on some arenite bedding surfaces (Olgers & others, 1974).

A number of subunits have been mapped — locally spherulitic rhyolite lava, dacite, and andesite have been included within subunit **Plr_v**; siliceous pebbly orthoconglomerates have been mapped as subunit **Plr_c**; fossiliferous and bioturbated litharenite and siltstone has been mapped as subunit **Plr_f**; epiclastic sequences with minor pyroclastics are included within subunit **Plr_e**; and undifferentiated sediments are mapped as subunit **Plr_s**.

The unit contains a late Early–early Late Permian marine macrofauna (Olgers & others, 1974; Dennis, 1974a). The Rhyolite Range beds are unconformable on or faulted against units of the Silverwood Group and are unconformably overlain by Jurassic units of the Marburg Subgroup.

Fitz Creek beds
(*Pf*, *Pf_d*, *Pf_r*)

The Fitz Creek beds (**Pf**) was originally included within the Connolly Volcanics by Olgers & others (1974), but the sequence was subsequently recognised as a separate unit by Dennis (1974b) and Van Noord (1999b), the latter proposing the name. The Fitz Creek beds occur as two irregular areas around 2.5km^2 each, situated ~18kms south of Warwick. The unit unconformably overlies or is faulted against rocks of the Silverwood Group (mainly the Connolly Volcanics), and is locally intruded by a small granitoid mass interpreted as part of the Herries Granite. Van Noord (1999b) estimated the sequence to range in thickness from 314m to ~1770m.

Conglomerate is the most common rock type, ranging from massive thick-bedded matrix-supported types to graded or inversely graded clast-supported varieties. Clasts are granule to boulder-sized volcanic and sedimentary lithics in a quartzofeldspathic matrix. Granitoid clasts occur locally. These conglomeratic sedimentary units are mapped as subunit **Pf$_d$**. Massive poorly sorted, dark grey rhyolitic lithic crystal tuff, lapilli tuff, and crystal tuff, together with minor massive very coarse grained volcaniclastic arenite make up most of the remainder of the sequence. Rhyolitic units have been mapped as subunit **Pf$_r$**. No body fossils have been recovered from the Fitz Creek beds, making the age of the sequence uncertain. However, lithogical similarities suggest a correlation with the nearby Rhyolite Range beds.

Condamine beds (*Puc*)

The Condamine beds (**Puc**) are exposed 20km south-east of Warwick as a small Upper Permian outlier occupying an area of ~10km^2. Olgers & others (1974) divided the unit into four sequences in the type area, each ~300m in thickness. The westernmost sequence comprises dark grey to black slightly calcareous mudstone with some thin beds of fine-grained arenite. These rocks locally contain a rich coral fauna. To the east of this package is a sequence of black fossiliferous mudstone, coarse grained arenite and conglomerate containing two thick beds of rhyolitic crystal lithic tuff. Further east is a sequence of poorly sorted fossiliferous arenite, pebbly arenite and conglomerate with thin tuff and epiclastic bands. This package is succeeded to the west by a sequence of unfossiliferous mudstone and fine grained arenite, lithologically similar to those occurring in the westernmost sequence. Olgers & others (1974) considered the sequence to young from east to west, but Briggs (1993) considered the fossil faunas and sedimentary younging criteria to indicate the reverse.

Strata within the unit dip mainly to the west with an average dip of ~50°, but steep easterly dips occur in the east. The Condamine beds are faulted against the Silverwood Group to the west and are unconformably overlain by the Jurassic sediments of the Marburg Subgroup to the east. The relatively abundant marine macrofossil faunas indicate a Late Permian (Tartarian) age (Briggs, 1993).

MESOZOIC ROCKS

CLARENCE–MORETON AND SURAT BASINS

The Clarence–Moreton Basin and the Surat Basin further to the west form contiguous Mesozoic intracratonic basins, notionally separated to the north of the Texas region by a meridional basement high, the Kumbarilla Ridge. In the Texas region, separation of the two basins is less distinct, with the major Clarence–Moreton Basin units in the eastern part of the region (the Marburg Subgroup and Walloon Coal Measures) also occurring as the basal part of the Surat Basin in the western part of the region.

The Clarence–Moreton Basin and Surat Basins contain fluviatile, paludal and locally lacustrine sediments that range from latest Triassic to Cretaceous age. The age of the constituent formations of the two basins and their stratigraphic relationships to each other were redefined in McKellar (1998).

The term Clarence Basin was widely used in New South Wales for the Mesozoic rocks in the north-eastern corner of New South Wales (McElroy, 1962,1969). McElroy’s definition included Late Triassic rocks of the Nymboida Coal Measures. The term “Moreton Basin” was first defined by Allen & Hogetoorn (1970) to include only the post-Late Triassic rocks of this basin in Queensland. Knowledge of the stratigraphy of the basin was upgraded during 1:250 000 mapping of the Warwick and Ipswich-Brisbane 1:250 000 Sheets (Olgers, 1974; Cranfield & others, 1976). Wells & O’Brien (1994), redefined the definition of the combined Clarence–Moreton Basin in terms of a basal package of rocks, the Bundamba Group, overlain by an upper sequence formed by the Walloon Coal Measures. They redefined the two previously recognised divisions within the Bundamba Group — the basal Woogaroo Subgroup and the overlying Marburg Subgroup. Only the Marburg Subgroup and Walloon Coal Measures are exposed in the study area. Overlying these units in the western part of the region is the Kumbarilla beds, which is confined to the Surat Basin.

Bundamba Group — Marburg Subgroup

The Marburg Subgroup, as defined by Wells & others (1990), forms the upper part of the Bundamba Group. At the base, the Marburg Subgroup is locally represented by the Koreelah Conglomerate Member of the Gatton Sandstone. The Koukandowie Formation is the topmost part of the unit but has not been mapped out in the study area. The subgroup has only been subdivided in the Warwick area in the north-east part of the study area, and elsewhere remains undivided. The subgroup forms low undulating hills and interfluves in the west, north and north-east part of the mapped area and is best exposed in road cuttings where the mainly subhorizontal bedding orientations are displayed.

Gatton Sandstone (*Jbmg, Jbmgk*)

The Marburg Subgroup has been subdivided into the Gatton Sandstone (**Jbmg**) and Koreelah Conglomerate Member (**Jbmgk**) in the north-east part of the study, where they crop out adjacent to exposed basement granites and meta-sediments. The Gatton Sandstone consists of thick-bedded, medium and coarse-grained, quartz-lithic and feldspathic sandstone, commonly with a calcareous cement. The unit characteristically displays large-scale trough and planar cross-bedding, and carbonised wood fragments and pebble beds are common in places.

The **Koreelah Conglomerate Member** occurs at the western margin of the basin as massive to crudely-bedded, clast-supported, polymictic, pebble to cobble conglomerate, massive matrix-supported sandy conglomerate and thick-bedded coarse sandstone. Clasts are derived mainly from local basement rocks. The clast-supported conglomerates locally show imbrication while the matrix-supported conglomerates occasionally show inverse grading and contain clasts up to 1m across. The sandstone beds form thick, crudely horizontal or cross-laminated beds and lenses and locally contain abundant fossil wood. The matrix of the conglomerate is similar to the Gatton Sandstone and the member grades gradually eastward into this formation. Clast and interstitial-sand grainsizes decrease rapidly eastwards away from the western basin margin, becoming better sorted and more rounded to the east (Wells & O'Brien, 1994).

Provenance and Environment of Deposition

The Gatton Sandstone was derived from erosion of uplifted Palaeozoic basement rocks of the Woolomin Province as well as Permian–Triassic granitic rocks of the New England Batholith situated to the west and south of the Clarence–Moreton Basin. Overall transport direction in the basin was to the north. The Gatton Sandstone was deposited in a fluviatile environment characterised by low sinuosity braided streams. The Koreelah Conglomerate Member represents valley-fill material, including gravelly channel deposits, fine-grained flood plain deposits, colluvium and debris-flow deposits (O'Brien & Wells, 1994).

Relationships

The unit unconformably overlies Palaeozoic rocks of the Texas beds, Silverwood Group and Permian to Triassic granitoids of the New England Batholith. The unit is conformably overlain by the Koukandowie Formation elsewhere in the basin, but the latter has not been delineated within the study area.

Age

No palynological studies have been made of the Gatton Sandstone in the study area, but the unit is considered to be Early Jurassic in age.

Correlatives

The Gatton Sandstone is probably broadly equivalent to the lower part of the Evergreen Formation in the Surat Basin.

Undivided Marburg Subgroup (*Jbm*)

Undivided sections of the Marburg Subgroup have been mapped in the north and west of the Texas region. The subgroup here comprises planar and trough cross-bedded, lithofeldspathic labile and sublabile sandstone with some siltstone and shale, as well as minor coal. The sandstone is fine to medium and locally coarse grained with some pebbly bands. Bedding ranges from thin in the fine-grained parts of the sequence to thick and very thick in the massive and cross-bedded sands. Fossil wood is common locally.

The sequence is likely to contain unmapped equivalents of the Koukandowie Formation (the uppermost unit of the Marburg Subgroup) which elsewhere in the basin is characterised by ferruginous oolite marker beds. However, no ferruginous oolites were identified during the current mapping.

Provenance and Environment of Deposition

The undivided Marburg Subgroup was derived from erosion of uplifted Palaeozoic basement rocks of the Woolomin Province as well as Permian–Triassic granitic rocks of the New England Batholith situated to the west and south of the Clarence–Moreton Basin.

The sediments are thought to have been deposited in a broad floodplain laced with sinuous to straight braided stream networks. Overall transport direction in the basin was to the north. Oolitic parts of the Clarence–Moreton Basin are thought to have formed in an extensive but short-lived shallow lacustrine environment (Cranfield & others, 1994).

Age

No palynological studies have been made of the Marburg Subgroup in the study area, but the sequence is considered to range from Early to Middle Jurassic.

Relationships

In the study area, rocks of the Marburg Subgroup unconformably overlie Palaeozoic rocks of the Texas beds, Silverwood Group and Permian to Triassic granitoids of the New England Batholith. In the Warwick area, rocks of the Marburg Subgroup are conformably overlain by the Walloon Coal Measures and unconformably overlain by lavas and sediments of the Main Range Volcanics.

Correlatives

The Marburg Subgroup is broadly equivalent to the Hutton Sandstone and Evergreen Formation of the Surat Basin sequence.

Walloon Coal Measures
(Jw)

The Walloon Coal Measures (Cameron, 1907; Reid, 1921; Whitehouse, 1955; Cameron, 1970) are of restricted extent in the study area, occurring mainly on ALLORA north and north-west of Warwick, and on INGLEWOOD north of Inglewood. The unit forms flat to low undulating terrain.

The unit is essentially a flat-lying sequence of lithic and feldspathic labile sandstone interbedded with siltstone, mudstone,carbonaceous shale and coal. Quartzose sandstone occurs rarely. The sandstones are generally fine-grained, thick-bedded and friable, consisting of feldspar and black lithic grains of andesitic material in a montmorillonitic matrix. Mudstone occurs either as thin interbeds alternating with sandstone and siltstone beds or as thicker massive beds. The unit is characterised by weathering-resistant clay ironstones and fossil wood fragments, which are commonly found dispersed within the blanketing soils. North-east of the study area, the coal seams reach commercially viable thicknesses and have been mined in the Rosewood–Walloon area.

Provenance and Environment of Deposition

The high proportion of andesitic detritus and montmorillonitic matrix of the sandstones indicate nearby contemporaneous volcanism. The unit was deposited under low energy fluvial conditions typified by wide flood plains traversed by mature highly sinuous river systems, combined with extensive shallow water backswamps.

Age

Plant macrofossils are abundant within the unit. Typical examples include *Equisetem laterale, Cladophlebis australe, Taeniopteris spatulata* and *Otozamites* sp (Gould, 1975). The microflora of the unit to the north-east of the study area was studied by de Jersey (1955a,b; 1959;1960a,b) and dinosaur footprints were described by Cameron (1970). The floral, faunal and stratigraphic evidence are indicative of a Middle Jurassic age.

Relationships

In the study area, the unit conformably overlies rocks of the Marburg Subgroup and is unconformably overlain by lavas and sediments of the Main Range Volcanics.

Correlatives

To the north of the study area, the Walloon Coal Measures extend across the Kumbarilla Ridge into the Surat Basin to the west. The Walloon Coal Measures of the Clarence–Moreton and Surat Basins are considered to be equivalents of the Birkhead Formation to the west within the Eromanga Basin and the Mulgildie Coal Measures further to the north in the Mulgildie Basin.

Kumbarilla beds
(JKk)

Sediments of the Kumbarilla beds are exposed within the lower part of the Surat Basin in the north-western part of INGLEWOOD, where they overlie the Walloon Coal Measures. The sediments are flat lying and form relatively subdued topography with low mesa landforms rising up to ~50m above broad, flat valleys. Within this area, the Kumbarilla beds mostly comprise thick beds of cross-bedded, medium- to coarse-grained, quartzose sandstone and pebble conglomerate. However, exposure on the Inglewood sheet represents only a thin interval of the Kumbarilla beds sequence. Elsewhere in the eastern Surat Basin the Kumbarilla beds reach a maximum thickness of ~800m and include well-bedded siltstones and mudstones representing overbank and lake deposits interspersed with sandstones ranging from fine to coarse-grained (Exon & Vine, 1970).

Age

The unit is thought to be Jurassic to Cretaceous in age.

CAINOZOIC ROCKS

LAMINGTON–MAIN RANGE VOLCANIC PROVINCE

The rocks of this province are dominated by volcanic deposits and minor sediments. Two major eruptive centres occur in south-east Queensland (the Tweed and Focal Peak shield volcanoes) as well as a number of smaller vents and fissures to the north and north-west where lavas and sills form the crest of the Great Dividing Range. Only remnants of these extensive flows occur in the study area and these have been assigned to the Main Range Volcanics.

Main Range Volcanics
(*Tm*)

This unit is exposed as low undulating flats in the Condamine River Valley in the north-east corner of ALLORA. A small quarried outlier also caps a low hill 12km east of Inglewood. The unit has a moderate to high aeromagnetic response and has a dark red-brown tone on K-Th-U radiometric images.

In the study area, the unit consists of massive, fine-grained olivine basalt, occurring mainly as flows. Very minor mudstone and fine-grained sandstone beds are locally intercalated with the flows.

The Main Range Volcanics unconformably overlie rocks of the Marburg Subgroup and Walloon Coal Measures.

No radiometric age dating has been attempted on the Main Range Volcanics in the study area. Age dating elsewhere in the sequence (Webb & others, 1967) indicates a probable Late Oligocene to Early Miocene age range.

Rhyolite plug (*Tir*)

A very small rhyolitic plug of probable Tertiary age was recorded from company mapping of the Mount Gammie North area on ALLORA. The unit intrudes the Texas beds and is probably a subvolcanic intrusion related to eruptions of the nearby Main Range Volcanics.

Undivided sedimentary deposits (*Ts* ,*TQs*)

Small isolated patches of probable Tertiary sediments (Ts) occur in the western part of the region on INGLEWOOD. The unit consists of quartzose to sublabile sandstone, claystone and conglomerate.

Younger, more poorly consolidated sand, gravel, silt and clay deposits (TQs) are developed on Mesozoic sandstone a few kilometres south of Leyburn on ALLORA.

MORPHOSTRATIGRAPHIC UNITS

Residual soil and colluvium (*TQr*, *TQrs*, *Qrs*)

The oldest (Tertiary-Quaternary) residual soil and colluvial deposits are designated as units TQr and TQrs, with younger (Quaternary) deposits designated as Qrs.

These map units were delineated on the geological maps mainly through photointerpretation and also in some cases from airborne radiometric images. The deposits are generally defined by pediment slope wash material mixed with some residual material near the base of the slope.

Unit TQrs covers large areas in the western part of the Texas region (mainly on INGLEWOOD and north-western TEXAS). These areas have distinctively low and flat topographic expression and comprise sandy to gravelly residual soil and colluvial deposits that are mostly developed on or over sediments of the Surat Basin. The residual soils and colluvium are mostly reddish brown in colour and are most likely derived from weathering and erosion of iron-rich quartzose sandstones and conglomerates. They comprise quartz grains and siliceous fragments reworked from Surat Basin sediments. Iron nodules are also locally abundant, particularly in the vicinity of Inglewood. Smaller bodies in the southern part of TEXAS mostly comprise colluvial deposits derived from the Texas Beds.

Unit TQr is much less extensive and occurs as small isolated areas, mainly in the eastern part of the Texas region. The unit comprises both coarse and fine colluvial detritus including pebbles and cobbles mixed with soil, silt and clay derived from variety of basement substrates.

The younger Qrs deposits occur as residual to colluvial deposits on the slopes and in depressions defining small valleys draining the adjacent Condamine River system on ALLORA.

Alluvium (*Qa*)

Alluvium (Qa) is present as present day valley-fill deposits associated with the major streams throughout the region. Locally, the alluvial channels contain isolated silt and clay deposits formed in small lakes and ponds (Qal). The most extensive alluvial deposits occur in the valleys, flood plains and channels of the Dumeresq River – Macintyre Brook – Canning Creek system in the south and west of the region and the Condamine River system in the north. The latter, however, is dominated by dark brown to black soil (Qa_b) derived from erosion of the extensive basalts of the Main Range Volcanics in the Warwick–Allora area.

INTRUSIVE ROCKS

Introduction

Granitic rocks forming the northern part of the New England Batholith (Wilkinson, 1969) make up a significant part of the New England Orogen in the Texas region. The granites were emplaced in the early Permian and late Permian–early Triassic. They intruded sequences of Palaeozoic sedimentary and volcanic rocks, and are uncomformably overlain by Mesozoic sedimentary rocks of the Clarence–Moreton and Surat Basins.

Shaw & Flood (1981) subdivided the granitic rocks of the New England Batholith into three I-type (Clarence River, Uralla, and Moonbi) and two S-type (Hillgrove and Bundarra) plutonic suites. Several economically significant and aerially extensive granites of felsic composition were not assigned to suites because of a lack of diagnostic mineralogy, the scarcity of inclusions, and the inability to accurately determine $^{87}Sr/^{86}Sr$ initial ratios (because of the very high Rb and low Sr contents). O'Neil & others (1977) had previously determined that most of these leucogranites (their terminology, *e.g.* page 316) yield relatively low $\delta^{18}O$ values consistent with derivation from I-type source rocks. The leucogranites, which include the Stanthorpe and Ruby Creek Granites of the Stanthorpe–Wallangarra region were assigned to a separate 'leucoadamellites' group (containing >74% SiO_2) by Shaw & Flood (1981, page 10 538).

Subsequent, more detailed chemical and petrographic studies of the leucogranites of the northern New England Batholith resulted in their inclusion in the Moonbi Supersuite (Blevin & Chappell, 1992, 1996; Chappell, 1994; Chappell & Bryant, 1994). The term 'supersuite' was used to replace the term 'plutonic suite' of Shaw & Flood (1981) to be consistent with nomenclature used for Lachlan Fold Belt granites. Blevin & Chappell (1996) assigned the felsic granites and genetically related, more mafic units to the Stanthorpe Granite Group of the Moonbi Supersuite (Chappell, 1978). The Moonbi Supersuite, so defined, crops out in two discrete areas, namely:

1. in the Tamworth–Bendemeer district of northern New South Wales (Moonbi Granite Group of Blevin & Chappell, 1996); and

2. in the Tenterfield (New South Wales)–Stanthorpe region farther north (Stanthorpe Granite Group of Blevin & Chappell, 1996).

Blevin & Chappell (1996) subdivided the Stanthorpe Granite Group into three main types using petrographic and chemical criteria, namely:

1. Bungulla Type,
2. Stanthorpe Type, and
3. Ruby Creek Type.

The above subdivision represents a transition from relatively mafic, unfractionated rock types to very felsic, highly fractionated compositions, as well as an age progression (at least on a local scale).

Mustard (2004) subsequently assigned the Bungulla and Stanthorpe Type granites of the Timbarra Tableland (Grafton 1:250 000 Sheet area, New South Wales) to the informal Timbarra Tablelands suite.

Several new supersuites and suites have been defined in this report, using recently acquired chemical data. A more detailed investigation may indicate that the granites of the northern New England Batholith can be further subdivided, in particular the very extensive Stanthorpe Suite. The reconnaissance nature of most of the mapping and the general lack of age dates determined using modern techniques (such as U–Pb zircon SHRIMP) are significant hindrances in attempts to subdivide these granites.

The following subdivisions were used to describe the grainsize of the granites; they refer to the average size of groundmass grains:

fine grained	<1mm;
medium grained	≥1mm and <5mm; and
coarse grained	≥5mm.

Acknowledgments

RJB wishes to express his sincere thanks to Dr D.C. Champion (Geoscience Australia) and Dr P.L. Blevin (Geological Survey of New South Wales) for many fruitful discussions and help in classifying the granites of the northern New England Batholith.

He also wishes to acknowledge the significant contribution of Emeritus Professor B.W. Chappell who facilitated sample preparation and analysis. Most of the samples collected by RJB from the northern New England Batholith were analysed in the Geoscience Australia laboratory (by XRF and ICP-MS), Canberra, the remainder at the Australian National University, Canberra (by XRF).

BULLAGANANG SUPERSUITE

Bullaganang Suite

Bullaganang Granite (*Pgbg*; new name)

The Bullaganang Granite forms a small ovoid stock (~18km^2) in the central-eastern part of the Texas 1:100 000 Sheet area, ~50km west-north-west of Stanthorpe. The granite is relatively resistant to erosion and forms a prominent hill with numerous bouldery outcrops and rock pavements. The

Table 1. Recent isotopic ages obtained from samples from the northern part of the New England Batholith

Sample Number	Unit	Age	Location		Method/ Operator
			Easting (mga94)	Northing (mga94)	
RJB2920	Stanthorpe Granite (subunit $Rgst_a$?)	246.9±2.0Ma	389732	6849071	U-Pb zircon (SHRIMP), Geoscience Australia
RJB2011	Palgrave Granite (depicted as subunit Pgh_b of the Herries Granite on the 1:100 000-scale, first edition Allora geological map)	256.0±1.8Ma	383827	6851791	U-Pb zircon (SHRIMP), Geoscience Australia
RJB1654	Greymare Granodiorite	279.6±2.6Ma	378959	6883206	U-Pb zircon (SHRIMP), PRISE, Research School of Earth Sciences, ANU
RJB2313	Bullaganang Granite	291.5±2.2Ma	344868	6836729	U-Pb zircon (SHRIMP), Geoscience Australia

designated type locality is at MGA 344868 6836729, on the southern flank of Mount Bullaganang. The unit is characterised by mainly pale pink tones on a composite RGB radiometric image. The Bullaganang Granite intrudes the Texas beds. Recently obtained U–Pb zircon (SHRIMP) data indicate the unit is early Permian (292±2Ma; Table 1) and significantly older than the Stanthorpe Granite (early Triassic) and Palgrave Granite (late Permian).

The granite is of interest because:

1. the pluton was emplaced into the core of the Texas Megafold of Murray & others (1987),
2. radiometric images imply the pluton is partly surrounded by an irregular zone of potassic alteration, and
3. the pluton crops out ~1.5km west-north-west of the abandoned Warroo gold mine, and may have contributed in some way to the Au mineralisation.

The Bullaganang Granite at the two sites examined in detail consists of pale pink to pale brownish pink, mainly medium-grained, uneven-grained, leucocratic biotite syenogranite. Grainsize ranges from ~0.3mm to ~4mm (average ~1.5–2mm). The rocks contain abundant pink K-feldspar. Most feldspar grains are turbid in thin section; some K-feldspar grains show microcline twinning. The granite contains ~2–3% biotite (commonly partly replaced by chlorite). Accessory and secondary minerals present include zircon, fluorite, titanite, allanite, opaques, sericite, and chlorite. Granophyric intergrowths between K-feldspar and quartz are poorly developed in places. Small (up to ~1.5cm across) miarolitic cavities are present locally, and the granite is commonly stained by secondary iron oxides.

The outcrop (at the type locality) from which the fresher sample was obtained yielded an averaged magnetic susceptibility of 307 x 10^{-5} SI units (range of 255–400 x 10^{-5} SI units for 20 readings). In contrast the outcrop from which the second sample was obtained yielded an averaged magnetic susceptibility of 31 x 10^{-5} SI units (range 0–95 x 10^{-5} SI units for 28 readings). These relatively low readings may reflect minor alteration of the granite at that locality where pervasive secondary iron oxide staining, for example, is common.

The Bullaganang Granite is a high-K (Figure 27), strongly evolved (terminology of Blevin, 2004; with K/Rb values of 197 and 200) I-type that has relatively high Ba and low Nb, Pb and Rb (*e.g.* Figures 28, 29, 52) contents compared to most analysed samples of Stanthorpe Suite granites (at similar SiO_2 contents). The granite is characterised by a pronounced negative Eu anomaly (Eu/Eu*[1] = 0.109–0.222 — average = 0.165), implying either extended plagioclase fractionation played a significant role in its evolution, or that plagioclase was a residual mineral in the source of the granite.

Granites of the Bullaganang and Mingimarny Suites are characterised by slightly higher Nb contents and lower ASI, Mg number, TiO_2, MgO, P_2O_5, Sr, Sc, and V compared to those of the Mount You You Supersuite.

Mingimarny Suite

Mingimarny Granite (*PRgmi*; new name)

The *Mingimarny Granite* is exposed as a small stock (~5km^2) near the central-northern boundary of the Inglewood 1:100 000 Sheet area, ~65km north-north-west of Mount Bullaganang. The granite forms a low rise (maximum relief of ~80m) with

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[1] Eu/Eu* = $Eu_N/\sqrt{[(Sm_N)*(Gd_N)]}$ after Taylor & McLennan (1985). Normalising values are those of Nakamura (1974), with additions from Haskin & others (1968).

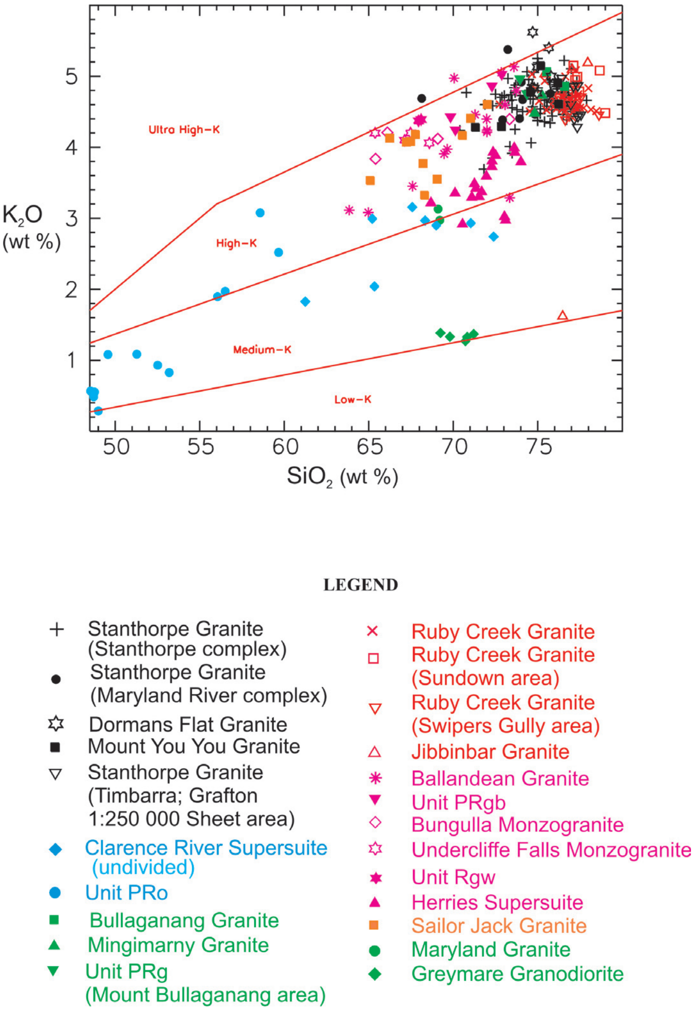

Figure 27. K$_2$O versus SiO$_2$ plot for selected intrusive rocks of the northern New England Batholith, showing their predominantly high-K character. The anomalously low K$_2$O value of one of the samples of Jibbinbar Granite may be a result of alteration.

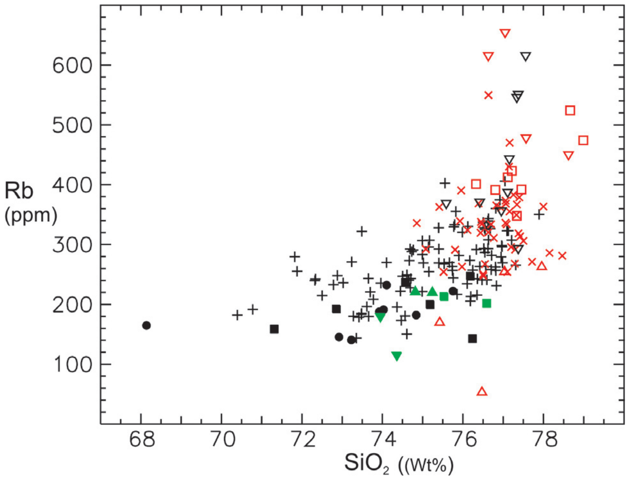

Figure 28. Rb versus SiO$_2$ plot comparing unit PRg, and Mount You You, Jibbinbar, Bullaganang, Mingimarny, Ruby Creek and Stanthorpe Granites. Note the relatively low Rb contents of the samples of unit PRg, and Mount You You, Jibbinbar, Mingimarny, and Bullaganang Granites compared to those of the Ruby Creek Granite. Symbols as in Figure 27.

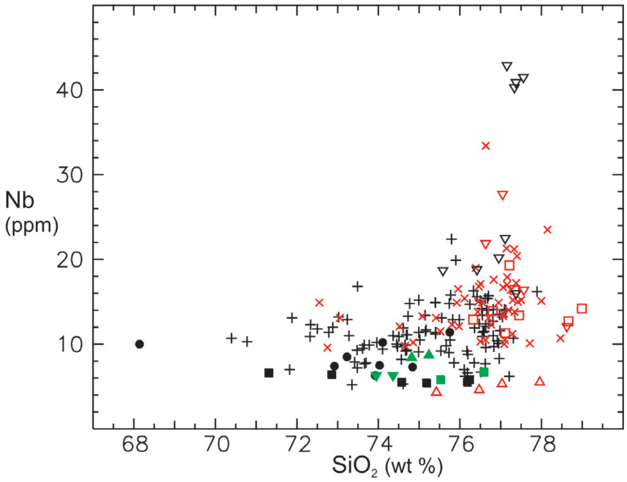

Figure 29. Nb versus SiO$_2$ plot for unit PRg, and Mount You You, Jibbinbar, Bullaganang, Mingimarny, Ruby Creek, and Stanthorpe Granites, showing the Nb-depleted character of unit PRg and Bullaganang, Mount You You, and Jibbinbar Granites compared to most of the Ruby Creek and Stanthorpe Granites. Symbols as in Figure 27.

extensive pavements and scattered boulders. It is drained by Mingimarny Creek and its tributaries. The shallow, residual, sandy soils on parts of the granite support stands of Cypress pine (*Callitris* sp.). The unit shows mainly white tones on a composite RGB radiometric image, reflecting its felsic character. The designated type locality is at MGA 326796 6897250, at the southern end of an abandoned rifle range in a state forest reserve.

The unit is most probably Permian or Triassic. Contacts with adjacent basement rocks are not exposed, the granite being surrounded by unconsolidated , to poorly consolidated sandy sediments of Tertiary–Quaternary age.

The unit comprises pale grey or white to buff, fine-grained (average size of groundmass grains ranges from ~0.3mm to ~0.6mm in the two samples examined in detail), moderately porphyritic, leucocratic biotite monzogranite. Biotite (~2–3%) is the main mafic mineral. K-feldspar (white) is more abundant than plagioclase. K-feldspar phenocrysts range up to ~2.5cm in length (most <1cm). Some K-feldspar grains show microcline twinning. The granite also contains phenocrysts of quartz (rounded, glassy, up to ~1cm across) and plagioclase (up to ~5mm in length; most <3mm). The cores of some plagioclase grains are partly to extensively replaced by calcite. The presence of sparse irregular miarolitic cavities, up to ~2.5cm in length, implies the granite was emplaced at shallow levels in the crust. The cavities are filled or partly filled with outer zones of quartz and K-feldspar (white) and inner zones (cores) of tourmaline?.

The white colour of the K-feldspar grains implies the granite is reduced and is consistent with the low intensities shown by the unit on aeromagnetic images. The rocks at the two sites examined in detail have magnetic susceptibilities of <20 x 10^{-5} SI units.

The Mingimarny Granite is a moderately evolved, high-K, I-type (Figure 27). The two samples analysed are not highly fractionated (*e.g.* Rb = ~220ppm, Figure 28), and have moderate negative Eu anomalies (Eu/Eu* ranges from 0.11–0.23). They are characterised by slightly higher CaO, P_2O_5, Nb, Ga, and Nd contents and lower K_2O, Zr, Ba, LREE, Eu, Hf and F compared to the Bullaganang Granite.

GREYMARE SUPERSUITE

Greymare Suite

Greymare Granodiorite (*Pggm*)

The I-type *Greymare Granodiorite* (Richards, 1918) forms an ovoid pluton (~45km^2), in the vicinity of Greymare railway siding (~30km west of Warwick). The unit crops out mainly as scattered boulders in extensive areas of soil and alluvium. Some of the larger boulders have been used as a source of dimension stone (Richards, 1918). The unit has yielded an early Permian U–Pb zircon (SHRIMP) age (see Table 1). It intrudes the Texas beds, and is cut by the large dyke swarm that extends from near Braeside in the south to Greymare in the north (Robertson, 1974). Samples examined by one of us (RJB) imply 'tonalite' is a more appropriate descriptor for the unit than 'granodiorite'.

The Greymare Granodiorite is distinguished from all other granites in the Stanthorpe–Wallangarra region by dark grey to black tones on a composite RGB radiometric image (implying it is very poor in K, Th, and U; Figure 30). The unit is also characterised by narrow curvilinear zones of relatively high magnetic intensities in the marginal parts of the pluton and a broad core of lower magnetic intensities (Figure 31). The average magnetic susceptibility ranges from ~135 x 10^{-5} SI units to ~430 x 10^{-5} SI units at the seven sites where measurements (>20 at each site) were taken.

The unit consists mainly of grey, fine to medium-grained, slightly porphyritic to uneven-grained, quartz-rich (up to ~35%) tonalite to granodiorite? containing ~5–15% biotite and traces of titanite, opaques, apatite, and zircon. Robertson (1974) also reported the presence of rare allanite. The widespread occurrence of scattered biotite phenocrysts, up to ~2cm across, and general absence of hornblende are characteristic features of the unit. Hornblende (minor) was only detected in one sample (from the Mountain Maid Road area — MGA 375727 6877038) examined in detail during the recent survey. K-feldspar is scarce to absent in the thin sections examined, and mafic inclusions are rare. Rare, thin pegmatite lenses (containing pale pink K-feldspar) and an irregular aplite dyke were observed at one locality. The Greymare Granodiorite is slightly to moderately altered; epidote, chlorite, calcite, and sericite/muscovite are the main secondary minerals. It is also slightly to moderately deformed; quartz and biotite grains commonly show undulose extinction and some quartz grains are partly recrystallised.

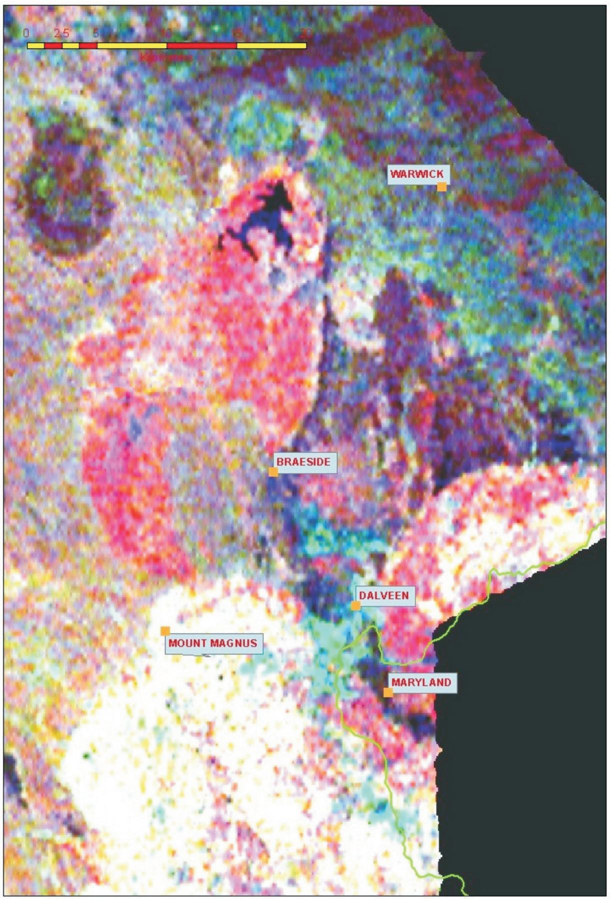

Figure 30. Ternary (RGB) radiometric image of the northern part of the New England Batholith. The highly evolved Stanthorpe and Ruby Creek Granites of the Stanthorpe complex (mainly south of Mount Magnus) are characterised by predominantly white tones. In contrast, less evolved granites of the Herries Supersuite (south-west of Warwick) and Stanthorpe Granite of the Maryland River complex (east and north-east of Maryland) show mainly pink tones. The primitive Greymare Granodiorite (ovoid intrusion in upper north-western part of image, beneath scale bar) is characterised by dark tones. The green line depicts the position of the border between Queensland and New South Wales.

The Greymare Granodiorite has many of the compositional characteristics of adakites [*e.g.* relatively high Al_2O_3 (>15%), low MgO (<1.5%), high Sr (>370ppm), low Y (<10ppm), high Sr/Y (>40), low Yb (<1ppm), high La/Yb (>19), low Nb (<3.5ppm); see Castillo, 2006]. It is distinguished from all other granites of similar SiO_2 contents analysed from the northern New England Batholith

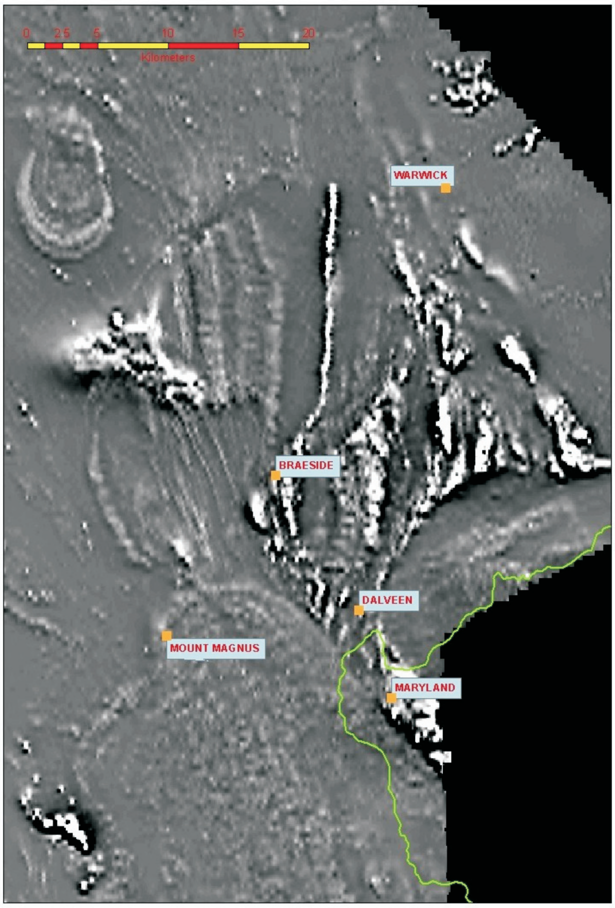

Figure 31. Grey-scale aeromagnetic image (first vertical derivative) of the northern New England Batholith and adjacent rock units. The image covers approximately the same area as Figure 30. The green line depicts the position of the border between Queensland and New South Wales.

by anomalously low FeO*, TiO_2, K_2O, Y, Nb, and Ta contents and high values for Mg number, Al_2O_3, Na_2O, K/Rb, and Sr/Y. It is a medium-K, I-type. Compared to the granites of the Bungulla and Stanthorpe Suites the Greymare Granodiorite is characterised by significantly higher Na_2O, Al_2O_3, and CaO contents, and K/Rb ratios (~400–450), and lower FeO*, K_2O, Rb, Ba, Th, Y, Nb, U, and Pb abundances, and Sr/Y ratios (Figures 27, 33, 46, 47, 50, 51). The granodiorite resembles the Clarence River Supersuite granites of Chappell & Bryant (1994) in some respects, but it has relatively high Al_2O_3, CaO, Na_2O, K/Rb, Sr/Y, and lower FeO*, K_2O, P_2O_5, Ba, Nb, Rb, Th, U, Y, Zn, Zr, and Rb/Sr values compared to most Clarence River Supersuite rocks with similar SiO_2 contents. These features attest to the compositionally unevolved character of the Greymare Granodiorite.

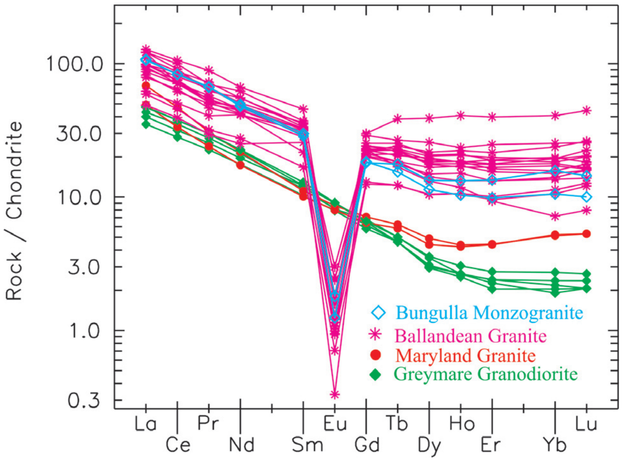

Figure 32. REE patterns of selected samples from the Ballandean Granite and Bungulla Monzogranite compared to those for the Maryland Granite and Greymare Granodiorite.

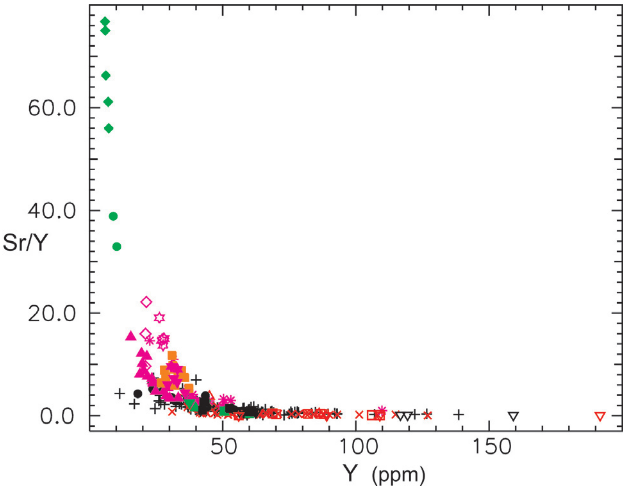

Figure 33. Sr/Y versus Y plot for selected intrusives of the northern New England Batholith, showing the Sr-undepleted, Y-depleted character of the Greymare Granodiorite and Maryland Granite compared to Bungulla and Stanthorpe Suite granites. Symbols as in Figure 27.

The Greymare Granodiorite is characterised by distinctive steep chondrite-normalised REE patterns with significant relative LREE enrichment (La ranges from ~35 to ~43 times chondrite, Yb <~3 times chondrite; $(La/Yb)_N$ =14.67–25.01, average = 19.38; Figure 32), and only slightly negative to slightly positive Eu anomalies (Eu/Eu* = 0.894–1.025; average = 0.977). The marked depletion in HREE is typical of magmas generated under relatively high P–T conditions (in most cases at relatively deep crustal levels) where plagioclase crystallisation was suppressed and garnet was either a fractionating phase or a residual mineral in the source. The involvement of garnet is also supported by the exceptionally high Sr/Y ratios compared to those of other units of the northern New England Batholith (Figure 33). Similar patterns have been described for units of the Clarence River Supersuite (*e.g.* Duncans Creek Trondhjemite; Bryant & others, 1997) and the Peninsular Ranges Batholith, U.S.A. (eastern and central parts; Gromet & Silver, 1987).

Clarence River Supersuite rocks are reported to have formed either as direct products of arc magmatism or by partial melting of juvenile, arc-derived rocks (Bryant & others, 1997, 2003) at an active continental margin (Chappell, 1994). The Greymare Granodiorite may have had a similar origin; *i.e.* it resulted primarily from partial melting of eclogite or garnet amphibolite.

MOUNT YOU YOU SUPERSUITE

Mount You You Suite

Mount You You Granite (*PRgmy*; new name)

The *Mount You You Granite* forms an elongate, north-north-westerly-trending stock (~14km^2), ~36km west of Stanthorpe. The granite is reasonably well exposed and forms undulating to low hilly country with scattered boulders, tors, pavements, and whalebacks. The designated type locality is at MGA 360338 6829295 on Beltana station. The unit forms prominent outcrops of pale grey to pale pink, fine to medium-grained, moderately porphyritic, leucocratic biotite syenogranite at this locality.

The unit forms a composite pluton (Virtue, 1985), and is texturally and, to a lesser extent, mineralogically heterogeneous. It consists mainly of pale grey to pale pink, buff–reddish brown, or cream, fine to medium-grained, variably porphyritic to uneven-grained biotite monzogranite to syenogranite. Minor hornblende-biotite monzogranite and rare, thin (<5cm thick) dykes of white, fine to medium-grained, aplitic leucogranite are also present in places (also see Virtue, 1985). The heterogeneous character of the pluton is also indicated by the range of colours (pale pink to red to white) displayed by the pluton on a composite RGB radiometric image.

The granitic rocks consist mainly of K-feldspar, quartz, subordinate plagioclase, and minor biotite (~2–5%). K-feldspar grains are commonly turbid and range from white to pink at different localities. Minor hornblende (pleochroic from brown or greenish brown to pale brown or pale greenish yellow) is present in one of the samples (at MGA 357881 6831143) examined in detail. Virtue (1985) reported up to ~5% hornblende in the southern and northern parts of the pluton. Accessory and secondary minerals include titanite, zircon, apatite, opaques, allanite, chlorite, epidote, sericite, pyrite, muscovite, and actinolite (rare). Granophyric intergrowths between quartz and K-feldspar are locally common. The local presence of small, irregular miarolitic cavities implies a relatively shallow level of emplacement. The granite also contains rare biotite-rich inclusions up to ~3cm across. All outcrops examined are characterised by low (<50 x 10^{-5} SI units) magnetic susceptibilities. These readings are consistent with the low magnetic intensities shown by the unit on aeromagnetic images.

The Mount You You Granite was previously mapped as part of the Ruby Creek Granite (Robertson, 1974). Athough it has some similarities, the Mount You You Granite differs from the Ruby Creek Granite in several significant aspects, namely:

1. titanite is a relatively common accessory mineral in the Mount You You Granite, but was not detected in the felsic Ruby Creek Granite,

2. parts of the Mount You You Granite contain minor hornblende, whereas hornblende has not been recorded in the Ruby Creek Granite,

3. the Mount You You Granite is not highly fractionated (*e.g.* Rb < 250ppm), and

4. the Mount You You Granite is unmineralised, in marked contrast to the Ruby Creek Granite.

The Mount You You Granite is a high-K (Figure 27), moderately to strongly evolved (K/Rb ~270–140), I type. The unit is characterised by relatively high TiO_2, P_2O_5, Ba, Sr, V, Zr, and low Na_2O, Nb, Pb, Rb, Th, Sn, and U contents compared to most of the Ruby Creek Granite (*e.g.* Figures 28, 29, 52). Relatively low Nb abundances, and high Ba contents and K/Rb ratios distinguish the Mount You You Granite from most of the Stanthorpe Suite.

The Mount You You Granite intrudes the Texas beds, as well as a sequence of mudstone, siltstone, and tuffaceous sedimentary rocks tentatively assigned to *unit Ps* of probable early Permian age. The granite is associated with several pods and lenses of gabbro (part of *unit PRo*). Contacts between the two rock types range from sharp (Figure 34a) to crenulate (Figure 34b).

The age of the Mount You You Granite is uncertain. Robertson (1974) interpreted the unit to be most probably early Triassic. However, the Bullaganang Granite (~13km to the north-west) and the Greymare Granodiorite (~45km to the north-north-east) have recently yielded early Permian isotopic ages (see Table 1), thereby raising the distinct possibility that the Mount You You Granite may be older than early Triassic.

Jibbinbar Granite (*PRgj*; new name)

The *Jibbinbar Granite* forms a small stock (~7km^2) west of the main granite belt. It is relatively resistant to erosion and forms Jibbinbar Mountain, a prominent topographic feature with numerous boulders, extensive pavements, and prominent bare rock outcrops. The unit is characterised by white tones on a ternary RGB radiometric image, and by relatively low, uniform (flat) magnetic intensities on aeromagnetic images. The designated type locality is at MGA 366185 6814118, where the unit forms extensive outcrops on the northern flank of Jibbinbar Mountain.

The age of the Jibbinbar Granite is poorly constrained. The unit intrudes the Texas beds, and

Figure 34a. Angular mafic inclusions in Mount You You Granite (creek bed at MGA 359763 6830040).

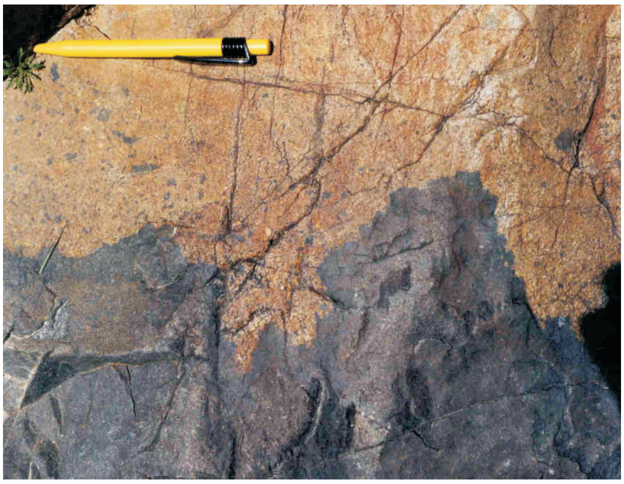

Figure 34b. Crenulate contact between mafic intrusive and Mount You You Granite.

was most probably emplaced in the Permian or early Triassic.

The unit consists of white to pale brown, pale grey, or brown to reddish brown, fine- to medium-grained, mainly even-grained biotite syenogranite. The syenogranite is slightly to moderately altered, with turbid feldspars, pervasive secondary iron oxide staining, biotite replaced by chlorite, and minor epidote (mainly in interstices). It contains ~1–2% biotite (extensively replaced by chlorite). Accessory and secondary minerals detected in the syenogranite include allanite, titanite, epidote (relatively common), chlorite, and muscovite (interstitial). Granophyric intergrowths between quartz and K-feldspar are common. However, miarolitic cavities and interconnected miarolitic textures were not recognised in the outcrops examined. The syenogranite contains inclusions of indurated country rock, up to several metres across, adjacent to the contact with the Texas beds in places (*e.g.* at MGA 365793 6813859). Grainsize increases slightly away from the margins of the pluton. The unit is also texturally heterogeneous. At MGA 366185 6814118, for example, even-grained leucogranite grades into slightly porphyritic leucogranite containing scattered slender white feldspar phenocrysts up to ~1cm long. Of 90 magnetic susceptibility determinations only 2 readings were >10 x 10^{-5} SI units — most readings were <5 x 10^{-5} SI units. These low readings are consistent with the low magnetic intensities that characterise the pluton on aeromagnetic images.

Available analyses of the Jibbinbar Granite imply the leucogranite is not highly fractionated (*e.g.* Rb <265ppm; Figure 28), in contrast to the Ruby Creek Granite of the nearby Red Rock area, as well as elsewhere. The widespread secondary alteration raises the possibility that there may have been leaching of relatively mobile elements (such as Rb, Pb, U) after the granite had crystallised. However, the granite is not associated with significant Sn mineralisation (in marked contrast to the Ruby Creek Granite). In addition, analysed samples are also distinguished by anomalously low Nb contents (a feature shared with the nearby Mount You You Granite; Figure 29; Nb is a relatively immobile high-field-strength element), and by the presence locally of minor primary titanite. Titanite has not been found in the felsic, highly fractionated Ruby Creek Granite samples. The available data, therefore, imply the aplitic leucogranite forming Jibbinbar Mountain is distinct from the Ruby Creek Granite.

Unit PRg (Mount Bullaganang area)

Unit PRg forms a broad, low north-westerly-trending ridge (~0.5km^2) ~7km north-north-west of Mount Bullaganang. The unit is deeply weathered and poorly exposed, as scattered boulders and bouldery rubble. It consists of dark pinkish grey to pink, fine- to medium-grained (average grainsize of groundmass components ranges from ~0.3mm to ~1mm), moderately porphyritic leucogranite, with scattered phenocrysts (in decreasing order of abundance) of plagioclase (up to ~2cm in length), quartz (up to ~1cm across), and K-feldspar (to ~2.5cm). K-feldspar phenocrysts range from white to pink; some are mantled by sodic plagioclase (rapakivi texture). Quartz grains are rounded, glassy, and commonly embayed. Poorly developed granophyric textures are present in places (*e.g.* at MGA 342852 6844215, MGA 342796 6844312). Some outcrops contain scattered, small, irregular miarolitic cavities, implying emplacement at shallow crustal levels. The cavities are commonly filled or partly filled with quartz + K-feldspar ± tourmaline.

The granite contains ~2–3% mafic minerals, and is slightly to moderately altered. K-feldspar grains are turbid and much more abundant than plagioclase grains (commonly sericitised). Biotite is the main mafic mineral in the sample collected from MGA 342852 6844215. Tourmaline, sericite, chlorite, muscovite, and clinozoisite? (traces) are the main accessory and secondary minerals.

In contrast, clinopyroxene and titanite are the main mafic minerals in the second sample, from MGA 342796 6844312. The presence of clinopyroxene, as unaltered, subhedral–euhedral, interstitial grains, associated with titanite (highly pleochroic), implies the rock has been affected by calcium metasomatism. The granite is too SiO_2-rich (SiO_2 = ~74%) for the clinopyroxene to have crystallised as a stable phase. The clinopyroxene and titanite grains show no evidence of having replaced earlier mineral phases. Traces of clinozoisite? (as a late-stage interstitial infilling and in thin veinlets), actinolite, secondary biotite (in interstices), and zircon are also present.

Unit PRg is a moderately evolved, high-K, I-type. It is characterised by relatively high Ba and Ni contents and K/Rb ratios, and low Nb concentrations (Figures 29, 52) compared to most of the Stanthorpe Granite (Stanthorpe complex). All of the granites analysed from west of the main Stanthorpe–Wallangarra belt, with the exception of the Mingimarny Granite, have relatively low Nb contents compared to most samples analysed from the Stanthorpe Suite. The least altered sample analysed from unit PRg is distinguished from the Bullaganang Granite by relatively low amounts of Na_2O, Hf, and Ta and high Sr, Pb, Sc, Mg number, K/Rb, and ASI.

The granite has not undergone extensive feldspar fractionation; Rb contents are <200ppm, and Eu/Eu* ranges from 0.29–0.33. The sample collected from MGA 342796 6844312 is characterised by anomalously low FeO*[2], Pb, Rb, and F contents, and high CaO and K/Rb, most probably as a result of alteration.

BOXWELL SUPERSUITE

Boxwell Suite

Boxwell Granodiorite (*Pgbo*)

The *Boxwell Granodiorite* (Stroud, 1992) forms gently undulating country with scattered bouldery outcrops, west of Texas. The unit crops out over ~22km^2 and extends south of the border into New South Wales, where it is traversed by the Bruxner Highway. The unit was informally referred to as the Mascotte granodiorite by Shaw (1981).

The Boxwell Granodiorite cuts the Texas beds and is partly overlain by Tertiary and Quaternary sediments. It has yielded four Rb–Sr biotite ages ranging from 252Ma–255Ma (Shaw & Flood, 1993; Shaw, 1994).

The unit is compositionally zoned. It has a monzodiorite–quartz monzodiorite margin that grades inwards into granodiorite and a core of monzogranite and leucocratic syenogranite (Shaw, 1981, *in* Stroud, 1992). Medium-grained, slightly porphyritic hornblende-biotite granodiorite (with abundant mafic enclaves) is the main rock type. The granodiorite is well exposed in the Smithfield–Mundoey area (*e.g.* at MGA 311464 6812182). It contains abundant plagioclase (~45%), which forms large, euhedral, oscillatory-zoned phenocrysts (Figure 35) with altered cores surrounded by fresher rims. K-feldspar (20%; locally poikilitic), and quartz (20%) form anhederal interstitial grains. Mafic phases include biotite (10%), hornblende (4%), and minor pyroxenes and opaque oxides (1%). Accessory phases include apatite and zircon. Hornblende-rich mafic enclaves are abundant throughout the granodiorite and range up to 15cm in diameter.

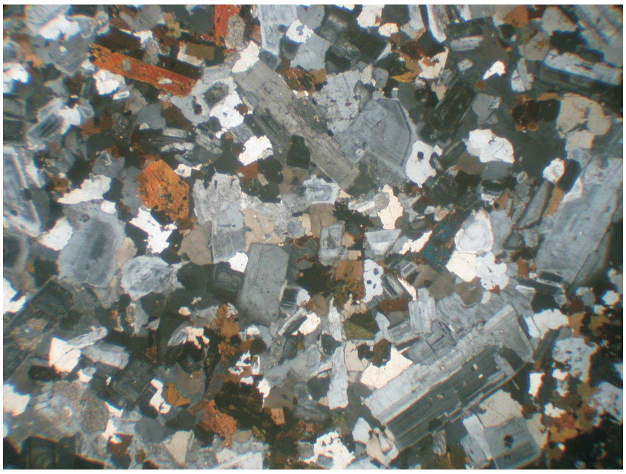

Figure 35. Thin section view of the Boxwell Granodiorite. Large, oscillatory zoned plagioclase phenocrysts are abundant and hornblende is common. K-feldspar and quartz form interstitial grains. Sample TXDP012 (MGA 311569 6812371), crossed polars, x-axis ~9mm.

Stroud (1992) reported that the Boxwell Granodiorite has geochemical similarities with Clarence River Supersuite granites; in particular low K, high Na, and relatively low Sr contents. The Clarence River Supersuite comprises compositionally diverse intrusions possibly derived from multiple mid- to lower-crustal sources. However, the Boxwell Granodiorite crops out more than 100km west of Clarence River Supersuite granites. It is also characterised by relatively low CaO and high TiO_2 and $Na_2O + K_2O$ contents.

HERRIES SUPERSUITE

Granites of the Herries Supersuite are characterised by:

1. the absence of felsic, highly fractionated rocks (*e.g.* none of the analysed samples has a Rb content >200ppm),
2. the almost complete absence of any known associated mineralisation, in marked contrast to the nearby Stanthorpe Granite,

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[2] $FeO^* = FeO + 0.8998Fe_2O_3$

3. the relative abundance of mafic minerals (~5–10%) and plagioclase (generally more abundant than K-feldspar),

4. the widespread distribution of hornblende, locally forming prominent laths up to ~2.5cm long,

5. the common presence of mafic enclaves, and

6. the absence of miarolitic cavities.

Herries Suite

Herries Granite

The *Herries Granite* (*Pgh*; Robertson, 1971) forms a relatively large, irregular, northerly aligned pluton, ~20km south-west of Warwick, as well as several smaller satellitic intrusions (total area ~161km^2). Much of the unit is deeply weathered and poorly exposed. Locally, the granite forms hilly country with numerous prominent boulders, tors and whalebacks. The unit consists mainly of pale pink to greyish pink, medium-grained (groundmass), slightly to moderately porphyritic hornblende-biotite monzogranite. Biotite is the dominant mafic mineral, and subordinate hornblende is generally present. Many samples also contain traces of titanite and/or allanite. The colour of K-feldspar grains ranges from pink to white.

The unit intrudes the Silverwood Group and Texas beds and is unconformably overlain by the Marburg Formation. It is interpreted to pre-date the nearby Stanthorpe Granite (Stanthorpe complex). The granite is cut by north-westerly trending felsic to mafic dykes.

The Herries Granite shows mainly pink tones on composite RGB radiometric images (Figure 30), and low to moderate intensities on aeromagnetic images (Figure 31).

Palgrave Granite
(*Pgpa*; new name)

The south-western lobe of Herries Granite depicted as subunit Pgh$_b$ on the 1:100 000-scale, first edition Allora geological map, is delineated as the *Palgrave Granite* (~62km^2) on the revised Allora Special geological map (1:100 000 scale). The Palgrave Granite is a recessive unit and forms gently undulating country with scattered boulders and low pavements. It is characterised by dark pink to red tones on a composite RGB radiometric image, in contrast to the white to pale pink tones displayed by the adjacent Stanthorpe and Fairleigh Granites (Figure 30). It is truncated by the Stanthorpe Granite to the south and is tentatively interpreted to post-date the Fairleigh Granite (subunit Pgh$_a$ of the Herries Granite on the 1:100 000-scale, first edition Allora geological map) to the north. Monzogranite from MGA 383827 6851781 has yielded a U–Pb zircon (SHRIMP) age of 256.0±1.8Ma (late Permian; Table 1). The designated type locality is on the western side of Palgrave Road, at MGA 384034 6854083. The unit is relatively well exposed at this locality, mainly as scattered large boulders.

The unit consists of pale grey to pinkish grey, medium- to fine-grained (average grainsize of groundmass components ranges from ~2mm to ~0.3mm), moderately porphyritic hornblende-biotite monzogranite containing ~5–10% mafic minerals (hornblende slightly less abundant than biotite). The monzogranite contains numerous plagioclase phenocrysts, subordinate very pale pink to pale pink K-feldspar phenocrysts (up to ~2.5cm long), and scattered rounded quartz phenocrysts or aggregates up to ~2cm in diameter. Plagioclase is more abundant than K-feldspar in the three samples examined in detail. Accessory and secondary minerals include opaques, allanite (commonly altered), zircon, apatite, titanite (primary and secondary), calcite, epidote, sericite, and chlorite. The granite also contains sparse, small (up to ~5cm across), mafic inclusions, and biotite-rich schlieren in places (*e.g.* at MGA 379641 6857802).

The unit is slightly to moderately deformed; quartz grains show undulose extinction and some subgrain development (*e.g.* at MGA383827 6851791), and traces of myrmekite are commonly present.

The granite is moderately reduced to moderately oxidised ($-0.03 \leq \Delta Ox \leq 0.19$, using the classification scheme of Blevin, 2004). Magnetic susceptibility measurements are mostly <30 x 10^{-5} SI units (but range up to 80 x 10^{-5} SI units).

Fairleigh Granite
(*Pgfa*; new name)

The central-western part of the Herries Granite (subunit Pgh$_a$) depicted on the 1:100 000-scale, first edition Allora geological map, is delineated as the *Fairleigh Granite* (~65km^2) on the revised Allora Special geological map (1:100 000 scale). The Fairleigh Granite is much better exposed than the Palgrave Granite. This unit is relatively resistant to erosion and forms hilly country with numerous prominent outcrops, extensive pavements, whalebacks, and large boulders. It consists of pale pink to pale greyish pink or white to pale grey, medium- to fine-grained (groundmass), moderately porphyritic hornblende-biotite monzogranite. The unit is distinguished from adjacent units by pale pink to white tones on a composite RGB radiometric image (the latter show dark pink to red tones). The proposed type locality is at MGA 387285 6866485, on the western side of Pikedale Road. The granite forms very large boulders and whalebacks in this area.

The granite contains ~5–10% mafic minerals (biotite > hornblende), numerous phenocrysts of plagioclase (to ~2.5cm) and quartz (to ~2cm), as well as subordinate pale pink to white K-feldspar phenocrysts (to ~3cm), and traces of muscovite, zircon, apatite, allanite, titanite, opaques, epidote,

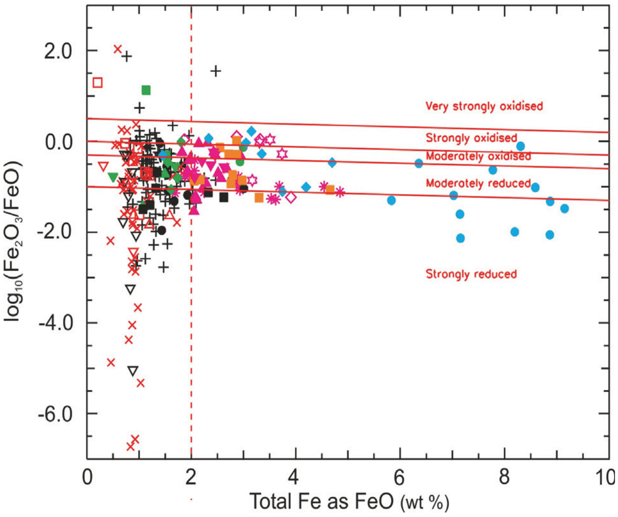

Figure 36. Redox classification scheme (after Blevin, 2004) for selected intrusive rocks of the northern New England Batholith. For granites with SiO_2 >~72%, and/or FeO* <~2%), Fe_2O_3/FeO ratios increase markedly to values that are unrealistic in terms of inferred magmatic fO_2 values, and other methods of determining relative oxidation state should be used (Blevin, 2004) — most of the samples from the Stanthorpe and Ruby Creek Granites are in this category. Symbols as in Figure 27.

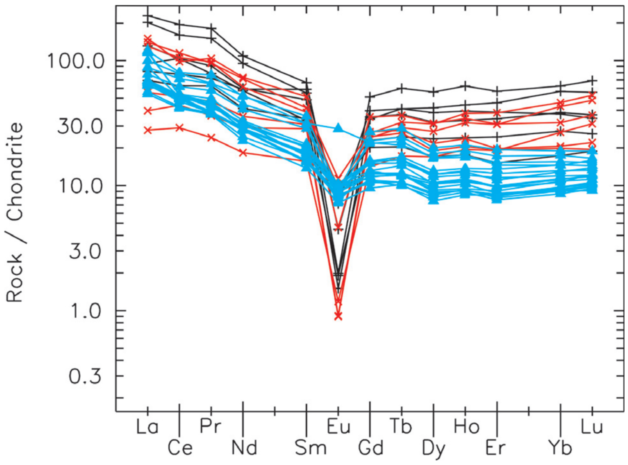

Figure 37. Plot of REE abundances for Herries Supersuite granites and selected samples of the Stanthorpe and Ruby Creek Granites, normalised to REE abundances in chondrites (using the values of Nakamura, 1974, with additions from Haskin & others, 1968). A range of values for the Stanthorpe and Ruby Creek Granites is shown rather than all the available analyses. Symbols as in Figure 27 except that Herries Supersuite granites (excluding the Boonoo and Maryland Granites) are shown in cyan.

calcite, sericite, and chlorite (not all of these minerals are present in every sample). Some samples (mainly in the north-east) contain sparse euhedral hornblende laths up to ~2.5cm long. The grainsize of the groundmass components ranges from fine to medium (from ~0.3mm to ~1.5mm). K-feldspar is subordinate to plagioclase and locally shows microcline twinning.

The unit contains sparse, ovoid to rounded, mafic inclusions up to ~30cm across (most <10cm). The granite is slightly deformed; quartz grains show undulose extinction and some subgrain development in places (*e.g.* at MGA386854 6864679).

The Fairleigh Granite ranges from moderately reduced to moderately oxidised ($-0.31 \leq \Delta Ox \leq 0.11$; classification of Blevin, 2004). Most magnetic susceptibility measurements are <30 x 10^{-5} SI units. Outcrops examined in the north-eastern part of the unit are exceptional, with magnetic susceptibilities ranging from ~250 x 10^{-5} SI units to ~550 x 10^{-5} SI units (three sites, with more than 20 readings taken at each site).

The granite is cut by numerous north-westerly trending dykes, locally forming swarms. The dykes examined during the recent survey range in composition from rhyolite and microgranite to andesite? and diorite. Robertson (1974) reported rhyolite, granophyre, trachyte, aplite, porphyritic microgranite (‘quartz-feldspar porphyry’, page 12), and basalt (rare) dykes in the large swarm, which extends for ~32km from south-west of Braeside in the south to the Greymare area in the north. The swarm ranges from ~800m to 3km in width (Robertson, 1974) and is clearly visible on images derived from airborne geophysical surveys.

Geochemistry

Granites of the Herries Supersuite are moderately reduced to strongly oxidised ($-0.3 \leq \Delta Ox \leq 0.6$; classification of Blevin, 2004; also see Figure 36), moderately to strongly evolved (K/Rb ~222–166), high to medium-K (Figure 27), I-types. They are distinguished from the Stanthorpe Supersuite granites by relatively low SiO_2, K_2O, $Na_2O + K_2O$, F, Nb, Pb, Rb, Y, Zr, and HREE (normalised) values (*e.g.* Figures 27, 37, 46, 47, 50, 51, 56), slightly higher CaO contents, and only moderate negative Eu anomalies (Eu/Eu* = 0.48–0.64).

Clare Hills Suite

Clare Hills Granite (*Pgch*; new name)

The western lobe of unit Pgh (undivided part of unit) depicted on the 1:100 000-scale, first edition Allora geological map, around Clare Hills homestead is delineated as the *Clare Hills Granite* (~17km^2) on the revised Allora Special geological map (1:100 000 scale). The Clare Hills Granite is a recessive unit and forms scattered boulders (some large) and tors. It is characterised by pink to red (locally white) tones on composite RGB radiometric images, in contrast to the predominantly pale pink tones of the adjacent Fairleigh Granite (Figure 31). The Clare Hills Granite intrudes the Texas beds and is tentatively interpreted to post-date the Fairleigh Granite although no contacts have been found. The designated type locality is beside Clare Hills Road, at MGA 382899 6866415. The granite is well exposed in the creek bed upstream of the road crossing at this locality and as large boulders in the ridge east and west of the creek.

The unit consists of pale pinkish grey to grey, fine to medium-grained, slightly to moderately porphyritic hornblende-biotite monzogranite. The monzogranite contains sparse, small (up to ~1cm across) plagioclase and quartz phenocrysts. K-feldspar (very pale pink) crystallised relatively late and forms irregular poikilitic grains. Accessory and secondary minerals include titanite, allanite, opaques, zircon, apatite, pyrite, chlorite, epidote, sericite, muscovite, and calcite. Mafic inclusions are rare or absent in most outcrops examined. Monzogranite exposed in Logan Creek at MGA 382899 6866415, adjacent to the contact with the Fairleigh Granite, is exceptional. It contains numerous mafic inclusions up to ~15cm across, and groundmass quartz and K-feldspar grains form granophyric intergrowths in places. Samples examined in detail from near the contact (at MGA 382899 6866415 and MGA 382658 6866709) are finer grained and more strongly porphyritic than monzogranite examined farther west in the vicinity of Clare Hills homestead. The granite is commonly slightly altered.

Average magnetic susceptibilities of 262 x 10^{-5} SI units, 730 x 10^{-5} SI units, and 1042 x 10^{-5} SI units (at least 20 readings at each site) were measured at three sites in the area around Clare Hills homestead. In contrast, most magnetic susceptibility measurements in adjacent parts of the Fairleigh Granite are <30 x 10^{-5} SI units (more than 20 readings taken at each site). The Clare Hills area is characterised by high magnetic intensities on aeromagnetic images (Figure 31). Farther north the Clare Hills Granite shows relatively low (flat) magnetic intensities.

The Clare Hills Granite is similar chemically to the Herries Suite granites, from which it is distinguished by anomalously high Sr contents and slightly lower Zr concentrations. This unit is moderately to strongly oxidised ($0.2 \leq \Delta Ox \leq 0.4$; classification of Blevin, 2004).

Maryland Suite

Maryland Granite

The small (~10km^2), poorly exposed *Maryland Granite (PRgma*; Saint-Smith, 1911) is the sole representative of the Maryland Suite. The unit shows mainly pink–red tones on composite RGB radiometric images, and is characterised by moderately high to high intensities on aeromagetic images. It differs significantly in appearance from the nearby coarsely porphyritic Undercliffe Falls Monzogranite. The two samples examined from the unit consist of medium grey, medium-grained, uneven-grained to slightly porphyritic monzogranite (also see Venables, 1984), with ~5–10% mafic minerals (biotite > hornblende), and traces of opaques, titanite, allanite, apatite, and zircon. K-feldspar is subordinate to plagioclase and forms white to (locally) very pale pink 'late-stage', irregular, poikilitic grains (oikocrysts). Quartz grains are locally pale greyish blue to bluish grey and characterised by highly undulose extinction, with some subgrain development. Mafic enclaves are common.

The Maryland Granite intrudes the Silverwood Group and is faulted against and cut by the Stanthorpe Granite (also see Robertson, 1974). It is unconformably overlain by the Marburg Formation (Jurassic).

The Maryland Granite is a moderately to strongly oxidised (using the classification scheme of Blevin, 2004; Figure 36), medium to high-K (Figure 27), I-type. The unit is moderately evolved (K/Rb ~225), and is characterised by anomalously high CaO and Sr/Y values, and low K_2O, TiO_2, P_2O_5, Ce, Nb, Rb, Sn, Y, Zn, Ga/Al, and Rb/Sr compared to nearby Bungulla Suite granites (Figures 27, 46, 47, 50, 53). The two analysed samples have negligible Eu anomalies (Eu/Eu* = 0.970–0.992) when normalised against chondritic abundances and are HREE depleted [$(La/Yb)_N$ = 9–13], in marked contrast to the granites of the Ballandean and Bungulla Suites (Figure 33). The latter show significant negative Eu anomalies (Eu/Eu* = 0.292–0.666) and $(La/Yb)_N$ values of ~1–16 (average ~7). The Maryland Granite is distinguished from other Herries Supersuite granites by relatively high Ba, Sr, and Sr/Y values and low TiO_2, P_2O_5, Y, Ni, and Ga contents; as well as by moderately depleted HREE (*cf.* Figures 32 and 37). The unit displays many of the compositional characteristics of adakitic rocks [*e.g.* relatively high Al_2O_3 (>14.9%), low MgO (<1.5%), high Sr (>330ppm), low Y (<10.5ppm), high Sr/Y (>32), low Yb (<1.2ppm); see Castillo, 2006], but not to the same extent as the Greymare Granodiorite.

Chappell & Wyborn (2004) attributed the chemical characteristics of the Maryland Granite to the presence of cumulative rocks. They postulated their cumulative character is implied by the lack of significant negative Eu anomalies, relatively low Ce abundances, and moderately high CaO, Sr and Ba contents (Chappell & Wyborn, 2004). The Eu/Eu* values of 0.970 and 0.992 are regarded as fortuitous and to represent a balance between the positive Eu anomaly of the accumulating feldspars and the negative Eu anomaly of the interstitial melt (Chappell & Wyborn, 2004).

Boonoo Suite

Boonoo Granite (*PRgbo*; new name)

The *Boonoo Granite* forms a small (~2.5km^2), irregular pluton in the south-western part of the Drake 1:100 000 Sheet area. It was referred to as the 'Spring Creek body' of the Bookookoorara Adamellite by Thomson (1976, page 69). The unit is named after Boonoo State Forest, the south-western extremity of which encroaches onto the granite. It crops out mainly as scattered rounded boulders (some large). The most accessible outcrops are in road cuttings along Mount Lindesay Road and adjacent areas. Consequently, the designated type area is beside Mount Lindesay Road, between MGA 411255 6797202 and MGA 411286 6797666. The irregular outline of the pluton is interpreted to indicate the Boonoo Granite pre-dates the enclosing Stanthorpe Granite, with which it has sharp contacts (Thomson, 1976).

The unit consists of grey to pinkish grey, fine to medium-grained, porphyritic (hornblende-titanite-) biotite monzogranite, with scattered feldspar (up to ~2.5cm long) and quartz (to ~1.5cm) phenocrysts. It is slightly to moderately altered. The monzogranite contains ~10% biotite, minor titanite (relatively common), traces of hornblende, and sparse, small (up to ~2cm in diameter) mafic inclusions. K-felspar grains are pale pink to cream (locally).

Accessory and secondary minerals include opaques (relatively common), zircon, apatite, allanite, muscovite, fluorite, chlorite (mainly after biotite), sericite, calcite (mainly after plagioclase), and epidote. Muscovite is relatively common — in interstices and associated with chlorite and sericite.

The unit is characterised by relatively high magnetic susceptibilities (average of >40 readings = 1192 x 10^{-5} SI units). In contrast, the Bookookoorara Monzogranite has a magnetic susceptibility of 113 x 10^{-5} SI units (average of 20 readings) at the one site examined in detail.

The Boonoo Granite is distinguished from the Bookookoorara Monzogranite by the following characteristics:

1. feldspar phenocrysts are less abundant,
2. mafic minerals are not as abundant,
3. the groundmass is finer grained,
4. magnetic susceptibilities are significantly higher, and
5. mafic inclusions are scarcer and smaller.

The Boonoo Granite is similar chemically to the Herries Suite granites, but is characterised by anomalously high F, Sn, and Sr contents, slightly higher Ga, Pb, and Rb concentrations, and relatively low K/Rb ratios.

BALLANDEAN SUPERSUITE

Ballandean and Sailor Jack Suites

Several additional, relatively mafic units were delineated in the Stanthorpe–Wallangarra region during the recent survey, namely:

1. the *Ballandean Granite (PRgba;* Ballandean Suite*)*,
2. the *Sailor Jack Granite (Rgsj;* Sailor Jack Suite*)*,
3. unit *Rgw* (Sailor Jack Suite) exposed north of Wallangarra, where it forms a dyke-like body that cuts the Wallangarra Volcanics (Purdy, 2003),
4. unit *PRgb* (Sailor Jack Suite), comprising coarsely porphyritic monzogranite to granodiorite? poorly exposed in the Eukey–Bald Rock area (south-east of Stanthorpe), and a small area of biotite-hornblende monzogranite exposed on the north-western margin of the Passchendaele State Forest (north-west of Stanthorpe).

These units are described in Appendix 1. They do not contain very large pink K-feldspar phenocrysts and coarse titanite grains like the Undercliffe Falls and Bungulla Monzogranites of the Bungulla Suite.

Saint-Smith (1914a) also reported a small isolated intrusion of apparently similar granite in rugged country between Mount Norman and Bald Rock.

The Ballandean Granite is characterised by pink–red tones on composite RGB radiometric images (implying it is enriched in potassium relative to thorium and uranium), in marked contrast to the white tones (indicating enrichment in all three radioelements) of the adjacent Stanthorpe Granite and Wallangarra Volcanics (Figures 38a,b). The northern extremity of the Sailor Jack Granite (the only part of the unit covered by the recent geophysical survey) also shows pale tones (pale pink to white) on a composite RGB radiometric image. The Ballandean Granite is also distinguished from the adjacent Stanthorpe Granite on magnetic images by relatively low, uniform (flat) magnetic intensities (Figure 40).

The Sailor Jack Granite is distinguished from the adjacent Ballandean Granite in the field by the widespread presence of pink K-feldspar and accessory titanite.

STANTHORPE SUPERSUITE

Bungulla Suite

Granites of the Bungulla Suite are preserved mainly as scattered remnant intrusions around the eastern and southern margins of the Stanthorpe Granite. This suite approximately corresponds to the Bungulla Type of Blevin & Chappell (1996). It contains most of the previously delineated, relatively mafic (~60% < SiO_2 < ~74%) granites (Undercliffe Falls Monzogranite, Bungulla Monzogranite, part Bookookoorara Monzogranite) but not the Maryland Granite and the ‘Spring Creek body’ (Thomson, 1976, page 69) of the Bookookoorara Monzogranite. The granites of this suite are generally deeply weathered and mainly form relatively low undulating country. The Undercliffe Falls and Bungulla

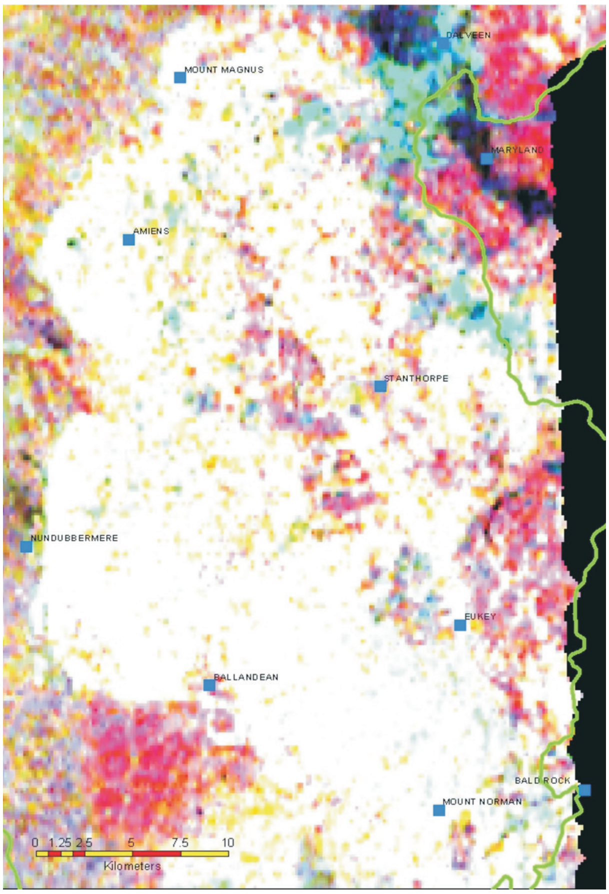

Figure 38a. Ternary (RGB) radiometric image of the Stanthorpe–Wallangarra region. The relatively evolved Stanthorpe and Ruby Creek Granites of the Stanthorpe complex show predominantly white tones, in contrast to the predominantly pink tones of the less evolved Ballandean Granite (south-west of Ballandean) and Stanthorpe Granite east and north-east of Maryland (Maryland River complex). The green line depicts the position of the border between Queensland and New South Wales.

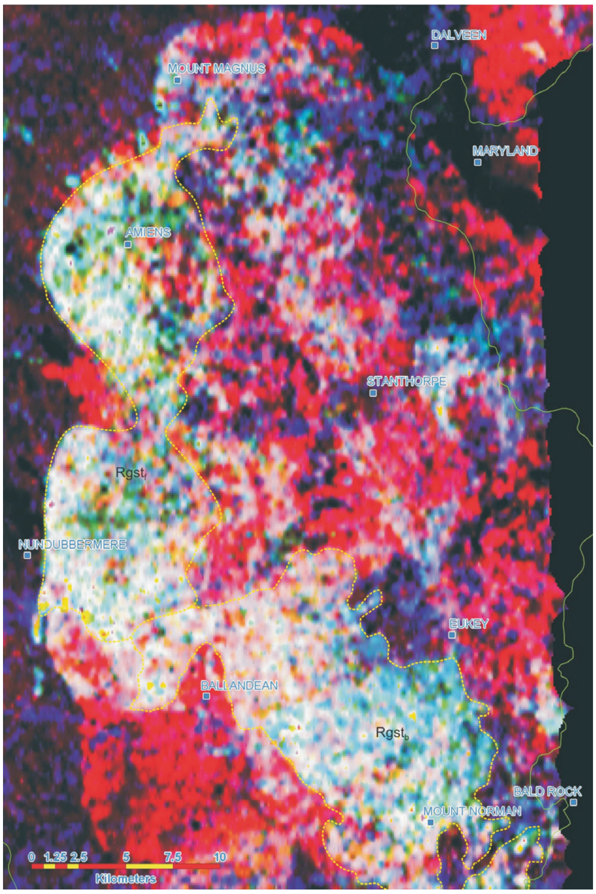

Figure 38b. Radiometric (RGB) image of the Stanthorpe–Wallangarra region. The image has been digitally manipulated (using local-area stretching techniques) to highlight internal differences within the Stanthorpe Granite. This image covers approximately the same area as the previous image.

Monzogranites are characterised by the presence of large (up to ~10cm long), euhedral, pale pink K-feldspar phenocrysts (Figure 39), large euhedral grains of titanite in the groundmass, and numerous mafic enclaves. The presence of titanite and pale pink K-feldspar indicates those rocks are oxidised.

Bungulla Monzogranite exposed in the Wallangarra area, on the Queensland–New South Wales border, is described in Appendix 1.

Stanthorpe Suite

Stanthorpe and Ruby Creek Granites

The *Stanthorpe (Rgst) and Ruby Creek (Rgru) Granites* are the main components of the northern part of the batholith. The Stanthorpe Granite, as currently mapped, is a composite unit, parts of which (mainly in subunits $Rgst_a$ and $Rgst_2$) may not belong to the Stanthorpe Suite. It crops out mainly in two discrete areas separated by a screen of older granitic, volcanic, and sedimentary rocks. Stanthorpe Granite (subunits $Rgst_{1-7}$), which crops out in the north-east is herein informally referred to as the *Maryland*

Figure 39. Undercliffe Falls Monzogranite (*PRguf*) with large euhedral pale pink K-feldspar phenocrysts and a groundmass relatively rich in mafic minerals. MGA 411326 6830598. Photograph taken by J.M. Bultitude.

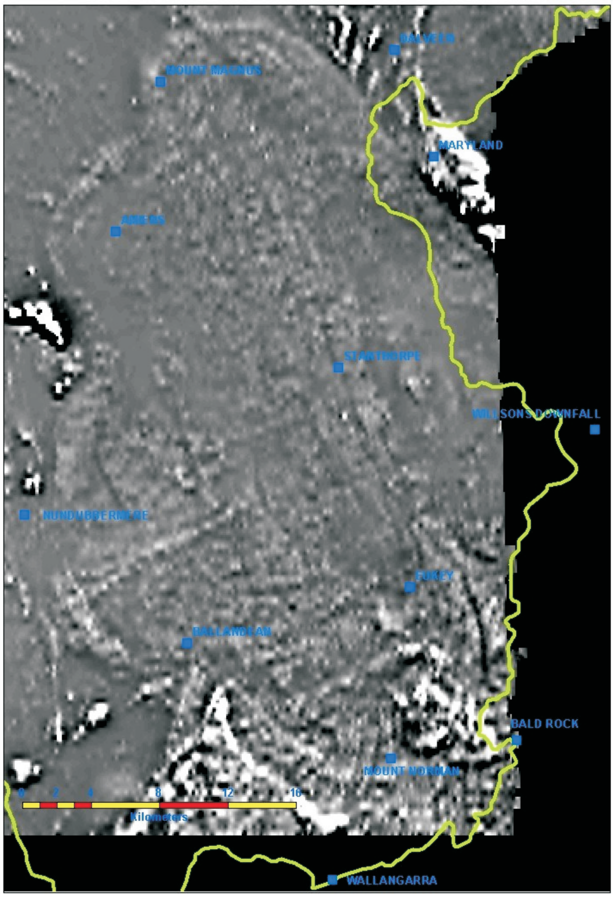

Figure 40. Grey-scale aeromagnetic image (first vertical derivative) of the area underlain by the Stanthorpe and Ruby Creek Granites (Stanthorpe complex) and adjacent rock units. The image covers approximately the same area as Figures 38a,b. The green line depicts the position of the border between Queensland and New South Wales.

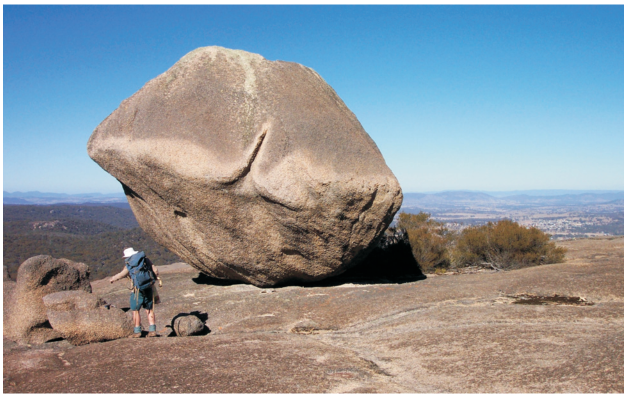

Figure 41. Large boulder and extensive outcrops of subunit $Rgst_b$ (Stanthorpe complex) on Mallee Ridge, Girraween National Park. Photograph taken by M.D. Livingstone.

Figure 42. Prominent dome (part of The Pyramids; locally known as Second Pyramid) in subunit $Rgst_b$ (Stanthorpe complex), Girraween National Park.

Figure 43. Massive outcrop of Stanthorpe Granite (subunit $Rgst_a$, Stanthorpe complex), Passchendaele State Forest (east of MGA 387886 6840664).

River complex; likewise Stanthorpe Granite, which forms extensive outcrops in the Stanthorpe–Wallangarra region (to the south-west) is referred to as the *Stanthorpe complex*.

The unit is very well exposed in places — *e.g.* in Girraween National Park and, to a lesser extent, in parts of Passchendaele State Forest. In these areas the granite forms rough, hilly country with numerous large boulders (Figure 41), domes or inselbergs (Girraween National Park; Figure 42), extensive bare-rock outcrops (Figure 43), and prominent tors.

Stanthorpe and Ruby Creek Granites. The Stanthorpe and Ruby Creek Granites show pink to red or white tones on composite (RGB) radiometric images (Figures 38a,b). Zones of relatively mafic, unevolved granite are characterised by pink–red tones on a 'standard' image (Figure 38a). They are most extensive in the north-eastern part of the Stanthorpe complex, east of a prominent north-westerly-trending lineament, but also form ‘screens’ between or marginal zones around more evolved (and presumably younger) granites in the western and southern parts of the complex. That part of the Stanthorpe Granite (Maryland River complex) covered by the geophysical survey farther to the north-east is also dominated by pink–red tones. The data are consistent with the interpretation that the unit was emplaced as numerous individual pulses or batches of magma. The data (including the results of mineralogical and chemical studies) also indicate the relatively mafic, unevolved phases/zones of the Stanthorpe Granite are concentrated in the eastern and north-eastern parts of the batholith.

Two or possibly three ovoid intrusions with north-westerly to northerly elongations have been identified in the western and southern parts of the Stanthorpe complex, namely in the Mount Norman area, east of Nundubbermere, and in the Amiens area (Figure 38b). The Mount Norman phase (subunit $Rgst_b$) is distinguished by its felsic character, coarse grainsize and abundant K-feldspar megacrysts (see description of subunit $Rgst_b$ in Appendix 1). Felsic granites in the Amiens area and east of Nundubbermere have been delineated as subunit $Rgst_f$. Samples analysed from subunits $Rgst_b$ and $Rgst_f$ define ‘tight’, coherent groups on Harker-type variation diagrams.

The Ruby Creek Granite is described in detail in Appendix 1. The close spatial relationship between the Ruby Creek Granite and the Stanthorpe Granite of the Stanthorpe complex is one of the most noteworthy features of the northern New England Batholith. The Stanthorpe Granite is cut by numerous dykes, pods, and irregular stocks of Ruby Creek Granite (Figure 44; also see Figure 58), only the larger of which are shown on the map. Blevin & Chappell (1996) proposed that extended fractional crystallisation within Stanthorpe magma chambers resulted in the generation of more highly evolved Ruby Creek magmas — some of which ponded in the upper parts of the magma chambers, some of which intruded into crystallised parts of the chambers as stocks and dykes, and some of which intruded into overlying country rocks (*e.g.* at Sundown and Kilminster).

The Ruby Creek and Stanthorpe Granites consist predominantly of leucogranite (SiO_2 >74%; modal biotite contents <~5%), and show considerable overlap in mineralogy and chemical composition (*e.g.* see Figures 46–54). Both are characterised by textural and mineralogical heterogeneity (also see Andrews & others, 1907; Saint-Smith, 1911, 1914a; Phillips, 1968; Thomson, 1976) resulting from processes such as volatile build-up and exsolution in a relatively shallow crustal environment (Blevin & Chappell, 1996). Consequently, distinguishing the two types is difficult in places. This is especially the case north-west of Stanthorpe (in the Passchendaele–Pozieres area), south of Stanthorpe, and east of Wallangarra. Uneven-grained to only slightly porphyritic biotite leucogranite crops out extensively in these areas. Saint-Smith noted (1914a, page 41) that “…it is at times a matter of considerable difficulty to definitely distinguish it [the Stanthorpe Granite] from the ‘Sandy’ granite [Ruby Creek Granite]”.

Figure 44. Dyke of fine-grained biotite leucogranite (Ruby Creek Granite) in Stanthorpe Granite (subunit $Rgst_a$, Stanthorpe complex), bed of Quart Pot Creek upstream of railway bridge, Stanthorpe.

The granites also display small-scale mineralogical heterogeneity in places. Stanthorpe Granite (subunit $Rgst_b$) forming extensive outcrops at MGA 388912 6818327, adjacent to the Stanthorpe–Wallangarra railway line, for example, contains biotite-rich zones (schlieren) intermixed with coarser grained, more leucocratic and highly porphyritic granite. The sample analysed from this locality is characterised by anomalously low SiO_2, K_2O, and Ba contents, and high FeO*, Rb, Zr, La, Ce, Nb, and F concentrations compared to other samples analysed from the subunit.

Most investigators have assigned outcrops of relatively fine-grained leucogranite to the Ruby Creek Granite and areas of coarser grained, more highly porphyritic granite to the Stanthorpe Granite. Where contacts between the two types have been found (*e.g.* at MGA 381475 6834929, MGA 381566 6833250) the finer grained variety intrudes the coarser grained variety, consistent with such an interpretation — the inclination of the contacts ranging from subhorizontal to subvertical. However, some coarser grained leucogranite may represent textural variants of Ruby Creek Granite. Relatively coarse-grained (average grainsize ~2mm) granite exposed in the Ruby Creek area, between Stanthorpe and Liston, for example, forms the central part of the main Ruby Creek pluton with significantly finer grained marginal zones (also see Saint-Smith, 1914a).

Conversely, some finer grained variants included in the Ruby Creek Granite may represent quenched marginal (including roof-zone) facies of Stanthorpe Granite. Blevin & Chappell (1996) and Blevin (2002) postulated that parts of the Ruby Creek Granite, particularly in areas west and north-west of Stanthorpe, might represent contact-zone variants of Stanthorpe Granite. The current investigation was not sufficiently detailed to resolve this problem. Intuitively, quenched contact-zone variants compared to more slowly cooled central parts of individual pulses/batches of Stanthorpe Type magma could be expected to be either:

1. relatively unevolved, or

2. of similar composition.

Miarolitic cavities and small pegmatite lenses (commonly vuggy; Figures 45a,b) are common, particularly in the Ruby Creek Granite. The widespread textural heterogeneity and distribution of miarolitic cavities implies the magmas were volatile-rich at the time of emplacement, and that they were emplaced at relatively high levels in the crust where confining pressures were sufficiently low to allow fluid-rich phases to exsolve from the crystallising magmas. The close spatial association between the granites and penecontemporaneous or slightly older volcanic rocks in the Wallangarra area is also supporting evidence for the high-level emplacement of the magmas.

Candela & Blevin (1995) postulated that the well-developed and widespread miarolitic textures in the Stanthorpe Suite granites formed at pressures of <2.5kbar. Amphibole geobarometry has yielded pressures of 1kbar (equivalent to a depth of ~3km) and 1–3.4kbar (equivalent to depths of ~3–10km) for the granites of the Stanthorpe and Bungulla Suites, respectively (Blevin & Chappell, 1996).

Relatively mafic granites, with mafic mineral abundances >5%, and SiO_2 contents ranging from ~70% to ~74%, are also present in the Stanthorpe Granite (*e.g.* see Figures 48, 51). Modal analyses of Stanthorpe Granite samples listed by Phillips (1968, 1969) and Thomson (1976) indicate the presence (at least locally) of relatively mafic zones with >5% biotite, commonly accompanied by minor hornblende and titanite. Blevin & Chappell (1992) had also noted that some so-called leucogranites are not particularly felsic and that use of the term in these cases was inappropriate.

Figure 45a. Irregular vuggy pegmatite lens in Stanthorpe Granite (subunit $Rgst_a$, Stanthorpe complex; MGA 388436 6837598).

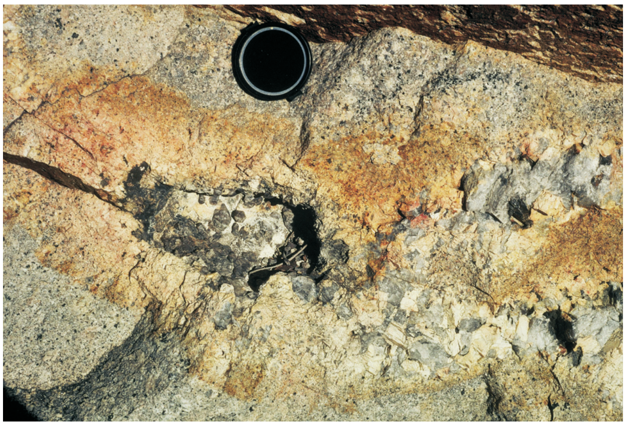

Figure 45b. Irregular vuggy pegmatite lens in subunit $Rgst_f$ of the Stanthorpe Granite (Stanthorpe complex), Amiens Road (MGA 390018 6832012).

Stanthorpe Granite (Maryland River complex). Available data indicate the Maryland River complex (~420km^2) is distinct from the Stanthorpe complex. The Maryland River complex, for example, does not contain significant amounts of highly felsic, fractionated granite (*e.g.* Rb contents range from ~140ppm to ~240ppm in the samples so far analysed — see Figure 46 — and Eu anomalies are not as pronounced). Furthermore, it contains very few intrusions of Ruby Creek Granite, in marked contrast to the Stanthorpe complex, and in keeping with the general lack of highly fractionated compositions. As a result there are very few known mineral deposits associated with the complex (*e.g.* see Thomson, 1976; Brown & others, 2001). The northern and western parts (the only parts covered by the recent geophysical survey) of the Maryland River complex are characterised by mainly pink–red tones on a composite RGB radiometric image, in contrast to the white tones, which characterise most of the Stanthorpe complex (Figure 38a).

A relatively mafic variant (~68% SiO_2, ~635ppm Ba, ~165ppm Rb) forms scattered boulders on the eastern side of Cullendore Road (MGA 415828 6848951). It contains minor hornblende and numerous pink K-feldspar phenocrysts and is more similar mineralogically (and chemically) to Sailor

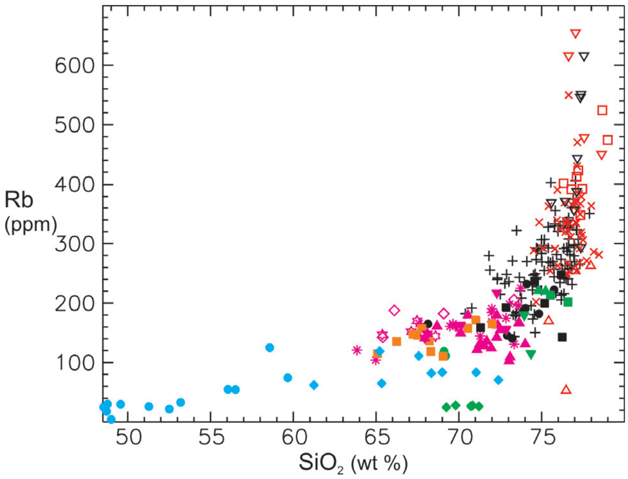

Figure 46. **Rb versus SiO_2 plot for selected intrusive rocks of the northern New England Batholith, showing the relatively mafic character of the Bungulla Suite, the trend to highly fractionated compositions in the Stanthorpe Suite, and the unevolved character of the Greymare Granodiorite. Symbols as in Figure 27.**

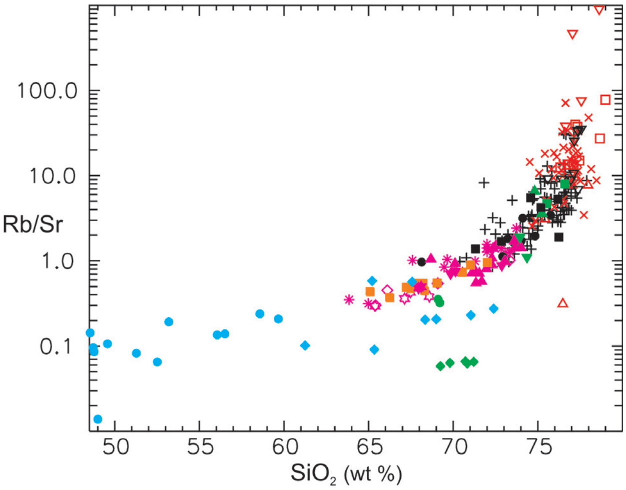

Figure 48. **Rb/Sr versus SiO_2 plot for selected intrusives of the northern New England Batholith, showing a trend to highly evolved compositions, defined mainly by the Bungulla and Stanthorpe Suites, and the relatively unevolved character of the Greymare Granodiorite. Symbols as in Figure 27.**

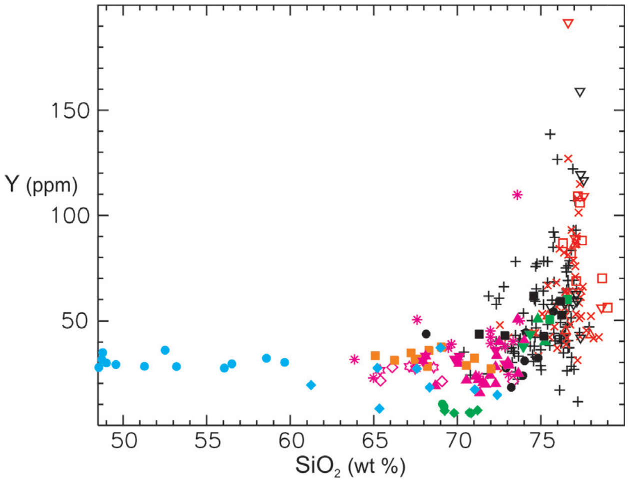

Figure 47. **Y versus SiO_2 plot for selected intrusives of the northern New England Batholith, showing a typical I-type trend of increasing enrichment with fractionation in the Bungulla and Stanthorpe Suites. Note the Y-poor character of the Greymare Granodiorite and Maryland Granite. Symbols as in Figure 27.**

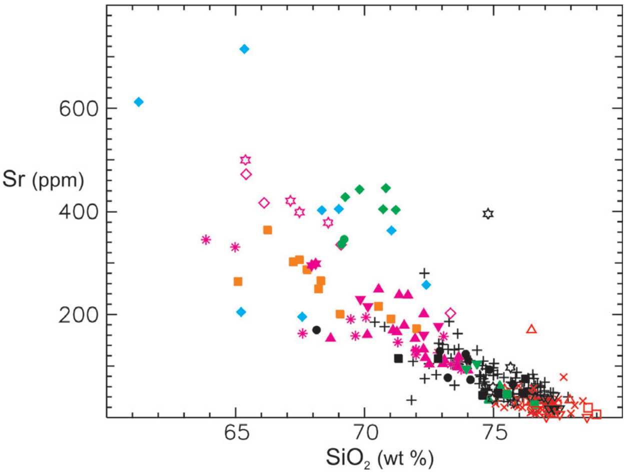

Figure 49. **Sr versus SiO_2 plot for selected intrusives of the northern New England Batholith, showing the Sr-rich character of the Greymare Granodiorite and Maryland, Bungulla and Undercliffe Falls Monzogranites. Symbols as in Figure 27.**

Jack and Bungulla Suite granites than to Stanthorpe Suite granites, but its extent is unknown.

Very fresh, leucocratic, fine to medium-grained (groundmass), porphyritic hornblende-biotite monzogranite exposed at MGA 411987 6837181, adjacent to the contact with the Undercliffe Falls Monzogranite (in New South Wales) contains relatively abundant allanite (~1%; unaltered) and zircon. It is mineralogically (and chemically) anomalous compared to the other samples examined from the complex. The presence of relatively abundant allanite and zircon is reflected by abnormally high LREE (Ce = 266ppm, La = 130ppm) and Zr (366ppm) contents. This phase is also characterised by significantly higher Na_2O, $Na_2O + K_2O$, and Zn abundances, as well as Rb/Sr, $(Ce/Y)_N$, Ga/Al, and K/Rb values (>400), and relatively low MgO, CaO, P_2O_5, Ba, Rb, Sr, V, F, and Eu contents compared with analysed samples from the Bungulla and Stanthorpe Suites. It has not been delineated as a discrete unit because its extent and relationships with adjacent phases/units are unknown, and the analysis has been omitted from most of the geochemical plots shown in this report.

The phase may form the marginal zone of a pluton roughly corresponding to subunit Rgst$_2$, which is characterised by the presence of relatively abundant accessory allanite (as comparatively large, mainly unaltered grains).

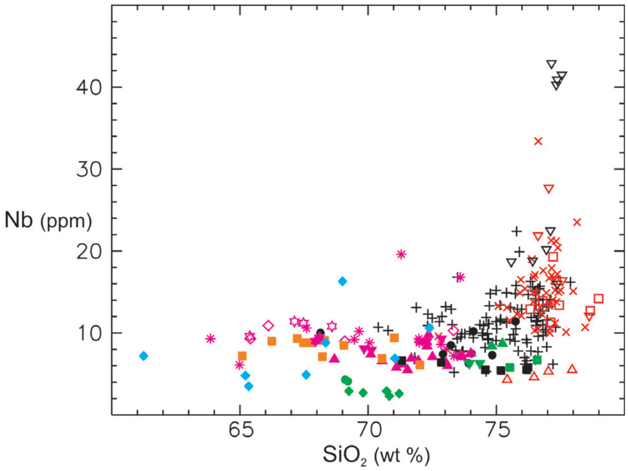

Figure 50. Nb versus SiO_2 plot for selected intrusives of the northern New England Batholith, showing a trend of significant enrichment in the Bungulla and Stanthorpe Suites with fractionation, and the relatively unevolved character of the Greymare Granodiorite and Maryland Granite. Symbols as in Figure 27.

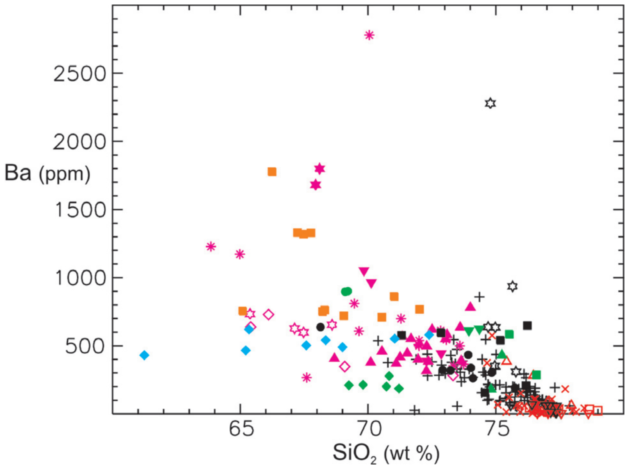

Figure 52. Ba versus SiO_2 plot for selected intrusives of the northern New England Batholith. Ba defines a trend of markedly decreasing abundances with increasing SiO_2 in the Bungulla and Stanthorpe Suites. Note the Ba-poor character of the Greymare Granodiorite. Symbols as in Figure 27.

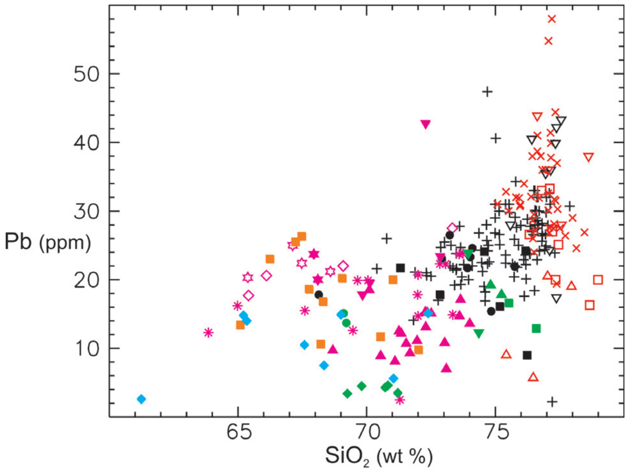

Figure 51. Pb versus SiO_2 plot for selected intrusives of the northern New England Batholith, showing a general trend of increasing Pb contents with fractionation (increasing SiO_2) in the Bungulla and Stanthorpe Suites. Also note the relatively low Pb contents of the Greymare Granodiorite samples. Symbols as in Figure 27.

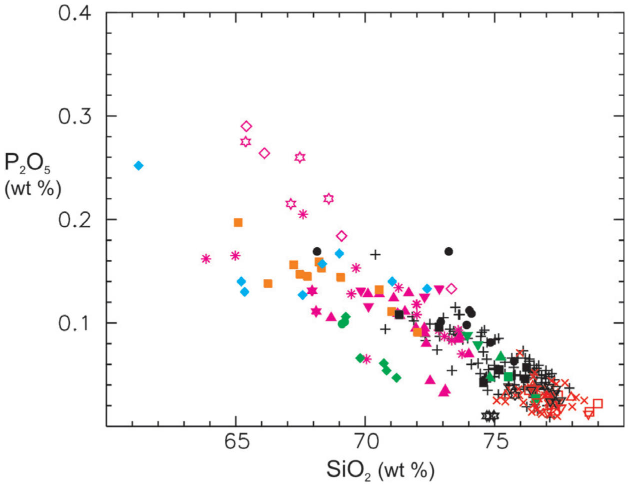

Figure 53. P_2O_5 versus SiO_2 plot for the granites of the northern New England Batholith, showing a well-defined trend of decreasing P_2O_5 (to very low levels) with fractionation (increasing SiO_2). Such a trend is typical of I-type granites. Symbols as in Figure 27.

Similarly, fine to medium-grained biotite granite samples (reduced, peraluminous, with relatively high Aluminium Saturation Indices — ASI) collected from the Cullendore–Maryland River area (and roughly corresponding to subunit Rgst$_6$), are also distinct from other rocks examined in the Maryland River complex. These contain minor late-stage muscovite and no allanite. However, they are also currently included in the Stanthorpe Granite for the same reasons as the above examples.

Sivell & Passmore (1999a) carried out detailed mapping (1:10 000 scale) of a small area north-east of Stanthorpe, in the upper Maryland River area. They identified six informal granite units, one of regional extent, in what is shown mainly as subunits Rgst$_1$ and Rgst$_2$ on the 100 000-scale geological map. Sivell & Passmore (1999a) delineated the south-western part of subunit Rgst$_2$, the most extensive variant mapped (as Rlsu2) in the Maryland River complex by Thomson (1976), as the Five Mile Creek syenogranite (informal name). They noted that this unit is of regional extent, but did not trace it beyond the Maryland River area.

These examples highlight a problem with the Stanthorpe Granite as it is currently delineated. It is a composite unit, much of which has not been mapped in detail, especially the Maryland River complex. The above examples demonstrate that the unit can be further subdivided; subunits Rgst$_a$ and

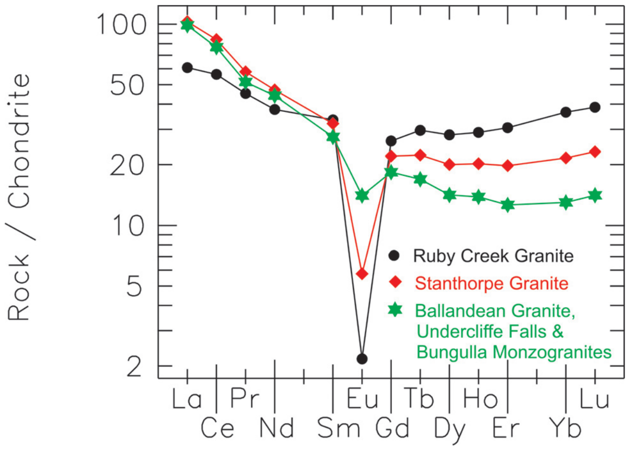

Figure 54. Rare earth element distribution patterns for Ruby Creek Granite (average of 50 samples), Stanthorpe Granite (average of 122 samples), and Ballandean and Bungulla Suite granites (average of 38 samples) of the Stanthorpe–Wallangarra region. The granites show progressive HREE enrichment and Eu depletion with fractionation, typical of I-types.

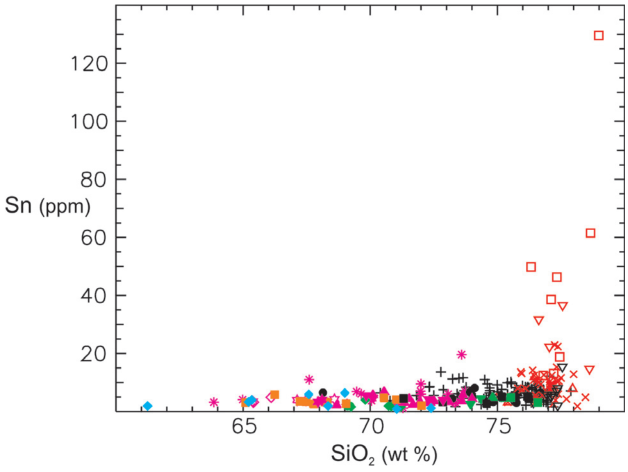

Figure 55. Sn versus SiO_2 plot for selected intrusives of the northern New England Batholith. The highly evolved (fractionated) Ruby Creek Granite (Sundown and Swipers Gully phases) shows significant enrichment in Sn. Symbols as in Figure 27.

$Rgst_2$, in particular, display extensive textural, mineralogical, and chemical variations compared to the other subunits delineated. Consequently, more than one suite may be represented.

Geochemical Characteristics

Granites of the Ballandean and Sailor Jack Suites are characterised by relatively low MgO, P_2O_5, Sr, and Th contents and La/Y ratios, as well as relatively low Ba and Zr concentrations, and ASI, compared to those of the Bungulla Suite. The Sailor Jack Suite is distinguished from the Ballandean Suite by slightly higher Al_2O_3, Na_2O, Ba, and Sr contents, and lower FeO*, TiO_2, Ga, Nb, Sc, and Zn concentrations.

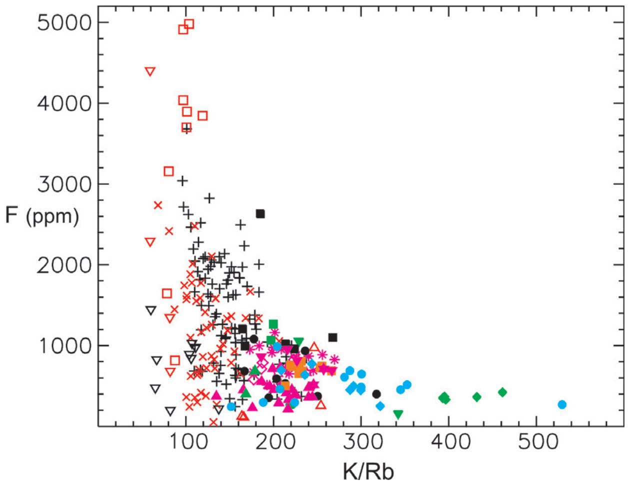

Figure 56. F versus K/Rb plot for selected intrusives of the northern New England Batholith. Note the significant increase in F contents in the Stanthorpe Supersuite with fractionation (decreasing K/Rb values). Symbols as in Figure 27.

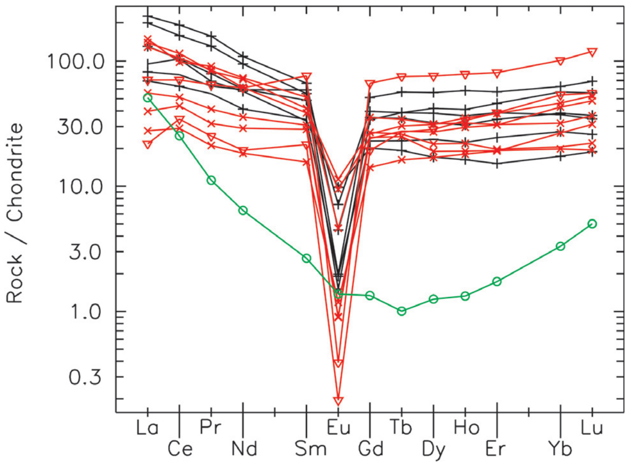

Figure 57. REE characteristics of aplitic leucogranite (open green circles) in Bungulla Monzogranite south of Wallangarra, compared to selected samples from the Ruby Creek and Stanthorpe Granites. Symbols as in Figure 27.

One sample of Ballandean Granite (from MGA 380831 6812857) has a slight positive Eu anomaly (Eu/Eu* = 1.12), possibly reflecting the presence of cumulate plagioclase. The sample is characterised by the presence of numerous plagioclase phenocrysts.

The Ballandean Granite, in particular, displays a fair amount of scatter on some geochemical plots. Some of this scatter may reflect the presence of cumulate rocks and/or the affects of variable degrees of alteration. However, a more detailed investigation may also indicate more than one suite is represented and that the unit can be subdivided. Such a study would be difficult because of the very poor outcrop over much of the area underlain by the unit.

Granites of the Ballandean, Sailor Jack, Bungulla and Stanthorpe Suites are predominantly high-K (Figure 27), I-types (Blevin & Chappell, 1996; Chappell & others, 1999). Some investigators (*e.g.* Shaw & Flood, 1981; Kleeman, 1982, 1984; Sivell & Passmore, 1999a, b) noted that some of the felsic granites of the New England Batholith, including the Ruby Creek Granite and Mole Granite (Grafton 1:250 000 Sheet area), have chemical compositions similar to those of A-types. However, the chemical continuum and linear to curvilinear trends displayed by relatively mafic granites of the Bungulla Suite (hornblende bearing I-types) and selected, more felsic Stanthorpe Suite granites on Harker-type variation diagrams have been interpreted to indicate the two suites are genetically related (*e.g.* Blevin & Chappell, 1996; Chappell & others, 1999; Mustard, 2004).

The granites show pronounced increases in Rb, Cs, Ta, Nb, Y, Th, Pb, U, Sn, F, HREE, Rb/Sr, Ca/Sr, Rb/K, Ga/Al, and decreases in P, Ba, Sr, Eu, and other compatible elements with increasing SiO_2, or decreasing K/Rb (*e.g.* Figures 46–54). P and Eu decrease to very low concentrations (Figures 53, 54). There is also a pronounced flattening of normalised rare-earth distribution patterns (Figure 54) due mainly to increases in HREE contents. These trends are typical of fractionated, I-type granites (*e.g.* Chappell & others, 1998). Compositional variation in the felsic granites (which have compositions close to the ternary minimum of Tuttle & Bowen, 1958) is attributed to fractional crystallisation of mainly quartz and feldspars.

The felsic granites of subunits $Rgst_b$, $Rgst_c$, and $Rgst_f$ display relatively coherent trends on Harker-type variation diagrams with limited scatter. In contrast, subunits $Rgst_a$ and $Rgst_2$ show considerable scatter and a general trend from highly felsic compositions (which ‘overlap’ with the above three subunits) to relatively mafic compositions (which ‘overlap’ with the Ballandean and Sailor Jack Suites). Subunits $Rgst_b$, $Rgst_c$, and $Rgst_f$ are the main components of the Stanthorpe Suite. However, a more detailed investigation is required to sort out the complexities within subunits $Rgst_a$ and $Rgst_2$, which may contain representatives of more than one suite.

The Ruby Creek Granite generally contains the more highly fractionated variants, but there is extensive overlap with the felsic subunits of the Stanthorpe Granite (*e.g.* Figures 46, 47). The more highly fractionated representatives of the Ruby Creek Granite are characterised by anomalously high Y, Nb, Sn, Ta, Ga, F, Rb, F, and As concentrations, as well as HREE abundances and Ca/Sr and Rb/Sr ratios, and low Ba, Eu, Sr, Zr, and CaO contents, and low $(Ce/Y)_N$ ratios compared with the Stanthorpe Granite (*e.g.* Figures 47, 55, 56). The Ruby Creek Granite is characterised by pronounced negative Eu anomalies (Eu/Eu* = 0.006–0.419; average = 0.073), consistent with extended feldspar (and quartz) fractionation. The two most highly evolved samples collected during the recent survey (from the Swipers Gully area, north-west of Stanthorpe) have Rb contents of 616ppm and 655ppm, and Eu/Eu* ratios of 0.005 and 0.010.

Aplitic muscovite-biotite leucogranite (SiO_2 >76%), which intrudes the Bungulla Monzogranite south of Wallangarra (at MGA 396095 6797056), is chemically distinct from the Ruby Creek Granite. Despite its felsic character the leucogranite has not undergone extensive feldspar fractionation (*e.g.* Rb = 209ppm), unlike the leucogranites of the Ruby Creek Granite. It is characterised by a smooth, curvilinear, concave-up REE distribution pattern with a steep slope in the lighter REE, lack of a pronounced negative Eu anomaly (Eu/Eu* = 0.729), and a broad minimum at Tb ($Tb_N < Lu_N$; Figure 57). This pattern contrasts with those shown by the Stanthorpe and Ruby Creek Granites and may indicate the leucogranite was derived from a source containing residual amphibole or in which amphibole was a fractionating phase (*e.g.* see Gromet & Silver, 1987; Wilson, 1989). The leucogranite is characterised by the presence of rare hornblende, as well as minor titanite. Titanite also partitions the middle REE relative to the light and heavy REE (*e.g.* Rollinson, 1993).

Chappell & others (1999) postulated that the extensive fractional crystallisation displayed by the granites of the Stanthorpe and Ruby Creek Granites started from a felsic melt composition after most, or all, of the restite component had been removed.

UNITS NOT ASSIGNED TO A SUPERSUITE

Dormans Flat Granite (*Rgdf*; new name)

The *Dormans Flat Granite* forms an elongate north-trending pluton (~11km^2), ~7–9km west and south-west of Wallangarra. Purdy (2003) delineated the pluton, and collected and analysed samples from it as part of a M.Sc study. The unit had previously been shown as Dundee Rhyodacite and Wallangarra Volcanics on geological maps of the region (*e.g.* Olgers & others, 1974). The granite consists of pale pinkish grey to reddish brown (‘iron stained’), fine-grained (groundmass), highly porphyritic (allanite-titanite-hornblende-) biotite monzogranite, which displays a well-developed quenched texture. The monzogranite contains numerous phenocrysts (up to ~1cm long) of plagioclase and white to very pale pink K-feldspar. Plagioclase is more abundant than K-feldspar. Biotite (~5%) forms scattered flakes up to ~6mm long. Rare hornblende is present locally, mainly as small inclusions in plagioclase phenocrysts. Interstices between the feldspar phenocrysts are filled with fine-grained (<1mm) aggregates of mainly quartz, K-feldspar, plagioclase, biotite and opaques. Opaque granules are relatively common. Accessory and secondary minerals include titanite, allanite, apatite (mainly as inclusions in biotite), chlorite, epidote, and sericite. The groundmass components form a relatively minor part of the rocks.

The Dormans Flat Granite intrudes the Wallangarra Volcanics (late Permian), and was most probably emplaced in the late Permian or early Triassic.

The Dormans Flat Granite is a high-K to ultra high-K (Figure 27), I type. Analysed samples (6) show a restricted range in SiO_2 contents, from ~74% to ~76% (Purdy, 2003). They most closely resemble the Stanthorpe Granite, but are distinguished by relatively low MgO and P_2O_5 (Figure 53), and high $K_2O + Na_2O$ and Ba (Figure 52) contents. Only Ba and Sr, of the trace elements, were determined. Additional samples should, therefore, be analysed for a greater number of trace elements before the unit is assigned to a supersuite.

Unit Rgx

Several small areas of leucogranite have been delineated as *unit Rgx* (total area ~21km^2). The unit crops out most extensively in the southern parts of the Stanthorpe and Drake 1:100 000 Sheet areas and extends into the adjacent Clive and Tenterfield 1:100 000 Sheet areas (New South Wales). It consists of pale pink to pink or reddish brown, medium-grained, essentially even-grained biotite leucogranite in these areas, and forms pavements, bouldery rubble, as well as scattered boulders, tors and rocky knolls. The leucogranite contains ~1% biotite, and abundant pale pink K-feldspar. Plagioclase grains are commonly altered. Inclusions are very rare.

Elsewhere, the unit forms a small irregular stock and several pods ~5–9km north-west of Liston, as well as a small pod on the Queensland–New South Wales border, ~4km north of Bald Rock. Outcrops north of Bald Rock (at MGA 405985 6811747) comprise dark reddish brown, medium-grained, slightly porphyritic biotite leucogranite, which forms very large boulders in places. The leucogranite contains ~1% biotite, and sparse phenocrysts of pink K-feldspar (up to ~2cm in length) and quartz (to ~2cm in diameter). It intrudes subunits $Rgst_b$ and $Rgst_2$ of the Stanthorpe Granite, as well as unit PRgb. Inclusions, up to ~1m across, of more biotite-rich and more highly porphyritic granite are common. Biotite-rich zones (schlieren) are also present adjacent to contacts with the more biotite-rich granite.

Unit Rgx north-west of Liston (DRAKE 1:100 000 Sheet area) incorporates three informal units delineated by Sivell & Passmore (1999a) — namely the Warroo monzogranite (around MGA 407137 6834940), the Kia-Ora syenogranite (around MGA 407984 6837533), and the Ridge monzogranite (around MGA 404862 6838909). Rock types range from highly porphyritic, leucocratic, granophyric biotite-hornblende monzogranite to medium-grained, uneven-grained to slightly porphyritic biotite monzogranite and syenogranite. These granites post-date the Undercliffe Falls Monzogranite and subunit $Rgst_1$ of the Stanthorpe Granite, and pre-date the Ruby Creek Granite (Sivell & Passmore, 1999a).

Although granites of unit Rgx are very felsic and moderately to strongly evolved, they are not highly fractionated. The four leucogranite samples analysed from this unit, for example, have SiO_2 contents of ~77%, and Rb contents ranging from 191–275ppm. The absence of associated mineralisation is consistent with the lack of highly fractionated compositions.

MAFIC ROCKS

Unit PRo

Scattered pods and stocks of poorly exposed gabbro, diorite, and quartz diorite (*unit PRo*) are spatially associated with the Stanthorpe, Ruby Creek (Sundown area), Sailor Jack, and Mount You You Granites.

The most extensive (~6.5km^2) mafic intrusive examined is poorly exposed in the Limestone Creek–Bruxner Highway area (New South Wales). These rocks pre-date the adjacent Sailor Jack Granite and are commonly altered and locally cut by granite dykes. The analysed samples (2) are quartz diorites. The sample examined in detail is medium grained and slightly porphyritic (in plagioclase). It consists mainly of calcic plagioclase, together with subordinate clinopyroxene, and minor brownish green hornblende, biotite, actinolite, primary quartz (in interstitices), opaques, interstitial K-feldspar, and traces of chlorite and zircon.

Gabbro associated with the Mount You You Granite is medium grained and characterised by a well-developed intersertal texture (also see Virtue, 1985). Virtue (1985) reported the gabbro to consist mainly of augite and calcic plagioclase, together with minor chlorite (after augite and actinolite), ilmenite, apatite, and rare quartz (only present locally). In addition, the sample examined in detail during the recent GSQ survey contains abundant greenish brown hornblende (partly replaced by actinolite). Clinopyroxene grains are generally rimmed and extensively replaced by hornblende.

Several small mafic intrusions (ranging in composition from gabbro to diorite) also crop out in the Sundown area. The intrusions are concentrated near the intersection of the east-north-east trending Severn River Fracture Zone and an orthogonal north-north-west trending fault. Gabbro examined from the Severn River area (at MGA 368989 6807273) is medium grained (average grainsize ~1mm), with a well-developed intersertal texture. It is extensively altered and contains abundant actinolite (mainly after clinopyroxene), as well as some relict clinopyroxene — as scarce, relatively large euhedral grains (up to ~1mm in length) and much smaller grains in interstices between plagioclase laths.

Sivell & Passmore (1999a,b; also see Venables, 1984) delineated fourteen mafic intrusions ('Karonstadt Hybrids', Sivell & Passmore, 1999a, page 308) ranging from ~10m to ~600m in diameter in the headwaters of the Maryland River north-east of Stanthorpe. These include two layered gabbro intrusions with a range of rock types represented (olivine gabbro, gabbro, hornblende gabbro, gabbronorite, ferrogabbro, pegmatitic gabbro). Sivell & Passmore (1999a) also reported the presence of numerous heterogeneous, hybrid (their terminology) intrusives (<10m to ~800m thick), ranging in composition from dolerite to monzogranite, in the same area. All of these intrusions are closely associated with subunit $Rgst_1$ of the Stanthorpe Granite and, to a much lesser extent, with the Undercliffe Falls Monzogranite. Phillips (1968) interpreted the mafic rocks to be older than the Undercliffe Falls Monzogranite and Stanthorpe Granite. In contrast, Sivell & Passmore (1999a) proposed that a very close temporal relationship exists between subunit $Rgst_1$ and the mafic units. Reasons given for this interpretation included:

1. the lack of chilled margins in the gabbros,
2. the presence of rare blocks of subunit $Rgst_1$ in one of the gabbro bodies,
3. the lack of mafic inclusions in subunit $Rgst_1$ adjacent to contacts with the gabbros,
4. the presence locally of a contact metamorphic aureole in subunit $Rgst_1$, and
5. the presence of a well-developed aplitic border zone around one of the gabbro bodies enclosed by subunit $Rgst_1$ — interpreted to have resulted from local melting induced in the Stanthorpe Granite by the emplacement of significantly higher temperature mafic magma.

Passmore & Sivell (1998) and Sivell & Passmore (1999a,b) interpreted this association, and the presence of hybrid rocks, to imply that processes such as mingling and mixing of mafic and felsic magmas played a significant role in the evolution of the granites. They noted that the common presence of rapakivi texture in the Bungulla and Stanthorpe Suites might also provide clues to their paragenesis. Pitcher (1997), for example, invoked a model involving decompression of crystal-bearing granitic magma that was changing composition by mixing with mafic magma.

Sivell & Passmore (1999a) also noted that mafic bodies do not occur in subunit $Rgst_2$, implying it is younger than the gabbros.

Chemical data indicate rocks of tholeiitic and calc-alkaline affinities are represented in the mafic complexes.

DYKES

Numerous dykes cut the granitic rocks. The dykes are concentrated in the eastern (Thomson, 1976), northern, and south-western parts of the region. Many of the more extensive dykes have north-easterly trends, which are parallel or subparallel to a prominent north-east trending joint system. North-easterly trending, porphyritic microgranite (quartz-feldspar porphyry of Robertson, 1974) dykes crop out in the Ballandean–Sundown–Mineral Hill area (~9km west-north-west of Ballandean) and in the Sugarloaf Creek area (~13km east-south-east of Stanthorpe) (Robertson, 1974). These dykes are in the north-east-trending Severn River Fracture Zone of Goode & others (1982). They are up to ~25m wide, contain randomly oriented K-feldspar phenocrysts (10–15mm across) in a fine-grained quartzofeldspathic groundmass, and are faulted and offset in many places (Robertson, 1974; Denaro & Burrows, 1992).

A dyke swarm, ranging from ~800m to ~1200m in width, extends in a north-easterly direction for ~8km, from Leran to near Accommodation Creek, south-south-west of Ballandean (Robertson, 1974). The dykes consist of aplite, rhyolite, granophyre, trachyte and diorite, and form the cores of reinforced ridges of granite (Robertson, 1974). The thickest (up to ~300m wide) and most extensive (~3km long) of these dykes (and the only one shown on the Stanthorpe 1:100 000-scale geological map) consists of dark grey, fine-grained, highly porphyritic hornblende diorite (unit Rgd; Purdy, 2003), containing numerous plagioclase and brown hornblende phenocrysts. A discontinuous, north-easterly-trending, linear zone of high magnetic intensities farther to the west may also represent a relatively thick dyke in the Ballandean Granite. However, the feature has not been identified on the ground.

A thick (up to ~350m wide) dyke of highly porphyritic biotite-hornblende monzogranite (unit Rgw) intrudes the Wallangarra Volcanics north of Wallangarra. This dyke has a north-north-west trend.

Another dyke swarm consisting of rhyolite, granophyre, trachyte, diorite, porphyritic microgranite (quartz-feldspar porphyry) and basalt (rare) extends in a north-north-westerly direction from near Braeside in the south to the Greymare area in the north (Robertson, 1974). The swarm cuts the Fairleigh Granite and Greymare Granodiorite (Robertson, 1974), as well as the Texas beds, but does not appear to cut the Stanthorpe Granite. The width of the swarm ranges from ~800m to ~3km (Robertson, 1974).

Several granitic dykes cut extensive sloping pavements of much coarser grained, coarsely porphyritic leucogranite (subunit $Rgst_b$ of the Stanthorpe Granite) in the Mallee Ridge area (around MGA 398716 6805856; Figure 58) of Girraween National Park. The dykes range in thickness from

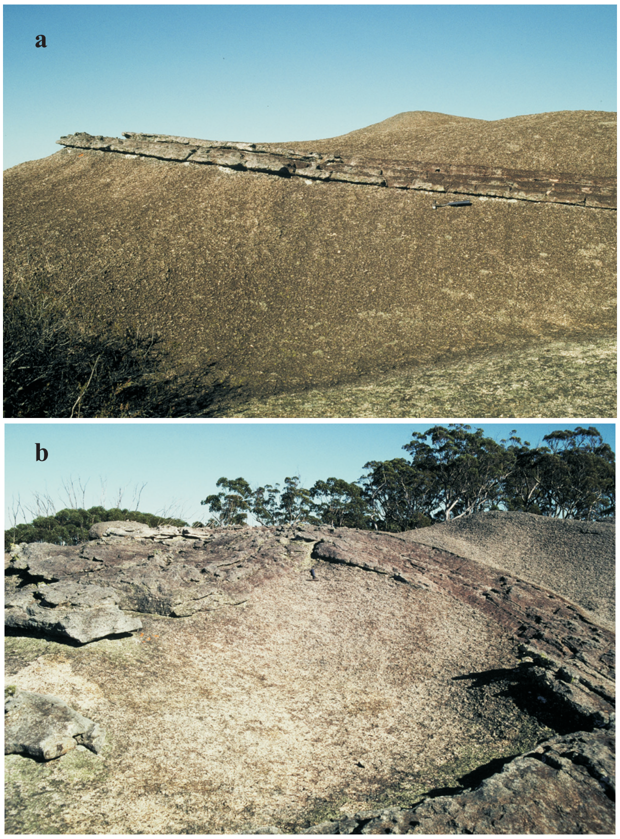

Figure 58. Dyke of relatively fine-grained biotite leucogranite (Ruby Creek Granite) in massive, coarser grained, coarsely porphyritic biotite leucogranite (subunit Rgst$_b$ of the Stanthorpe Granite, Stanthorpe complex), Mallee Ridge area, Girraween National Park (MGA 398718 6805856). Note the change in inclination of the dyke, from gently (a) to moderately steeply dipping (b, right-hand-side). An indication of scale is given by the geological hammer in the upper middle part of each photograph, below the contact between the dyke and enclosing granite.

~3cm to ~5m, with subhorizontal to subvertical dips. It is not uncommon for individual dykes to show significant changes in dip along strike (Figure 58). Some of the thicker dykes (*e.g.* at MGA 398483 6805814) contain inclusions (up to ~40cm across) of the enclosing granite, irregular miarolitic cavities (up to ~15cm across), and vuggy pegmatite lenses (up to ~2m long), and locally show flow banding. The dykes consist predominantly of fine to medium-grained, even-grained to moderately porphyritic biotite leucogranite (Ruby Creek Granite; also see Thomson, 1976, page 76). Contacts with the enclosing granite are generally knife sharp. Some of these dykes contain minor amounts of pyrite, molybdenite, or cassiterite. The dykes are interpreted to represent more highly fractionated magmas, which segregated from the Stanthorpe Granite as it solidified. Similar dykes of Ruby Creek Granite are common throughout the Stanthorpe complex.

Rare dykes of more mafic microgranite have also been found. A 20m-thick dyke of dark grey, very fine-grained, porphyritic (hornblende-) biotite granite (~69% SiO_2) cuts subunit Rgst$_2$ at MGA 403687 6837599. The dyke is characterised by a well-developed flow foliation.

Saint-Smith (1914a) reported numerous thin (up to ~30cm thick), mafic (‘diorite’, page 23) dykes on the north-eastern flank of Lees Hill, ~3km south of Stanthorpe; as well as isolated examples in the Broadwater Creek and Severn River areas west and south-west of Stanthorpe. The Broadwater Creek example is noteworthy because it truncates a dyke of aplitic granite (Saint-Smith, 1914a). Saint-Smith assigned a Tertiary age to these dykes. Skertchly (1898) also reported diorite dykes in the Sugarloaf Creek, Pikedale Creek, and Ballandean areas.

ISOTOPIC DATING

Isotopic age data compiled by Shaw & Flood (1993) and Shaw (1994) for the granites of the northern New England Batholith imply the Bungulla Suite granites are ~245Ma, whereas those of the Stanthorpe Suite are ~238Ma–244Ma. The dates are Rb–Sr biotite ages based on an assumed whole-rock initial Sr^{87}/Sr^{86} ratio of 0.705 for all units. Rb–Sr dating of these rocks is somewhat problematical because of their very high Rb/Sr ratios. Molybdenite in the Ruby Creek Granite at Carpenter’s Gully (Sundown National Park) has yielded a Re–Os age of 225±40Ma (Harding, 1966).

More recently, a pegmatitic microgranite sample (from MGA 389406 6832088) west of Stanthorpe yielded a U–Pb zircon (SHRIMP) age of 249.6±5Ma and a U–Pb monazite (SHRIMP) age of 234.9±7Ma (Chorley, 1997). There is some uncertainty as to whether the microgranite forms part of the Stanthorpe Granite (Blevin, 2002) or Ruby Creek Granite (Chappell & Bryant, 1994; Chorley, 1997). Previously, granites of the Stanthorpe and Bungulla Suites exposed in the Timbarra (or Rocky) River area (east of Tenterfield, Grafton 1:250 000 Sheet area) had yielded U–Pb zircon (SHRIMP) ages of 237±4Ma and 247±3Ma, respectively; and a mafic enclave in Bungulla Suite granite from the same area yielded a U–Pb zircon (SHRIMP) age of 239±4Ma (Hughes, 1993). A possible explanation for the apparent discrepancy in the ages of the Bungulla Suite granite and the enclave is that the samples were obtained from two discrete intrusions of Bungulla Suite granite, the two sample sites being several kilometres apart (P.L. Blevin, PetroChem Consultants, personal communication, May 2003).

Flood & Shaw (2001) reported a crystallisation age of 249±1Ma (LAM–ICP-MS U–Pb microanalysis of zircon grains) for a Moonbi Supersuite pluton (Walcha Road Monzogranite) in the southern part of the batholith. Blevin (2002) reported a Re–Os age of 248.7±0.5Ma (weighted average of 2 samples) for coarse molybdenite obtained from a quartz-molybdenite-chalcopyrite vein in Stanthorpe Type granite at Poverty Point (Timbarra Tableland, east of Tenterfield; Grafton 1:250 000 Sheet area).

More recently, Norman & others (2004) reported a Re–Os crystallisation age of 242.1±0.7Ma for molybdenite from the Ruby Creek Granite in the Wilsons downfall area (MGA 409856 6827176; P.L. Blevin, Geological Survey of New South Wales, personal communication, March 2007).

Four granite samples (one each from the Stanthorpe, Palgrave, and Bullaganang Granites, and one from the Greymare Granodiorite) from the northern New England Batholith were submitted for U–Pb zircon (SHRIMP) dating as part of the recent investigation by GSQ.

The ages obtained are summarised in Table 1. They indicate magmatism in the northern part of the batholith extended over a much longer period than previously thought.

TECTONIC EVOLUTION

The Palaeozoic rocks of the Texas region form part of the New England Orogen (NEO), the easternmost and youngest section of the Tasman Orogenic Zone defining the eastern margin of continental Australia. The NEO is thought to have been dominated by collisional tectonics at the palaeo-cratonic margin, mainly involving west-dipping subduction.

Devonian-Carboniferous subduction. The earliest structural element exposed in the Texas region is represented by the **Silverwood Province,** a sequence of marine mafic to intermediate volcanics, volcaniclastics and limestones ranging in age from Silurian to Devonian. These rocks are thought to represent either an island arc terrane separated from the Australian continent by a marginal sea or an exotic terrane or terranes which originally lay to the east of a wide ocean basin.

After accretion of the Silverwood terrane to the craton margin in mid- to late Devonian times, westward-dipping subduction continued into the Carboniferous accompanied by episodic mainly calc-alkaline volcanism. By this time, the architecture of the collisional margin had evolved to include a magmatic arc with an adjacent forearc basin, flanked further to the east by an accretionary complex dominated by arc and craton derived turbiditic sediments. The forearc rocks are not exposed in the Texas region where they are are blanketed by younger cover rocks of the Surat Basin. However, to the south in New South Wales, this sequence is exposed as the Tamworth Belt — a complex series of volcanics, and volcaniclastic sediments containing scattered oolitic limestone bodies consistent with a relatively shallow marine environment. Equivalent lithologically similar sequences have been mapped to the north in central Queensland as the Yarrol Province. In the northern New South Wales/southern Queensland portion of the convergent margin, Carboniferous arc-related volcanism began in the Visean and increased in intensity in the Namurian and Westphalian (Roberts & others, 2004)

In the Texas segment of the NEO, the only part of the collisional orogen exposed is the accretionary wedge, represented by the turbidite-dominated **Texas beds** which crop out over a wide area. This sequence is thought to represent mainly landward-derived detritus progressively incorporated into the subduction zone over a prolonged period during the Carboniferous. Local oolite deposition recorded from a probable early Carboniferous section of the Texas beds is likely to correlate with similar aged oolitic accretionary wedge rocks characteristically deposited along much of the northern NEO at this time (Murray & others, 1987). The oolitic detritus is thought to have been swept from the oolitic shoals of the forearc by tubiditic flows traversing the shelf towards deeper water to the east.

Also interleaved with the accretionary wedge turbidites are slivers of material off-scraped from the incoming oceanic plate. These include deep marine cherts, jaspers and associated fine grained sediments as well as mafic volcanics and associated limestones. Some of the limestones may be allochthonous blocks slumped from the forearc Tamworth Shelf to the west. The mafic rocks include pillow lavas and pyroclastics, the latter indicating relatively shallow water (<500m) eruption facies at many sites. The lavas invariably have an “Ocean Island Basalt” (OIB) geochemical signature (see earlier section), indicating that these bodies once formed upstanding topographic features such as aseismic ridges or seamounts, probably with variable degrees of limestone reef development.

Coral faunas from the limestones throughout the Texas region give Early Carboniferous ages (Olgers & others, 1974) but Flood (personal communication, 2002) suggests that tens of millions of years elapsed between growth of the corals in the palaeo-Pacific far from the continent and their final entrainment within the subduction zone. He applies the same model to all distal oceanic-derived material, interpreting the mainly Visean radiolarian chert ages of Aitchison & Flood (1990a) to significantly predate (by ~30–40Ma) the deposition of the enclosing turbidite succession. Thus, Flood interprets a mid- to Late Carboniferous age for the bulk of the accretionary wedge greywackes in the Texas region. However, we favour an early Carboniferous age for the lower part of the sequence (subunit Ctx_m; unit Ct1 of Flood & Fergusson,1984), as the Visean radiolarians in this part of the section are contained within volcaniclastic rocks that we interpret as being as being relatively proximal to the active magmatic arc.

A change in sedimentary character marks the transition from what we interpret as the early

Carboniferous Ctx$_m$ sequence to the overlying mid- and late Carboniferous rocks. A subtle increase in sediment supply to the subduction zone seems to have taken place at this time, with large influxes of volcaniclastic detritus being more common. Large seamount fragments and associated oceanic-floor facies were also episodically incorporated into the accretionary wedge at this time. The change in sedimentary regime is consistent with an increase in volcanic activity and/or uplift in the hinterland, perhaps caused by higher plate convergence velocities. Time-equivalent forearc rocks in New South Wales also record these changes, showing an onset of volcanism in the Visean with an increase in intensity in the Namurian and Westphalian (Roberts & others, 2004). Uplift and/or increased sediment supply to the forearc is also reflected as a change from marine conditions in the Tournasian to largely continental conditions in post middle-Visean time (Roberts & others, 2004).

Uplift of the arc and an increase in volcanic activity may have also resulted from subduction of anomalously hot, plume-related, buoyant oceanic crust whose surface expression was marked by numerous hotspot-type volcanic island chains and seamounts (whose remnants are commonly preserved in the accretionary wedge in the Texas region). The physical size (*i.e.* 'subductibility') of these volcanic edifices would probably not have been large enough to alter subduction zone dynamics (Cloos, 1993), except for the largest volcanic body in the Texas region which stretches for over 5km along Mosquito Creek. The latter may be a remnant of an even larger body which locally produced uplift of the arc/forearc region, producing the overlying conglomeratic unit (subunit Ctx$_{cg}$) containing fragments of dissected arc material.

Cessation of Subduction. Subduction ceased in the Texas region in the late Carboniferous (early Stephanian), possibly accompanied by subduction rollback and outstepping of the subduction zone to the east. The tectonic setting of the New England Orogen at this time is believed to have changed from a purely convergent plate margin to a combination of transform faulting and subduction. This change started in the north of the Yarrol Province and migrated gradually southwards. A possible mechanism for this change is the collision of a mid-ocean ridge with the offshore trench (Murray & others, 1987). The postulated dextral transform faulting moved the eastern part of the New England Fold Orogen ~500km south along the Gogango–Baryulgil Fault Zone, duplicated the fore-arc basin and accretionary wedge sequences across the New England region in north-eastern New South Wales, and folded the accretionary wedge and forearc into a large double orocline (Texas–Coffs Harbour Megafold). An alternative model for the formation of the Texas–Coffs Harbour Megafold by major dextral strike-slip faulting along the eastern edge of the Bowen–Sydney Basin has been presented by Harrington & Korsch (1987) and Korsch & Harrington (1987).

Early Permian deposition and plutonism. In the Texas region, Early Permian diamictite-rich sediments and minor felsic to mafic volcanics were unconformably deposited over the inactive accretionary wedge, within deep marine basins ranging from broad extensional types (related to regional back-arc extension or gravitational collapse of the accretionary wedge) to transtensional types probably related to more local-scale tectonics. The back-arc extensional style is probably represented by the fledgling Bowen Basin (flanking the Texas region under cover to the west), while the Alum Rock Conglomerate was dumped into a narrow fault-controlled transtensional basin. Analogous narrow Early Permian fault basins have been documented from the southern NEO, where they have been shown to have a complex transtensional to transpressional history related to syn- and post-depositional movement along the Peel–Manning Fault system separating the forearc from the accretionary wedge sequence (Vickers, 1999).

The Silver Spur Basin north-east of Texas exhibits both broader extensional character and fault-controlled transtensional character. Disconnected depocentres of the Terrica Basin may have developed in a structurally complex zone near the core of the megafold. At this time the Texas region may have represented a transitional zone in the central part of the NEO between a volcanic arc setting to the north in Central Queensland and a back-arc environment to the south in New South Wales.

As well as Early Permian sedimentation, the Texas region was the site of localised Early Permian magmatism within the inactive accretionary wedge sequence (represented by the Bullaganang Granite and Greymare Granodiorite). To the south in New South Wales, the S-type Bundarra and Hillgrove Suites were also intruded into the accretionary wedge rocks in the Early Permian, accompanied by compressive deformation whose effects have not been recognised in the Texas region.

Megafold Timing. The Early Permian sediments and intrusives provide equivocal constraints on the timing of megafold formation. Lennox & Flood (1997) suggested that variable cleavage development (which they relate to the megafold) within the Early Permian basins indicates their staggered formation during the course of the megafold's evolution. However, to the north-west of the Texas region, the subsurface Early Permian margin of the Sydney–Bowen Basin (which displays no megafold-related deformation) diverges from its meridianal trend north-west of the Texas region and follows the broad curve of the megafold, suggesting that the structure existed prior to Early Permian sedimentation. An earliest Permian (Asselian) or older age for the megafold event is further supported by recent Early Permian SHRIMP ages obtained from undeformed post-megafold granitoid bodies intruding the accretionary wedge in the Texas region (~291Ma and ~280Ma for the Bullaganang Granite and Greymare Granodiorite respectively). Detailed stratigraphic mapping and SHRIMP radiometric dating of the New South Wales part of the forearc sequence (Roberts & others, 2004) indicates a hiatus in volcanism associated with the cessation of subduction during the Stephanian, which may represent the onset of megafolding.

It remains difficult, however, to reconcile this timing with seismic surveys of the covered north-western margin of the megafold, which imply no major pre-Early Permian structural break, as a conformable to slightly unconformable relationship exists between basal Bowen Basin sediments and underlying Late Carboniferous forearc strata (Wartenberg & others, 1999). If the megafolding did take place prior to the Early Permian, then these relationships between the forearc sequence and the overlying Permian rocks suggest that the megafolding process had little or no effect on the regional palaeo-geography of those areas.

Late Permian. After the period of Early Permian extension and magmatic activity, the Texas region was affected by uplift, faulting and local folding related to the first phase of the episodic Hunter–Bowen Orogeny. The latter is thought to have resulted from major plate compressive forces along the craton margin to the east, transmitted inboard as deformation of varying character and intensity. This uplift was succeeded by post-orogenic Late Permian volcanism and sedimentation, accompanied by the emplacement of numerous co-magmatic granitic plutons ranging from small stocks to large composite batholiths. The latter were dominantly hornblende-bearing I-type plutons (mainly the Stanthorpe and Herries Supersuite granites in Queensland), which continued to be intruded until the Early Triassic.

In a regional context, the Late Permian to Late Triassic magmatism is clearly post-orogenic because it post-dates the main folding events. Some writers have argued that the magmatism was not related to subduction, whereas others have postulated an origin above a west-dipping subduction zone. The abundance of silicic magmatism in this area during the Late Permian – Early Triassic may reflect significant heating of crust thickened by arc activity. Increased magma flux to the warm crust in the Late Permian due to renewed subduction (Caprarelli & Leitch, 1998; 2001) or westward arc migration (Jenkins & others, 2002) may have promoted large-scale melting and development of voluminous silicic magma bodies now represented by the Wandsworth Volcanic Group (Purdy, 2003). If subduction was involved, the associated trench must have been far to the east (Cawood, 1984).

In mid-Triassic times, the region was affected by another phase of Hunter–Bowen compression, recognised as folding of Early Triassic sediments in the Esk Trough to the north-east of the Texas region (Cranfield & others, 2001). This event also produced westward thrusting of forearc Tamworth Belt rocks over younger Bowen Basin rocks prior to deposition of later Jurassic Surat Basin cover rocks (Goondiwindi Event of Korsch & others, 1998). Pre-Jurassic tilting of the Upper Permian Condamine beds south-east of Warwick (Olgers & others, 1974) probably results from this deformation.

Surat/Clarence Moreton Basins. In the Late Triassic broad intracontinental extension was initiated to the north-west and north-east of the Texas region forming the Surat and Clarence–Moreton Basins respectively. Except for the lowermost units, the two basins were continuous across the basement high defined by the Kumbarilla Ridge (see Figure 2). Large volumes of quartz-rich sand were derived mainly from uplifted and unroofed granitic rocks. The Clarence–Moreton basin was broadly confined to the northward-opening segment of the orocline, where dominantly fluvial sedimentation occurred within a number of structurally controlled sub-basins confined by basement highs. Subsidence has been attributed to thermal relaxation following orocline-related dextral transtension initiated in the Late Permian (O'Brien & others, 1994). Sedimentation ceased in these basins by the Early Cretaceous.

In the mid-Cretaceous, an extensional environment became dominant in eastern Australia, initiating its separation from the rest of Gondwanaland, and eventually culminating in the opening of the Tasman Sea in the Late Cretaceous and Early Tertiary.

O'Sullivan & others (1999) demonstrated three distinct cooling episodes affecting the northern NEO since the end of the Hunter–Bowen Orogeny in the Late Triassic. These episodes occurred in response to either kilometre-scale denudation, cooling due to thermal relaxation associated with rifting, or a combination of both. Based on earlier work from southern Australia, O'Sullivan & others (1999) suggested the mid-Cretaceous (105–90Ma) cooling event occurred in response to the onset of continental extension in the Tasman Sea at ~96Ma.

Cooling at this time may have resulted in kilometre-scale denudation over parts of the eastern highlands of south-eastern Queensland and may have been caused by underplating inboard of the rift. The effects of the third period of cooling (75–60Ma) were most significant along the eastern margin and may be due to break up of the continent and major rifting that commenced during the Late Cretaceous and continued into the Early Tertiary.

From the late Eocene the eastern Australian continental margin behaved as a passive margin moving northwards over a hot spot (Johnson & others, 1989). Tertiary intraplate volcanism resulted in the formation of a number of shield volcanoes which erupted basalt, and subordinate rhyolite and trachyte of the Main Range Volcanics.

These deposits formed the elevated scarp of the north-north-west trending Great Dividing Range to the east of the Texas region. The flows travelled over long distances from their sources, often channelled by ancient stream valleys and depressions.

Major flows occupied the ancestral Condamine River valley, and the remnants of these are exposed along the north-eastern margin of the Texas region.

MINING HISTORY

INTRODUCTION

Most of the mining activity in the Texas region occurred during the late 1800s and early 1900s. Tin was the dominant mineral commodity extracted from the Stanthorpe area (mainly from 1872–1882), although silver, lead, zinc, copper, arsenic, wolframite and molybdenite were also worked from time to time. Further north in the Warwick area, gold was the main commodity mined during the period between 1863 and 1903. Further sporadic working of the major commodities took place throughout last century, but production was small and the known deposits are currently exhausted or subeconomic. The small regional mining districts declared during the peak of mining activity (see following text) were incorporated into the Brisbane Mining District in 1990. An overview of the mining history of the Texas region on the Queensland side of the border is given below on a commodity basis. More detailed accounts of the mining history of various parts of the region are given by Denaro (1989), Denaro & Burrows (1992), Olgers & others (1974), and de Havelland (1987). Production histories of individual deposits are contained in the Department of Mines and Energy's MINOCC database.

GOLD

Gold was first discovered in the region in 1852 at Lord John Swamp (south of Warwick in the Lucky Valley area), where a number of small creeks and gullies were found to contain alluvial deposits. Further discoveries of both reef and alluvial gold were made to the west from 1863 onwards in the Leyburn, Canal Creek, Thanes Creek, Talgai and Palgrave areas (which were subsequently gazetted as Mining Fields). There are eight historical goldfields in the Warwick–Texas District–Canal Creek, Talgai, Thanes Creek, Leyburn, Palgrave, Pikedale, Lucky Valley and Macdonald (see Figure 59). Olgers & others (1974), Morton (1933), Ball (1903a,b, 1905, 1906) and Skertchly (1898) provided interesting historical accounts on the gold fields. The discovery of gold in Gympie in 1867 marked the decline of the Warwick gold fields, and the fields were not worked from 1905 until 1930. The advent of the depression in 1930 was accompanied by government assistance, which promoted the re-opening of several mines. However, by 1941, significant mining in the district had ceased (Waring, 1981). The histories of the individual gold fields in the region are described below.

Canal Creek Goldfield

Alluvial gold was first discovered along a gully 6km north of the old Canal Creek Station in 1863, and the Canal Creek alluvial flat was proclaimed a goldfield in 1868. The main alluvial area is situated on the eastern side of Canal Creek north of Herries Range. Between 1863 and 1887, an estimated 565kg of gold were recovered from the Canal Creek goldfield (Olgers & others, 1974), though this amount may be misleading due to the lack of proper production records. The main alluvial mining period occurred before 1900, with later mining epochs from 1933 to 1934, 1976 to 1986 and between 1987 and 1998. The three main hard-rock mines (Last Hope, Stony Point and Poverty Point) were operated between 1933 and 1936 by Longton and Sons who hand-picked or selectively mined the deposits. The ore grades commonly ranged from 3.22g/t Au and 4.65g/t Ag (de Havelland, 1987) to a high of 2488.32g/t (Wynn, 1959). As well as the major mines, numerous shallow shafts (*e.g.* Rosaleda, Ironbark) were sunk into the country rocks, but it is unknown if these small mines were payable. Some sporadically payable eluvial operations have taken place from time to time in the area over the last decade.

Talgai Goldfield

Gold was also discovered to the north-east of Canal Creek in 1863 in an area originally known as Darkie's Flat in the Talgai area. The **Talgai Goldfield** was subsequently gazetted in 1882, with a refinement of the goldfield boundary in 1902. The goldfield covered 200km^2, encompassing the highland region around Mount Gammie North, between the Condamine River to the east and the Thanes Creek to the west. The goldfield, originally known as Darkie's Flat, supported both alluvial and reef mining. The main period of intensive mining predates 1903, and later small-scale and sporadic activities were in the periods of 1931–1933, 1936–1938, 1965, and from 1980–1985.

The alluvial gold was won from a number of creek systems including Friday Gully, Maccabies Creek, Gum Tree Flat, Spring Gully, Louisa Gully, Big Hill Gully, Dunns Gully and Gladstone Gully. The alluvium was patchy in distribution and varied in depth from 0.5–6m. The gold nuggets were generally coarse and rounded, with larger pieces having quartz attached to them. Many nuggets weighed between 25–450g; the largest nugget weighing 1.5kg was found on the Gum Tree Flat (Olgers & others, 1974). Traces of cassiterite were associated with the alluvial gold, the most plentiful being in Dunns Gully,

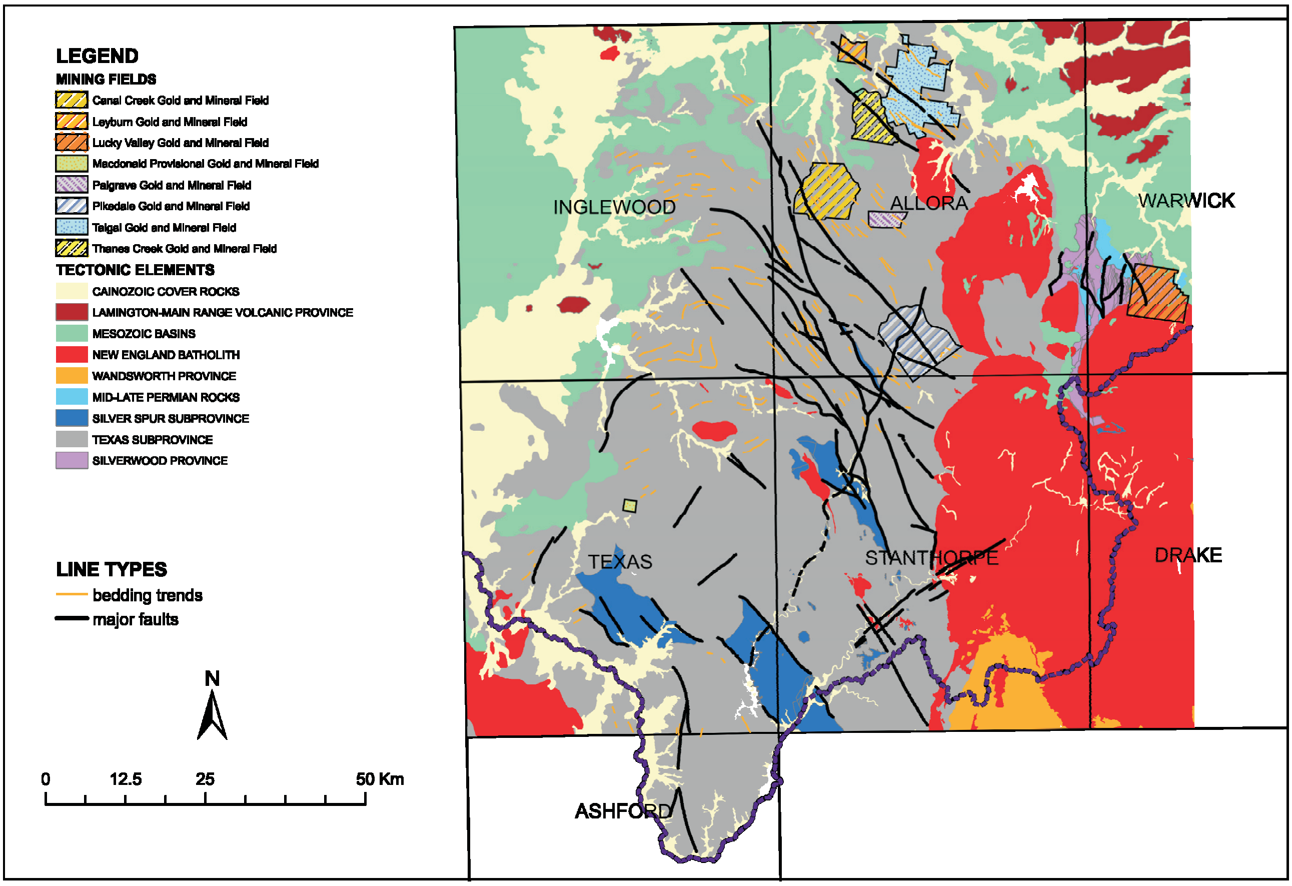

Figure 59. Location of Gold and Mineral Fields of Texas Region in relation to geological/tectonic elements

though no economic tin deposits were recorded or mined.

As well as the alluvial deposits found in many of the creeks within the goldfield, five main reefal ore systems were worked — the Big Hill group, Malakoff/Sunny South, Gladstone/Guiding Star, St Patrick, and the Sultan and Taylor/Prince of Wales. The Queenslander, part of the Big Hill group at Mount Gammie North, distinguished itself as being the first lode mine in the Warwick area as well as the first in the state of Queensland (Jack, 1892a). The total recorded production of the Queenslander was 134kg of gold (de Havelland, 1987), but the remainder of the mines in the group produced <50kg each. Mining of reefal systems on the Talgai Field had ceased by 1903 as a result of factors such as low grades, small reserves, or groundwater and faulting problems. Later sporadic, mostly small-scale activity occurred in the periods between 1931–1933, 1936–1938, 1965, and from 1980–1985.

Thanes Creek Goldfield

During development of the Talgai deposits, an area immediately to the west around Thanes Creek, was also being exploited for gold. This area was gazetted as the **Thanes Creek Goldfield** in 1864 (with a subsequent refinement of boundaries in 1882). Most gold production came from reef mining with only limited production from alluvial sources. The numerous gold mines in the Thanes Creek Goldfield were characteristically small (de Havelland, 1987; Skertchly; 1898). The Just-in-Time claim was one of the biggest workings on the goldfield, producing 28.9kg of gold from 738.1t of ore (bulk grade of 39g/t). Other significant producers include the Queen Mine that produced a total of 21kg of gold from 937t of ore (bulk grade of 22.4g/t), and the Beaconsfield mine that produced 1.24kg gold at 32–39g/t. The documented bulk grade from the Anzac Claim was 9–16g/t, while the grades from the Hidden Treasure and Phar Lap mines were 9.2g/t and 31g/t respectively. The decline in mining in the Thanes Creek Goldfield is attributed to the erratic gold values and faulting of the ore-shoots (Olgers & others, 1974).

Palgrave Goldfield

Gold was also found during the late 1800s over a 13km^2 area in the headwaters of Thanes Creek, north of the Herries Range, culminating in the gazetting of the **Palgrave Goldfield** in 1897. Native gold and silver (nuggets) were won from fault-controlled quartz reefs in the area, the two major reef mines being the Mountain Maid and Madam Ross. The Mountain Maid mine was worked between 1880–1890, and produced ~5.1kg of gold. The Madam Ross was worked from 1897–1901, producing ~174t of ore yielding 3.5kg of gold (de Havelland, 1987). Most of the mines were abandoned due to high pyrite and arsenopyrite contents combined with decreasing gold contents.

Leyburn Goldfield

Gold was discovered to the north of Thanes Creek in the Leyburn area in 1872, and in 1875 the 21km^2 **Leyburn Goldfield** was proclaimed (Olgers & others, 1974). Most of the workings were located on the south-eastern slopes of the hilly terrain to the west of Thanes Creek. The major mines in the Leyburn Goldfield were the Lady Caroline, Depression, Perseverance, Beil's Pride and Biddle's Revival. The Depression mine was the first major deposit to be exploited in the area, being first worked from 1870–1875, and again much later between 1931–1938, producing a total of 4.13kg of gold from 176t of hand-picked ore. The Lady Caroline workings were worked from 1882–1889 and were characterised by low ore grades rarely exceeding 15g/t, and often averaging <8g/t (de Havelland, 1987). The Beil's Pride mine yielded 0.37kg of gold from 46.2t of ore (bulk grade of 8.0g/t). The main periods of mining activity on this goldfield were 1882–1901, 1931–1938 and in the1980s.

Pikedale Goldfield

Further gold discoveries were made to the south-west of Warwick resulting in the gazetting of the 80km^2 **Pikedale Goldfield** in 1877. Gold production was confined to reef mining. All of the mines were small with grades varying from very rich to sub-economic. An added difficulty to gold mining was encountered with low gold recovery due to its association with pyrite. The Kaffir Chief was the biggest mine in the Pikedale Goldfield, producing 7.12kg of gold from a total of 177t of ore (bulk ore-grade of 40.3g/t). This was followed by the Cameron Claim which produced 3.5kg of gold (ore-grades of 96–471g/t); the Pikedale Reef (Painted Gold) which produced 1.63kg; and the McLucas mine (worked in 1914) that produced 0.9kg of gold with an average ore grade of 9.2g/t.

Lucky Valley Goldfield

In the late 1800s, mining also took place south-east of Warwick around the site of alluvials where gold was first recorded in the area. The surrounding area (~65km^2) was proclaimed as the **Lucky Valley Goldfield** in 1869. The main gold production came from alluvial mining along the valleys and tributaries of Lucky Valley and Elbow Gully. A number of lode gold deposits were operated in the goldfield, though production was generally small and grades varied substantially from sub-economic to rich. The total documented production from reef mining is 4.8kg, extracted from the Golden Bush, Big Shaft, Dragg's Claim, New Era, Gold Top Stout, and Golden Rush mines (de Havelland, 1987; Ball, 1921). The main mining periods were pre-1900s and from 1933–1938.

Stanthorpe area

In the late 1800s minor gold was also recorded from the Sundown and Jibbinbar areas, south-west of Stanthorpe, where quartz vein/greisen systems were primarily exploited for tin, copper and arsenic production. No worthwhile gold production was recorded in the Sundown area, although low gold grades were reported. These included lode assay results of 3.3g/t for the Beecroft mine (Rands, 1890); and 27.5g/t (Rands, 1890) to 24.5g/t (Ball, 1904a) for the Sundown Copper mine. In the Jibbinbar area, 1 tonne of ore from the State Arsenic mine yielded 3.8g of gold. In 1897, a small amount of gold production (1.56kg) was recorded as a by-product of mining copper and silver at the Pikedale Silver mine, west of Stanthorpe.

Rands (1887, 1888) reported assay results of 28–50g/t Au for the Pikedale lode, which occurred within the Ruby Creek Granite, 15km west-north-west of Stanthorpe. A trial shipment to Sydney of 0.3t returned 3g Au (all from arsenopyrite) but the deposit proved uneconomic.

Macdonald Provisional Goldfield

This goldfield is located in the central eastern part of TEXAS, where gold was first discovered in 1905. The only reported crushing from the field was 40.5t for a return of ~2.7kg of gold in 1905. A number of parties worked the field until it was abandoned in 1908. The Wantee, Wantee East and 'la Mascotte' were the only recorded workings.

Waroo–Commodore Area

The Waroo mine and the associated copper-rich Commodore deposit are situated south-east of Mount Bullaganang in the north-eastern part of TEXAS. The first lease in the Waroo area was applied for in 1906. The Waroo Mining Company was formed in 1908 and a reverberatory furnace was erected. The mine was closed in 1911 because the ore was not payable, but was re-opened from 1912–1913 by tributers using cyanidation. The mine workings were rehabilitated in 1931 but no payable ore was retrieved. Total recorded production for this early period was 2480t of ore (including 43t from the Commodore Copper Mine) for a return of 26.3kg of gold, 38t of copper, and 36.5kg of silver.

A mining lease over Waroo was granted in 1976 and purchased by Valdora Minerals Ltd. in 1987. The

Figure 60. Abandoned pit at Waroo mine

company set up a heap-leaching operation and established on open pit to extract the ore during the period 1988–1993 (see Figure 60). During this period 330 000t of ore were produced for a total of 373.2kg of gold. The leases have changed hands several times since closure of the mine, but no further production has taken place. There remain probable ore reserves of 76 000t at 2.36g/t gold (J. Walsh, Hillcrest Resources, October 2000).

TIN

Tin has historically been the most important commodity mined from the Stanthorpe area. Cassiterite was probably first found in Queensland in 1853 in the Stanthorpe area (Lees, 1907; Denaro & Burrows, 1992). Mining of alluvial cassiterite deposits commenced in 1872 and the Stanthorpe Mineral Field was proclaimed in 1883. Both alluvial and lode cassiterite have been mined. By far the greatest production has come from alluvial and eluvial deposits.

The total recorded production for the Stanthorpe Mining District (1872–1989) is 56 537t of cassiterite concentrates (of which 41 800t was produced between 1872–1882; Skertchly, 1898) including only 337t of lode tin. Production from the district declined gradually over time (Figure 61).

LODE TIN

Numerous small quartz-greisen veins were discovered in the Stanthorpe and Sugarloaf areas in the early 1880s, but none of these proved to be economic. The only tin lodes of any consequence were discovered in the Sundown, Red Rock, and Mineral Hill areas in the Ballandean district and in the Sugarloaf area east of Stanthorpe. Most of the lode mining activity occurred in the late 1800s and early 1900s. No production has been recorded since 1989. The total recorded production of cassiterite from known lode mines is >337t. The histories of the main deposits are given below.

Sundown area

The Sundown Tin mine was the major lode tin producer in the Stanthorpe district. Lode tin was discovered on ML 24 on Little Sundown Creek in August 1893. Claims were taken up and successfully worked and applications were made for three leases. There was no machinery on the field and the mines could not be developed due to a lack of capital. Mining declined in 1894 because of the falling tin price, lack of ore, and insufficient capital. The mine closed in 1896. No further records are available until 1904, when the "Sundown Claim" was worked by tributers (Gunn and party). Ball (1904a) referred to the mine as "Clare's Opencut". The Lawson Brothers worked the mine on tribute in 1906. Production up until 1904 was 68.8t of cassiterite concentrates.

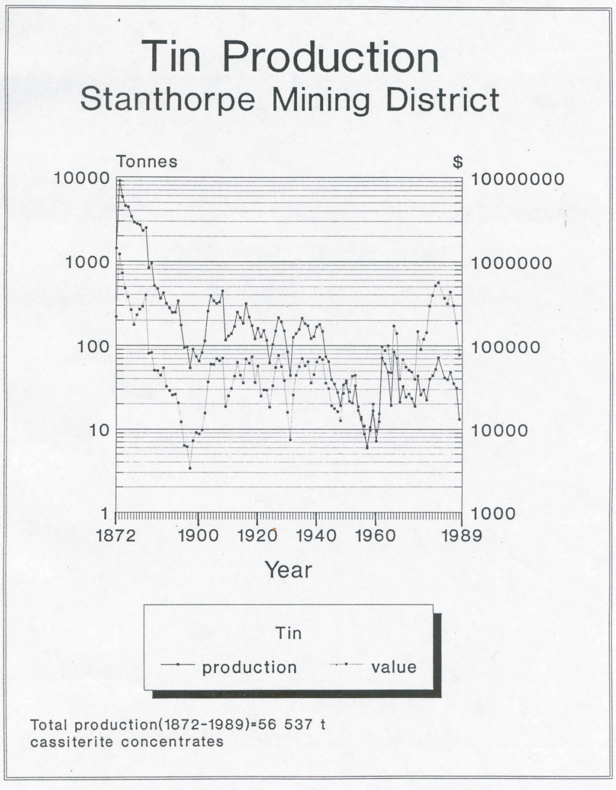

Figure 61. Tin production — Stanthorpe–Drake area 1872–1989

In May 1908, two claims were being worked. These were the "Sundown P.C. Welsby's" and "Sundown Extended". The Sundown mine was worked by tributers from 1909–1913 and 15.4 t of dressed ore was produced. The "Sundown Reward Claim No. 4" was worked by W. Welsby with four men in 1913; 35t of 18% tin ore was raised and much developmental work was carried out.

The Sundown Tin and Copper Mining Company N.L erected a 10-head battery in 1914 and started to treat the large quantities of ore on hand. Some work was also done at the adjacent Sundown Copper mine. From 1915 onwards, production from the copper mine was included with that of the tin mine. Production from the tin mine probably lapsed during this period; in 1921, only copper was produced. The Sundown Tin and Copper Mines and the Comet Tin and Copper Mine were amalgamated in 1921. Arsenic Ltd took over the mines in 1922 and produced white arsenic at treatment works in NSW, but went into liquidation in 1924. A.J. Atkinson held ML 301 and produced some tin and copper from 1953–1956.

Total recorded production from the Sundown Tin mine (1893–1923, 1953–1956) was 288t cassiterite and 68t arsenic oxide.

Lode cassiterite was also recorded from other mines in the Sundown area. However, these mines were mainly worked for copper and arsenic. Details of their histories are given under those commodities.

Red Rock Creek area

Most of the tin production in this area centred around Carpenters Gully (a southern tributary of Red Rock Creek) and the Beehive mine area on the northern slopes of Red Rock Gorge. The first reference to workings in the Carpenters Gully area was by Rands (1890), who referred to trenches and a shaft excavated by a Mr Smith in the Red Rock area. The first lease taken out was ML 60 (J. Fletcher, 1893–1894), south of a Protection Area held by Gilchrist and Johnson. Skertchly (1898) reported that no work had been done since Rands' visit.

Curtain and Pettiford obtained some rich ore from a shaft in 1903. Ball (1904a) reported on the Morris Claim (PA 49), which almost certainly covered the Carpenter's Gully workings. W. Moffat took out ML 91 in 1907 and then transferred the lease to the Carpenters Gully Tin Company Ltd. This company excavated the main shaft. As a result of a report by Rands (1909), the shareholders decided to discontinue operations and the company was wound up in June 1909.

Gilchrist and Johnson started working the ground in 1911 and took out ML 145 in 1913. They deepened the main shaft and produced >4.8t of cassiterite. A 5t trial shipment of ore to Melbourne in 1911 averaged 10% cassiterite.

Lee and Addison took out ML 259 in 1927 and transferred the lease to Carpenter Creek Tin Mines Ltd in 1930. This company was registered in 1929 and worked both the Carpenters Gully and Orient deposits. Much machinery was purchased and set up on the property. A dam and battery were erected in 1930 and a treatment plant in 1932. From 1932–1935, 21.9t of cassiterite was produced. The company went into liquidation in 1936.

Total recorded production for the Carpenter's Gully workings (1909–1913, 1933–1935) was >28.2t of cassiterite from >560t of ore.

In 1912, Lynam and Marstella discovered further tin deposits located a little over 1km to the north-east of the Carpenters Gully workings in precipitous country on the northern side of Red Rock Creek. Marstella obtained 1.5t of cassiterite from very rich surface deposits. One piece weighing 6.7kg assayed 51% metallic tin.

Mining leases 121 to 125 and ML 131 were taken out and transferred to the Beehive Tin Mining Company Ltd in 1913. Other leases on the north side of Red Rock Creek were ML 114 (H. Clark), ML 128 (E. Marstella) and ML 129 "Stanton" (H. Benjamin). These other leases were never developed seriously.

The Beehive Company carried out much development work in 1913, but no mining. Numerous open cuts and pits were excavated along the granite-hornfels contact. A dam was built on Red Rock Creek and machinery installed. Saint-Smith (1914b) reported that the company despatched 4t of 26% ore. The Beehive Company carried out some sluicing of the granite soils in 1914 and attempted alluvial mining along Red Rock Creek. There is no record of any production after 1914. The company was wound up and the leases were forfeited in 1917.

Total recorded production of the Beehive workings (1912–1914) was 2.5t of cassiterite.

Mineral Hill area

Two groups of workings occur in this area — the Mineral Hill Group and the Lord Nolan Group situated a little over 1km further south. The first descriptions of development at Mineral Hill were made by Skertchly (1898) who reported that 12 holes had been excavated in granite and alluvium at Folly Paddock (Mineral Hill), and a fair quantity of cassiterite recovered. The main lode deposits in the area are Wall's Claim, and Chalmer's Silver-Lead Claim. There is no record of the production of any of these mines.

Little information is available on Chalmer's Silver-Lead Claim. Ball (1904a) reported that several hundredweight of cassiterite ore was produced. A quantity of ore was sent to Cockle Creek in 1918, but apparently was not payable. Rhodda's Claim was a small molybdenite show downstream of Chalmer's Claim.

Wall's Claim was opened in 1903 by the Ballandean Tin Mining Company Ltd and an adit was driven for 24.7m. The company was struck off the register in 1906. From 1906–1918, the mine was worked sporadically by Wall, Long and Thomson, who extended the adit and exposed several veins by surface trenching. The mine was worked for arsenic in 1918, but no production was recorded.

To the south, in the Lord Nolan area (referred to as 'Burnt Hut Paddock' by Skertchly, 1898) alluvial, eluvial and lode cassiterite was mined. Very rich patches of cassiterite (up to 25kg) were found in potholes and trenches. A Mr Carpenter obtained a considerable quantity of eluvial cassiterite from deposits up to 0.6m deep; the claim was abandoned due to lack of water. Ball (1904a) reported that from a shaft excavated to 10m in depth 2t of cassiterite was recovered from scattered, rich bunches of ore.

The Lord Nolan Tin Syndicate Ltd was registered in August 1909. During 1910, a battery and a Wilfley concentrator were erected; after a run of only a few weeks, the plant was not working. No returns were provided, but the yield was only ~0.02% cassiterite. The battery was sold and the syndicate went into voluntary liquidation in 1911. The lease was forfeited in 1912 and a portion of the ground was taken up as ML 111 "Mount Bischoff Mine". In 1913, one man struck a rich "dab" which yielded 2.6t of cassiterite in a couple of weeks. The mine was abandoned in the same year.

Saint-Smith (1914b) reported that the average depth of payable alluvium was 2.6m. The northern part of the Lord Nolan area was bulldozed and sluiced by Blanche in the early 1950s for the recovery of 4.5t of cassiterite and 4.0t of wolframite. The Holdfast Mining Company worked the hill in 1965 and 1966. Total recorded production from the Lord Nolan area (1898, 1904, 1910, 1913, 1953 to 1954, 1965) was 12.2t cassiterite and 4.0t of wolframite.

Sugarloaf area

Sampson and Cokehill discovered cassiterite on Lode Hill (just over the border in NSW) in about 1880. A considerable amount of work was done but only a small amount of cassiterite was produced. One flat vein, a few centimetres thick, yielded 3t of coarse cassiterite crystals. Funnel and Golding also found good prospects for lode tin at the head of Herding Yard Creek in 1882. Rands (1884) reported a number of lode cassiterite occurrences along the Border range near Sugarloaf. The Wellesley Lode Tin Mining Company and the Lode Creek Tin Mining Company worked a number of quartz-greisen veins on MS 347 in the late 1880s. The work was abandoned in 1888 after crushings proved unsuccessful. The Noble Tin Mining Company opened up a number of veins on adjoining MS 351 and MS 352.

ALLUVIAL TIN

Economic exploitation of the alluvial cassiterite deposits commenced in February 1872. In the early years the worked deposits were extremely rich, but primitive concentration methods resulted in poor recoveries. Despite this, the first ten years yielded approximately two-thirds of the total production to date. A gradual decline in output followed until the commencement of dredging operations in 1901 when production rose appreciably. Following this brief revival, production once again declined to <20t per year. Renewals of activity in 1962, 1966 and 1982 resulted in annual productions of <100t of concentrates. No tin production has been recorded since 1989.

Most of the alluvial tin workings were located along the Severn River and its tributaries in the Stanthorpe and Drake 1:100 000 map Sheet areas. Exceptions are Ten Mile Creek, a westerly-flowing tributary of Maryland Creek and Pike Creek. The Severn River and its tributaries mostly drain extensive areas of Stanthorpe Granite north and south of Stanthorpe. The major easterly flowing tributary of the Severn River to the west of Stanthorpe is Spring Creek, which contains workings along its tributaries Black Swamp Gully and Broadwater Creek. The major tributary of the Severn River adjacent to Stanthorpe is Quart Pot Creek.

The main alluvial deposits were restricted to Holocene alluvium flats, although deposits locally occurred within stream channels along the present drainage. The stanniferous alluvium comprised granite-derived sand containing subangular to well-rounded pebbles of quartz and occasional boulders of granite. The characteristics of the alluvial wash vary within the region from weakly to strongly cemented and the stanniferous wash is preserved at the base of this layer. The average depth of alluvium is ~0.6m, but varies from ~10cm to 6m in depth. Mottled very low grade stanniferous gravels, sand and clay of probable Pleistocene age occur on ridge tops above the present streams. The grain size of the cassiterite varies from very fine sand to coarsely crystalline aggregates >2.5cm in diameter. The colour of the cassiterite is dominantly black, but notable proportions of white, yellow, amber and ruby coloured varieties are present. Widespread cairngorm and topaz, monazite and lesser amounts of sapphire, zircon, tourmaline and beryl and occasional flakes of gold as well as ilmentite and a few small diamonds have been found (Cutler, 1965). Some areas also recorded corundum, wolframite, and amethyst.

TUNGSTEN AND MOLYBDENUM

There have been no major individual producers of tungsten or molybdenum in the Stanthorpe–Warwick area. The aggregate production from the small mines in the Stanthorpe Mining District is shown in Figures 62 and 63.

TUNGSTEN

Total recorded production of tungsten concentrates is >36t wolframite and 0.4t scheelite. Production has been sporadic and has mainly been influenced by higher prices during the World Wars. Most of the wolframite has come from alluvial and eluvial deposits. Only 10.35t is known to have come from lode mines.

The only significant lode mines were Staines Wolfram Mine and Sugarloaf Mountain. Allison’s Wolfram Syndicate and R. Waterson were reported to have produced >3t of wolframite from veins on Sugarloaf Mountain in 1915 and 1916.

Staines Wolfram mine was first worked in about 1913. Teague and Benjamin worked it as the Victory Wolfram mine in 1916. Total recorded production was 7.1t of wolframite from 56.9t of ore. Leases have been held over the old workings on several occasions, but no further production is recorded.

The main producers of eluvial and alluvial wolframite were Wolfram and Tin, Lord Nolan and Blanche’s Hill. The Wolfram and Tin deposit was worked by the Phoenix Tin Mining Company from 1883–1885. J. Alldridge mined wolframite in the area in 1916 and H. Jones carried out prospecting for cassiterite in 1929. The Wolfram and Tin Company (H. Jones) carried out mining from 1951–1956. Although some wolframite has been produced from

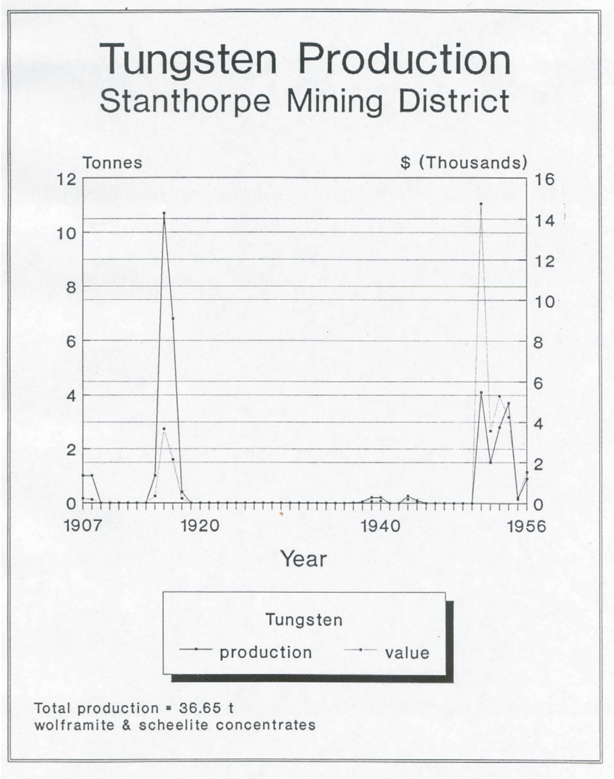

Figure 62. Tungsten production — Stanthorpe Mining District

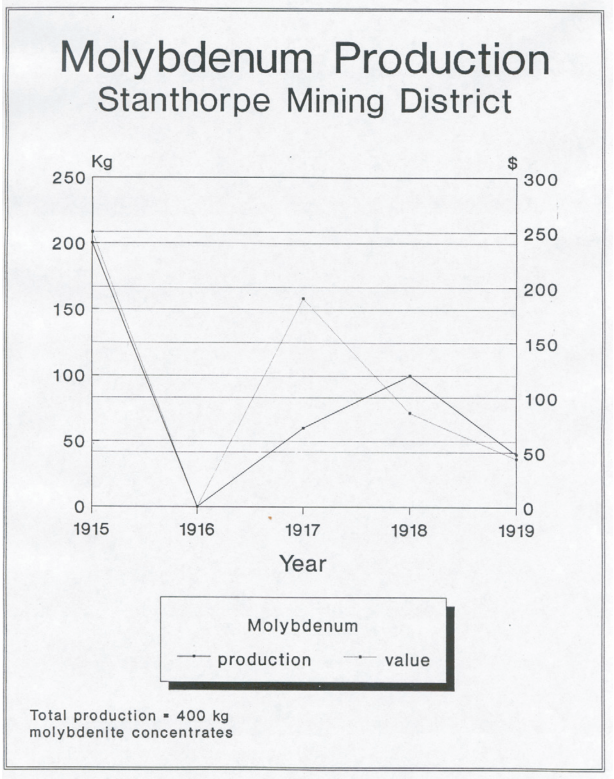

Figure 63. Molybdenum production — Stanthorpe Mining District

quartz veins at the deposit, most of the 14.5t of wolframite and 5t of cassiterite produced has probably come from eluvial deposits and alluvium along Kettle Swamp Creek. Recorded production of eluvial wolframite from the Lord Nolan and Blanche's Hill areas is 4.0t and 3.9t respectively.

MOLYBDENUM

In 1914, the price of molybdenite rose from $120 to $1000 per ton. A total of 700kg of concentrates was produced from 1915–1919. The main producers were Leis' molybdenite mine and Benjamin's molybdenite mine. Prospecting was carried out at the Wasem mine and Chalmer's molybdenite claim. All of these deposits were subeconomic.

Leis' molybdenite mine produced 0.2t of molybdenite from 1916 to 1919. Benjamin's molybdenite mine produced 0.5t of molybdenite from 1915 to 1918. Newman and Higgins sank a shaft in 1915 and produced 27kg of molybdenite and some bismuth. They abandoned the claim in the same year. The deposit was worked by H. Benjamin in 1917 and 1918, but was abandoned in 1919 because it wasn't payable.

Molybdenite was discovered at Chalmer's molybdenite claim in 1914 and several leases were applied for over the Mineral Hill area. No production is recorded.

Stewart and party discovered molybdenite in a tributary of Carpenters Gully in 1919. They held ML 222 "Constellation" over the deposit until 1920. The only recorded production was 3.5t of ore in 1919. Texins Development/Geophoto Pty Ltd carried out investigations at the site in 1970 and 1971. They excavated an adit and a shaft and called the deposit the Wasem mine.

ARSENIC

Jensen (1917) reported that experiments by Mr O.C. Roberts and Dr J. White had demonstrated that arsenic, in the form of arsenic acid or arsenious chloride, was at that time the only specific poison for prickly pear destruction. An estimated 12 000 000ha of Queensland was infested and prickly pear was spreading at a rate of 400 000ha per year.

Arsenic was also used in cattle dips and for hardening lead for bullets. The outbreak of the First World War had caused a dramatic increase in the arsenic price. Consequently, the Queensland Government examined options for the supply of subsidised arsenic oxide to farmers in an effort to combat the prickly pear infestation.

Jensen (1918) examined a number of arsenic deposits in southern Queensland. The only promising deposits for the mining of arsenic alone were at Jibbinbar and Sundown. Jibbinbar was considered to have more extensive, if slightly less rich deposits.

The State Arsenic Mine at Jibbinbar was opened in 1918. Arsenic was mined in the Sundown area by

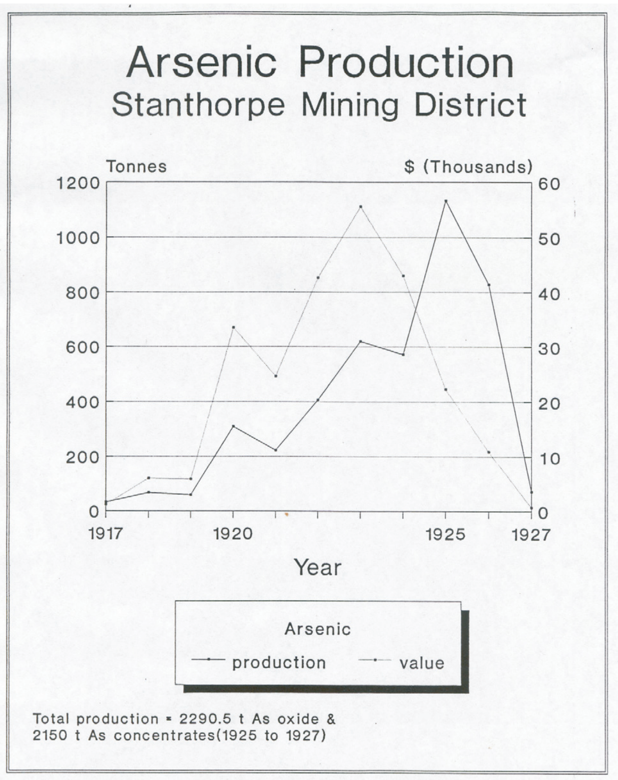

Figure 64. Arsenic production — Stanthorpe Mining District

private companies at the Beecroft, Orient and Sundown copper mines. Numerous arsenical lodes were prospected in the Jibbinbar and Sundown areas and treatment plants were erected at Jibbinbar, Sundown and Wallangarra. Total recorded production from the Stanthorpe Mining District (1917–1927) is 2290.5t of arsenic oxide and 2150.3t of arsenic concentrates (Figure 64).

State Arsenic Mine

Numerous leases were taken out in the Jibbinbar area (north of Mount Jibbinbar) in 1888. The prospectors were looking for silver mineralisation but, although the lodes did carry argentiferous galena, the ore was not economic to treat.

The State Arsenic Mine lode was initially covered by ML 29, which was taken out by J.D. Steele in 1888. Apparently the lease was worked by J. Fletcher, who excavated two shafts. One tonne of stone was sent to the Sydney Mint for a return of 3.8g gold. The lease was forfeited in 1890. Rands (1890) and Jack (1892b) both inspected the lodes on the flanks of Mount Jibbinbar.

The Queensland Government resumed 60ha in the Jibbinbar area in 1917 and the State Arsenic Reserve was proclaimed in January 1918. Mining commenced in 1918 and the crushing plant and furnace were commissioned in 1920. The ore was roasted and the grey arsenic (As_4O_6) collected in flues. Approximately 20% of the arsenic in the ore was not recovered, probably due to losses from the flues.

The mine was worked until 1924. Production ceased in 1925 because cheaper arsenic from Japan made the mine uneconomic. The mine officially closed in 1932 and the machinery was disposed of. P. Flood applied for MLA 461 in 1976 and the State Arsenic Reserve was revoked in 1977. The lease application was rejected in 1979 because of numerous objections from the local populace and Government bodies concerned about potential contamination of Pine Creek.

The total recorded production (1919–1924) was 1953t of grey arsenic from 12 500t of ore.

Beecroft Mine

ML 23 “Beecroft No. 1" was held by J.H. Beecroft from 1888–1889; Beecroft was prospecting for silver. Rands (1890) reported assay results for the lode. Skertchly (1898) also inspected the lode. Ball (1904a) reported that an adit was commenced in a cassiterite-rich formation.

G. Buzacott held ML 82 from 1906–1907; the mine was worked intermittently during part of 1907, probably for copper. J. Chalmers held ML 108 from 1911–1913. I. Smith took out ML 180 in 1915. The mine produced 214.1t of arsenic concentrates (averaging 30% arsenic) during 1917 and 1918. The concentrates were shipped to Leggo’s Arsenic Works in Bendigo, Victoria, for treatment. Lawson, Teague and Rogerson (ML 224) produced 2.5t of arsenic concentrates in 1919.

The mine was worked until 1922, but no returns are recorded. O.C. Roberts Ltd took over the mine in 1922 and produced >1915t of >30% arsenic concentrates from 1923–1927. The concentrates were sent to Wallangarra for treatment. J.L. Mann held ML 313 from 1950–1972, but there is no record of any production.

Total recorded production (1917–1919, 1923–1927) was >2130t of arsenic concentrates from >2696t of ore.

Orient Mine

This mine was originally worked for tin. W. Moffat took out ML 91 in 1907 and transferred it to the Carpenter’s Gully Tin Company Ltd in 1908. This company excavated a shaft to 30m depth. A fair amount of ore was at grass in 1908. The lease was surrendered in 1909 and the company was wound up in June 1909. The company also held ML 97 to cover any south-western extension of the lode.

Curtain and Pettiford produced 12.2t of ore in 1911. Saint-Smith (1914b) reported that 6t of cassiterite was produced from one opencut on the lode. Leases in force in the 1911–1914 period included ML 109 (J. Long), ML 130 (Curtain and Pettiford) and ML 139 (J. Long).

The Orient leases were worked for arsenic in 1918. Leases in force at this time included ML 196 "Planet" (W. Walsh), ML 198 "North Star" (R. Macansh), ML 200 "Orient" (R. Macansh) and ML 210 "The Lost Chord" (B. Besley). W. Walsh excavated the adit still exposed in the workings and produced 20.3t of 35% arsenic concentrates in 1918. R. Macansh raised 16t of ore in 1918.

Lee and Addison took out ML 259 in 1927. Carpenter Creek Tin Mines Ltd took over the lease in 1930; no production is recorded. This company also worked the Carpenters Gully mine and went into liquidation in 1936.

Total recorded production (1911, 1918) was >6t of cassiterite and 20.3t of arsenic concentrates from >28t of ore.

COPPER

Most of the copper production in the region came from the Stanthorpe area, mainly during the period from 1897–1908. The Sundown Copper and Comet mines were the main producers, with some contributions also from the Silver Queen and Pikedale Silver mine. Total recorded production for the Stanthorpe 1:100 000 Sheet area (1897–1900, 1904–1908, 1915–1924) is 55t copper, 201t copper concentrates and 102t copper matte.

Small amounts of copper were also won from mines in the Silverwood district (a few kilometres south of Warwick) during the early 1900s and briefly in the late 1960s, from the Waroo–Ashton area around the turn of last century, and from the Texas and Tooliambi Copper mines (north-east of Texas) from the turn of last century into the 1920s.

The history of these mines (except for the Pikedale Silver Mine and Silver Queen which are discussed under "SILVER, LEAD AND ZINC") is summarised below.

Sundown Copper Mine

The lode was discovered by J. Fletcher in 1888; he took out ML 24 for silver mining. Rands (1890) reported that two shafts had been excavated on a gossanous lode. Excavation of an adit commenced in 1897. The Sundown Silver and Copper Mine Syndicate was formed in 1898 to develop the mine, and in 1899, 570t of ore was smelted. Only 50t of copper matte was produced in 1900, and production ceased in the following year due to cash flow and water problems. The mine was in a state of disrepair when Ball (1904a) inspected it.

The Sundown Tin and Copper Mining Company N.L. reopened the mine in 1914 and worked it in conjunction with the Sundown tin mine. The mine was worked until 1924; only arsenic was produced from 1922–1924.

Total recorded production (1897–1900, 1915–1924) was 40t copper, 201t copper concentrates, 100kg silver, and 200t arsenic oxide.

Comet Mine

Skertchly (1898) described an arsenic-copper lode in an opencut on ML 28. Almost certainly, he was referring to the earliest workings on the Comet lode, there being no workings in the ML 28 area. Wall and Phillips held ML 110 over the Comet lode from 1911–1913, but little work was done.

The Comet Tin and Copper Mine Ltd was registered in Brisbane in 1914 with a capital of $4000. This company took out ML 173 in 1915 and excavated an adit to intersect the lode. The company was reconstructed in 1917.

The mine was under exemption for part of 1918 because of lack of water and capital; a dam and plant were completed in the same year. Work continued intermittently until 1921, when the mine was amalgamated with the Sundown Tin and Copper mines. ML 173 was transferred to Sundown Options Ltd in 1921, then to Arsenic Ltd in 1923, and then forfeited in 1925. The only recorded production (1917) was 12.7t of copper ore. Total production would have been significantly higher than this.

Silverwood Mine

The Silverwood mine is located south-east of Warwick just east of ALLORA on the Warwick 1:100 000 sheet area. The workings were first developed in 1917 when a shaft was sunk by Mr Johnson on the Day Dawn lode (Saint-Smith, 1924). Further mineralisation was located at the nearby Wilson's lode, and a Warwick syndicate was formed to develop the deposits. A total of 10t of ore was subsequently extracted and sent to Port Kembla with an average grade of 10.6% Cu. Little further activity is recorded until 1923, when George Wilson discovered the Myrtle lode 500m to the south. A shaft/drive/winze was then excavated with the mining managed by H. Locke on behalf of the Warwick syndicate. In 1923, a bulk 5t sample was sent to Mount Morgan averaging 6.55% Cu and 6g/t per ton Ag.

A further hiatus in activity occurred until 1966, when the Stanthorpe Mining Company began mining the lodes, and erected a small flotation plant and smelter 5.6km south of Warwick. The Queensland Mines Department undertook exploratory drilling of the orebody during 1967/68, and concluded that the copper mineralisation was confined to narrow breccia zones marginal to an arcuate feldspar porphyry dyke (Sawers, 1969). Smelting trials of the ore were not successful, and the small parcels of ore sent to Port Kembla gave low returns. However, significant tonnages were produced until cessation of production in 1971. The total production of the Silverwood workings is thought to be >2000t of ore, with a total recorded yield of 42.5t of copper and

19.4kg of silver (mainly from the 1966–71 period). The crushing plant in 1979 was being used to crush limestone from Grieve's Quarry.

Texas Copper Mine

The deposit was discovered in 1888 and worked until 1894. Production was minor and not recorded. In 1905, the mine was reopened and 15t of ore was sold to the Silver Spur Mining Company. In 1906, it was renamed the Silver Spur Copper Mine and the ore raised that year averaged 21% copper. The mine was worked on tribute for the last 2 or 3 months of 1907 and 61t of ore averaging 22% copper was produced. The mine closed down in 1907 when the oxidised ore cut out at 30m depth. The mine has been investigated by numerous companies since its closure but nothing of economic interest was found. The Queensland Department of Mines drilled a number of holes at the site in 1971 (Siemon, 1972), but no economic mineralisation was found. Core samples contained grades of 2.4–16.2g/t silver, but there is no record of silver production during the working life of the mine.

Tooliambi Copper mine

The deposit was discovered in 1918. A mining lease was taken out in 1919 and the deposit was worked from 1920–1922 when 69.4t of ore was produced for a return of 8t of copper and 39.5kg of silver (Saint-Smith, 1923). The mine (Figure 65) was unsuccessfully reopened in 1929, and in 1946 a new mining lease was taken out. The lease was transferred to Tooliambi Mines Pty Ltd in 1960, and 0.5t of copper is reported to have been produced in 1961. In 1964, 10t of ore was railed to a smelter for testing which yielded a 50% copper return, but too high a silica content for direct smelting. A flotation plant was purchased in 1966, and in 1967, 4.4t of copper ore was produced. No further production is recorded from the deposit. In 1971, the Queensland Department of Mines drilled 7 cored holes at the mine, but did not intersect any economic mineralisation (Krosch, 1972).

Ashton/Angus Valley/Commodore

These deposits are situated north-north-west of Mount Bullaganang in the north-eastern part of TEXAS. The Ashton copper deposit was discovered prior to 1897 and worked in the late 1890s, but no production records are known. An ore assay in 1898 gave grades of 638g/t silver and 30% copper (Cribb, 1944).

The Angus Valley deposit 1km to the south-east of Ashton is believed to have been worked around the turn of last century. Denaro (1989) suggests that at this time the mine was referred to as the Cyprus copper mine which is recorded as having a small lode of rich copper carbonate ore.

The Commodore copper mine was discovered in 1905 and is 1km north-west of the Waroo gold deposit. The ground was worked sporadically until 1914 when the site was abandoned. Total recorded production (for the period 1906–1912) was 206t of ore for a return of 17t of copper. The ore ranged from 6–25% copper and averaged 25g/t gold (Senior, 1973). There is no record of any gold production.

Figure 65. Headframe and shaft developed along Tooliambi lode

SILVER, LEAD AND ZINC

The first discovery of silver mineralisation in the study area was in 1880 at the site of the Pikedale silver mine. Silver-bearing arsenopyrite lodes were discovered at Jibbinbar and Sundown in 1888. Numerous leases were taken out and prospecting work was carried out, but no production was recorded. The Silver Spur deposit, east of Texas, was discovered in 1890 and worked at various times mostly from 1892–1925.

The main period of silver, lead and zinc production in the Stanthorpe area was 1896–1908, when the Pikedale silver mine and Silver Queen mine were worked. Some silver was also produced at the Sundown copper mine. Total recorded production for the Stanthorpe 1:100 000 Sheet area is 286kg silver, 10.7t lead and 70t zinc.

Further west near Texas, production from the Silver Spur mine from 1892–1976 totalled 68t of silver, 140kg of gold, 990t of copper, 1050t of lead, and 690t of zinc ore.

Base metal sulphide mineralisation was also reported from the Silverwood area (south of Warwick) in the early 1900s, but no production is recorded. The Department of Mines drilled one of these occurrences contained within limestone at Grieve's Quarry, but no economic mineralisation was found (Siemon & Huber, 1979).

Pikedale Silver Mine

A small outcrop of gossanous ore in Woolshed Gully was first noted in about 1880 but no work was done. The Pikedale silver mine was opened up in late 1896, when a smelter was erected by the Pikedale Copper, Gold and Silver Mining Company. The mine was worked until late 1897 when operations were suspended because of smelter problems; 102t of matte containing 30–40% copper, 4.6–9.2kg/t silver, and 15.3g/t gold, was shipped to Europe. Attempts to raise capital for a new type of smelter failed and the mine was closed in 1898.

Some underground development was carried out in 1906 and 437t of ore was treated in 1907. Work was suspended in 1907 and Government assistance was sought to erect a roasting furnace, zinc flume condenser, copper smelter, Wilfrey table and magnetic concentrator. Cameron (1908) reported that the ore body was not sufficiently proven and no subsidy was granted. There is no record of any subsequent mining activity other than the shipment of 10t of ore to Great Britain for treatment investigations in 1908.

Total recorded production (1897–1899, 1907–1908) was 1341t of ore yielding 15t copper, 186kg silver, 10.7t lead, 70t zinc and 102t copper matte.

Silver Queen Mine

The lode was discovered in 1896 and the Severn River Copper and Silver Mining Syndicate worked the mine (ML 72) from 1897–1900. The mine is close to the Severn River and there was talk of utilising the river water as the motive power for winding and other purposes. Approximately 53t of ore was sent to Cockle Creek for treatment in 1899, but little work was done in 1900, pending the raising of more capital.

The mine was worked by the Baker Brothers of New South Wales for about nine months in 1904. A good deal of development work was done and $1200 worth of machinery was installed; 48t of ore valued at $314 was shipped.

The mine changed hands in 1905 and work began on development and the erection of a new plant for treating the ore. Despite the new concentrating plant, it was reported in 1906 that a fair percentage of the minerals was being lost. Another new plant was then installed but production was not recorded.

The Ballandean Queen Silver Lead and Copper Mining Company N.L. was registered in 1906 and work continued until 1908. The mine was not payable; most of the sulphide ore had been mined out and only the oxide ore was left. The lease was surrendered in 1909. After this, the only work done was hand dressing of the ore at grass.

There are no records of the mine from 1909–1912, when the Silver Queen Silver Lead Zinc Mining Company Ltd was registered. There is no record of any work being done and the company was struck off the register in 1919.

Since 1919, various people have attempted to reopen the mine, but without success. Baker and Martin attempted to dewater the mine in 1952.

Total recorded production (1899, 1904–1908) was 372t of ore and 89t of concentrates (containing approximately 2.3t copper, 21.6t lead, 5.1t zinc and 55.1kg silver).

Silver Spur Mine

The Silver Spur mine was one of the notable producers of silver, gold, lead and copper in the state. Ore was mined to a depth of 158m. The main product was argentiferous copper matte. Some lead-copper matte, lead bullion, and silver and zinc ore were marketed also. Total recorded production (1892–1925, 1952, 1970, 1976) is ~100 000t of ore for a return of 68t of silver, 140kg of gold, 990t of copper, 1050t of lead, and 690t of zinc ore.

The deposit was found in 1890 as a malachite-stained gossanous outcrop. After unsuccessful searches for payable copper ore, numerous syndicates took over the operation from 1892 onwards. The Silver Spur Mining Company N.L. was formed in 1894, and erected a reverberatory furnace in 1898, a pyritic smelter in 1899 and a lead smelter in 1900. A second company, the Silver Spur Proprietary Company, was formed in 1907 and worked an area on the southern boundary of the parent company's mine. Mining at Silver Spur went into decline from 1909, as the smelting methods were inefficient and high grade ore became scarce. By 1911, only one-third of the total metal was being extracted. The ore also contained insufficient copper metal to collect all of the silver and gold during smelting. Labour shortages brought about by World War I forced closure of the mine in 1914.

A new company (Silver Spur Ltd.) reopened the mine in 1917, but produced only small amounts of ore from small, rich, relatively shallow lenses until 1926. Lack of high grade ore, smelting difficulties and low metal prices were significant factors forcing the mine closure.

After a long period of inactivity, the mine was once again worked in 1952, when 171t of ore was recovered for a return of 290kg of silver, 8.7t of lead, and 964g of gold. In 1970, Mount Carrington Mines Ltd. obtained the leases, raised 2t of ore and set about rehabilitating the workings. In 1973, the Queensland Department of Mines drilled five cored drillholes at the site, but did not locate any major ore bodies (Kay, 1975). In 1976, 196t of ore was milled for a return of 2.88t of lead and 68.5kg of silver. The mine is currently inactive, and the leases are controlled by Texas Silver Mines Pty Ltd, a subsidiary of MACMIN Ltd.

LIMESTONE

Extensive limestone resources occur throughout the region and have been mined over a considerable period of time (Siemon, 1973, 1992).

SILVERWOOD–LUCKY VALLEY AREA

Limestone and marble are thought to have been quarried intermittently for over a century from a number of variably metamorphosed limestone lenses south and south-east of Warwick. The largest of these resources are the Elbow Valley quarries (situated in the Lucky Valley area). Unimin Australia Limited (formerly David Mitchell Pty. Ltd.) operates two leases ("O'Dea extended" and the "Warwick Plant"). Limestone and marble have been extracted from a group of lenses for chips for terrazzo and pool finishes, cement and glass manufacture and for various other agricultural and industrial uses. The "O'Dea extended" lease has produced 505 118t of crushed rock, 10 977t of marble and 75 917t of calcined ore during the period 1997–2004. The "Warwick Plant" lease has produced 89 583t of crushed rock, 7396t of calcined ore, and 1183t of marble during the period 1998–2004. Much of the marble has been used for terrazzo-style products and landscaping.

Smaller limestone and marble and deposits have been quarried to the west in the Silverwood area, mainly from Locke's Quarry and Grieve's Quarry. The resource at Grieve's Quarry is associated with subeconomic copper-silver-lead-zinc sulphide mineralisation. The first recorded period of activity at Grieve's Quarry is from 1901–12, although earlier mining activity is likely. Locke's Quarry was also probably worked at this time, when between 5000–10 000t of crushed limestone is thought to have been produced from these two sites. During the period 1971–76, Grieve's Quarry was worked to produce 15 498t of crushed limestone for agricultural and foundry use, as well as a stone dusting agent in coal mines.

CEMENT MILLS

Large limestone lenses were discovered over a century ago south of Gore at Cement Mills on the far western margin of the Warwick 1:250 000 Sheet area, locally associated with phosphatic deposits (Ball, 1917). The limestone deposits were first quarried in 1914 and were worked mostly continuously by a variety of companies until 1969, producing ~1 140 000t of crushed limestone for use in cement making or for agricultural purposes. Operations began again in 1998 and up until the end of 2004, a further 151 826t was produced.

Reserves of around 2Mt of limestone remain at Cement Mills.

TEXAS AREA

Lime Products Marble Quarry

The quarry was first worked in the early 1920s, but there is no record of production. A new lease was taken out in 1931 and the quarry has been worked intermittently since then, mainly producing marble blocks and terrazzo chips. Some high-grade, excellent quality ornamental marble was produced and used as finishing stone in the construction industry. Total production from 1932–1938 was 713t. Actual production from 1939 is not known as production was included with figures for the Limevale Quarry (22 080t from 1939–1975).

Limevale Quarry

A mining lease was first taken out over the deposit in 1923, but production records only document intermittent production of limestone and marble from 1932 up until 1997. The lease is currently held by Unimin Pty Ltd. under care and maintenance. The Marbarete Company Pty. Ltd. who held the site from 1953–1975, quarried the deposit for marble for monumental and building purposes as well as for terrazo chips. Later lease holders produced marble and limestone chips, crushed lime and burnt lime. There is one open cut at the site with most later production restricted to the southern section because of seepage problems in the northern section. Recorded production of 38 063t from 1939–1999 includes some production from the Lime Products marble quarry. There is no record of production from 1976–1981. Production from 1982–1988 included 4097t of agricultural lime, 1671t of limestone flux, and 5770t of other limestone. Production in 1999 included 129t of marble dimension stone, which has been the sole commodity produced since that time (458t for the period 2000–2003).

Marble Queen

Marble was known from the site since 1919, but a mining lease was not applied for until 1964. The lease was granted in 1973 and surrendered in 1982. Random stone was produced from a number of pits and opencuts, but pricing was not competitive with Italian marble. Recorded production from 1965–1971 was 1600t.

Pinnacle Limestone Quarry

This site is situated opposite a prominent limestone pinnacle adjacent to the Glen Lyon Dam – Texas road. The deposit had been known for many years before a mining lease was granted over the site in 1997 to Australian Limestone Pty Ltd. In the year 2000, the company extracted 92 661t of limestone from the site, of which 702t was used as decorative aggregate. Unimin Pty Ltd currently holds the lease over the deposit.

Riverton Quarry

A lease over the Riverton deposit was first taken out by Tooliambi Mines Pty Ltd in 1974. The lease changed hands a number of times before a new lease over the deposit was granted to the current operators of the quarry, Unimin Pty Ltd, in 1998. This large deposit comprises high-grade, low-iron limestone used mainly as a filler and in glass manufacturing, although some decorative aggregate has been produced. During the period 1998–2003, 678 886t of crushed rock and 71t of marble were produced.

MANGANESE

Sporadic mining of manganiferous jasperoidal bodies in the Texas beds has occurred since the late 1800s. Most of the major manganese mines (War Effort, Mount Fuller and Mount Devine) are located on the Goondiwindi 1:250 000 Sheet, although some small deposits (Mount Gammie, The Glen) also occur to the east on the Warwick 1:250 000 Sheet.

War Effort Mine

This mine consisted of two groups of workings — the main workings (3 opencuts) and another open cut (War Effort West) 600m west-south-west of the main workings. The mine was discovered prior to 1904 when a mining claim is recorded over the area. The mine was worked again from 1940–1942, and was re-opened by P. Flood in 1963 who extracted manganese ore for sale to Union Carbide (Australia) Ltd. in Sydney until 1964. Total production from the deposit was ~400t of ore.

Mount Fuller Mine

ML 192 was first taken out over the Mount Fuller lode in 1917. Approximately 210t of ore was sent to the Broken Hill Proprietary at Newcastle. The lease was forfeited in 1921. ML 209 was taken out in 1918 at Mount Fuller West, but the lease was abandoned after a few months. ML 240 was taken out over the manganese lodes in 1922 and ~90t of ore was produced from an opencut, shafts and trenches. The lease was forfeited in 1924, and no further mining activity is recorded.

Mount Devine Mine

This manganese deposit was discovered in 1918 and worked in the same year as ML 212, before being forfeited in 1919. The same area was worked in 1923–1924 as ML 241. Mining was carried out from two opencuts, and the total production from both leases was 83t of manganese ore.

Mount Gammie

The earliest known operation on the Warwick 1:250 000 Sheet area was at Mount Gammie west of Pratten, where a 4m deep shaft was sunk in 1896 at the southern end of a manganiferous ridge. A total of 4.06t of ore was extracted, with the surface ore assaying 48.9% manganese (Ball, 1904b,c).

The Glen

At the Glen mine, situated 10km south-west of Warwick, several small manganiferous lenses in the Texas beds adjacent to the Herries Granite have been worked intermittently since 1903, but no production records area available. The manganese content of the ore is low and since 1962, the main interest has been rhodonite. Small quantities of rhodonite have also been extracted from a deposit within manganiferous jaspers 22km west of Stanthorpe.

MAGNETITE

During 1996/97 ~6000t of magnetite was produced from the Tatong magnetite deposit, 12km south-south-east of Warwick within the Silverwood Group. The limestone-hosted skarn deposit was mined by open cut methods.

BUILDING STONE

SANDSTONE

Sandstone has occasionally been quarried from exposures of the Marburg Subgroup in the Warwick area. The oldest deposits are at Yangan, 18km east of Warwick, and are thought to have supplied building stone to the area for a short time in the 1930s. Two mining leases currently exist over the sandstone quarries at Yangan, with production from 1996–1998 recorded as 362.86t. No current activity has been reported. Other sandstone leases currently exist over the Socks and Tanamerah sandstone deposits a few kilometres to the north-north-west of Warwick. These deposits are more suitable for the supply of landscaping materials. The Socks resource produced 189t of stone during the 1999–2000 period.

GRANITE

Edwards and Roberts quarried small quantities of Stanthorpe Granite near the Stanthorpe Railway Station in 1915. This red granite was reported to take an excellent polish and was of satisfactory quality and durability. During the early 1900s, large boulders of Greymare Granodiorite were extracted from a locality near the Greymare railway siding for use as dimension stone (Richards, 1918). Little further activity occurred until the last three decades, when several unsuccessful attempts were made to exploit granite in the region.

There appears to have been little interest in the potential of the Stanthorpe district as a source of building stone up until 1973, when Consolidated Mining Industries Ltd applied for ML 451 “Jolly’s Lease”. This company intended to remove granite in block form, but no mining was carried out and the lease application was abandoned in 1974.

During 1987 and 1988, Emidex Pty Ltd investigated a dyke and small pluton of gabbroic material (Unnamed at MGA 390706/6805988) as possible sources of “black granite” facing stone. The depth of weathering was too great and the unweathered tors and boulders were too small to quarry.

In early 1990, Mr B. Kassulke (trading as South Queensland Granite) entered into a joint venture with New England Granites to quarry and market granite from Kassulke’s Quarry, south of Pozieres, as Dimension Granite Pty Ltd; the proposed joint venture development was not followed through.

In September 1991, the Tradex Group was reported to have purchased South Queensland Granite. The company had planned to be fully operational and for exports of tiles and slabs of “Highland Fawn granite” to have commenced by early 1992 (Ray & Trezise, 1992), but this venture was also not followed through. In October 1996, Mr Kassulke sold the lease to the current holders (P.M. Groen and A & A Ceramic Imports Pty Ltd) but to date no development has taken place. The resource is estimated to contain 10Mt.

GEMSTONES

Gemstones were commonly found since the early tin mining days in the stanniferous alluvium of the Stanthorpe district. The main varieties include topaz, clear and smoky quartz, green and blue sapphire, diamond, beryl, tourmaline, spinel, zircon and amethyst. Sapphires were recorded from the Broadwater (including Eberhardt’s Claim), Ketttle Swamp Creek, Brittania gully, Four Mile Creek, Blue Mountain Creek, and further to the west at Red Rock. Diamonds were recorded at The Broadwater (and including Broadwater Proprietary Tin Dredging Company, where they ranged from 0.3–0.5 carat) at Kettle Swamp Creek (0.12–1 carat), and at Four Mile Creek.

Ball (1903c, 1904a) described diamonds recovered from the Broadwater and Kettle Swamp Creek. As the deposits are of only minor commercial value, little actual effort has been made to recover them. Skertchly (1898) reported that Hunt set up a diamond-saving machine on Spring Creek in 1873; only three or four diamonds were recovered. A diamond-saving machine was also set up on Kettle Swamp Creek in 1874, but no diamonds were recovered.

More recently, public fossicking areas have been established at Swipers Gully and Fossicker’s Park. There are private fossicking areas at the Blue Topaz Caravan Park and the Gemstone Café and Camel Park.

MINERALISATION STYLES AND POTENTIAL

NORTHERN NEW ENGLAND BATHOLITH

Mineral deposits in the Stanthorpe and Drake 1:100 000 Sheet areas have been described in detail by Denaro & Burrows (1992). The leucogranites comprise by far the most important group with regard to mineralisation in the New England Batholith. Mineralisation styles related to the leucogranites have been divided into Mo, Sn, polymetallic vein, and Au associations (Blevin & Chappell, 1992, 1995; Blevin, 2004).

Granites of the northern New England Batholith which show petrographic and compositional changes consistent with extended fractional crystallisation processes are most likely to be associated with significant mineralisation (Blevin & Chappell, 1992). Such granites are common in the Stanthorpe–Wallangarra region where they have been mapped as Ruby Creek Granite or, less commonly, Stanthorpe Granite.

The relative oxidation state of magmas is of major importance in controlling the compatible/incompatible nature of many ore elements — *e.g.* Cu, Mo, and Au deposits are typically related to magnetite-bearing (*i.e.* oxidised) granites and Sn (± W) with ilmenite-bearing (*i.e.* reduced) granites (Isihara, 1977, 1981; Isihara & others, 1979; Blevin & Chappell, 1992; Blevin, 2004). An apparent anomaly is the oxidised character indicated by the presence of pale pink K-feldspar in parts of the Ruby Creek Granite, which is associated with significant Sn mineralisation. A possible explanation is that the Fe and Ti contents in suites which evolve to very felsic compositions decrease to such low concentrations that Fe-Ti oxides, titanite, and biotite only crystallise late, if at all. In such cases Sn may be concentrated in the melt fraction even if the melt is relatively oxidised because there are no appropriate hosts into which it can be sequestered (Blevin & others, 1996).

Parts of the Ruby Creek Granite are highly fractionated as in the Sugarloaf, Kilminster and Sundown areas. The Ruby Creek Granite in these areas is associated with Sn, Mo, W, Bi, base metal, and Au mineralisation (Saint-Smith, 1914a; Denaro & Burrows, 1992). The most fractionated samples (with Rb = 655, 616ppm, Y = 89, 192ppm, Sn = 22, 32ppm, and K/Rb = 59; Figures 46, 47) collected during the recent survey are from the Swipers Gully area, north-west of Stanthorpe. Perhaps not surprisingly, tin and gold mineralisation has been reported in this area, which was the site of small-scale lode and alluvial mining in the late 1800s – early 1900s (Skertchly, 1898; Denaro & Burrows, 1992). Rands (1887, 1888) reported assay results of 28–50g/t Au for the Pikedale lode (MGA 381676 6835028), the main producer in the area, but the deposit proved uneconomic. Total recorded production in the Swipers Gully area is small (Denaro & Burrows, 1992).

Similarly, aplitic leucogranite from the Sundown area contains up to ~520ppm Rb and ~130ppm Sn (Figures 46, 55), and is associated with Sn, Mo, As, W and base-metal mineralisation. Large tonnage – low grade mineralisation in the form of stockwork and/or sheeted vein systems in country rocks overlying granite cupolas and ridges has been found in this area (Wegmann & Sceney, 1983; Denaro & Burrows, 1992; Blevin & Chappell, 1992).

Felsic granite forming Jibbinbar Mountain is associated with significant arsenic mineralisation (see Denaro & Burrows, 1992). However, unlike the Ruby Creek Granite in the nearby Sundown area, the Jibbinbar Granite does not appear to be highly fractionated (*e.g.* Figure 46), although it is very leucocratic. The arsenopyrite is concentrated in quartz veins and quartz-rich lodes distributed along east to north-east-trending shear zones and/or faults in the granite (Denaro & Burrows, 1992). The deposits also contain erratic Au values (up to 5g/t; Denaro & Burrows, 1992).

Much of the veining and dyking in the Stanthorpe granites (and adjacent country rocks) is joint controlled and spatially related to the north-east to east-north-east-trending fracture system which cuts the Stanthorpe Granite pluton. The largest of these systems is the Severn River Fracture Zone (SRFZ) which crosscuts the granite and extends south-westward into the Sundown area.

Norman & others (2004) reported a Re–Os crystallisation age of 242.1±0.7Ma for molybdenite from the Ruby Creek Granite. This result is in good agreement with other radiometric ages obtained for the unit, and implies the mineralisation is related to the main late Permian–early Triassic magmatism and not to a younger, unrelated event.

Potential. The northern part of the New England Batholith remains an enigmatic region with regards to mineralisation. It contains extensive areas of fractionated, highly prospective leucogranite. However, despite the presence of numerous small mines and mineral deposits, economically viable ore bodies have not been found. Cupolas and ridges in the roof zones of plutons and the apical parts of discrete intrusions with relatively small cross sectional areas relative to their vertical extent are favoured sites for the concentration of buoyant plumes of fractionated melt and exsolving hydrothermal fluids from a crystallising granite magma. The Stanthorpe Suite granites appear to have been emplaced as areally extensive bodies with relatively regular roof zones. Consequently, mineralised fluids were dispersed throughout the intrusions and adjacent country rocks, and the ore minerals deposited as uneconomic disseminations and joint and fracture linings.

Sheeted cassiterite + wolframite greisen veins in the Sugarloaf–Storm King Dam area offer the best potential for large tonnage, low-grade deposits in the northern part of the batholith. Exploration has concentrated on the Sugarloaf area, but little drilling has been carried out. Little exploration has been carried out in the Storm King Dam area. No significant argillic alteration, which could produce ‘soft’ deposits, has been found; argillic alteration is generally associated with tourmaline-rich deposits in other tin fields.

Although the Ruby Creek Granite is considered to be the mineralising intrusive phase of the batholith, it is not considered to have much potential for economic ore deposits. Cassiterite is disseminated in veins and small zones of greisen and pegmatite. No significant lodes or veins have been found. Stockwork systems tested at Blanche’s Hill and Lord Nolan proved to be small in tonnage and low in grade.

The Ruby Creek Granite is the unit most likely to host significant deposits of Mo + W ± Bi. All deposits found so far have proved to be small and subeconomic. Potential exists for discovery of new deposits related to cupolas of Ruby Creek Granite, but there is little potential for the discovery of economic deposits.

Silver and gold occur in arsenopyrite lodes at Jibbinbar, but grades are erratic. There may be potential for massive greisen systems in Ruby Creek Granite beneath the Wallangarra Volcanics.

The Stanthorpe Granite has potential for more Timbarra-style Au deposits. The Timbarra deposit, east of Tenterfield in New South Wales (Grafton 1:250 000 Sheet area) is hosted by leucogranite, which has been mapped as part of the Stanthorpe

Granite (Stanthorpe Monzogranite, NSW terminology; Henley & others, 2001). Exploration for this style would focus on finding the roof zones of plutons and cupola-style traps for late-stage gold-rich fluids (*e.g.* see Mustard, 2001, 2004).

TEXAS BEDS

STANTHORPE–SUNDOWN AREA

Within the Severn River Fracture Zone (SRFZ) close to the margin of the New England Batholith (in the Mineral Hill–Silver Queen area), more diversified polymetallic mineralisation occurs, with significant deposits of Cu, Pb, Zn, As, Mo and W (as well as Sn) having been worked.

The south-western extension of the SRFZ contains the well-known Sn/polymetallic deposits of the Sundown area, ~10km to the west of the batholith. These deposits are joint controlled sheeted vein systems (quartz-cassiterite and quartz-arsenopyrite-cassiterite veins) that are clustered close to the intersection of the SRFZ and a major north-west-trending fault extending from south of the New South Wales border into the Jibbinbar area. The deposits are hosted within hornfelsed Texas beds capping very shallow-level and probably extensive plutons of Ruby Creek Granite that supplied the mineralising fluids. The Ruby Creek Granite is exposed in a small erosional window at Red Rock Gorge and has been intersected at shallow depths in holes drilled in the Discovery Creek area (Goode & others, 1982). The best-developed examples of sheeted vein systems are the deposits delineated by Shell and BHP at their Sundown and Discovery Creek prospects in the Sundown area (Goode & others, 1982). The Sundown sheeted vein systems have also historically been worked for Cu, Ag and As and also contain minor Au, Mo and W.

The Jibbinbar Granite, north-west of Sundown, contains small shear-hosted As, Pb, Ag, Zn and Cu deposits. However, the granite is not associated with significant Sn mineralisation in marked contrast to the Ruby Creek Granite of the Sundown area. Available data imply the Jibbinbar Granite is not as highly fractionated as, and is chemically and mineralogically distinct from the Ruby Creek Granite (see previous section).

Potential. There are undoubtedly further Sn and polymetallic resources to be exploited in the Sundown area, but land access difficulties and low grades discourage significant exploration. The Sundown and Discovery Creek Prospects have subeconomic grades (30Mt at 0.1% Sn; Taylor & Pollard, 1984), although some prospective anomalies in the Sundown area remain untested (Krosch, 1985). Taylor (1969) concluded that commercially viable low-grade tin deposits are rare in eastern Australia as grades rarely bulk greater than 0.2% Sn. A resource of >1Mt at 0.3–0.4% Sn would be required to establish an opencut mine (Taylor, 1969). These types of deposits generally require special conditions to become economic, for example, associated elements and innovative mining and/or metallurgical approaches.

The existence of Sundown-style sheeted vein systems on the New South Wales side of the border at Back Creek and Taronga may indicate a subsurface connection between the Red Rock pluton and the Mole Granite (on the CLIVE 1:100 000 sheet). Alternatively, there may be a line of buried plutons between Red Rock and the Mole Granite. Detailed gravity surveys might prove more successful in locating buried granite ridges and cupolas than the aeromagnetics used so far.

The potential for replacement type mineralisation in the area is considered to be minimal. There are few calcareous beds and those that do occur are quite small. The main belts of limestone outcrops in the Texas beds are in the Texas area, well away from known granite intrusions. Lode deposits of the Sundown Tin/Copper mine type offer some potential for small tonnage, high-grade deposits. However, Offenburg (1982) noted that the complex sulphide and oxide assemblages (often with abundant arsenopyrite) are metallurgically difficult to separate and recover. This factor plus the small tonnage limits the exploration potential of these deposits.

Arsenic-rich lodes and veins at Sundown and Jibbinbar would no longer be economic to mine for their arsenic content alone. The sometimes high, but erratic, associated silver and gold grades have attracted some interest, but it is considered that the tonnages and grades are insufficient in view of the metallurgical and environmental problems that would confront any resource development.

OTHER AREAS

Gold: Metamorphic Fissure Vein Deposits

Gold mineralisation within the Texas beds is dominated by small, epithermal to mesothermal fissure vein-style Au deposits, which at a few mines in the Pikedale and Talgai and MacDonald Goldfields are associated with Ag. These are mainly fracture or shear controlled with some possibly associated with late stage dykes or sills (*e.g.* the Wantee deposit north-east of Texas). The Au and Ag of these deposits were probably transported over great distances as bisulphide complexes in silica-rich hydrothermal fluids generated by metamorphic dehydration reactions. Fluid temperatures in these environments are generally high (200°–450°C). The metal deposits precipitate into structurally favourable sites such as faults, fractures and breccia zones as quartz veins, stockworks or breccia fill. Precipitation occurs because of factors such as a drop in pressure and/or temperature as well as chemical changes induced by the host rock.

No obvious spatial, temporal or genetic relationship has been established been large intrusive granitoid bodies and gold deposits of this type.

Some of the larger deposits in the Leyburn–Talgai areas appear to be spatially related to stratabound magnetic anomalies and may represent secondary concentration of earlier syngenetic deposits (see later section).

Potential. Some potential for small low to moderate grade lode deposits still exists in the Talgai area and on TEXAS and INGLEWOOD where shallow Mesozoic cover mantles prospective basement rocks.

Gold: Granite Related Mineralisation

Waroo–Ashton area

The north-west-trending ***Waroo–Ashton*** mineralised corridor is part of a large hydrothermal Au-Cu-Ag mineralising system whose primary fluid and/or metal source is probably the Early Permian Bullaganang Granite intrusion and the small related granite body immediately to the north-west of that pluton. Mineral zoning in this area typically shows Cu/Au assemblages (with low Ag) giving way to Cu/Ag assemblages (with low Au). Minor Zn and Pb mineralisation has also been recorded.

Radiometric images indicate an elliptical zone of potassic alteration enclosing the two granite bodies, with known deposits situated close to radiometric maxima. The latter appear to be related to silica-sericite-sulphide alteration of the country rocks (Texas beds and unnamed Permian? sediments). Magnetic images over the area indicate that the exposed plutons are small, structurally controlled apophyses of a much large igneous pluton currently at moderate to shallow depths beneath the surface.

Mineralisation in the area shows a strong structural control — the most obvious being the north-west-trending fault defining the line of lode of the Waroo–Commodore system, as well as east-west-trending moderate to steep south-dipping shears visible on the ground. Other significant features include a set of moderate to shallow-dipping faults and fractures, which dip away from the Mount Bullaganang pluton to the north-west and to the south-east. These generally define zones of intense silicification. The best documented of these structures is the Flatmake Shear exposed in the pit at Waroo. This undulating low angle feature controls gold mineralisation and has subvertical feeders streaming off the hanging wall, acting as channelways for both primary sulphide deposition and supergene enrichment (Catherall & Hockings, 1992). It is unknown if the shallow-dipping shears dipping away from the granite to the north-west and south-east are extensional faults or thrusts. They may have had an early extensional history, perhaps accommodating early emplacement of the Bullaganang pluton, followed by thrusting during later compressional events affecting the region.

Conflicting evidence exists concerning the temperatures of the mineralising fluids. At Waroo the mineralised Flatmake Shear was reported to have comb-textured quartz indicative of epithermal conditions, while Hockings (1991) reported somewhat higher temperature (>573°) hexagonal paramorphs of β-quartz in fractures at Waroo. The extensive kaolinisation of feldspars at Waroo (Catherall & Hockings, 1992) suggests alteration at higher crustal levels. The mineralisation was most likely related to mixing of heated meteoric groundwater cells with magmatic hydrothermal fluids, accompanied by the characteristic silica-sericite-sulphide alteration. The mineralisation is reported by Denaro (1989) to be a vein-hosted deposit, but Walsh (2000) reported that quartz vein material at Waroo and Commodore was rare. Most of the more recently mined material occurred in fractures, faults and shears as well some vein, stockwork and disseminated material. Supergene alteration was extremely important at Waroo for economic grade ore returns.

Potential. "Carlin-type" models were used by company explorers in the 1980s although no known carbonate host rocks are known from the Waroo–Ashton area. However, limestone bodies do occur to the north-east, and many areas of poor outcrop within the mineralising system may contain undetected limestone bodies. The possibility is further strengthened by the presence of an unusual clinopyroxene-bearing phase of the granitoid body south of Ashton, which may be indicative of an endoskarn assemblage.

There may be links between the Waroo–Ashton style of mineralisation and that of the silver-rich Early Permian-hosted Twin Hills style mineralisation to the south. Both deposits are associated with silica-potassium alteration, and the presence of possible Early Permian host rocks at Waroo–Ashton further strengthens their links. Early Permian sediments and volcaniclastics may represent a chemically and mechanically favourable environment for this mineralisation style.

Considering the size of the potassic alteration envelope in the Waroo–Ashton area, there may yet be some scope for small high grade or large low grade bulk tonnage Au/Cu deposits. Significant metal/fluid volumes and heat generating capacity could be expected from the large subsurface pluton identified at depth beneath the Waroo–Ashton system. The buried pluton may have been important as a 'heat engine' driving convecting epithermal fluids and/or as a source of mineralising hydrothermal fluid forming mesothermal deposits.

Investigation of other significant plutons and their peripheries beneath shallow Cainozoic of Mesozoic cover may yield significant finds. In particular, the Mingimarny Granite (60km to the north-north-west) is similar petrologically to the Bullaganang Granite, but nothing is known of its country rock envelope due to mantling by thin cover.

Besshi-type Cu-Au deposits

Some of the characteristics of this style of deposit exist within the Texas beds, but no deposits have yet been identified in Queensland. We consider that some of the syngenetic to epigenetic magnetite alteration of chert-jasper-mafic volcanic packages may represent submarine spreading centre environments favourable for the formation of Besshi-style VMS Cu and/or Au deposits. The magnetite-rich bodies dispersed throughout the Texas beds probably result from prograde regional metamorphism of iron-rich exhalites or other hematite-rich clastic sediments flanking submarine volcanic centres. Some of the magnetite may also result from hydrothermal alteration under reducing conditions beneath the sediment-water interface. Analogous hydrothermal magnetite alteration of radiolarian chert interbedded with basalt has been reported from the Mount Browne copper deposit within Texas bed-equivalent turbidites in New South Wales (Korsch & Perkin, 1993).

Potential. The potential for finding this type of deposit is low, as most basalts so far analysed have a seamount-type rather than spreading ridge-type geochemical signature. However, numerous examples of this type of alteration can be identified using the regional magnetic data and some potential targets may still exist.

Magnetite-altered jasperoids and associated linear magnetic anomalies may be related to gold mineralisation in the Leyburn and Talgai areas. One of these anomalies is concealed under shallow Mesozoic cover north-east of Pratten, and may be worth considering as an exploration target.

Base Metal Mineralisation

Minor basemetal (±Au/Ag) mineralisation occurs throughout the Texas beds. Examples on the TEXAS sheet include include: Devlin's Prospect (Zn, Pb, Cu, Ag), a pipe-like skarn deposit; Arcot (Ag, Au with anomalous Pb, Zn, Cu and Pt) formed by replacement of fragmental limestone; the Wantee deposit (Au, Pb, Ag?) which occurs as quartz veins and masses in altered gabbro dykes; minor galena recorded from quartz veins cutting chert within the MacDonald Provisional Goldfield; and the Glen Lyon Prospect (Cu, Ag, minor Pb) in a quartz reef in siliceous siltstone.

Within the Talgai Goldfield on ALLORA, some Sn as well as Au, Cu, Ag mineralisation is recorded from fissure veins with high grade sections along faulted lithological contacts at the Malakoff mine. To the south in the Pikedale Goldfield, Au and Pb mineralisation is reported from quartz veins at the Rocklands deposit at the contact with the Clare Hills Granite.

Base-metal sulphide mineralisation is reported from a limestone body at Grieve's Quarry in the Silverwood area,south of Warwick (Siemon & Huber, 1979).

Potential. The potential for discovery of economic reef-style basemetal deposits style is considered to be very low, although there is some potential for small high-grade skarn-type deposits in the Silverwood area.

EARLY PERMIAN BASINS

Precious/Base Metals

Ag(±Au)-base metal (Cu, Pb, Zn) mineralisation is spatially associated with Early Permian rocks of the Silver Spur and Pikedale beds. However, the Alum Rock Conglomerate, Terrica beds and the Queensland portion of the extensive Early Permian Bondonga beds have no significant mineralisation. The Silver Spur beds is the most intensely studied unit and Ag deposits in the area currently being energetically developed by MACMIN Silver Ltd. at Twin Hills and Mount Gunyan.

A volcanogenic sedimentary origin has been proposed for the major historical deposits within the Silver Spur beds, the Silver Spur and Silver King deposits (Kay, 1975; Pearson, 1976). More recently, Jupp (1998) proposed a modified SEDEX model for the Silver Spur deposit. He recognised three deposit groupings within the Silver Spur beds:

1. stratiform Ag-base metal sulphides (Silver Spur mine),

2. disseminated Ag (+Au, Pb, Zn) (Twin Hills and Mount Gunyan), and

3. vein stockwork Cu/Ag, base metals (Texas Copper, Eggleston's, Silver King and Tooliambi).

Jupp's model involves convective flow of groundwater and leaching of the underlying Texas beds by migrating brines and syn-depositonal concentration into structural sites (for deposit types 1 and 2) along with higher temperature epigenetic mineralisation below the sediment-water interface along shear zones (type 3). The Bundarra Batholith across the border in New South Wales was considered a likely heat source for such convective cells, although the subsurface extension of the Mount Bullaganang Granite is also a possible heat source.

Basement fault structures in the Texas beds would most likely have been important in the channelling of convective fluids and also may have influenced fault patterns in the overlying Permian basin rocks. Reducing carbonaceous shales may be important in controlling the localisation of the Silver Spur-style deposits.

The recently-discovered Twin Hills-style deposits are marked by pervasive potassic-silicic alteration of the host rocks, and an epigenetic origin is favoured by MACMIN. Similar mineralisation models probably apply to the Pikedale deposit which is a stratabound carbonate breccia with no obvious granitic source.

We consider it likely that the Silver Spur–Twin Hills system has a composite syngenetic/epigenetic history involving recrystallisation and remobilisation of the originally SEDEX-style deposits followed by focussing and concentration of mineralisation into structurally and/or chemically favourable sites. The timing of post-Early Permian remobilisation and concentration is purely speculative at this time and may relate to Hunter–Bowen deformation events and/or any of the numerous Permo-Triassic igneous intrusive events.

North-west-trending fault sets are significant in the preservation (and perhaps initiation) of the Silver Spur and Bondonga Basins. Faults of this trend locally compartmentalise mineralisation assemblages, while more northerly trends define zones of alteration around Twin Hills. These two orientations may represent elements of a regional wrench system which may have been active episodically over a considerable period of time, focussing fluids into dilational sites from time of basin closure in the mid-Permian to later during the Hunter–Bowen Orogeny.

In a wrench environment, episodic transcurrent movement along these faults possibly producing north to north-east trending Reidel and P shears linking adjacent shear domains (see Figure 66). These secondary faults linked to primary north-west-trending structures (as well as their intersections) may represent the structural controls for Twin Hills and Mount Gunyan style mineralisation. The timing of these structures is more-than-likely post-megafold, although a similar fault array may have existed during megafold development.

Potential. Unless diagnostic fossils occur, favourable Early Permian host rocks are difficult to distinguish from older Texas beds basement, with shallow dips also occurring in both units in the structurally complex zone in the core of the Texas Megafold. There is thus potential for discovery of deposits in as yet unrecognised Early Permian sediments.

The presence of a large Early Permian intrusive complex at depth beneath these Early Permian basins (whose surface expression is the Mount Bullaganang Granite) would have provided a favourable environment for circulation of mineralising fluids during basin development. SEDEX and volcanogenic-related models therefore need to be fully tested throughout the area of Permian outcrop.

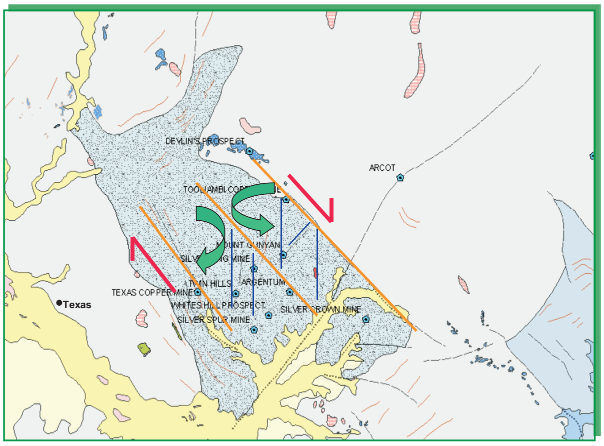

Figure 66. Possible wrench faults (orange) and complementary dilational faults (blue) controlling circulation of mineralising fluids within the Silver Spur beds

As well as syngenetic styles, epigenetic types such as the Twin Hills-style mineralisation deserve exploration attention throughout the region. This style may be found by thorough investigation of anomalous silica and/or potassic alteration throughout the region combined with detailed soil and rock chip geochemistry. The latter is essential as this style of mineralisation is extremely fine-grained and the host rocks are not obviously mineralised.

To the north-east of Twin Hills, the Pikedale beds still have some potential for small, high grade silver-base metal sulphide-rich ore bodies. Only the oxidised ore was extracted by the early miners at the Pikedale Mine.

WALLANGARRA VOLCANICS

The Wallangarra Volcanics have been correlated with the Drake Volcanics (Olgers & others, 1974) and the Emmaville Volcanics (Godden, 1982). The Drake Volcanics host gold, silver and copper mineralisation in veins related to volcanic activity and A-type leucogranites and gold, silver, copper, lead and zinc mineralisation in stratabound deposits genetically related to volcanic activity (Herbert, 1983; Bottomer, 1986). A possibly significant difference is that the Drake Volcanics were deposited, at least partly, in a marine environment (Perkins, 1988). The Emmaville Volcanics host tin mineralisation in widespread vein stockworks (Wood, 1982).

The only mineralisation known to occur within the Wallangarra Volcanics is minor disseminated arsenopyrite. Ruby Creek Granite does crop out in the vicinity of the volcanics, particularly along the eastern margin.

Potential. Little exploration has been carried out over the volcanics, which form rugged topography with difficult access. The Wallangarra Volcanics may be prospective for tin mineralisation and possibly also for volcanic-related gold and silver. Cupolas of Ruby Creek Granite beneath thin cover of the volcanics may have potential for the development of massive greisen systems with low-grade disseminated cassiterite.

ALLUVIUM/ELUVIUM

Alluvial tin deposits have been formed in drainage systems and resultant deposits successively developed through geological time over the area of the Stanthorpe and Ruby Creek Granites.

Potential. Krosch (1985) noted that several areas still possess potential to support viable alluvial tin mining. Swampy areas which were often too wet for early mining methods probably offer the best prospects. As well, it has been shown that the tailings of old workings can be retreated profitably by modern, efficient methods, especially if mined in conjunction with some high-grade patches of virgin ground.

Palaeogravel systems offer very good prospects for new discoveries. These systems were generally mined in the past only where they are cut by recent stream channels. Detailed surface mapping and geomorphological interpretation are required to delineate the locations and extent of palaeodrainage systems.

Stanthorpe Tin has postulated that the palaeogravels are basal sheetwash deposits of the Marburg Formation. If this is so, the basal gravelly units of the Marburg Formation north of Dalveen may have potential for undiscovered tin deposits.

Eluvial deposits are developed in areas of known vein mineralisation. Generally, the depth of weathering is not sufficient for development of extensive deposits. Areas such as Lode Hill–Lode Creek, where combinations of eluvial, alluvial and palaeogravels exist, offer good potential for economic deposits.

However, there are major impediments to delineation and mining of alluvial deposits in the Stanthorpe area, including extensive past reworking of ground, high density of agricultural development, presence of large quarantined areas such as national parks, the prevalence of Mineral Freehold titles in the area, and the prevailing low tin price.

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APPENDIX 1

DETAILED DESCRIPTIONS OF SELECTED UNITS, NORTHERN NEW ENGLAND BATHOLITH

DETAILED DESCRIPTIONS OF SELECTED UNITS, NORTHERN NEW ENGLAND BATHOLITH

Ballandean Granite (Pgba; new name)

The *Ballandean Granite* (~60km^2) crops out as sparse, scattered boulders and pavements, and rare whalebacks, south and south-west of Ballandean. The unit was previously mapped as part of the Stanthorpe Granite. The proposed type locality is beside Lynams Road, around MGA 382406 6812031. The unit, at this locality, forms large boulders (disturbed during roadworks) on the southern side of Pigsty Creek, as well as numerous pavements and boulders in the paddock northeast of the road.

The Ballandean Granite was emplaced in the late Permian–early Triassic. It cuts the Texas beds, the Wallangarra Volcanics (late Permian), and Dundee Rhyodacite (late Permian). Scattered pendants of Wallangarra Volcanics (lower unit) are common in the Ballandean Granite south-west of Loughmore homestead (Purdy, 2003). The unit pre-dates the Stanthorpe and Ruby Creek Granites, and probably also the Sailor Jack Granite (contact not found). The Stanthorpe Granite displays a well-developed quenched texture and contains inclusions of hornblende-biotite granite south-east of Ballandean (Days Road area), adjacent to the contact with the Ballandean Granite (*e.g.* at MGA 388277 6811369).

The Ballandean Granite is cut by a thin dyke of Stanthorpe Granite at MGA 388119 6811972 (gutter on northern side of Jacobsen Road; Figure 67), by dykes (up to ~5m thick) of fine–medium-grained biotite leucogranite of the Ruby Creek Granite; (*e.g.* at MGA 383660 6812488, MGA 380220 6811617), as well as by scarce dykes (up to ~10m thick) of porphyritic rhyolite (*e.g.* at MGA 381648 6811559). In addition, the unit is cut by a relatively extensive and thick, north-easterly trending dyke of dark grey, fine-grained, highly porphyritic hornblende diorite (unit Rgd; Purdy, 2003), containing numerous plagioclase and brown hornblende phenocrysts. The Ballandean Granite at these localities, (as well as elsewhere), is cut by numerous thin chloritic shear zones.

Biotite flakes and, to a lesser extent, hornblende grains in Ballandean Granite exposed adjacent to the contact with the Stanthorpe Granite, at MGA 383448 6812112, are extensively recrystallised, probably as a result of hornfelsing by the adjacent younger granite. The hornblende aggregates show triple-point junctions between grains in places. Boulders of Stanthorpe Granite on the eastern side of Days Road (at MGA 388277 6811369, adjacent to the mapped contact with the Ballandean Granite) contain inclusions, up to ~20cm across, of Ballandean Granite (Figure 68). The inclusions contain scattered hornblende laths, and are characterised by relatively low magnetic susceptibilities (<50 x 10^{-5} SI units)

Figure 67. Contact between Stanthorpe Granite (pale coloured zone in lower half of photo) and more mafic Ballandean Granite (dark coloured zone in upper part of photo), northern side of Jacobsens Road (MGA 388119 6811972), ~2.5km south-east of Ballandean. Note the fine-grained (aphlitic?) margin to the Stanthorpe Granite (*cf.* Figure 68).

Figure 68. Large, elongate inclusion of Ballandean Granite (to left of lens cap) in subunit $Rgst_a$ (Stanthorpe complex), eastern side of Days Road (MGA 388277 6811369). Compare the diffuse, irregular nature of the contacts with the sharp contacts depicted in Figure 67.

compared to the enclosing Stanthorpe Granite (>500 x 10^{-5} SI units). Another noteworthy feature is the diffuse character of the contacts between some of the inclusions and enclosing granite, implying the Ballandean Granite may not be significantly older than the enclosing Stanthorpe (subunit $Rg2t_a$) Granite at this locality.

The Ballandean Granite ranges in modal composition from quartz monzonite to granodiorite, monzogranite being the dominant rock type. It is characterised by a fine- to medium-grained groundmass and is variably porphyritic. K-feldspar forms prominent phenocrysts up to ~4cm long in the more felsic monzogranites (and also in the quartz monzonite), whereas it forms interstitial groundmass grains in the sample of relatively mafic granodiorite. A few K-feldspar phenocrysts have narrow rims of sodic plagioclase (*e.g.* at MGA 385206 6812588, MGA 385606 6812688). Quartz phenocrysts and scarce granophyric intergrowths between groundmass quartz and K-feldspar are also present in some of the monzogranites and the granodiorite. Biotite and hornblende (up to ~15%) are significantly more abundant than in the Stanthorpe Granite.

Plagioclase phenocrysts are common in the relatively mafic rocks, which have hornblende as the main mafic mineral. Granodiorite at MGA 387406 6812388 also contains traces of clinopyroxene as relict cores in hornblende grains. Biotite is the dominant mafic mineral in the more felsic rocks. Accessory and secondary minerals include allanite (rare), apatite, zircon, opaques, actinolite, muscovite, sericite, chlorite, and epidote. Sparse mafic inclusions, up to ~30cm across (most <10cm), are also generally present.

The unit is moderately reduced to moderately oxidised (using the chemical classification scheme of Blevin, 2004; Figure 36). K-feldspar grains are white rather than pink in the majority of samples examined, and titanite has not been detected. Furthermore, biotite grains in some thin sections display bright reddish brown (‘fox-red’) to pale yellowish brown (‘straw’) pleochroism, similar to that displayed by biotites in reduced granites. Magnetic susceptibility readings are also generally low (average of <50 x 10^{-5} SI units for 11 of 13 sample sites). Average values of 238 and 711 x 10^{-5} SI units were obtained from two sites in the eastern part of the unit (at MGA 386731 6810515 and 388278 6807550, respectively).

Very pale pink K-feldspar phenocrysts have been recorded in a few places (*e.g.* at MGA 386706 6810488, MGA 385206 6812588, MGA 385606 6812688).

The unit is commonly slightly to moderately altered, and locally deformed (with curved biotite flakes and subgrain development in quartz grains). Thin chlorite-rich shear zones are abundant in places.

Bungulla Monzogranite (PRgbu)

A small, poorly exposed, elongate intrusion (~18km^2) of *Bungulla Monzogranite* (Bungulla Porphyritic Adamellite of Shaw, 1969; Robertson, 1974; Olgers, 1974; Olgers & others, 1974) extends north and south of Wallangarra, on the Queensland–New South Wales border. Olgers & others (1974) noted that the Bungulla Monzogranite and Undercliffe Falls Adamellite (now Undercliffe Falls Monzogranite) are very similar, based on outcrop, textural, and mineralogical characteristics. Thomson (1976) included the Bungulla Monzogranite in the Undercliffe Falls Adamellite because the latter name has priority (Phillips, 1968).

A sample collected from near the southern margin (MGA 396106 6796988) of the pluton is relatively mafic (~15% mafic minerals and ~66% SiO_2). It is characterised by the presence of euhedral, pale pink K-feldspar (microperthite) phenocrysts up to ~10cm long, smaller (to ~5cm) plagioclase phenocrysts, hornblende laths to ~3cm in length, and abundant coarse titanite in a fine to medium-grained groundmass. Hornblende is only slightly less abundant than biotite. Many of the K-feldspar phenocrysts have mantles of sodic plagioclase (rapakivi texture). Relatively coarse, euhedral apatite grains are locally abundant, mainly as inclusions in plagioclase, hornblende and biotite phenocrysts. Zircon is scarce — much scarcer than in most samples of Stanthorpe Granite. Biotite-rich schlieren are locally present, and the rocks contain sparse mafic enclaves up to ~3cm across.

In contrast, rocks mapped as part of the same unit from the northern outskirts (MGA 396041 6800932) of Wallangarra are significantly more felsic (~5% mafic minerals and ~73% SiO_2). Feldspar phenocrysts are not as common and tend to be smaller, hornblende is rare (mainly as small inclusions in plagioclase phenocrysts), titanite is relatively scarce, and the groundmass contains abundant pale pink K-feldspar (commonly forming granophyric intergrowths with quartz). Robertson (1974) noted that the pink K-feldspar phenocrysts tend to be aligned in a north-north-westerly direction throughout most of the pluton — the main exceptions being in zones adjacent to intrusive contacts where the phenocrysts are aligned parallel to the contacts.

The unit is strongly oxidised (using the classification scheme of Blevin, 2004), consistent with the presence of pink K-feldspar and titanite, and contrasts markedly with the nearby, more reduced Ballandean Granite.

The Bungulla Monzogranite is intruded by the Stanthorpe and Ruby Creek Granites, and was most probably emplaced in the late Permian–early Triassic. The unit is also cut by a small pod or lens (too small to be delineated as a separate unit) of fine to medium-grained, aplitic muscovite–biotite leucogranite south of Wallangarra (at MGA 396095 6797056). The leucogranite is mineralogically and chemically distinct from the Ruby Creek Granite, despite similarities in the field. Much of the biotite and muscovite appears to be secondary — the micas commonly show radial extinction and/or form aggregates of small flakes. Despite its felsic character (SiO_2 >76%) the leucogranite has not undergone extensive feldspar fractionation (*e.g.* Rb = 209ppm), unlike the leucogranites of the Ruby Creek Granite. The presence of minor (but relatively abundant for such a felsic rock) brown-pinkish brown titanite, as well as traces of altered allanite and rare interstitial grains of green hornblende, are noteworthy features. Titanite and hornblende were not detected in the samples of Ruby Creek Granite examined in detail during the recent survey.

Ruby Creek Granite (Rgru)

The *Ruby Creek Granite* (the 'Sandy Granite' of Saint-Smith, 1914a, page 31; total area ~225km^2) was first described in the Liston area, east of Stanthorpe (Andrews, 1905; Saint-Smith, 1914a). The unit forms a relatively large, elongate, irregular, north-west-trending pluton, which extends from the Eukey–Wilsons Downfall area (in the south-east) to the Mount Magnus area (in the north-west). The roof of the pluton is irregularly exposed north-west of Stanthorpe, in the Applethorpe–Bullecourt area (also see Denaro & Burrows, 1992). A much smaller belt of scattered stocks extends from east and south-east of Wallangarra to the Sundown area. Elsewhere, a texturally diverse range of leucogranites forming dykes, pods, and several small stocks has been assigned to the Ruby Creek Granite. The unit is cut by a set of prominent north-north-east-trending vertical joints.

The main intrusion forms undulating to low hilly country, with numerous boulders, tors, and extensive pavements in places (*e.g.* east of Stanthorpe), as well as gently undulating to flat country with extensive soil development and sparse outcrop (*e.g.* in the Applethorpe area). It is characterised by mainly white tones on 'standard' ternary (RGB) radiometric images (Figure 38a), but is distinguished from the enclosing Stanthorpe Granite by relatively low, uniform (flat) magnetic intensities (Figure 40).

Figure 69. Contact between porphyritic Stanthorpe Granite (left hand side) and more even grained, finer grained Ruby Creek Granite (right hand side; *cf.* Figure 71). Western side of Cannon Creek Road (MGA 388542 6837786).

Figure 70. Contact between porphyritic Stanthorpe Granite (bottom half of photograph) and even grained, finer grained Ruby Creek Granite (top half of photograph). Large sloping pavement ~35km south-west of Amiens (MGA 380772 6834685). Note the thin irregular pegmatitic zone at the contact.

Figure 71. Contact zone between porphyritic Stanthorpe Granite (left hand side) and more even grained, finer grained Ruby Creek Granite (right hand side). The two rock types are separated by an irregular, vuggy pegmatite lens in this boulder. Western side of Cannon Creek Road (MGA 388542 6837786).

Contacts between the Ruby Creek Granite and Texas beds are generally sharp. Diffuse boundaries and highly irregular margins have been reported in small pods of the granite west-north-west of Ballandean (Robertson, 1974). The Ruby Creek Granite extensively intrudes the Stanthorpe Granite (Stanthorpe complex) with which it has a close spatial and genetic relationship. Dykes of Ruby Creek Granite are also very common in the Stanthorpe Granite (Figures 44, 58a,b). Contacts between the two granite types are almost invariably abrupt (Figures 69, 70). Locally, the contacts range from slightly (*e.g.* at MGA 386721 6834685) to highly (*e.g.* in the bed of Quart Pot Creek near the railway bridge, Saint-Smith, 1913, figure 3) irregular, and are marked in places by the presence of irregular, vuggy pegmatite zones up to ~30cm thick (*e.g.* at MGA 380772 6834685; Figures 70, 71). Scarce pods of relatively fine-grained leucogranite mapped as Ruby Creek Granite also intrude the Ballandean Granite, Bungulla Monzogranite, and the Maryland River complex of the Stanthorpe Granite.

The designated type specimen is from an outcrop adjacent to the Stanthorpe–Amosfield road near Ruby Creek (Phillips, 1969). Some of the most accessible outcrops in this area are beside the Stanthorpe to Amosfield road between MGA 404106 6831988 and MGA 405706 6830988 (Thomson, 1976), the logical locality to designate as the type area. Outcrops on the eastern side of the bridge over Ruby Creek comprise pale pink to pale brown, medium to fine-grained (average grainsize ~2mm), somewhat uneven-grained leucocratic biotite monzogranite, consisting mainly of quartz, plagioclase (oligoclase; Phillips, 1969) and pale pink K-feldspar.

The relatively coarse grainsize of the granite in this area is noteworthy, being comparable to or coarser than that displayed by some outcrops of Stanthorpe Granite. Granophyric intergrowths between quartz and K-feldspar are locally common. Minor and accessory minerals include biotite (~2%), apatite, zircon, muscovite, cassiterite and xenotime (P.L. Blevin, PetroChem Consultants, personal communication, November 2002). Y increases in I-type magmas that have evolved by extended fractional crystallisation resulting in the precipitation of accessory xenotime. Cassiterite concentrates mined from Ruby Creek and adjacent watercourses draining the unit were characterised by the absence of significant amounts of ilmenite or other dark accessory minerals (mainly wolframite; Skertchly, 1898; Saint-Smith, 1913). Grainsize is reported to decrease significantly towards the margins of the pluton in this area (Saint-Smith, 1914a; Phillips, 1968, 1969; Robertson, 1974; Thomson, 1976).

Elsewhere, the leucogranites are mainly pink to white or pale to medium grey. Grainsize ranges from fine to medium, the marginal zones being significantly finer grained than the adjacent Stanthorpe Granite, and also finer grained than the central parts of the larger intrusions of Ruby Creek Granite. Textures range from equigranular to porphyritic. Grainsize increases to ~2mm towards the centre of the main pluton and the rocks become more even grained. Robertson (1974), Thomson (1976), Denaro & Burrows (1992), and Sivell & Passmore (1999a) reported that a marginal zone up to 300m wide of fine-grained, slightly porphyritic, aplitic leucogranite is commonly present, and that dykes of this aplitic phase extend into the adjacent country rocks. Sivell & Passmore (1999a) interpreted small ‘pods’ of compositionally and texturally identical leucogranite exposed several kilometres from the contact with the Stanthorpe Granite (*e.g.* east of Old Maryland Lane) to represent inliers of the quenched roof zone of the pluton.

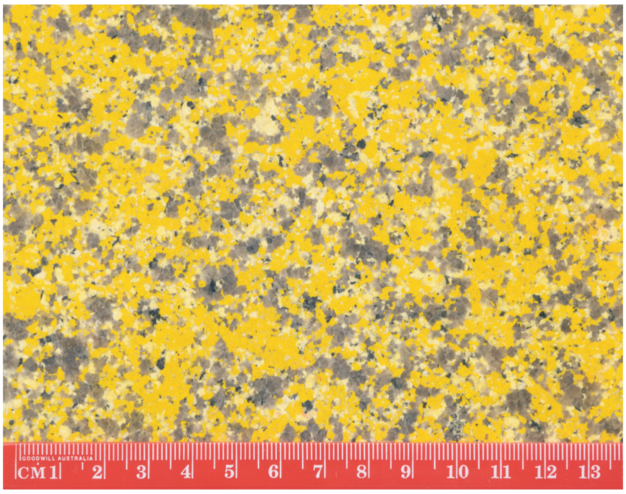

Figure 72. Stained slab (K-feldspar grains stained yellow) of Ruby Creek Granite? (Whiskey Gully quarry; MGA 394329 6826612). Note the relatively uniform grainsize, the abundance of K-feldspar, and the grey colour of the quartz grains.

A north-westerly trending belt of syenogranite (Figure 72) south of Stanthorpe has also been tentatively included in the unit. The syenogranite is very well exposed in a large abandoned quarry (at MGA 394329 6826612) on the eastern side of the New England Highway, ~4.5km south-south-west of Stanthorpe. It is leucocratic (biotite <~3%, SiO_2>76%) medium to fine-grained (average grainsize ~2mm), and uneven-grained to slightly porphyritic. Miarolitic cavities (some relatively large) and fluorite are relatively common. The leucogranite is not typical of that mapped as Stanthorpe Granite and is similar petrographically and chemically to the granite exposed in the Ruby Creek area. It is cut in several places by dykes, up to ~30cm thick, of fine-grained aplitic biotite leucogranite and pegmatite (*e.g.* at MGA 395951 6824719, MGA 398221 6819312).

The contact between the Ruby Creek and Stanthorpe Granites is exposed at MGA 391251 6833975 in the Applethorpe area. Both units consist of biotite leucogranite, but the Ruby Creek Granite is significantly finer grained (average grainsize ~0.5mm) than the Stanthorpe Granite (average grainsize ~2mm), and it contains less biotite (~1% or less). Similar fine-grained biotite leucogranite containing scattered small phenocrysts of quartz and plagioclase and traces of muscovite and fluorite crops out in the Donnellys Castle area (*e.g.* at MGA 391338 6839373), adjacent to the mapped contact (not exposed) with the Stanthorpe Granite (subunit $Rgst_c$). The leucogranite at MGA 391338 6839373 is more evolved (*e.g.* SiO_2 = 76.8%, Rb = 365ppm, Y = 93ppm, K/Rb = 101) than the nearby coarser grained Stanthorpe Granite sampled at MGA 390702 6838407 (SiO_2 = 75.2%, Rb = 296ppm, Y = 64ppm, K/Rb = 125).

Intrusive contacts between phases of Ruby Creek Granite have also been found, consistent with the interpretation that this unit, like the Stanthorpe Granite, was emplaced as several magma pulses from one or more deeper level magma chambers.

Most rocks are either K-feldspar rich monzogranites or syenogranites. Modal analyses listed by Phillips (1968, 1969), and Thomson (1976) plot in the monzogranite field. Sivell & Passmore (1999a,b) reported the main intrusion south of Maryland station to consist of alkali feldspar granite. Aplitic leucogranite forming the marginal zone of an irregular stock ~11km north-west of Ballandean is a syenogranite (Robertson, 1974; Olgers & others, 1974).

Modal biotite contents are generally <~3%. Hornblende and titanite have not been detected in the leucogranites examined during the recent survey. Accessory and secondary minerals include fluorite, zircon, allanite, apatite, muscovite, monazite, chlorite, carbonate, cassiterite, xenotime, pyrite, molybdenite, chalcopyrite, wolframite, and arsenopyrite. Grains of molybdenite and pyrite, in particular, are locally disseminated throughout the rocks; however, there is generally little macroscopic evidence of hydrothermal alteration. Quartz phenocrysts and relatively coarse quartz grains lining and filling miarolitic cavities and pegmatite lenses are commonly dark grey to black (smoky).

One of the most noteworthy characteristics of the Ruby Creek Granite is the widespread distribution of miarolitic cavities up to ~5cm across and, to a lesser extent, vuggy pegmatite lenses. The cavities are commonly filled or partly filled with coarse quartz (commonly smoky) and K-feldspar ± minor biotite ± minor molybdenite ± minor fluorite, commonly yielding a two-domain texture comprising a relatively coarse (pegmatitic) anastomosing and externally nucleated domain enclosing internally nucleated domains (terminology of Blevin & Chappell, 1996). This was termed an ‘interconnected miarolitic texture’ by Candela & Blevin (1995, page 2310), who interpreted it as evidence for permeability of the magmatic volatile phase during crystallisation. The silicate phases are commonly associated with sulphide minerals (mainly pyrite and molybdenite). Some intrusions contain significant mineralisation (mainly molybdenite — *e.g.* the Moly King prospect at MGA 396286 6803788, ~4km north-north-east of Wallangarra; Denaro & Burrows, 1992).

Fluorite-bearing, slightly porphyritic leucogranite forming an extensive pavement on the southern bank of the Severn River at MGA 378047 6814905 is characterised by the presence of numerous miarolitic cavities up to 10cm across (most <5cm). In addition, ovoid–circular pipes or pods of pegmatite, 0.2–10m in diameter, are scattered throughout the granite. The pegmatites contain euhedral quartz crystals up to ~25cm across (Figure 73), as well as minor wolframite (Denaro & Burrows, 1992).


Figure 73. Irregular, quartz-rich pegmatite pipe or pod in Ruby Creek Granite, southern bank of Severn River. MGA 378047 6814905.


Figure 74. Roof zone of Ruby Creek Granite forming high cliffs, Red Rock Falls area, Sundown National Park. The timbered country above the cliffs is formed of hornfelsed Texas beds (‘trap rock’). The narrow valley on the left hand side of the photograph is drained by Red Rock Creek.

A small stock of Ruby Creek Granite has been mapped in Sundown National Park (Red Rock Creek area) to the west of the main granite belt (Saint-Smith, 1914a; Robertson, 1974; Olgers, 1974). The roof zone of the pluton is well exposed beneath a capping of hornfelsed Texas beds (‘trap rock’) in the Red Rock Falls–Carpenters Gully area (Figure 74). The leucogranite is miarolitic, and cut by numerous thin quartz veins (Figure 75), commonly bearing cassiterite and wolframite. Thin dyke-like greisen zones are present locally (Saint-Smith, 1914a; Denaro & Burrows, 1992). Fine to medium-grained aplitic leucogranite is exposed over a vertical distance of ~250–300m in Red Rock Creek (from above Red Rock Falls to the contact with the Texas beds downstream of the falls). About 255m of aplitic leucogranite were intersected in inclined (nominally 70° towards 125°) hole, SSD10, drilled in the Discovery Creek area to the south (Wegmann & Sceney, 1983). The hole was spudded in Texas beds and bottomed in leucogranite.

The upper 5m or so of the granite exposed in the area around the site of the abandoned Wasem mine (~MGA 372654 6807860, Carpenters Gully area) has

Figure 75. Thin, vuggy quartz veins cutting altered, aplitic granite (Ruby Creek Granite), southern bank of Severn River. MGA 378048 6814660.

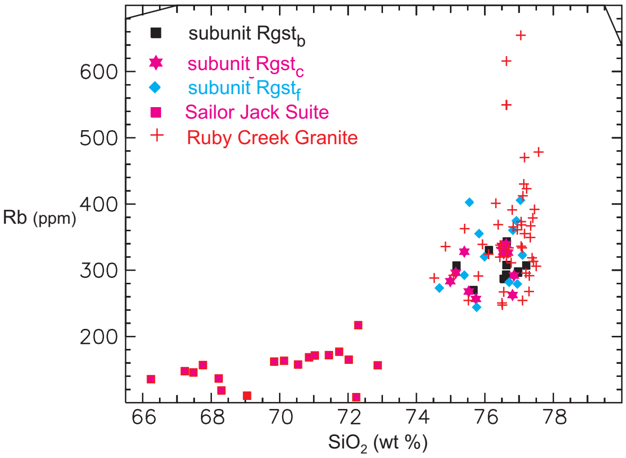

Figure 76. Rb versus SiO_2 plot for selected intrusives of the Stanthorpe Supersuite. The granites define a curvilinear, fractional crystallisation trend of increasing Rb with increasing SiO_2 to ~76.5% SiO_2, beyond which Rb increases with little change in SiO_2 content. Note the compositional overlap between the Ruby Creek Granite and felsic subunits Rgst$_b$, Rgst$_c$, and Rgst$_f$ of the Stanthorpe Granite, with the Ruby Creek Granite extending the trend to significantly higher Rb values (*i.e.* to more highly fractionated compositions). The 'compositional gap' between the Sailor Jack Suite and more felsic units is filled by granites of subunit Rgst$_a$ (*e.g.* see Figure 81).

been intensely silicified. The altered granite contains abundant molybdenite and minor wolframite. Elsewhere, apparently little-altered leucogranite commonly contains minor disseminated molybdenite that was deposited relatively late, mainly in interstices between silicate minerals and in miarolitic cavities. Small 'slugs' of molybdenite, up to ~2.5cm across, for example, have been found in miarolitic leucogranite exposed in the upper reaches of Red Rock Creek. The Ruby Creek Granite is also locally cut by thin (<1cm thick) molybdenite-bearing quartz veins (*e.g.* at MGA 409856 6827176).

Saint-Smith (1914a) described the presence of a ~25cm thick aplo-pegmatite zone at the contact between the granite and country rocks in Red Rock Creek. He reported quartz grains up to ~15cm long and K-feldspar grains up to ~3cm in length, as well as minor biotite, muscovite, and tourmaline in the pegmatite.

The Ruby Creek Granite shows extensive overlap chemically with the felsic parts (mainly subunits Rgst$_b$, Rgst$_c$, and Rgst$_f$) of the Stanthorpe Granite (*e.g.* Figure 76). However, the Ruby Creek Granite also contains the most highly fractionated rocks in the complex, defined, for example, by anomalously high Rb contents (Figure 76).

Sailor Jack Granite (Rgsj; new name)

The Sailor Jack Granite (~30km^2) forms an elongate, curvilinear, north-westerly to north-easterly-trending pluton, which extends from near the Bruxner Highway in New South Wales north to the vicinity of Leran homestead. The unit forms prominent outcrops on Sailor Jack station, which abuts the New South Wales–Queensland border, west of Wallangarra. The roof/contact zone of the pluton is well exposed in hill slopes (*e.g.* at MGA 379891 6796872) beneath cappings of hornfelsed Texas beds, north of Sailor Jack Mountain (MGA 378906 6794888, at the south-western end of Roberts Range). The granite also forms numerous pavements and tors in the valley west of Roberts Range. Farther south (between the Bruxner Highway and Limestone Creek) the topography is more subdued and the unit forms low undulating country with scattered boulders and pavements. The designated type area is around MGA 379891 6796872, on Sailor Jack station. The granite forms an extensive sloping pavement in the hill slope at this locality, beneath a capping of hornfelsed Texas beds.

The Sailor Jack Granite intrudes the Texas beds and the Wallangarra Volcanics (lower unit). It is also interpreted to post-date unit PRo, and the Ballandean Granite, although intrusive contacts have not been found. The unit was most probably emplaced in the late Permian or early Triassic.

The Sailor Jack Granite is grey, pinkish grey or pale pink to pink, fine to medium grained, and moderately to highly porphyritic. It ranges in modal composition from clinopyroxene-biotite-hornblende granodiorite with ~20% mafic minerals to hornblende-biotite monzogranite containing ~5% mafic minerals. Pink to white (locally) K-feldspar phenocrysts, up to ~3cm long, are common. In addition, most rocks contain subordinate and smaller plagioclase (up to ~1cm), quartz (to ~5mm), biotite (to ~1.5mm), and hornblende (to ~4mm) phenocrysts. Clinopyroxene, mainly as cores in hornblende grains but also as discrete groundmass grains, is relatively common in the mafic granodiorite (from MGA 377606 6792088), but was not detected in the other samples examined. Hornblende is the dominant mafic mineral in the more mafic rocks, biotite in the more felsic rocks. Titanite (primary), allanite (generally fresh), apatite, zircon, and opaques are common accessory minerals. Epidote, chlorite, calcite, and sericite are the main secondary minerals, but are generally present in only minor amounts. Granophyric intergrowths between quartz and K-feldspar are common in a few samples (*e.g.* those from MGA 377906 6790988, MGA 377606 6792088). The unit also contains scattered mafic enclaves up to ~3cm across, as well as larger (up to ~30cm) inclusions of country rocks.

Samples collected from adjacent to the contact with the Texas beds (at MGA 379111 6798997) and unit PRo (at MGA 379407 6787769) show evidence of deformation, implying the contacts at these localities are faulted. Quartz and biotite grains are characterised by undulose extinction and some biotite flakes are bent or kinked.

The unit is distinguished from the nearby Stanthorpe Granite by:

1. a significantly finer grained groundmass (average grainsize in the northern part of the pluton is ~0.2–0.3mm, and is only slightly coarser in the southern part) probably caused by rapid crystallisation during quenching in the marginal zone of the pluton,

2. a relative abundance (~5–20%) of mafic minerals, and the presence of hornblende in all samples examined in detail,

3. a relative scarcity of zircon grains,

4. the absence of fluorite, smoky quartz, miarolitic cavities and pegmatitic zones in all outcrops examined,

5. the absence of dykes and pods of Ruby Creek Granite, and

6. the lack of any known mineralisation.

The Sailor Jack Granite is a strongly oxidised to moderately reduced (using the classification scheme of Blevin, 2004), high-K, I-type (see Figures 27, 36). The variable oxidation state is also reflected in magnetic susceptibilities measured at 10 sites within the unit. Averaged values recorded range from 3 to 1201 x10^{-5} SI units (at least 13 measurements were made at each site, with >20 recorded at 7 sites; 3 sites recorded a range of 3 to 14 x10^{-5} SI units, 4 sites a range of 229 to 684 x10^{-5} SI units, and the remaining 3 a range of 842 to 1201 x10^{-5} SI units). Four samples collected from the unit (three from the southern part and one from farther north) have slightly lower CaO (Figure 77) and FeO* contents and somewhat higher Ba (Figure 52) and Na_2O + K_2O abundances compared to the remaining samples analysed from the unit.

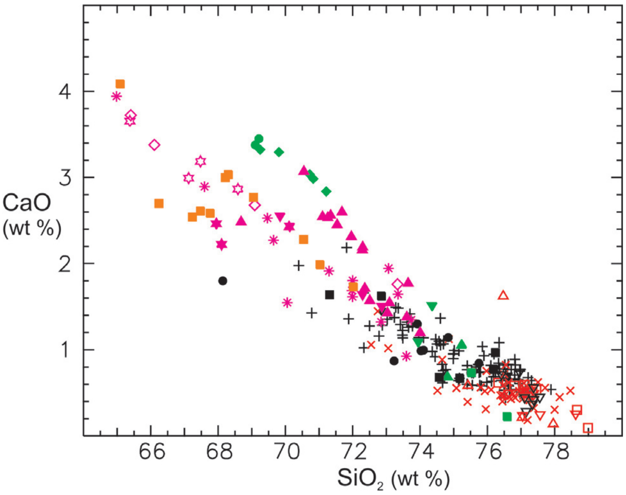

Figure 77. CaO versus SiO_2 plot for selected intrusives of the northern New England Batholith, highlighting the relatively CaO-rich character of the Greymare Granodiorite, Maryland Granite, and some other Herries Supersuite granites. Most map units show extended compositional ranges, consistent with the presence of zoned plutons and/or several discrete intrusions. Symbols as in Figure 27.

Stanthorpe Granite (Stanthorpe complex)

The *Stanthorpe Granite* (Saint-Smith, 1914a, page 39) is by far the most extensive plutonic unit in the region. The unit, as currently mapped, forms two large intrusive complexes: one more or less centred on Stanthorpe (Stanthorpe complex), and the other (Maryland River complex) east of a ‘screen’ formed of older sedimentary, volcanic, and mafic igneous rocks, Undercliffe Falls Monzogranite, and Maryland Granite. Phillips (1968) recognised three variants of the Stanthorpe Granite in the Liston–Amosfield area (Drake 1:100 000 Sheet area), but noted that they were not readily divisible into mappable units. Robertson (1974; *in* Olgers & others, 1974) described a fourth textural variety, best developed beside the Stanthorpe–Nundubbermere road, ~1km north of Nundubbermere homestead. Thomson (1976) delineated four phases in the Drake 1:100 000 Sheet area. She noted that complex relationships made it impossible to map the extent of each phase accurately. She also reported that contacts between the various phases are difficult to find, and where found difficult to interpret; many appeared to be gradational. The presence of internal contacts, as well as its areal extent, led Blevin & Chappell (1996) to conclude that the Stanthorpe

Granite was emplaced as several pulses of magma. The presence of quenched zones in places (*e.g.* at MGA 385644 6830417, MGA 381566 6833250, MGA 388231 6811027) is consistent with such an interpretation.

The Stanthorpe Granite is typically medium-grained (groundmass), porphyritic, and leucocratic. K-feldspar (microperthite) is generally more abundant than plagioclase, the rocks ranging in composition from monzogranite to syenogranite. Modal analyses listed by Phillips (1968, 1969), Shaw (1969), and Thomson (1976) plot in the monzogranite field on a Quartz-K-feldspar-Plagioclase plot (classification scheme of le Maitre, 2002). The samples are from the eastern part of the complex, where relatively mafic compositions (with up to ~10% biotite, minor hornblende and titanite, and plagioclase more abundant than K-feldspar) are comparatively common. K-feldspar grains are generally pink, although in some phases/zones the K-feldspar is white to pale brown (*e.g.* in subunit $Rgst_d$, and in parts of subunits $Rgst_a$ and $Rgst_b$), implying both oxidised and reduced zones are present in the unit. K-feldspar phenocrysts commonly have sodic plagioclase rims (rapakivi texture), and locally show a preferred orientation. Biotite is the main mafic mineral, but is generally present in only minor amounts (<~6%). Minor hornblende is present in more mafic variants where it has two modes of occurrence:

1. as small inclusions in plagioclase phenocrysts, and
2. as scattered euhedral to subhedral grains in the groundmass.

Parts of the unit contain dark grey to almost black quartz grains, reflecting radiation damage from anomalously high concentrations of radioactive elements.

The most common accessory minerals (not all present in every sample) are zircon (commonly as relatively coarse, zoned, euhedral grains), opaques, fluorite, monazite, allanite, titanite, apatite/fluor-apatite (Phillips, 1968), and muscovite. Allanite forms euhedral, zoned grains, most of which are unaltered. Primary titanite decreases markedly in abundance with increasing SiO_2 content, and is absent from the highly felsic rocks. Traces of fluorite are present in most of the rocks examined from the unit. The fluorite crystallised relatively late and is found in interstices, in miarolitic cavities, and associated with altered biotite. Mafic enclaves are absent or rare in most outcrops and, where present, are generally less than 10cm across. However, 'dioritic' inclusions ranging up to ~15m across have been found at a few localities (Figure 78).

Notwithstanding the widespread distribution of pink K-feldspar in the unit, many outcrops have relatively low (<~50 x 10^{-5} SI units) magnetic susceptibilities, indicating a general scarcity of highly magnetic minerals (mainly magnetite). Magnetic susceptibilities measured at 78 sites out of a total of 206 recorded averaged readings of 2100 x 10^{-5} SI units (>20 readings generally taken at each site). Averaged readings at the 206 sites range from 0 to 1777 x 10^{-5} SI units.

Figure 78. Large 'dioritic' inclusion in subunit $Rgst_b$ (Stanthorpe complex, MGA 400825 6810593), Girraween National Park.

Although leucogranite is the dominant rock type in the Stanthorpe Granite, more mafic granites with up to ~15% mafic minerals and plagioclase > K-feldspar are also represented (also see Thomson, 1976). Granite sampled by Purdy (2003) adjacent to the contact with the Wallangarra Volcanics in the Bald Mountain area (at MGA 394415 6803773), for example, is significantly finer grained and more mafics-rich than nearby granite (subunit $Rgst_b$) forming massive outcrops in Girraween National Park. This mafic variant is fine to medium grained, only slightly porphyritic (with phenocrysts of mainly plagioclase) and contains ~10% mafic minerals (biotite > hornblende). Plagioclase is more abundant than K-feldspar, and minor titanite is present. In contrast, nearby granite of subunit $Rgst_b$ is highly and coarsely porphyritic (in K-feldspar), and contains <~3% biotite (hornblende and titanite absent) and greater amounts of K-feldspar than plagioclase. The relationship between this relatively mafic variant (part of subunit $Rgst_a$) and the coarse-grained felsic granite of subunit $Rgst_b$ has not been established.

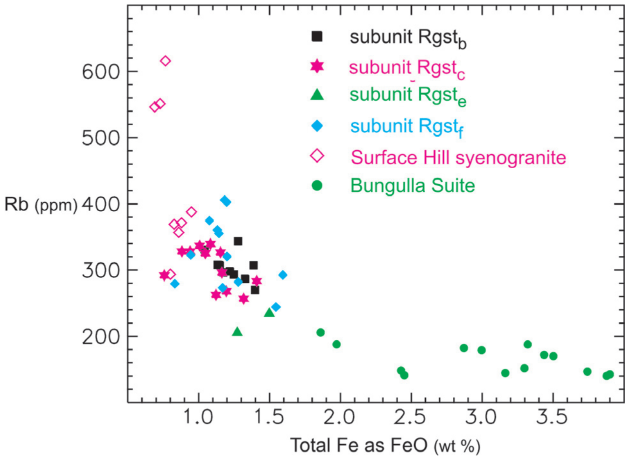

Figure 79. Rb versus FeO* plot for subunits Rgst$_b$, Rgst$_c$, Rgst$_e$, and Rgst$_f$ of the Stanthorpe Granite, granites of the Bungulla Suite, and the Surface Hill syenogranite (Timbarra Tableland, Grafton 1:250 000 Sheet area; Mustard, 2004). Note the curvilinear trend of increasing Rb to highly fractionated compositions with decreasing FeO* (*i.e.* increasing SiO$_2$), and the relatively small fields defined by subunits Rgst$_b$, Rgst$_c$, Rgst$_e$, and Rgst$_f$ (*cf.* subunit Rgst$_a$ in Figure 81).

Another mafic granite crops out in the area around MGA 420232 6818965, where the granite (part of subunit Rgst$_2$) forms extensive pavements in the bed of the Boonoo Boonoo River. There, the granite contains ~10% biotite + hornblende, relatively abundant and coarse titanite, numerous pale pink K-feldspar phenocrysts (up to ~3cm long), traces of allanite and fluorite, and scattered mafic (microdioritic; up to ~40cm across) and granitic (to ~1m across) inclusions. The granite also contains rare elongate inclusions of granitic gneiss (to ~10cm in length).

Detailed mapping (1:10 000 scale) by Sivell & Passmore (1999a) of a small area south-east of Maryland station also revealed significant petrological diversity within the complex. Numerous discrete intrusions in what had previously been mapped as Stanthorpe Adamellite or Undercliffe Falls Adamellite were delineated, and contact relationships between most units established. The intrusives range in composition from quartz diorite to syenogranite. According to Sivell & Passmore, contacts between many of the units (in particular, subunits Rgst$_1$and Rgst$_2$ of the Stanthorpe Granite) are discordant and intrusive rather than gradational as previously suggested (*e.g.* Phillips, 1968; Thomson, 1976; Venables, 1984). Sivell & Passmore (1999b) interpreted the fine-scale systematic geochemical variation displayed by the various units to indicate they evolved by emplacement of numerous discrete batches or pulses of magma.

Subdivisions. Several informal subdivisions (subunits) were delineated during the current investigation using mainly geomorphological, textural, and compositional characteristics, combined with geophysical data and air-photo interpretation.

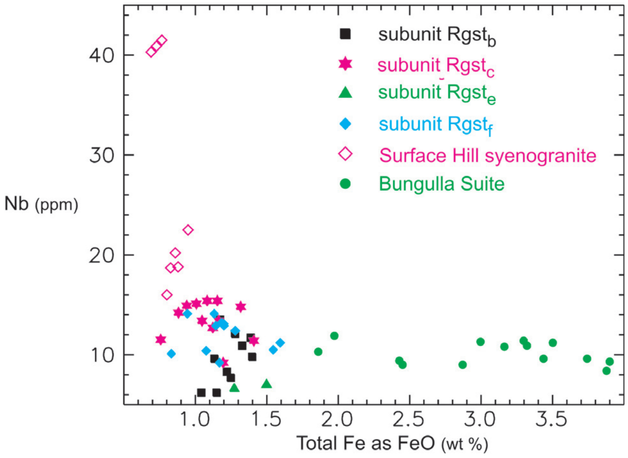

Figure 80. Nb versus FeO* plot for subunits Rgst$_b$, Rgst$_c$, Rgst$_e$, and Rgst$_f$ of the Stanthorpe Granite, granites of the Bungulla Suite, and the Surface Hill syenogranite (Timbarra Tableland, Grafton 1:250 000 Sheet area; Mustard, 2004). The granites define a trend of increasing Nb with decreasing FeO* (*i.e.* increasing SiO$_2$).

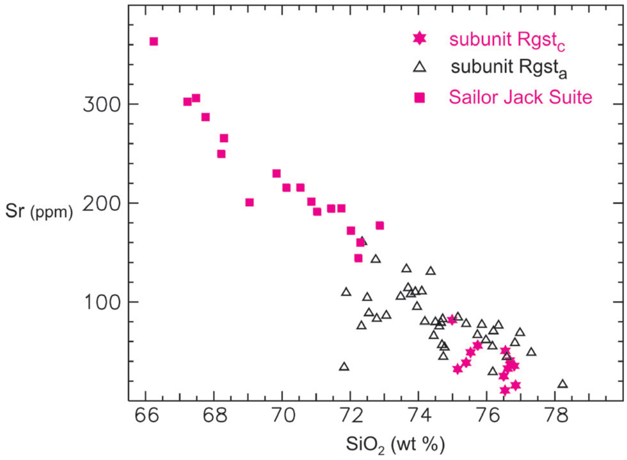

Figure 81. Sr versus SiO$_2$ for subunits Rgst$_a$ and Rgst$_c$ of the Stanthorpe Granite and granites of the Sailor Jack Suite. Subunit Rgst$_a$ consists predominantly of rocks with SiO$_2$ contents in the 'compositional gap' between ~72% and ~75%, but displays an extended range of compositions compared to most other subunits in the Stanthorpe Granite; the subunit may be composite.

The distribution of individual subunits shown on the map is only approximate because of inadequate time in the field. Relationships between most juxtaposed subunits have not been determined because of the general difficulty of finding exposed contacts.

Subunits Rgst$_b$, Rgst$_c$, Rgst$_f$, and Rgst$_e$ would have been formally named, but for the fact that their relationships with adjacent 'phases' of the complex have not been positively established. They define discrete zones on digitally manipulated, radiometric images (Figure 38b), and outline reasonably 'tight' groups (overlapping) on geochemical plots (*e.g.* Figures 79, 80). The first three subunits are relatively felsic (evolved) and are interpreted to represent the youngest parts of the complex, apart from the Ruby Creek Granite and some dykes. In contrast, less evolved subunit $Rgst_e$ is thought to form a relatively old part of the complex. Subunits $Rgst_b$, $Rgst_c$, and $Rgst_f$ are also similar mineralogically and chemically to the Surface Hill syenogranite of Mustard (2004). The Surface Hill syenogranite crops out on the Timbarra Tableland (Grafton 1:250 000 Sheet area, New South Wales) and was formerly mapped as part of the Stanthorpe Granite/Monzogranite (*e.g.* Henley & others, 2001).

Subunit $Rgst_a$ (~213km^2) is generally deeply weathered and forms mainly subdued, undulating country, characterised by poor outcrop and extensive soil cover (much of the farming country in the Stanthorpe district is on this subunit). Locally, for example, in Passchendaele State Forest (Figure 43), in parts of Stanthorpe, and west and south-east of Ballandean, the subunit forms undulating to hilly country with abundant outcrop. The subunit is distinguished from adjacent subunits by a predominance of relatively unevolved, mafic compositions. Rb contents are <300ppm in the majority of samples analysed, and SiO_2 contents are commonly <75% (Figure 81). It typically shows pink tones on composite RGB radiometric images (implying the unit is enriched in K relative to Th and U), in contrast to the white tones (indicating those subunits are rich in all three radioelements), which characterise the more felsic (fractionated) subunits delineated in the Stanthorpe Granite.

The subunit, where examined south and west of Stanthorpe, consists mainly of pink, medium- to fine-grained, slightly to moderately porphyritic (fluorite-muscovite-allanite-hornblende-) biotite monzogranite to ?syenogranite. Some K-feldspar phenocrysts (~2–4cm) are rimmed by sodic plagioclase. Plagioclase grains are extensively altered in places. Allanite is a relatively common accessory mineral, as euhedral groundmass grains (generally unaltered and showing pronounced zoning). Mafic enclaves (up to ~10cm across) and miarolitic cavities are present in some exposures. The subunit contains scattered lenses and pipes or pods of vuggy pegmatite up to ~40cm in diameter in places (*e.g.* at MGA 387886 6840664 in Passchendaele State Forest).

Similar granite exposed in the Ballandean area has also been assigned to this subunit. A noteworthy variant forms prominent boulders and pavements in the hills ~4.5km west-north-west of Ballandean. Monzogranite collected from MGA 381806 6814439 is one of the most mafic samples (~72% SiO_2) analysed from the Stanthorpe Granite during the recent survey. It contains relatively coarse and abundant titanite and minor hornblende (forms scattered laths up to ~1.5cm long), as well as biotite (total mafics content ~6%). The pink K-feldspar phenocrysts are commonly mantled by sodic plagioclase.

Sparse miarolitic cavities (up to ~3cm across) and biotite-rich schlieren are present in fluorite-bearing granite exposed farther south (at MGA 381723 6813286).

Porphyritic monzogranite tentatively assigned to this subunit in the far north (at MGA 394859 6848280, near the faulted north-eastern margin of the unit) is also relatively mafic (~73.5% SiO_2). It is pale pinkish grey to pale greenish grey, medium grained (average grainsize of the groundmass ~3mm), and contains minor biotite (~4–5%), hornblende (<biotite) and titanite.

Also included in this subunit is some more leucocratic (~1–3%biotite) K-feldspar-rich monzogranite to ?syenogranite, which forms low-lying country around and north of Stanthorpe. Small miarolitic cavities are common in boulders excavated from a low cutting beside Plant Lane (MGA39111526832807). The granite at this locality also contains scarce pegmatite lenses up to ~10cm long and 5cm wide.

Outcrops of grey to pinkish grey, porphyritic biotite granite south of Applethorpe (*e.g.* at MGA 398000 6832839, MGA 398098 6827111, MGA 398549 6828870, MGA 397847 6832947, MGA 397831 6832617) and east-south-east of Stanthorpe (*e.g.* at MGA 398549 6828870) have also been delineated as part of subunit $Rgst_a$. The samples examined from these areas are fine grained and relatively rich in biotite. Minor hornblende and titanite are also present locally. SiO_2 (~72% to ~75%) and Rb (<300ppm) contents are comparatively low. This belt of relatively mafic, fine-grained granite forms a zone, up to ~400m wide, which abuts the main Ruby Creek Granite pluton to the east. The rocks are more similar texturally to the Ruby Creek Granite than to the Stanthorpe Granite. However, the relatively mafic character of the rocks of the belt is not in accord with the interpretation of the Ruby Creek Granite as representing highly fractionated magmas derived from extended fractional crystallisation of Stanthorpe Granite type magmas (*e.g.* Blevin & Chappell, 1996; Blevin, 2002).

The samples from MGA 398000 6832839 and MGA 397831 6832617 (south of Applethorpe) display well-developed quenched textures. The grainsize of the groundmass components ranges from ~0.1mm to ~0.5mm. Subhedral to anhedral phenocrysts (up to ~1cm in length) of K-feldspar (generally white) and plagioclase are common. Biotite is relatively abundant (~5%), as small (~0.2mm) interstitial flakes (pleochroic from very dark brown to pale yellowish brown) in the groundmass, and as scattered microphenocrysts (to ~2mm) in the sample from MGA 397831 6832617. This sample also contains anhedral quartz phenocrysts up to ~3mm in diameter. A noteworthy feature is the presence of titanite (traces – ~1%) as irregular to subhedral grains ranging from ~0.1–1mm across (in interstices, as inclusions in plagioclase phenocrysts, and as rare microphenocrysts). Traces of allanite, fluorite, and zircon are also present. The sample from MGA 398000 6832839 also contains traces of molybdenite.

Monzogranite collected at MGA 398549 6828870, ~4km farther south also has a fine-grained groundmass (average grainsize ~0.3mm), with scattered phenocrysts (up to ~3mm long) of (in decreasing order of abundance) plagioclase, K-feldspar, and quartz. Biotite is relatively abundant (~5%) and characterised by bright red-brown to pale yellow pleochroism (similar to that displayed by biotites in reduced granites). The granite also contains minor muscovite (relatively common), and rare anhedral garnet grains (associated with biotite, pale green 'muscovite', and quartz).

The subunit also displays a well developed quenched texture south-east of Ballandean (Days Road area), adjacent to the contact with the Ballandean Granite (*e.g.* at MGA 388277 6811369, MGA 388231 6811027). It consists of pale grey to pale pinkish grey, fine-grained (average groundmass grainsize ~0.2–0.3mm), moderately porphyritic (allanite-titanite-) hornblende-biotite monzogranite in this area, and forms low undulating country. The granite contains ~4–5% mafic minerals (mainly biotite, as fine, interstitial flakes) and numerous phenocrysts of very pale pink K-feldspar (up to ~1.5cm long), as well as smaller phenocrysts of quartz and plagioclase. Scarce granophyric intergrowths between quartz and K-feldspar are present locally in the groundmass.

Monzogranite exposed ~700m to the north-east (MGA 388842 6811822) is more leucocratic, richer in K-feldspar, and slightly coarser grained (average groundmass grainsize ~0.6mm). Hornblende, allanite, and titanite were not detected in the thin section of the sample from this site. The monzogranite in this area also contains sparse pegmatite lenses. Grainsize increases farther to the south-east where the subunit forms huge boulders and prominent bare rock outcrops in places (*e.g.* at MGA 389354 6811431) similar to those in adjacent subunit Rgst$_b$. Subunit Rgst$_a$ may form a marginal zone of subunit Rgst$_b$ in this area.

The subunit is also locally heterogeneous on an outcrop scale. Pink, medium-grained, porphyritic, leucocratic biotite monzogranite exposed in a road cutting at MGA 391882 6829542 on the main Stanthorpe–Texas road, for example, contains zones (schlieren?) of finer grained, more even-grained, relatively biotite-rich monzogranite.

Subunit Rgst$_b$ (~205km^2) is relatively resistant to erosion, due mainly to its felsic composition and massive, sparsely jointed character. Consequently, it forms rough hilly country with numerous conspicuous and extensive bare-rock outcrops (Figures 42, 82, 83, 84). The subunit is characterised by white tones on a composite gamma-ray spectrometric image (Figure 38a), and by low to moderate magnetic intensities (Figure 40). A digitally manipulated radiometric image outlines an ovoid intrusion extending in a north-westerly direction from the Mount Norman area in the south-east to north-north-east of Ballandean (Figure 38b). This image shows an abrupt tonal change (from predominantly blue tones to predominantly pink tones) across a north-easterly trending lineament east of Ballandean (Figure 38b). A more detailed investigation, therefore, may indicate the subunit can be subdivided.

Figure 82. Prominent outcrops of Stanthorpe Granite (subunit Rgst$_b$, Stanthorpe complex), with a dome of massive granite (Middle Rock) in the middle distance, Girraween National Park.

Figure 83. Massive outcrop of Stanthorpe Granite (subunit Rgst$_b$, Stanthorpe complex), Mallee Ridge area, Girraween National Park. Photograph taken by M.D. Livingstone.

Figure 84. Bald Rock, a large granite dome formed in massive Stanthorpe Granite (subunit Rgst$_b$, Stanthorpe complex), Bald Rock National Park, New South Wales.

The subunit is very well exposed in Girraween National Park, where it shows classic granite

Figure 85a. Prominent shallow drainage channel (rille or runnel; *e.g.* see Migon & Goudie, 2000) formed in massive granite (subunit Rgst$_b$, Stanthorpe Granite), lower flank of West Bald Rock (Girraween National Park), as a result of chemical weathering processes. An indication of scale is provided by the person at the base of the slope, in the upper left of the photograph.

Figure 85b. Small weathering pits (gnammas) partly filled with water, at head of shallow drainage channel (rille or runnel) in massive granite (subunit Rgst$_b$, Stanthorpe Granite), upper flank of West Bald Rock, Girraween National Park. Chemical weathering has resulted in the accumulation of soil and decomposed rock debris in the larger pit (at bottom, left hand side of photograph) , which supports a specialised plant community.

landforms — mainly inselbergs (domes), large boulders, extensive bare-rock pavements, and prominent tors (Figures 42, 82, 83). Bald Rock, the western flank of which marks the border with New South Wales, is reputed to be the largest granite dome in the southern hemisphere (~750m long, 50m wide, and rising ~260m above the surrounding country; Figure 84). Inselberg slopes are relatively smooth and are gently (in upper parts) to steeply (in central and lower parts) inclined. They host a range of small-scale weathering features such as shallow grooves (rillen; Figures 85a,b) and shallow pits or rock holes (gnammas; Figure 85b). Weathering along subhorizontal joints has produced recesses and overhangs. The steepening of joint planes from the summit area to the base facilitates removal of exfoliated slabs, evident from the presence of numerous boulders of various sizes on the slopes and the large amounts of coarse talus around the bases of the inselbergs.

The subunit consists of mainly pale pink to pale brown, or brown to reddish brown (‘iron’ stained), medium to coarse-grained (groundmass), highly and coarsely porphyritic (in K-feldspar), leucocratic (<~3% biotite) (muscovite-fluorite-allanite-) biotite monzogranite to syenogranite. Mafic enclaves (most <~10cm, but ranging up to ~15m across) and inclusions (to ~1m) of fine to medium-grained, porphyritic leucogranite, possibly representing blocks derived from the quenched marginal zone of the pluton, are present locally. K-feldspar phenocrysts commonly show microcline twinning. Hornblende and titanite have not been found. Rare pseudomorphs (consisting mainly of biotite) after hornblende were detected in a sample from South Bald Rock (MGA 403706 6803788).

Samples from the Bald Rock Creek – Bald Rock – South Bald Rock – Little Bald Rock area are characterised by the presence of numerous white (mainly) to very pale pink K-feldspar phenocrysts, up to ~4cm long; quartz shows a marked tendency to form aggregates of several grains, and plagioclase is relatively scarce. Skertchly (1898) reported K-feldspar phenocrysts up to 5cm long in the Bald Rock area. The rocks range in modal composition from syenogranite to K-feldspar-rich monzogranite. Monzogranite forming the northern part of the subunit is not as coarsely porphyritic in K-feldspar and is richer in plagioclase.

Outcrops in the Bald Rock Creek area (MGA 401711 6808792, MGA 400956 6810599) are relatively fine grained compared to most of the unit, with fine- to medium-grained groundmasses, possibly indicating the presence of a quenched zone adjacent to contacts with subunit Rgst$_2$. There is also a significant concentration of mafic inclusions in this area compared to outcrops elsewhere, consistent with such an interpretation (*e.g.* see Sivell & Passmore, 1999a). The other noteworthy feature about the mafic inclusions is their size compared to inclusions found in other parts of the Stanthorpe Granite —

many are between 10–30cm in diameter and several are between 10–15m across (Figure 78).

Subunit $\mathrm{Rgst_b}$ is very similar chemically to subunit $\mathrm{Rgst_f}$, but is distinguished by lower average Th, U, Y, Nd, and HREE contents.

Subunit $Rgst_c$ (~55km^2) forms rough hilly country north-north-west of Stanthorpe, with prominent bare slopes, extensive rock pavements, numerous tors, very large boulders, and whalebacks. This subunit comprises mainly pale pink to pale brownish pink, medium to coarse-grained, slightly to moderately porphyritic (fluorite-muscovite-allanite-) biotite monzogranite, locally with rare mafic enclaves up to ~5cm across. The monzogranite contains phenocrysts of pale pink K-feldspar to ~3cm in length, as well as subordinate phenocrysts of plagioclase (to ~2cm long) and quartz (to ~1.5cm across). Much of the subunit is relatively rich in biotite (~4–5%). Quartz grains are commonly dark grey.

Fluorite-bearing porphyritic biotite granite forming prominent, massive outcrops in hillsides in the Cannon Creek area has been investigated as a potential dimension stone resource (Trezise, 1990). Blocks have been extracted at Kassulke's quarry (at MGA 390702 6838407; also referred to as Pozieres quarry; Trezise, 1990) for testing but the venture has not progressed any further. The presence of scattered phenocrysts (up to ~2cm long) of altered plagioclase, miarolitic cavities up to ~4cm x 2cm, and vuggy pegmatite lenses (up to ~15cm long and 2.5cm wide) detract from the suitability of the rock for such a purpose.

Subunit $\mathrm{Rgst_c}$ is very similar chemically to subunit $\mathrm{Rgst_b}$, from which it is distinguished by slightly higher Na_2O and Nb contents.

The prominent rocky hill forming Mount Marley, on the outskirts of Stanthorpe, has been delineated as *subunit* $Rgst_d$ (~<0.5km^2). The extent of the subunit has been slightly exaggerated on the Stanthorpe Special 1:100 000-scale geological map. Outcrops examined beside the road to the subunit consist of pale grey to pale pink, fine-grained (average grainsize of groundmass components ~0.6mm), moderately porphyritic (fluorite-allanite-titanite-) biotite monzogranite, with numerous phenocrysts of plagioclase (up to ~1cm in length), K-feldspar (up to ~2.5cm), and quartz (to ~1cm, rounded), and sparse mafic enclaves (up to ~3cm across). The uneven-grained groundmass contains scattered granophyric intergrowths of quartz and K-feldspar in places. Some K-feldspar grains show microcline twinning. Noteworthy features are the well-developed quenched texture and the relatively mafic (~74.7% SiO_2), unfractionated (*e.g.* Rb<250ppm) character of the subunit. The subunit is tentatively interpreted to represent a quenched variant (roof zone?) of enclosing subunit $\mathrm{Rgst_a}$ that is compositionally similar.

Subunit $\mathrm{Rgst_d}$ is cut by dykes of Ruby Creek Granite (Saint-Smith, 1913, 1914a).

Subunit $Rgst_e$ (~10km^2) crops out over a small, elongate area ~15km west of Stanthorpe. The subunit forms scattered bouldery outcrops and pavements north and south of the main Stanthorpe–Texas road, adjacent to the contact with the Texas beds. It is distinguished by pink to red tones on a composite RGB radiometric image — in contrast to the white tones of adjacent subunit $\mathrm{Rgst_f}$ (see Figure 38a).

Samples from this subunit examined in detail consist of pale grey to pale pinkish grey, or pink, medium-grained, moderately porphyritic biotite monzogranite. Phenocrysts comprise, in decreasing order of abundance and size, white to pale pink K-feldspar (up to ~3cm long), plagioclase and quartz. Biotite is relatively abundant (~4–5%) and locally forms small aggregates.

The subunit is cut by numerous chlorite-rich veinlets, which follow mainly joints and fractures, as well as by scarce aplite dykes up to ~15cm thick. The relatively altered character of the subunit implies it is older than adjacent subunit $\mathrm{Rgst_f}$.

Subunit $Rgst_f$ forms a northerly trending belt (~197km^2) west of Stanthorpe and north of Ballandean. The subunit is generally very well exposed, typically forming hilly country with numerous large boulders, tors, whalebacks, and extensive pavements. Outcrop patterns are similar to those for subunit $\mathrm{Rgst_b}$, but overall the topography is more subdued. The subunit is characterised by white tones on a composite radiometric image, and by low to moderate magnetic intensities (Figure 40). A manipulated radiometric image (Figure 38a) shows the subunit as possibly forming two distinct ovoid, northerly-trending intrusions — one to the east of Nundubbermere, and the other in the Amiens area (Figure 38b).

The subunit typically consists of pale pink to pale pinkish grey, medium-grained (groundmass), moderately porphyritic, leucocratic biotite monzogranite to syenogranite. Biotite (~2–4%) is the main mafic mineral. Phenocrysts consist of (in decreasing order of abundance) pale pink–pink K-feldspar (to ~4cm in length), quartz (up to ~2.5cm across), and plagioclase (to ~2.5cm; commonly altered). Rapakivi textures are locally common (*e.g.* at MGA 382242 6840073), and many of the larger quartz grains are dark grey. K-feldspar is almost invariably much more abundant than plagioclase. Miarolitic cavities up to ~5cm across (*e.g.* at MGA 386810 6827557, MGA 382302 6824844) and vuggy pegmatite/aplo-pegmatite lenses (to ~1m in length; *e.g.* at MGA 384172 6839379, MGA 386876 6832365, MGA 386810 6827557; Figure 45b) are present in places. The main accessory minerals are zircon (commonly as relatively large, euhedral, zoned grains), apatite, fluorite (scarce), muscovite, and opaques. Traces of titanite and/or allanite are also present locally (*e.g.* at MGA 378968 6837453, MGA 382242 6840073). Sparse mafic (dioritic–granodioritic) inclusions, up to ~10cm across, have been found at a few localities (*e.g.* at MGA 386348 6827350, MGA 381806 6814439).

The subunit is texturally and compositionally heterogeneous. Monzogranite from MGA 378968 6837453, for example, is significantly finer grained (average size of groundmass grains ~0.5mm) and more highly porphyritic than other samples examined from the subunit. It is similar chemically to coarser grained samples collected farther to the east, and may represent a quenched variant. Relatively fine-grained, slightly porphyritic monzogranite also crops out at MGA 386876 6832365. Elsewhere, some samples are relatively rich in pink K-feldspar and poor in quartz (~20%).

Subunit Rgst₁ (~190km^2; Thomson, 1976) forms scattered outcrops east and north-east of Eukey (south-east of Stanthorpe), and extends east of the border into New South Wales. The subunit consists of pale pink, buff, or pale-brown to brown (iron stained), medium to fine-grained, porphyritic biotite monzogranite to syenogranite. It is characterised by pink tones (reflecting high K contents relative to Th and U abundances) on a composite RGB radiometric image, in contrast to the white tones (reflecting relatively high K, Th, and U values), which characterise most of the Stanthorpe and Ruby Creek Granites.

Subunit Rgst$_1$ west of the border contains numerous pale pink to white K-feldspar phenocrysts up to ~5cm long (K-feldspar > plagioclase) and ~3–5% biotite. Minor titanite is generally present, and traces of fluorite and allanite were detected locally. Hornblende was not observed in the two thin sections examined of samples collected from the Queensland side of the border, whereas the sample from east of the border, at MGA 412367 6803058, contains traces of hornblende and titanite. Thomson (1976) also reported hornblende (~2%) in the sample of this subunit, which she described in detail (appendix 1, page 139). The sample from east of the border is also relatively rich in plagioclase (~41%) and biotite (~8%), and poor in K-feldspar (~25%).

The three samples analysed from this subunit have SiO_2 contents ranging from ~73% to ~75%. K_2O contents are relatively high (~4.7% – ~5.3%), but the rocks are not as highly fractionated (*e.g.* Rb ranges from 196–214ppm) as most samples analysed from the Stanthorpe Granite.

Subunit Rgst$_1$ is intruded by subunit Rgst$_2$ of the Stanthorpe Granite (Sivell & Passmore, 1999a), and by the Ruby Creek Granite. It is interpreted to post-date the Bookookoorara Monzogranite (Thomson, 1976) and Bungulla Monzogranite.

Subunit Rgst₂ (~550km^2; Thomson, 1976) crops out extensively east and north-east of Wallangarra, along the Queensland–New South Wales border. The subunit has also been delineated north-east of Stanthorpe. It forms undulating country with numerous scattered pavements, boulders, and tors, in contrast to the rough hilly country with extensive outcrops formed on adjacent subunit Rgst$_b$.

Outcrops examined east of Wallangarra consist mainly of pale pink to pale brown, buff, pale greyish brown, or reddish brown ('iron stained'), fine to medium-grained (groundmass), uneven-grained to moderately porphyritic, leucocratic biotite monzogranite. Phenocrysts comprise, in decreasing order of abundance, K-feldspar (up to ~3cm), quartz (up to ~2cm) and plagioclase (up to ~1.5cm). K-feldspar phenocrysts range from pale pink to white, and commonly have rims of sodic plagioclase. Many of the quartz phenocrysts as well as groundmass grains in some of the coarser grained rocks are dark grey. Biotite (~1–5%) is the main mafic mineral. Granophyric intergrowths between quartz and K-feldspar are present in places (*e.g.* at MGA 402874 6806203).

Accessory and secondary minerals (not all present in every sample) include opaques, allanite, titanite, muscovite, sericite, chlorite, and epidote. Traces of titanite (as small groundmass grains and inclusions in plagioclase) are present in the three samples examined in detail (from MGA 402874 6806203, MGA 402893 6801808, MGA399693 6803419). The sample from MGA 402874 6806203 is noteworthy in that it contains minor muscovite (~1%) as well as biotite.

Small (up to ~5cm long), irregular miarolitic cavities are present in some rocks, and are locally common. Minor pegmatite (vuggy in places) and rare mafic enclaves up to ~2.5cm across have also been recorded.

Granite exposed in the headwaters of Racecourse and Tarban Creeks (along the state border, north-east of Wallangarra) is uneven grained to slightly porphyritic, and very leucocratic (~1–2% biotite, SiO_2 >75%).

In contrast, one of the most mafic samples (with ~70% SiO_2) of Stanthorpe Granite analysed as part of the recent survey is also from this subunit — *viz* monzogranite on the western side of Old Maryland Lane, north-east of Stanthorpe (at MGA 404239 6836488). The monzogranite is characterised by a well-developed porphyritic (quenched) texture, has a fine-grained, uneven-grained groundmass (average grainsize ~0.7mm), and contains ~8% mafic minerals (biotite > hornblende), as well as traces of titanite (in interstices, associated with hornblende). Pale pink K-feldspar forms the largest phenocrysts (up to ~3cm), but plagioclase phenocrysts (up to ~2.5cm in length) are the more abundant. The monzogranite also contains sparse, small (up to ~5cm across) mafic inclusions.

According to Sivell & Passmore (1999a,b), biotite syenogranite forms a significant part of the subunit in this area. Sivell & Passmore also noted that

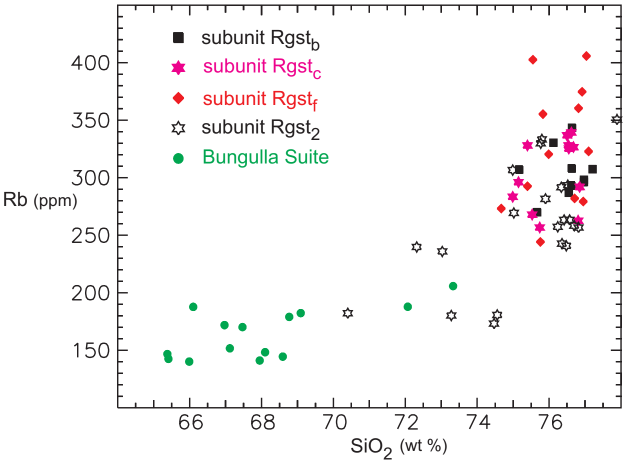

Figure 86. Rb versus SiO$_2$ plot for subunits Rgst$_b$, Rgst$_c$, Rgst$_f$, and Rgst$_2$, and granites of the Bungulla Suite. The granites show a curvilinear, fractional crystallisation trend of increasing Rb with increasing SiO$_2$. Most analysed samples from subunit Rgst$_2$ overlap compositionally with felsic subunits Rgst$_b$, Rgst$_c$, and Rgst$_f$. The few relatively mafic rocks analysed are compositionally more similar to Bungulla Suite rocks.

grainsize increases and the granite becomes more even grained with increasing distance from contacts with subunit Rgst$_1$, and that the abundance of mafic minerals decreases. Granite (possibly a syenogranite) examined at MGA 400799 6839924 is medium grained, slightly uneven grained (average grainsize ~3mm), and contains ~3–4% biotite (hornblende not detected), abundant K-feldspar, and rare titanite. The textural and mineralogical variations described above are consistent with the interpretation of Sivell & Passmore (1999a) that subunit Rgst$_2$ intrudes nearby subunit Rgst$_1$.

Subunit Rgst$_2$ is also interpreted to intrude the Bungulla Monzogranite, and to be cut by the Ruby Creek Granite and unit Rgx.

The textural, mineralogical, and compositional heterogeneity (*e.g.* Figure 86) displayed by this subunit implies it can probably be subdivided with more detailed investigation.

Unit PRgb

Distinctive, relatively mafic, coarsely porphyritic monzogranite to ?granodiorite, which crops out in four small areas (total area ~5.5km^2) in the Eukey–Bald Rock district, has been delineated as *unit PRgb*. These rocks are generally deeply weathered and poorly exposed, and may be more extensive than shown on the map.

K-feldspar phenocrysts range from white (*e.g.* at MGA 305706 6811188, MGA 403106 6818700, MGA 405748 6811180) to pale pink (*e.g.* at MGA 403006 6818788), and locally (*e.g.* at MGA 402605 6822388, MGA 430106 6818488) show preferred orientations. The colour variation displayed by the K-feldspar phenocrysts implies the oxidation state of the granite ranges from oxidised to reduced. Such a conclusion is also supported by magnetic susceptibility measurements. Monzogranite examined ~37km north-east of Eukey is oxidised, with relatively high magnetic susceptibilities (average readings of 371, 473, and 526 x 10^{-5} SI units at 3 localities). In contrast, pale grey monzogranite exposed on the eastern side of Neilsons Road (at MGA 402592 6822358) is reduced and characterised by a low magnetic susceptibility (average reading of 10 x 10^{-5} SI units). The granites contain significantly higher proportions of mafic minerals (~10–15%) compared to Stanthorpe Suite granites, and hornblende is relatively abundant. Minor titanite is also present in some of the outcrops (*e.g.* those at MGA 405748 6811180, north of Bald Rock). Relatively abundant and coarse apatite and/or coarse (up to ~2mm long) zoned allanite grains are present in some of the samples examined in detail (*e.g.* those from MGA 402606 6822388, MGA 405748 6811180).

A small (~4km^2) remnant of pale grey, medium-grained, only slightly porphyritic (allanite-) titanite-biotite- hornblende monzogranite exposed on the north-western margin of Passchendaele State Forest (north-west of Stanthorpe) has also been assigned to the unit. Magnetic susceptibilities measured in this area display a similar range to outcrops in the south-east; average readings of 41, 203, and 331 x 10^{-5} SI units were recorded in this area.

Analysed samples from the unit are moderately oxidised (classification scheme of Blevin, 2004). The unit is a high-K, I-type.

Unit PRgb pre-dates the Stanthorpe and Ruby Creek Granites, and is probably late Permian–early Triassic.

Unit Rgw

Unit Rgw (~1km^2) forms a thick (up to ~350m wide), somewhat irregular, north-north-westerly-trending dyke, 1–5km north of Wallangarra. The unit was emplaced mainly along the contact between the upper and lower units of the Wallangarra Volcanics (Purdy, 2003), most probably in the very late Permian or early Triassic.

The unit consists of pale grey to pale brownish grey, highly porphyritic monzogranite, with a fine-grained groundmass (0.1–0.2mm). The phenocryst assemblage is dominated by relatively coarse (up to ~2.5cm) plagioclase and subordinate, very pale pink K-feldspar. In addition, the monzogranite contains scattered phenocrysts of hornblende (to ~1cm), biotite (to ~1.5mm), quartz (to ~2mm), and magnetite (to ~0.5mm). The larger quartz phenocrysts are commonly embayed. Biotite phenocrysts in the two thin sections examined are bent and show undulose extinction, indicating deformation of the unit after emplacement. Accessory minerals identified are titanite, allanite, apatite, and opaques (mainly magnetite). Titanite mainly forms irregular grains in interstices in the groundmass but also occurs with hornblende and opaque oxide phenocrysts and as rare microphenocrysts (up to ~0.6mm across). Rare ?cummingtonite was detected in one thin section. The unit is little altered and contains only minor amounts of epidote, chlorite, and sericite. Scattered lithic inclusions (mainly felsic volcanic rocks) range from <3cm to ~30cm across.

The two samples analysed indicate the unit is an oxidised, moderately evolved (K/Rb = 246–257), high-K, I-type.

The outcrop on the western side of the New England Highway (at MGA 394157 6801910) has an average magnetic susceptibility of 1860 x 10^{-5} SI units (average of 21 readings).