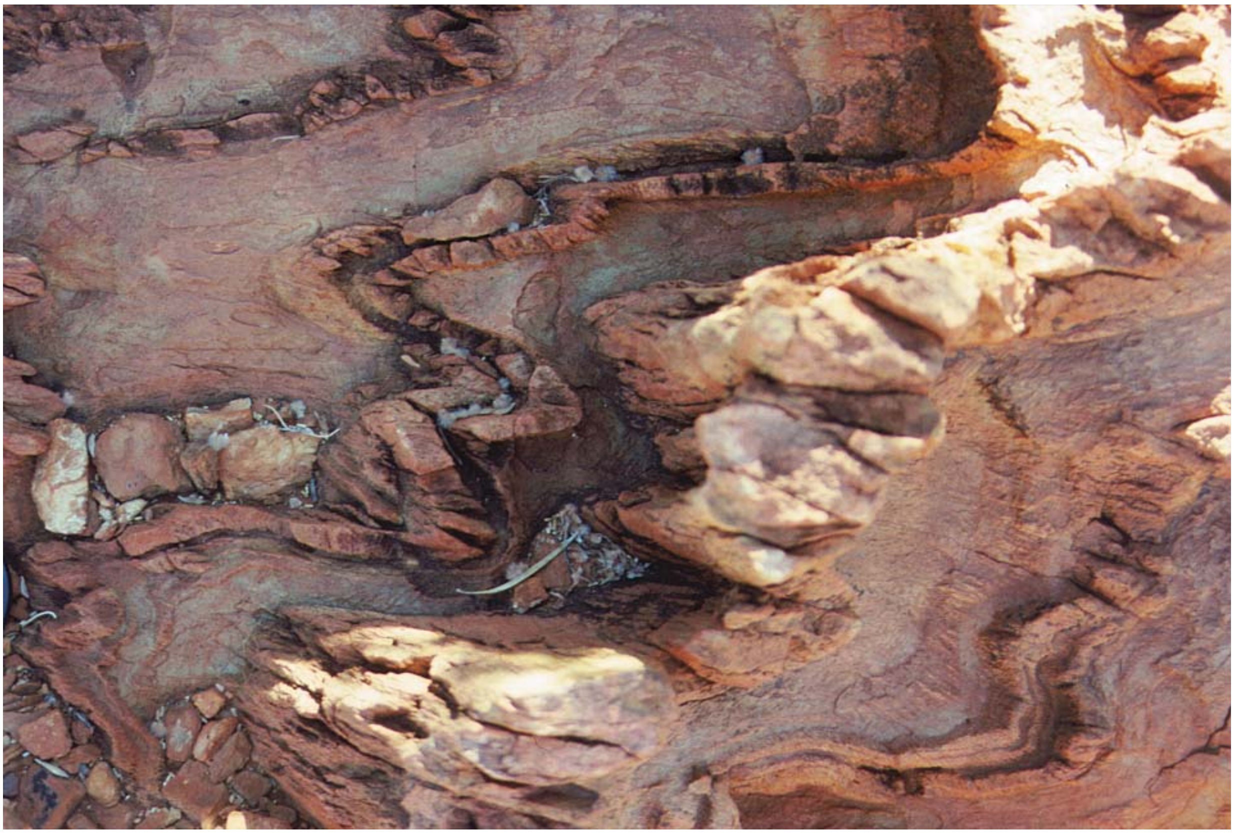
EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

GEOLOGY OF THE MILGUN 1:100 000 SHEET

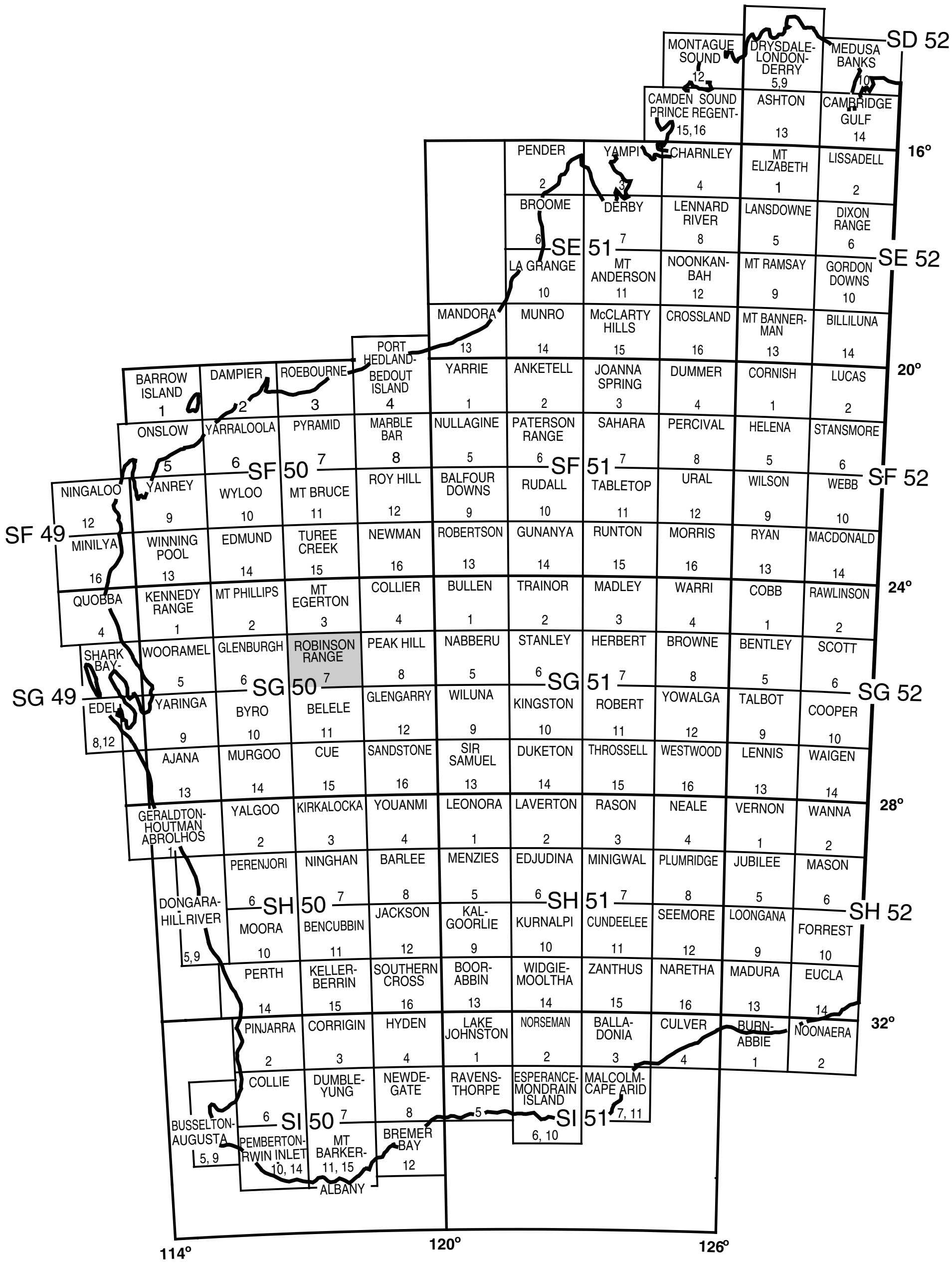
by C. P. Swager and J. S. Myers

1:100 000 GEOLOGICAL SERIES



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY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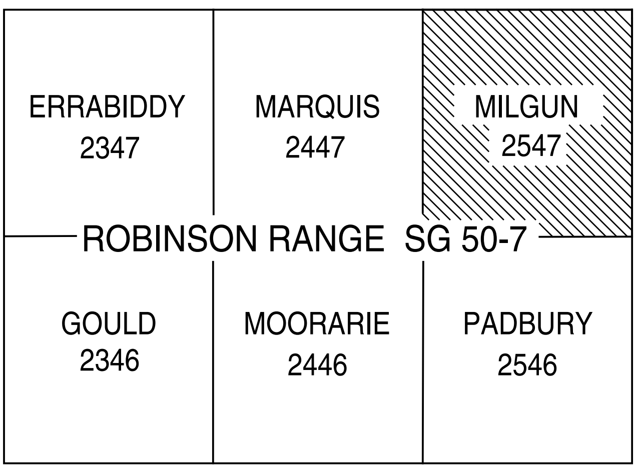
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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY
OF THE MILGUN
1:100 000 SHEET

by
C. P. Swager and J. S. Myers

Perth 1999

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Tight folding in a graded quartz wacke of the Labouchere Formation, between the Wilthorpe and Kinders Faults.

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Geology of the Milgun 1:100 000 sheet

by

C. P. Swager and J. S. Myers

Abstract

Three main tectonic units are represented in the area covered by the MILGUN 1:100 000 map sheet in Western Australia. These are the Archaean rocks of the Narryer Terrane in the southwest, the Palaeoproterozoic Bryah and Padbury Groups in the central and southern parts, and the Mesoproterozoic Bangemall Group in the north. The Bryah and Padbury Groups were deposited and deformed during the c. 1.9 – 1.8 Ga Capricorn Orogeny. To the east, the Bryah Group is in faulted contact with the underlying Palaeoproterozoic Yerrida Group, which rests unconformably on the Archaean Yilgarn Craton.

The Narryer Terrane contains undeformed to strongly foliated granite and granitic gneiss with numerous quartzite, amphibolite, and banded iron-formation layers and lenses. Several stages of granite magmatism are inferred from intrusive and structural–metamorphic relationships. The rocks have been metamorphosed to middle to upper amphibolite facies, and affected by at least four episodes of late Archaean regional deformation. They are locally overprinted by Capricorn Orogeny structures and greenschist- to lower amphibolite-facies metamorphism.

The volcano-sedimentary rocks of the Bryah Group are interpreted to represent a rift-basin succession. Mafic volcanic rocks of the Narracoota Formation and lithic wacke of the Ravelstone Formation are overlain by ferruginous–manganiferous shale and banded iron-formation of the Horseshoe Formation. These rocks are in unconformable contact, mostly reactivated during subsequent deformation, with the overlying Padbury Group. The Padbury Group comprises quartz wacke and quartz arenite (Labouchere Formation), quartz wacke and quartz-pebble conglomerate (Wilthorpe Formation), and ferruginous shale and banded iron-formation (Robinson Range Formation). The Padbury Group can be interpreted as a peripheral foreland-basin succession.

The Palaeoproterozoic volcano-sedimentary rocks were metamorphosed to lower–middle greenschist facies, except for a narrow marginal zone against the Narryer Terrane characterized by lower amphibolite-facies assemblages. Four deformation stages of Capricorn age are recognized: D_1 subhorizontal folding and south-vergent thrusting; D_2 regional upright, easterly trending folds formed during continued north–south compression; D_3 northerly trending folds, which increase in intensity towards the Narryer Terrane and are largely restricted to the area covered by MILGUN; and D_4 north-northeast–south-southwest compression resulting in widespread small-scale folds and cleavage development as well as shear zones and faults in the Archaean granite–gneisses. The D_1 and D_2–D_3 events represent a progressive deformation regime. The D_2 and D_3 structures show a mutually exclusive distribution, and probably developed largely at the same time.

Epigenetic gold mineralization at Fortnum, Nathans Deep South, and Labouchere is in D_3–D_4 structures, mainly associated with quartz-vein systems in the Narracoota Formation, and in the Labouchere and Wilthorpe Formations and their (tectonic) contacts.

The Bangemall Group contains two subgroups, the Edmund and Collier Subgroups, both of which are present on MILGUN. The contact between the subgroups, however, is not exposed. Complex fault and fold patterns characterize the contact of the Bangemall Group with the Narryer Terrane, and the Bryah and Padbury Groups, which form the basement for the Bangemall Basin.

KEYWORDS: Capricorn Orogen, Archaean, Palaeoproterozoic, Bryah Basin, Padbury Basin, Narryer Terrane, volcanic rocks, sedimentary successions, rift basin, foreland basin, gneiss.

Introduction

The MILGUN[1] 1:100 000 sheet (SG 50-7, 2547) covers the area between latitudes 25°00' and 25°30'S, and longitudes 118°00' and 118°30'E in the northeastern part of the ROBINSON RANGE 1:250 000 sheet (SG 50-7). The map sheet is named after Milgun Homestead (AMG 307242)[2] in the northern part of the sheet. Elias and Williams (1980) compiled the first edition of the Robinson Range 1:250 000 geological map sheet. These Notes and the accompanying 1:100 000 geological map are based on fieldwork carried out between May and November 1995.

MILGUN contains Archaean gneissic rocks and Palaeoproterozoic[3] volcano-sedimentary successions that were deformed during the Palaeoproterozoic Capricorn Orogeny. The three main tectonic units on MILGUN are the Archaean Narryer Terrane in the southwest, the Palaeoproterozoic Bryah and Padbury Groups in the southeast (formerly included in the now-superseded 'Glengarry Basin' of Gee and Grey, 1993), and the Mesoproterozoic Bangemall Group in the north (Fig. 1).

There are three main access roads to MILGUN: the major, unsealed Ashburton Downs – Meekatharra road, which connects with the Great Northern Highway to the southeast and passes through Peak Hill, Milgun, and Mulgul; a road branching off to the Fortnum mine; and the Mount Padbury – Yarlarweelor–Milgun road (Fig. 2). Pastoral tracks provide reasonable access, although many are overgrown or partly washed out; such tracks provide the only access to the southwestern part of the sheet. The area is sparsely settled, with the only permanent habitation at Milgun Homestead and temporary mining camps at the Fortnum mine and near the Nathan Bitter mine. Pastoral activity is largely restricted to cattle grazing.

MILGUN lies within the Peak Hill Mineral Field and contains the Horseshoe mining centre. At the time of writing (June 1996) active opencut mining and associated mineral exploration was being carried out at the Fortnum mine. The Fortnum mine (also known as the Fortnum group of workings) consists of the Trevs, Starlight, Twilight, Ricks, Toms Hill, Alton, Eldorado, Callies, D39, and Yarlarweelor deposits. The Labouchere group of workings includes the Labouchere and Central Valley deposits, and the Nathans group includes the Labouchere-Nathans, Nathan Bitter, and Nathans Deep South deposits.

An early publication on the geology of the area dealt with gold-mining activity just south of MILGUN (Montgomery, 1910). Regional reconnaissance mapping, mainly of the area to the south, appeared much later (Johnson, 1950). The first modern regional geological studies and overviews were published in the 1970s and early 1980s (MacLeod, 1970; Barnett, 1975; Brakel and Muhling, 1976; Muhling and Brakel, 1985; Bunting et al., 1977; Gee, 1979; Elias and Williams, 1980; Williams, 1986). More recently, renewed regional studies and compilations (Gee, 1987; Myers, 1990, 1993; Windh, 1992), as well as more-detailed, semi-regional studies dealing with geochemical (Hynes and Gee, 1986) and sedimentological (Martin, 1994) aspects, have focused on the geology of the 'Glengarry Basin'. Results of the Glengarry project carried out by the Geological Survey of Western Australia (GSWA) between 1994 and 1996 (of which this report is a part) include a regional reassessment of the 'Glengarry Basin' (Pirajno et al., 1995a, 1996). Airborne total magnetic intensity and radiometric surveys were flown in 1994 as part of GSWA's regional geoscience mapping project, and these data are available from the Department of Minerals and Energy.

Climate and physiography

The MILGUN region has an arid climate with hot, dry summers (with an average daily maximum temperature of 38°C in January), and winters characterized by mild days and cool to cold nights (with an average daily maximum temperature of 19°C in July). Mean annual rainfall figures of between 190 and 240 mm have been recorded at different towns and homesteads in the region. Heavy falls in the summer months (between November and April) occur as a result of rain-bearing depressions derived from weakening cyclones from the northwest, and from more-localized thunderstorms. In the winter months, rain is associated mostly with tropical cloud bands from the north-northwest interacting with low-pressure systems associated with strong cold fronts approaching the continent from the southwest.

Prominent ridges and plateaus rise up to 200 m above the broad floodplains of the Gascoyne River and its tributary, Yarlarweelor Creek, in the northern half of MILGUN. The main river channels are braided, sandy watercourses with a few pools lined by spectacular river red gums (*Eucalyptus camaldulensis*), creekline miniritchie (*Acacia cyperophylla*), and low bushes of red grevillea (*Grevillea deflexa*). Various types of acacia shrubland are found on the hills and ranges, whereas open mulga–acacia shrublands dominate the plains. Bluebush, saltbush, and halophytic shrublands dominate the floodplains surrounding the main watercourses. A prominent ridge of north-northwesterly striking quartz arenite culminates in the 722 m-high Mount Labouchere (AMG 303126), which dominates the landscape in this northern part of the sheet. In the northeast, ridges and high plateaus of nearly flat-lying sedimentary rocks form the Dunns Range. In the southern half of MILGUN, the ground rises from the river plains formed by Yarlarweelor Creek to low and high ridges in the east, and a broad plateau with low rolling hills and laterite mesas over granite in the west. The mesas are the remnants of a ?Tertiary land surface that has been incised by numerous river systems. The Talbot Divide, which is the watershed between the Gascoyne River drainage to the north and the Murchison

1 Capitalized names refer to standard 1:100 000 map sheets, unless otherwise indicated.

2 Localities are specified by the Australian Map Grid (AMG) standard six-figure reference system whereby the first group of three figures (eastings) and the second group (northings) together uniquely define position, on this sheet, to within 100 m. AMG coordinates of localities mentioned in the text are listed in Appendix 1.

3 The terms 'Early Proterozoic' and 'Middle Proterozoic' were used on the MILGUN map sheet (published in 1997). In these Notes these terms have been replaced by 'Palaeoproterozoic' and 'Mesoproterozoic' respectively.

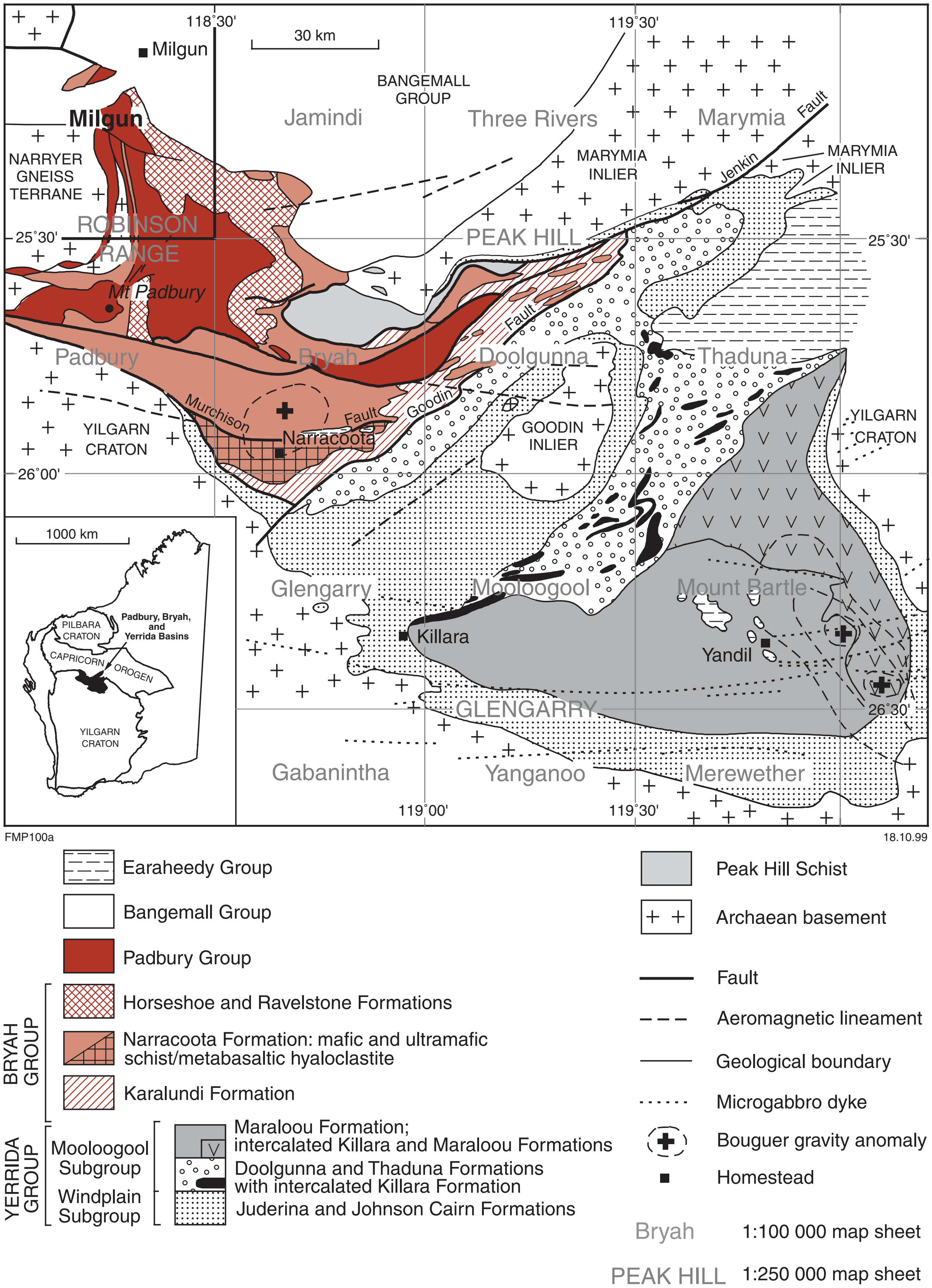

Figure 1. **Regional geological context of MILGUN. Three main tectonic units are represented on MILGUN: the Narryer Terrane, Bryah and Padbury Basins, and the Mesoproterozoic Bangemall Basin**

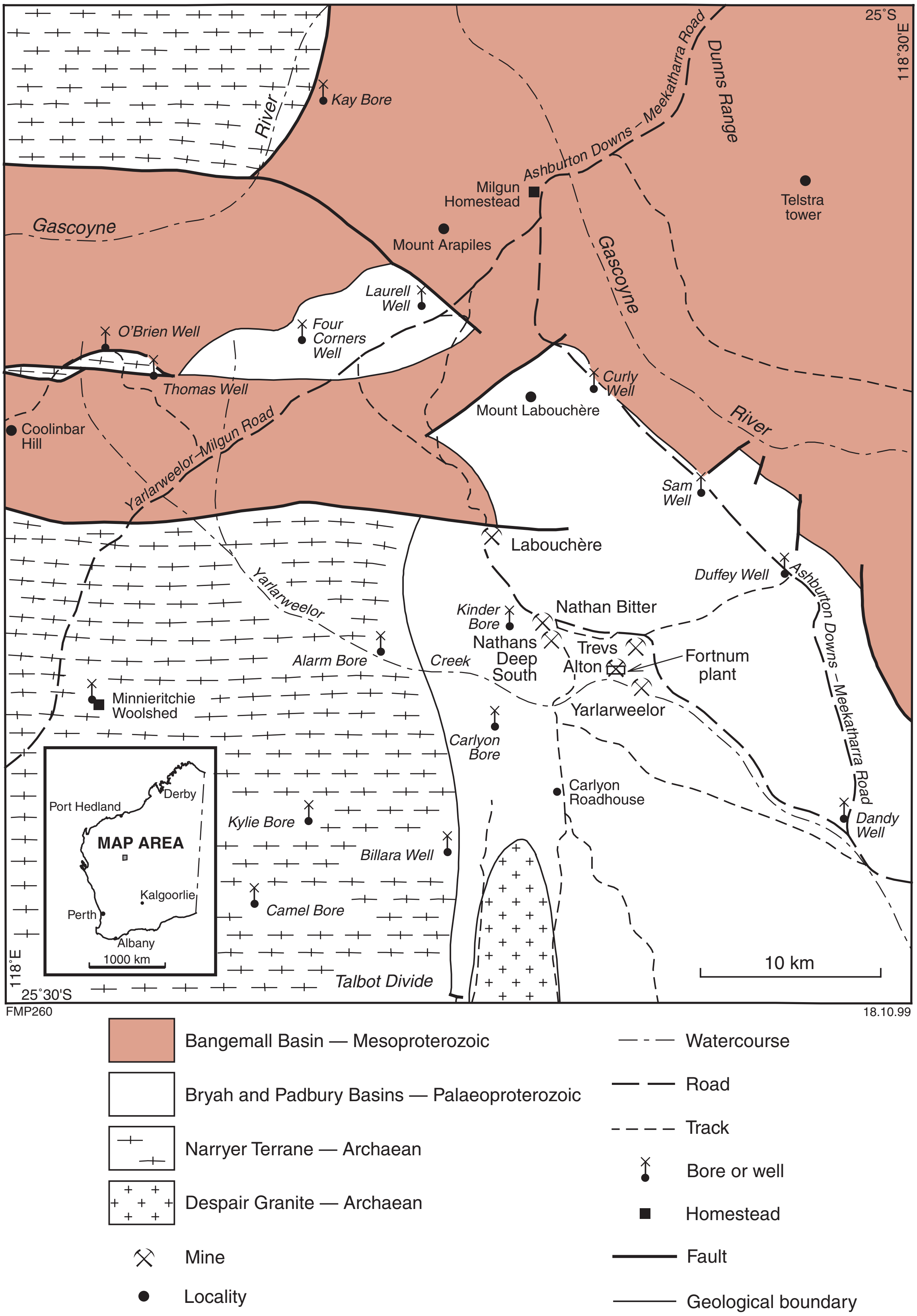

Figure 2. Simplified geology of MILGUN with the main cultural and topographical features

River drainage to the south, runs along the southern boundary of MILGUN.

Regional geology

MILGUN contains three major tectonic units (Figs 1–3):

- Archaean granite–gneiss, granite, and interleaved supracrustal rocks of the Narryer Terrane (Myers, 1993) and Despair Granite in the southwest, which were formerly known under various other names and included in the Gascoyne Province by Williams (1986);
- the volcano-sedimentary rocks of the Palaeoproterozoic Bryah and Padbury Groups (Pirajno et al., 1996) in the southeastern and central parts of MILGUN, including parts of the now-superseded 'Glengarry Group' of Gee and Grey (1993);
- the Mesoproterozoic Bangemall Group in the north (Muhling and Brakel, 1985), with typically easterly–westerly trending structures of the Edmund fold belt.

The Bryah and Padbury Groups are part of a belt of Palaeoproterozoic volcano-sedimentary rocks that were deposited, and then deformed and metamorphosed, during the Capricorn Orogeny between c. 1.9 and 1.8 Ma (Gee, 1979, 1990; Myers, 1993; McMillan et al., 1995; Myers et al., 1996). Some workers have suggested that a continuous Archaean basement between the Pilbara and Yilgarn Cratons underlies the volcano-sedimentary deposits of the Capricorn Orogen, and hence postulated an ensialic (or intracontinental) setting (Gee, 1979; Windh, 1992). Others have suggested that the Capricorn Orogen reflects convergence, collision, and post-collisional movements of the Pilbara Craton to the north and the Yilgarn Craton to the south (Muhling, 1988; Tyler and Thorne, 1990; Myers, 1990, 1993; Martin, 1994). The Bangemall Basin was formed on the deformed and eroded rocks of the Yilgarn Craton and Capricorn Orogen, and contains rocks ranging in age from c. 1650 to 1100 Ma (Muhling and Brakel, 1985; Myers, 1993).

Each of the three major tectonic units (Figs 2 and 3) is characterized by a particular set of structures. The Archaean fabrics in the Narryer Terrane were reoriented and overprinted during the Palaeoproterozoic Capricorn Orogeny. This c. 1.9 – 1.8 Ga orogeny was responsible for the fold and foliation patterns in the Padbury and Bryah Groups. On a regional scale, the geometry of these Palaeoproterozoic fold and foliation patterns changes dramatically away from the Narryer Terrane. The Coolinbar–Chalba fault systems mark the boundary with rocks of the Mesoproterozoic Bangemall Basin. The actual contacts include easterly to east-southeasterly trending faults, with rotational movements and intervening fault blocks where the basal unconformity of subhorizontal Bangemall Group rocks overlying strongly foliated rocks of the Padbury and Bryah Groups is preserved. Easterly trending folds of variable intensity (open–close to tight) and, locally, northwesterly trending folds and slaty cleavage are associated with the Edmund fold belt (Muhling and Brakel, 1985).

The three main tectonic units on MILGUN are characterized by different grades of regional metamorphism. High-grade (up to upper-amphibolite facies) assemblages dominate the Narryer Terrane, and lower to middle greenschist-facies conditions are characteristic of the Bryah and Padbury Groups. The Bangemall Basin succession is metamorphosed to very low grades.

Archaean geology

The Narryer Terrane (Myers, 1990, 1993) on MILGUN mainly consists of middle to late Archaean granite interleaved and intensely deformed with quartzite, banded iron-formation (BIF), and amphibolite, and intruded by late Archaean granite. At least four episodes of Archaean deformation (D_{A1-A4}) and two stages of high-grade metamorphism were recognized by Myers (1993). The older granite and supracrustal rocks were metamorphosed to granulite facies and then extensively retrogressed to amphibolite facies during prograde metamorphism of the younger granite. These rocks were then overprinted by Palaeoproterozoic deformation (D_1, D_2, D_3, and D_4) and greenschist-facies metamorphism during the Capricorn Orogeny (Muhling, 1988).

No isotopic ages have been determined on MILGUN, and inferred ages are extrapolated from similar rocks to the west and southwest where sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon dating has been reported (Kinny et al., 1988, 1990; Nutman et al., 1991; Wiedenbeck, 1992).

The Narryer Terrane is part of the Yilgarn Craton, and was probably accreted or amalgamated with the Murchison Terrane during the late Archaean (Myers, 1993). The reworked Narryer Terrane rocks on MILGUN were formerly included in the Gascoyne Complex (Williams, 1986; Myers, 1990), and are now regarded as the foreland of the Palaeoproterozoic Gascoyne Complex, which forms the high-grade crystalline core of the Capricorn Orogen. The rocks are exposed in a domal structure, here referred to as the Yarlarweelor Dome (Fig. 4). Elias and Williams (1980) and Williams (1986) described these reworked Narryer Terrane rocks as the 'Yarlarweelor gneiss belt', which includes the Mica Bore fold complex. The extent to which the Archaean fabrics and mineral assemblages were overprinted by Capricorn Orogeny deformation and metamorphism was discussed by Williams (1986), and is also discussed in **Archaean structure and metamorphism**. Elias and Williams (1980) suggested that metamorphic grade commonly increases from east to west. The granitic rocks of the Narryer Terrane on MILGUN are interpreted as middle–late Archaean in age. Nutman et al. (1991) dated orthogneiss at c. 3.3 Ga, or 3298 ± 6 Ma as quoted by Windh (1992), about 20 km to the southwest on MOORARIE.

Windh (1992) suggested that what she informally named the 'Wilthorpe granite', but was later formally named the Despair Granite by Occhipinti et al. (1998a), is a Palaeoproterozoic pluton along the Narryer Terrane

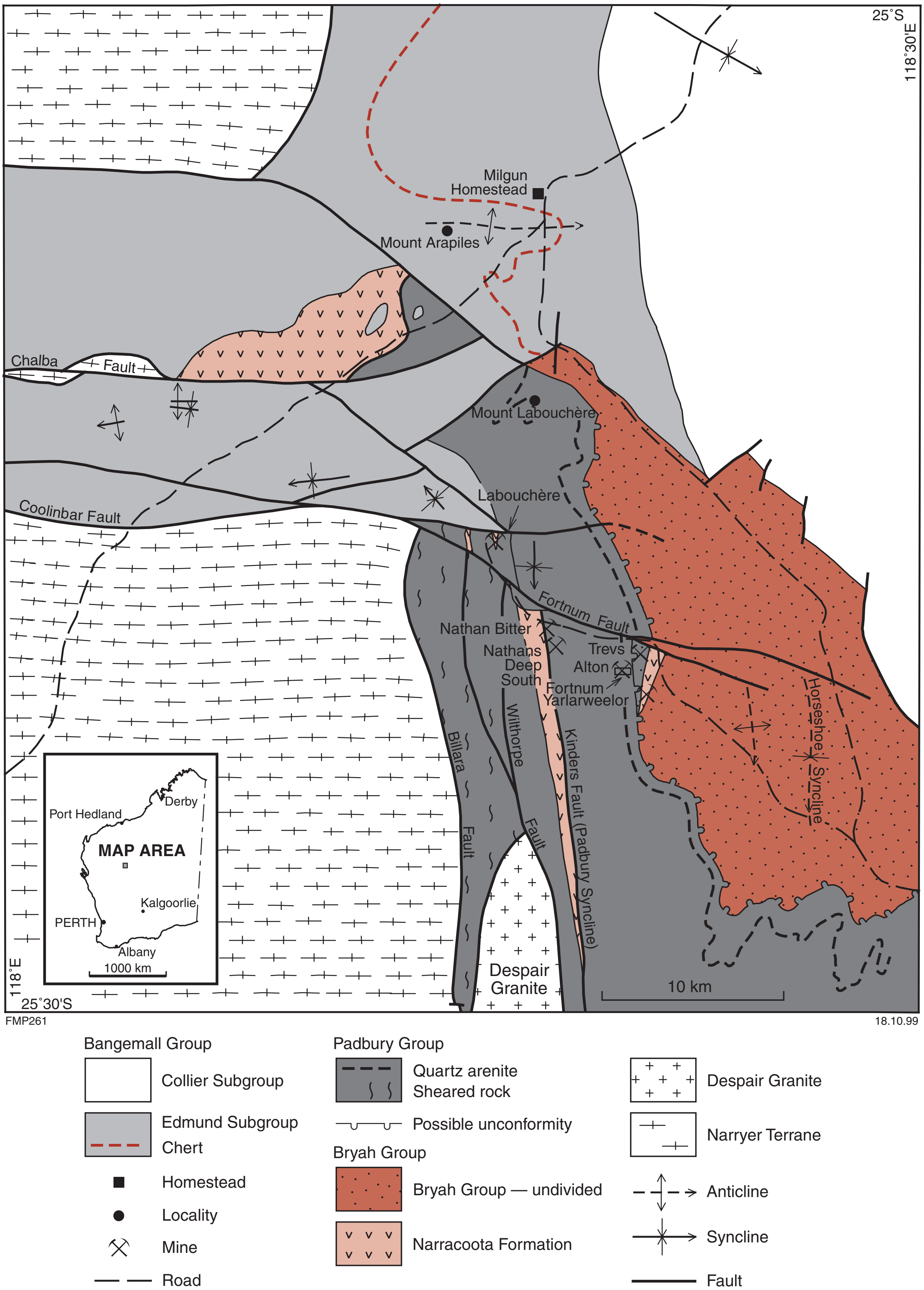

Figure 3. Main tectonic units on Milgun and their regional structures and geometry

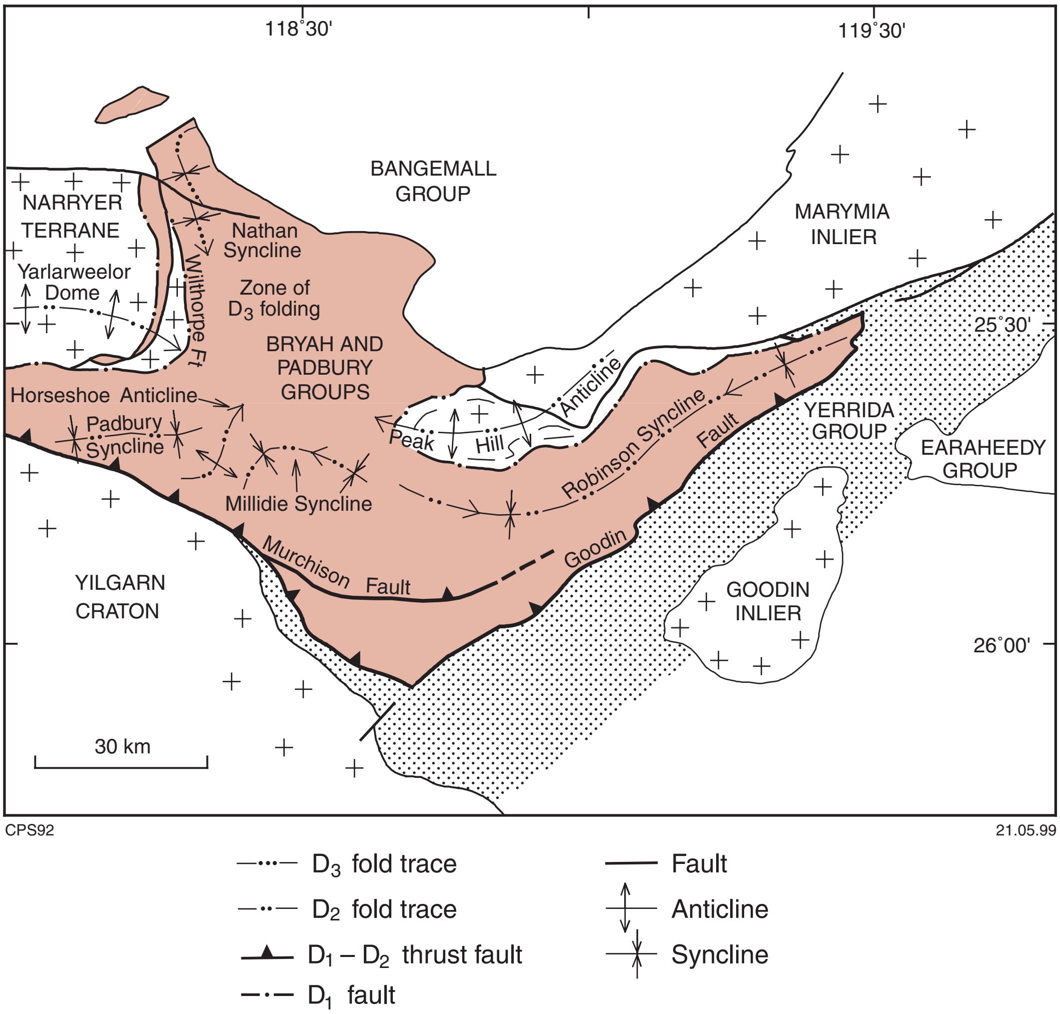

Figure 4. Regional distribution of D_2 and D_3 folds, including the Peak Hill Anticline and the Yarlarweelor Dome

boundary with the Palaeoproterozoic supracrustal rocks. However, here the deformed Despair Granite is interpreted as a fault-bounded slice of late Archaean granite distinct from granitic gneiss in the Narryer Terrane (Myers, 1990). Contrary to Windh's (1992) suggestion of a gradational contact over many tens of kilometres between the Narryer Terrane and the Bryah and Padbury Groups, we propose sharp, faulted contacts, but with regional-scale tectonic interleaving. A fault slice of quartz schist derived from the Padbury Group is tectonically interleaved between the Narryer Terrane and Despair Granite (Figs 3 and 4).

Narryer Terrane

Supracrustal rocks (*Asq, Asi, Aba, Aup, Au, Anp*)

Layers of supracrustal rocks, a few centimetres to a few hundred metres thick, are present within granite and granitic gneiss throughout the Narryer Terrane on MILGUN. Similar rocks are present throughout the Narryer Terrane, and U–Pb ages of detrital zircons in quartzites from a number of localities range from c. 4300 Ma (the oldest known traces of terrestrial rocks) to c. 3100 Ma (Froude et al., 1983; Compston and Pidgeon, 1986; Kinny et al., 1990; Nutman et al., 1991). These quartzites and spatially associated supracrustal rocks are therefore thought to be late Archaean deposits.

Quartzites (*Asq*), the most abundant supracrustal rocks, are particularly widespread south of Billarra Well in the southern part of MILGUN. Most quartzites are fairly massive quartz-rich rocks, but a few contain compositional layering, a few centimetres thick, marked by alternations of pure quartz with quartz–cordierite–sillimanite and quartz–amphibole rocks. The quartzites are mostly coarse grained aggregates of quartz with granoblastic textures overprinting an older layering. Several quartzites contain clusters of cordierite or mica after cordierite, and a few contain radiating clusters of sillimanite or relict sillimanite within the main schistosity, or compositional banding.

Banded iron-formation (*Asi*) forms a minor component of the supracrustal rocks, and is much less abundant relative to quartzite on MILGUN than is typical elsewhere in the Narryer Terrane. The rocks are finely banded and intensely deformed, and comprise alternations of fine-grained polygonal–granoblastic quartz and quartz–magnetite. The banded iron-formation and ferruginous chert (*Asi*) are also present within the western part of the Despair Granite, where the BIF layers locally contain the same northwesterly plunging mineral lineation as the foliated granite. Fine specular hematite in some samples is regarded as secondary.

Amphibolite (*Aba*) is widespread as layers, a few metres to a few hundred metres thick, within granitic gneiss or interlayered with quartzite. Most amphibolites are relatively massive hornblende–clinopyroxene–plagioclase rocks with coarse-grained granoblastic textures. This texture overprints a compositional layering in places. Elsewhere, amphibolite consists of fine-grained hornblende with a strong preferred orientation, and plagioclase as fine-grained platy crystals in the matrix or as fine-grained recrystallized aggregates presumably representing coarser precursor crystals. A few amphibolites were converted by D_3 deformation and associated retrograde metamorphism to schistose hornblende–plagioclase rocks. The spatial association of amphibolite with quartzite suggests that they formed part of the same supracrustal succession, and may have originated either as basaltic lava flows or basaltic sills and dykes.

Serpentinite (*Aup*) forms a lens within strongly foliated granite close to the Coolinbar Fault (in the central part of MILGUN), which separates the Narryer Terrane and the Bangemall succession. The massive, very fine to medium-grained serpentine is recrystallized, kinked, and associated with minor chlorite and talc. Original textures are not preserved. The serpentinite is associated with medium-grained amphibolite or mafic schist and metagabbro. Amphibole is fine to medium grained and shows a well-developed preferred orientation; plagioclase is fine grained and altered to sericite and epidote–zoisite. Fine quartz and sphene are present in places. Along strike to the south, similar small lenses of amphibolite contain small patches of calc-silicate (epidote–garnet) alteration.

Small linear outcrops of metamorphosed ultramafic rocks (*Au*) are present within the lens of serpentinized peridotite.

Small lenses of clinopyroxene–amphibole quartzofeldspathic gneiss (*Anp*) are present within foliated granite (*Angn*), including one lens within 25 m of the Billarra Fault in central MILGUN. Such gneiss is characterized by strong banding with shape-preferred orientation of most minerals, interleaved with layered high-grade polygonal–granoblastic textures and assemblages. Clinopyroxene is medium to coarse grained, and may be part of the matrix or in distinct layers. Very light green pleochroic amphibole (?actinolite) locally replaces clinopyroxene, whereas, elsewhere, highly poikiloblastic hornblende appears in equilibrium with clinopyroxene. Quartz, plagioclase, and, locally, antiperthitic K-feldspar are fine to medium grained and also present as elongate aggregates or lenses. Minor phases include sphene and zoisite, the latter associated with hornblende. Locally, relics of ?poikiloblastic orthopyroxene hint at earlier granulite-facies metamorphism.

Granitic gneiss and granite (*Angn, Agd*)

Granitic gneiss (*Angn*) shows complex relationships and diffuse boundaries on all scales between heterogeneously deformed and recrystallized granitic gneiss, and intrusive sheets and veins of foliated granite and pegmatite.

Granitic gneiss forms sheets separating thin layers of supracrustal rocks and contains tectonic fabrics parallel to the layering. The gneiss can locally be seen to have intruded the supracrustal rocks, cutting across compositional layering. The granitic gneiss mainly consists of strongly deformed biotite monzogranite in which pegmatite veins have been rotated into parallelism and subsequently attenuated, so that the granite was converted into pegmatite-banded gneiss. This main tectonic fabric formed during the D_{A1} and D_{A2} episodes of late Archaean deformation (see **Archaean structure and metamorphism**), but protoliths may include c. 3.4 – 3.3 Ga granite (cf. zircon age from banded gneiss at Midnight Bore on MOORARIE; Nutman et al., 1991; Occhipinti and Myers, 1999) as well as c. 2700 Ma granite. Peak metamorphic conditions probably reached granulite facies during and after D_{A2} deformation, resulting in granoblastic textures.

The intensity of the D_{A1} and D_{A2} deformation was heterogeneous. The deformation was most intense along boundaries with more competent rocks, such as quartzite and ultramafic rocks. The fabric of the granitic gneiss generated during the D_{A1} and D_{A2} deformation was also modified by a third episode of late Archaean deformation (D_{A3}) and associated metamorphism, and again during early Proterozoic deformation. During D_{A3} deformation the gneissosity was intensified by further flattening and attenuation, accompanied by retrograde recrystallization to amphibolite facies.

Granite sheets and veins cut across the D_{A1} and D_{A2} tectonic structures and fabrics of granitic gneiss and supracrustal rocks. In a few places they form large sheet-like bodies within the older layering of the granitic gneiss and supracrustal rocks. On a regional scale, the boundaries between granitic gneiss and later granite are diffuse because the whole region is permeated with smaller granite sheets and veins. The later granite consists of coarse-grained monzogranite that has been heterogeneously deformed (D_{A3}) and recrystallized under amphibolite-facies conditions. The unit is often little deformed and thus distinct from most granitic gneiss, but in a few places it is strongly deformed into a pegmatite-banded gneiss. In the latter case it cannot easily be distinguished from earlier granitic gneisses unless these exhibit a more complex deformation history that preceded D_{A3}, or contain evidence of amphibolite-facies retrogression of the older granulite-facies assemblages.

Foliated granite exposed south of O'Brien Well (AMG 066157), in the western part of MILGUN, is interpreted as uplifted Archaean–Palaeoproterozoic basement to the Bangemall succession. This granite is very strongly foliated adjacent to a major fault outlined by a large quartz blow, but less deformed in the low-lying outcrops and subcrops away from the fault. Sericitization of feldspar is widespread, but quartz aggregates and apatite crystals have partly preserved the igneous texture. The granite is shown on the map as Archaean in age, but, alternatively, it may be Palaeoproterozoic (*Eg*) in age.

Tonalite–granodiorite (*Agd*) is present as a weakly foliated lens within the granitic gneiss (*Angn*) along the faulted contact with the Bangemall Group. Fine- to medium-grained plagioclase (60–50%) shows some sericitization, and is accompanied by quartz (30–40%) and interstitial biotite (2–3%) associated with minor epidote. The lenses may have been emplaced after most of the deformation in the strongly foliated host had taken place.

Despair Granite (*Agde*)

The Despair Granite (*Agde*) was informally named the Wilthorpe granite by Windh (1992) and originally defined by Elias and Williams (1980) as a late Archaean granite reworked during one or more Proterozoic events. Myers (1989) mapped the Despair Granite as a fault-bounded slice of late Archaean granite, distinct from the Narryer Terrane to the west. Windh (1992) subsequently interpreted the Despair Granite as a Proterozoic granite that intruded the Padbury Group after east–west shortening. Zircons from massive Despair Granite with near-concordant late Archaean U–Pb ages (c. 2.65 Ga; Windh, 1992) were therefore interpreted as xenocrysts by Windh (1992).

In these Notes the Despair Granite is defined as a heterogeneously deformed biotite monzogranite bounded by the Wilthorpe Fault to the east and a wedge of strongly foliated Proterozoic metasedimentary schist (derived from the Labouchere Formation) to the west (Fig. 3). The Despair Granite thus forms a tectonic slice that is cut out to the west near Relief Bore on PADBURY and to the north near Carlyon Bore (AMG 264948). The medium-grained biotite monzogranite locally contains K-feldspar phenocrysts, is relatively uniform, and has one main tectonic fabric.

The Wilthorpe Fault is marked in many areas by angular cutoffs of folded foliation in granite, and of bedding and foliation in the metasedimentary rocks, against the sharp fault surface. Locally, strong foliations in the granite are subparallel to the main structure in foliated quartz wacke across the fault.

The main foliation in the Despair Granite is interpreted to be Archaean in age, and defines a gentle arcuate trend from a north to north-northeasterly strike in the north to east-northeasterly in the south. Locally, this main foliation is overprinted by a north–south foliation with an approximately 50° (north-)northwesterly plunging mineral lineation. This fabric is here tentatively interpreted as the D_3 Capricorn Orogeny foliation overprinting an Archaean foliation. Small-scale D_4 Capricorn folds with axial planar foliation are more commonly recognized throughout the Despair Granite.

In strongly deformed zones, the main Archaean banding is defined by quartz and quartz–feldspar domains, biotite trails, and boudinaged larger K-feldspar crystals. Such feldspar crystals show recrystallization along their grain boundaries and quartz–muscovite infill in boudin gaps. Intrafolial folds are locally associated with the main foliation. In less deformed zones, original igneous textures can still be recognized, with plagioclase retaining magmatic zoning, preserved biotite(–epidote) aggregates, and local K-feldspar phenocrysts. This main foliation is overprinted by D_4 (Capricorn) west-northwesterly trending (280–310°) fold zones and axial plane foliations, as well as shear zones and faults of Palaeoproterozoic age outlined by quartz blows (see **Archaean structure and metamorphism**).

The Despair Granite contains lenses of Archaean banded iron-formation, ferruginous quartzite, amphibolite, and biotite schist. A distinct magnetic lineament divides the Despair Granite into eastern and western parts; the western part contains the high-grade metasedimentary lenses. Martin (1994, 1998) correlated the western part with Archaean orthogneiss, and interpreted the eastern part as (Palaeoproterozoic) Despair Granite. Martin (1994, 1998) also recorded complex interleaving between strongly foliated metasedimentary rocks and Despair Granite. Windh (1992) recorded inliers of regularly bedded metasedimentary rocks on PADBURY and interpreted them as Palaeoproterozoic in age and intruded by Despair Granite. Occhipinti et al. (1998a) reinterpreted these inliers as tectonic slices.

Archaean structure and metamorphism

The Narryer Terrane on MILGUN is dominated by complex, late Archaean fold interference structures. These structures are most prominent in the supracrustal rocks that define canoe-shaped antiforms and synforms. These formed from two sets of folds (D_{A2} and D_{A3}) with axial surfaces at high angles to each other. They were superimposed on interlayered granitic gneiss and supracrustal rocks that were interleaved during D_{A1} deformation. The D_{A3} structures and fabrics, together with reoriented D_{A1} and D_{A2} structures and fabrics, form the dominant structural grain of the region. This main tectonic grain commonly trends easterly, except in the northeast where it trends northerly. The D_{A2}–D_{A3} fold interference structures were themselves refolded into large open folds (D_{A4}), as seen south of Billarra Well in the southern part of the map sheet.

The gneiss complex was deformed again during the Palaeoproterozoic Capricorn Orogeny when the Narryer Terrane formed the basement beneath a cover of Palaeoproterozoic sedimentary rocks. There was a major décollement between the basement and cover, and the gneiss complex was intensely deformed immediately below this décollement. The décollement was reactivated during later stages of Capricorn deformation. Along the Billarra Fault, granitic gneiss and granite was transformed into quartz–feldspar schist with well-developed elongate grain shapes aligned along preferred orientations, trails of very fine grained sphene or rutile, biotite or muscovite, and some partially preserved larger feldspar crystals. Some interleaving of Archaean and Proterozoic rock types may have occurred along the Billarra Fault, which is marked northeast of Alarm Bore (AMG 217984) by a ridge of prominent quartz blows within muscovite–quartz schist derived from quartz wacke of the Labouchere Formation.

The Narryer Terrane was cut by late-stage (D_4) Capricorn age faults and shear zones in which the Archaean rocks were converted to mylonite and schist at conditions of greenschist-facies metamorphism. The Proterozoic cover was repeatedly folded, independent of the basement.

The high-grade metamorphic conditions in the Narryer Terrane rocks are illustrated by clinopyroxene–hornblende–plagioclase assemblages in amphibolite and calc-silicate gneiss layers and lenses, which indicate middle–upper amphibolite conditions. Locally, possible relics of orthopyroxene suggest retrogression from earlier granulite-facies conditions (D_{A1}–D_{A2}). These assemblages are all thought to be Archaean in age; however, they were preserved during the reworking of the Narryer Terrane during the Capricorn Orogeny (i.e. apart from the localized retrograde shear zones). Muhling (1998) argued that for an area about 100 km west of MILGUN, gneissic Archaean rocks were still at deep crustal levels (i.e. granulite-facies conditions) early in the Capricorn Orogeny, and then uplifted during the later stages of this orogeny. Such a scenario may explain the preservation of Archaean high-grade assemblages on MILGUN.

Palaeoproterozoic geology

The Bryah and Padbury Groups are newly defined units of the now-superseded 'Glengarry Basin' of Gee and Grey (1993). These groups were deposited and deformed along the northern margin of the Yilgarn Craton between 2.0 and 1.65 Ga (Gee, 1990; Myers et al., 1996). Windh (1992) proposed a more restricted time frame, with deposition around c. 1.92 Ga and deformation between 1.9 and 1.8 Ga, based mostly on Pb–Pb model ages of sulfides. Recent SHRIMP U–Pb zircon and isotopic studies by McMillan and McNaughton (1995) and McMillan et al. (1995) indicated probable Capricorn Orogeny metamorphism and hydrothermal activity at c. 1.72 Ga.

The Glengarry Group was originally thought to represent the western sub-basin of the much larger Nabberu Basin (Hall and Goode, 1978; Gee, 1990), but was elevated to basin status by Gee and Grey (1993). The regional stratigraphy was established in the Peak Hill region (Bunting et al., 1977; Gee, 1979, 1987). Subsequent amendments were based on detailed work in the southern part of the basin by Gee and Grey (1993), and in the western part by Windh (1992) and Martin (1994), who redefined the lower boundary of the Padbury Group.

Substantial modification of the basin stratigraphy and structure has been proposed by Pirajno (1996) and Pirajno et al. (1996, 1998; Table 1). The original 'Glengarry Basin', of Gee and Grey (1993) is now divided into two groups: the Bryah Group and Yerrida Group, which are in faulted contact with each other everywhere. The Yerrida Group is subdivided into the Windplain Subgroup, which contains a basal sag-basin succession unconformably overlying the Yilgarn Craton, and the Mooloogool Subgroup, which contains a rift succession. The rocks of the Bryah Group are interpreted as a rift succession with mafic–ultramafic volcanic rocks that are totally different from those in the rift succession of the Yerrida Group (Pirajno et al., 1998). The Padbury Group unconformably overlies the Bryah Group (Windh, 1992; Martin, 1994), but in most places the contacts are faulted (Pirajno and Occhipinti, 1996; Occhipinti et al., 1998a,b). The Padbury Group probably represents a retro-arc foreland basin, as suggested by a detailed and regional-scale sedimentological study of the clastic succession exposed on MILGUN (Gee, 1990; Windh, 1992; Martin, 1992, 1994). The Bryah Group, together with the overlying Padbury Group, was probably emplaced as a large-scale thrust complex against and on top of the autochthonous Yerrida Group.

Deformation intensity and metamorphic grade typically increase from (south)east to (north)west in the Palaeoproterozoic basins. Regional deformation histories for the Bryah and Padbury Basins proposed by Gee (1990), Gee and Grey (1993), Windh (1992), Martin (1994), and Pirajno and Occhipinti (1998) all emphasized major north–south shortening. Recent regional mapping has resulted in the recognition of four distinct groups of structures (D_1, D_2, D_3, and D_4) that are not developed everywhere throughout the basins. This deformation history is in broad agreement with earlier structural histories proposed for the Capricorn Orogeny.

The chronological constraints on deposition and deformation are still poorly defined. Gee (1990) inferred a depositional age between 2.0 and 1.8 Ga, but recently Russell et al. (1994) reported a Pb–Pb isochron of 2258 ± 180 Ma for stromatolitic carbonate in the basal Juderina Formation of the Yerrida Group. Windh (1992) presented a Pb–Pb model age of 1920 ± 35 Ma for presumed syngenetic pyrite from a volcanic succession (Narracoota Formation, Bryah Group) at the Horseshoe Lights copper and gold mine on JAMINDI. Windh (1992) also inferred a maximum depositional age of 2.0 – 1.9 Ga for the regional quartz arenite marker in the Labouchere Formation (Padbury Group) from the youngest population of detrital zircons. Nelson (1997) inferred a maximum age for the Beatty Park Member of the Wilthorpe Formation (Padbury Group) of 1996 ± 35 Ma on the basis of the U–Pb age of a single, slightly abraded, detrital zircon crystal. This is compatible with a similarly derived maximum age for the underlying Ravelstone Formation (Bryah Group) of 2014 ± 22 Ma (Nelson, 1997).

Age constraints on regional deformation (and hence minimum age constraints on deposition) are provided by Palaeoproterozoic granites in the Narryer Terrane, which are interpreted to be synchronous with tectonic movements responsible for the strong north–south foliation in Padbury and Bryah Group rocks on MILGUN. The SHRIMP U–Pb zircon ages of these granites are reported as 1.9 Ga (Nutman et al., 1991) and c. 1.8 Ga (Windh, 1992). Pirajno and Occhipinti (1998) reported a Pb–Pb model age of 1.7 Ga for pyrite formed during late-stage gold

Table 1. Historical evolution of terminology for volcano-sedimentary basins in the northern Yilgarn Craton

Hall and Goode (1978)	*Gee and Grey (1993)*	*Windh (1992); Martin (1994, 1998)*	*Pirajno et al. (1996, 1998)*	
Nabberu Basin	Earaheedy Basin	Earaheedy Basin	Earaheedy Basin	
		Padbury Basin (peripheral foreland basin)	Padbury Basin (peripheral foreland basin)	
	Glengarry Basin		Bryah Basin (rift basin)	
		Glengarry Basin		
			Yerrida Basin	Mooloogool Subgroup (rift basin)
				Windplain Subgroup (sag basin)

mineralization at Mikhabura mine (on BRYAH). Windh (1992) obtained Pb–Pb ages of 1.9 – 1.8 Ga for pyrite and galena associated with late-stage gold deposition at the Nathans Deep South opencut mine. Windh (1992) concluded that deposition occurred at about 1.92 Ga and deformation between 1.9 and 1.8 Ga.

Tectonic models for the Palaeoproterozoic basins include development as ensialic or intracontinental basins (Gee, 1979; Hynes and Gee, 1986; Windh, 1992), as a back-arc basin above a southerly dipping subduction zone underneath the Yilgarn Craton (Tyler and Thorne, 1990; Myers, 1993), as obducted oceanic crust and volcanic arc (Myers, 1990, 1993), and as pull-apart basins under sinistral transpression during oblique convergence and collision between the Yilgarn and Pilbara Cratons (Pirajno et al., 1995a; Pirajno, 1996). Martin (1994) and Windh (1992) interpreted the Padbury Group as a retro-arc foreland basin developed during the early stages of shortening of the Bryah and Yerrida Basins after collision of the Yilgarn and Pilbara Cratons. This foreland basin developed by tectonic loading and crustal flexure when a northern continent was thrust over the Yilgarn Craton and the Bryah Basin from north to south.

On MILGUN the upper part of the Bryah Group (consisting of the Narracoota, Ravelstone, and Horseshoe Formations) and the lower part of the Padbury Group (Labouchere, Wilthorpe, and Robinson Range Formations) are exposed (Table 2). These rocks have been the subject of two recent detailed studies: a structural–stratigraphic interpretation, based on data collected mainly on MILGUN and adjacent areas while covering the remainder of the now superseded 'Glengarry Basin' in a reconnaissance manner (Windh, 1992) and, secondly, a sedimentological – sequence stratigraphic analysis focusing on the Padbury Group as exposed on MILGUN (Martin, 1994, 1998).

Windh (1992) and Martin (1994) clarified the relationship between the Padbury Group and the underlying Bryah Group, which had not previously been well defined (Gee, 1987; Gee and Grey, 1993). Distinct differences exist between the clastic lithologies of the two groups. Martin (1994) suggested a regional unconformity between the two, which is best illustrated by the low-angle cut-out of a magnetic banded iron-formation unit in the Horseshoe Formation against the base of the Labouchere Formation. Hynes and Gee (1986), Pirajno and Occhipinti (1998) and Occhipinti et al. (1998a) suggested tectonic contacts between the two groups on BRYAH and PADBURY. These interpretations are not necessarily incompatible because the Padbury Group was apparently deposited during initial stages of deformation in the Bryah Group, and subsequent deformation, with increasing intensity to the west, has resulted in several stages of tectonic reactivation of the contact.

The Ravelstone and Horseshoe Formations have a gradational transition from turbiditic, lithic wacke–siltstone to finely bedded ferruginous siltstone–shale with interleaved white chert layers or lenses and banded iron-formation. Good examples of this transitional contact may be seen immediately southeast of MILGUN in the Horseshoe Ranges on JAMINDI, as well as in the low hills east of the Fortnum mine. The Horseshoe Formation is characterized by a high manganese content, which is typically enriched in duricrusts of the laterite profile.

The mafic–ultramafic volcanic and intrusive rocks of the Narracoota Formation are interleaved on various scales with the Ravelstone Formation, and the underlying Karalundi Formation as has been noted on BRYAH (Pirajno and Occhipinti, 1998). On MILGUN the occurrences of mafic volcanic rocks, including strongly foliated mafic–ultramafic schists, with or without jasperoidal chert lenses, are interpreted as part of the Narracoota Formation (Martin, 1994). Several of the mafic volcanic schist occurrences are in apparent faulted or sheared contact with rocks of the Labouchere, Wilthorpe, and Robinson Range Formations. A fault-bounded segment of the Narracoota Formation has been delineated during mineral exploration at the Fortnum group of workings. Hill and Cranney (1990; and Cranney, P. J., 1995, pers. comm.) documented a succession of ultramafic to mafic schists, with or without jasperoidal chert lenses, overlain by fragmental volcaniclastic rocks, fine-grained siltstone, and felsic (intermediate and dacitic) crystal tuffs. These are in turn overlain by the Ravelstone and Horseshoe Formations.

Table 2. Stratigraphy of the Yerrida, Bryah, and Padbury Basins

Basin/Group	*Subgroup*	*Formation*	*Rock types*
Padbury Basin (retro-arc foreland basin)			
Padbury Group		Millidie Creek	Sericitic siltstone, chloritic siltstone, BIF, dolomitic arenite
		Robinson Range	Ferruginous shale, BIF
		Wilthorpe	Quartz pebble conglomerate, siltstone, wacke
		Beatty Park Member	Mafic siltstone and wacke
		Heines Member	Polymictic conglomerate
		Labouchere	Turbidite succession (quartz wacke, siltstone)
Unconformable contact — commonly tectonized			
Bryah Basin (rift basin)			
Bryah Group			
		Horseshoe	BIF, wacke, shale
		Ravelstone	Quartz lithic wacke
		Narracoota	Mafic–ultramafic volcanic and intercalated sedimentary rocks
		Karalundi	Conglomerate, quartz wacke
Faulted contact			
Yerrida Basin (sag and rift basin)			
Yerrida Group	Mooloogool Subgroup (rift-basin succession)	Maraloou	Black shale, siltstone, carbonate
		Killara	Mafic extrusive and intrusive rocks
		Doolgunna	Mixtite and clastic rocks
		Thaduna	Lithic wacke, siltstone, shale, minor arkose
	Windplain Subgroup (sag-basin succession)	Johnson Cairn	Siltstone, shale, carbonate, minor lithic wacke
		Juderina	
		Bubble Well Member	Arenite, conglomerate, minor carbonate
		Finlayson Member	Silicified carbonate with evaporites, arenite

SOURCES: Modified from Pirajno et al. (1996); data for Padbury Group from Martin (1994)

Prominent basalt – mafic schist occurrences are found in the area west of Mount Arapiles in the central-northern part of Milgun, and a lens with intermittent exposure and drill intersections west of the Kinders Fault, which can be traced from west of the Nathan Bitter mine shafts southward to the map sheet boundary (Fig. 3).

The Labouchere Formation, the lowermost formation in the Padbury Group, contains a turbiditic succession dominated by graded bedded quartz wacke and siltstone. The formation has a regional quartz arenite marker unit that forms a prominent ridge north of the Fortnum mine plant, and can be traced southward for tens of kilometres on to Jamindi and Bryah. Gradational transitions to the Wilthorpe Formation are found in the hills along the southern map sheet boundary, and north of Nathan Bitter mine. The Wilthorpe Formation is characterized by quartz-pebble to quartz-boulder conglomerate grading into quartz wacke and siltstone. Transitions from the Wilthorpe to the Robinson Range Formation show siltstone grading into ferruginous siltstone–shale with interleaved banded iron-formation. Martin (1994, 1998) erected a detailed, composite stratigraphic section based on numerous traverses for this succession.

The clastic rock types of the Bryah and Padbury Groups both record the filling in and shallowing of the Bryah and Padbury Basins. The major differences between the two basins lie in the different provenances and the presence of a major mafic volcanic succession in the former. These differences are important elements in the different tectonic models proposed for the basins.

In the southeastern part of Milgun, the rocks show disharmonic, tight to isoclinal folds about northerly trending axial planes, and pervasive foliation development. Increasing strain and metamorphism are recorded westward to the contact with the Archaean granitic rocks. This contact is characterized by tectonic interleaving on a regional scale (Fig. 5). The Billarra Fault bounds the westernmost occurrence of strongly deformed meta-sedimentary rocks, and the easternmost occurrence of Archaean granitoid rocks is limited by the Wilthorpe Fault — formerly known as the 'Wilthorpe Lineament' (Elias and Williams, 1980).

The northerly trending contact zone is abruptly terminated by the approximately easterly trending Coolinbar–Fortnum Fault, which juxtaposes Bangemall Group rocks against both the Narryer Terrane and the Bryah and Padbury Groups. Eastward, the main fault branches into several subsidiary faults that die out further east, suggesting scissor movements along the faults. The Fortnum Fault, the southernmost of these branching faults, strikes east-southeasterly and can be traced for about 15 km until it dies out. North of the Fortnum Fault, the

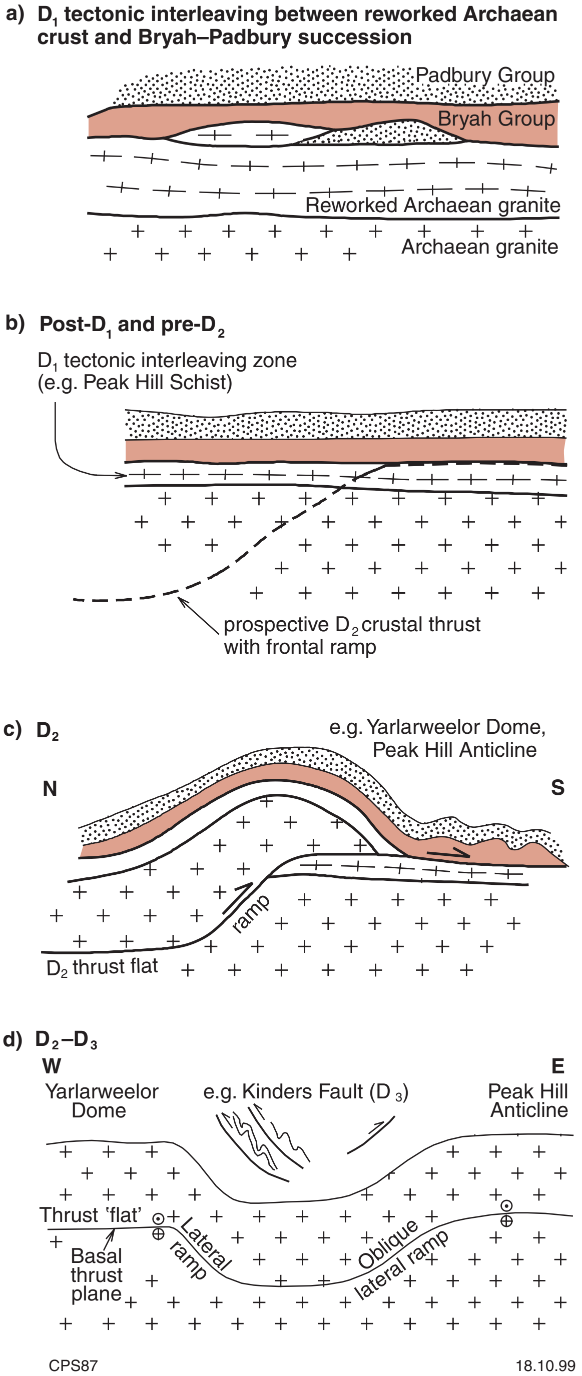

Figure 5. Schematic model for the structural development of the Bryah–Padbury succession: a) Zone of D_1 subhorizontal tectonic interleaving between reworked Archaean crust and overlying rocks of the Bryah–Padbury succession. This zone includes high-strain or mylonitic rocks; b) Post-D_1 geometry with trace of incipient D_2 crustal-scale thrust with frontal ramp; c) D_2 geometry with fault-bend fold developed above the crustal D_2 thrust ramp. The Peak Hill Anticline on BRYAH and Yarlarweelor Dome are interpreted to have developed this way; d) Geometry of the D_2 thrust fault, including frontal and lateral ramps. Also shown are the styles of D_3 north–south fold development between the two lateral ramps

Bryah and Padbury Groups successions are rotated towards a north-northwesterly strike. Unconformable contacts with the overlying Bangemall Group are locally preserved, but the contact zone is characterized by complex fault patterns, as well as local east–west folding of the Bryah and Padbury Groups parallel to the main fold direction in the Bangemall succession.

Palaeoproterozoic granitoid rocks (*Ᵽg, Ᵽgdn*)

Palaeoproterozoic granitoid rocks (*#g, #gdn*) are exposed at a few localities on MILGUN. Small dykes (*#g*) resemble the muscovite(–tourmaline)-bearing granite sheets that become increasingly more common towards the west in the Narryer Terrane. Windh (1992) described a 'muscovite-bearing granite sill within feldspathic gneiss' near a fenceline about 4 km west-northwest of Alarm Well (AMG 217984). This site lies within the variably foliated to gneissic Archaean granite (*Angn*) with scattered layers and lenses of BIF, gneiss, and amphibolite. The muscovite-bearing granitoid sill contains several zircon age populations of 3.4 – 3.3 Ga, 2.75 – 2.65 Ga, 2.2 – 2.1 Ga and c. 1.8 Ga (Windh, 1992). The youngest fraction was interpreted as representing the c. 1.8 Ga emplacement age of the muscovite-bearing granite. Windh (1992) correlated this granite sill with the Despair Granite, although it is not along strike as Windh (1992) claimed. This granite with coarse muscovite is interpreted herein as a Proterozoic granite or pegmatite lens (*#g*). Elsewhere, zones of coarse-grained and unoriented muscovite alteration of biotite are present locally within Archaean granitoids (*Angn*) and within Palaeoproterozoic quartz schists (*#Pl*). These zones of alteration may be related to nearby (i.e. ?subsurface) granitoid or pegmatite sills of Capricorn age.

Martin (1994, 1998) reported a small plug of granodiorite, rather than a more substantial pluton as suggested by Hanna and Ivey (1990), within quartz schist derived from quartz wacke 2.5 km south of the Labouchere opencut mine.

A medium-grained porphyritic granite (the Discretion Granite, *Ᵽgdn*) with well-developed tabular phenocrysts is mapped along the western boundary of MILGUN, and well exposed on MARQUIS (Sheppard and Swager, 1999)

Bryah Group

The upper three formations of the Bryah Group (the Narracoota, Ravelstone, and Horseshoe Formations) are exposed on MILGUN (Figs 1 and 6; Table 2).

Narracoota Formation (*ᏢAn, ᏢAnd, ᏢAne, ᏢAnu, ᏢAnc*)

The Narracoota Formation contains, in its type area, metamorphosed iron- and magnesium-rich tholeiitic (hyaloclastic) basalt, ultramafic rocks mainly preserved as schists, associated volcaniclastic and subvolcanic rocks, interflow sedimentary rocks including chert, and locally,

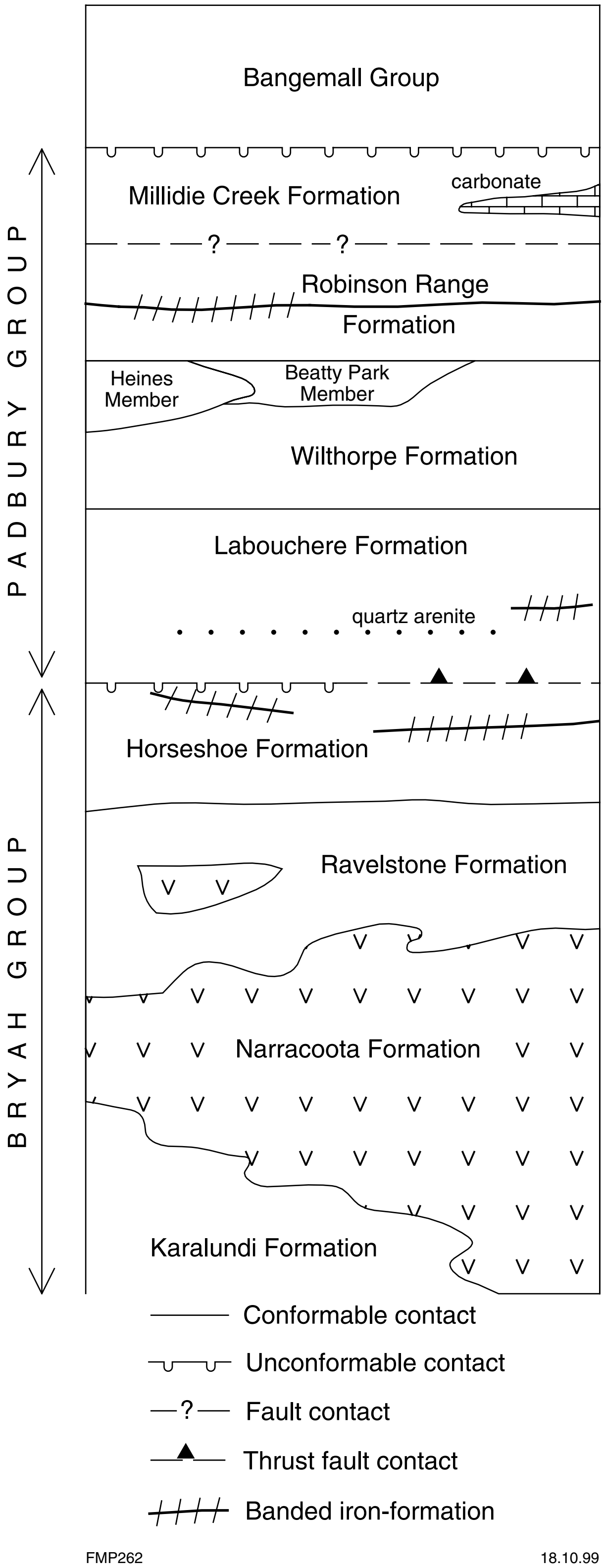

Figure 6. Stratigraphic column of Bryah and Padbury Groups as represented on MILGUN

at the top of the formation, felsic volcanic and volcaniclastic rocks (Hynes and Gee, 1986; Gee, 1987; Pirajno et al., 1998). Well-preserved mafic and ultramafic flows are found in the Dimble area on PADBURY (Hynes and Gee, 1986; Occhipinti et al., 1998a). The Narracoota Formation is overlain by, interfingers with, and locally forms lenses within the Ravelstone Formation. Recent mapping and mineral exploration on MILGUN (Windh, 1992; Martin, 1994) revealed several occurrences of (high-Mg) metabasalt and mafic schist that appear in faulted contact with rocks of the Padbury Group. Preserved volcanic textures and whole-rock geochemistry (high levels of MgO, Ni, and Cr, and rare earth element patterns — see below) suggest that these mafic rocks can be correlated with the Narracoota Formation. They include a continuous belt extending southward from Kinder Bore to the southern boundary of MILGUN. A similar lens was discovered by exploration drilling 4 km west of Gigbywabby Well, and extensive flat outcrops are present between Laurel and 4 Corners Wells. The westerly younging succession in the Fortnum mine area contains schistose mafic–ultramafic volcanic rocks that include coarse mafic fragmental rocks. They are overlain by crystal–lithic wacke–siltstone with quartz and feldspar crystals (?derived from felsic volcanic rocks) and mafic volcanic fragments.

The metabasalt (*ꝐAn*) shows relict igneous textures of prismatic plagioclase and interstitial amphibole and, more abundantly, unoriented prisms or acicular grains of fine- to medium-grained amphibole with interstitial and enclosed plagioclase. Sheaf-like aggregates of acicular amphibole are interpreted as primary igneous textures. A few plagioclase phenocrysts (3–5 mm in length) are preserved. The amphibole is colourless to pale-green pleochroic actinolite. The plagioclase is albite, and typically pseudomorphed by clinozoisite–epidote or sericitized in zones of alteration. Minor constituents include chlorite, quartz, and sphene–leucoxene, with local zones of massive epidote(–carbonate). Heterogeneously foliated metabasalt west of Nathans Deep South mine and east of 4 Corners Well contains 9.0 – 9.9% magnesium oxide.

Fragmental textures are locally preserved despite strong deformation. In the Fortnum mine area, mafic fragmental rocks, fine-grained mafic ?volcaniclastic rocks, and spatially associated jasperoidal chert pods or lenses are present within the volcanic succession. The fragmental rocks are strongly schistose, with flattened and stretched fragments and pebbles of chlorite schist, quartz–chlorite schist with plagioclase phenocrysts, and quartz–feldspar–amphibole rock (metabasalt), as well as medium-grained plagioclase grains and rare quartz crystals in a fine-grained matrix. Finely layered mafic schists consist of an amphibole–plagioclase matrix with scattered prismatic to ovoid plagioclase phenocrysts and quartz 'eyes'. Amphibole, accessory biotite, and sericite lenses have a strong preferred orientation, suggesting that recrystallization in these fine-grained rocks has destroyed any tuffaceous texture. Medium-grained doleritic-textured domains (*ꝐAnd*), as found in the high-strain zone east of the Billarra Fault, are shown separately on the map.

Very fine grained, grey–black metamorphosed shale and slate (*ꝐAne*) form lenses of interflow sedimentary rocks within the volcanic succession. Where more deformed and metamorphosed, these slates were converted into finely laminated biotite–chlorite schist.

Mafic and ultramafic schists (*ⱣAnu*) consist mainly of actinolite–tremolite, chlorite, and epidote, and are locally talc bearing in alteration zones. In high-strain zones, a complete new fabric is defined by alignment of amphibole prisms, elongate epidote, and quartz. These schists are commonly characterized by well-developed 'pencil cleavage' as a result of two intersecting pervasive fabrics.

Jasperoidal chert lenses (*ⱣAnc*) are a characteristic feature of the Narracoota Formation (Gee, 1987; Hill and Cranney, 1990; Pirajno and Occhipinti, 1998). The reddish to grey, massive to banded chert is extensively veined by quartz. The chert consists of very fine grained recrystallized quartz with equant to elongate polygonal–granoblastic textures, locally with a crystallographic preferred orientation. Minute opaque grains, locally including magnetite or pyrite, define trails parallel to the quartz foliation. In the Yarlarweelor opencut (Fortnum mine), pebbles of these cherts in overlying mafic fragmental rocks (Cranney, P. J., 1995, pers. comm.) suggest that the cherts formed as exhalative deposits related to volcanism rather than as secondary deposits in and along major shear zones. In the Yarlarweelor opencut the chert pods host epigenetic gold mineralization associated with quartz(–pyrite) vein systems (Hill and Cranney, 1990).

Windh (1992) recognized several types of chert within the now-superseded 'Glengarry Basin', of Gee and Grey (1993), and attempted to establish criteria to distinguish between: 1) syngenetic exhalative ferruginous chert — probably the most common type (diagnosed by its geological setting as described above); 2) silicified volcanic and sedimentary rock (high Ni–Cr values and preserved textures); 3) shear-zone-related occurrences (structural setting); and 4) surface silicification.

Whole-rock geochemistry of the mafic and ultramafic metavolcanic rocks on MILGUN (Table 3) and PADBURY has been used to establish their correlation with the type area of the Narracoota Formation on BRYAH (Hynes and Gee, 1986; Pirajno and Occhipinti, 1998). The rocks are Fe–Mg-rich subalkaline tholeiites with mixed MORB (mid-oceanic ridge basalt) – oceanic island and continental signatures on tectonic discrimination plots (Pirajno and Davy, 1996). Typical characteristics include high MgO levels, high Ni and Cr, moderate rare-earth element (REE) abundances, and flat REE patterns with weak Eu anomalies. Ultramafic rocks are komatiitic, and have low REE abundances. The Ti–Zr plots are not particularly diagnostic, and may only demonstrate the mafic–ultramafic character of the rocks (Martin, 1994).

Table 3. Whole-rock geochemistry of foliated high-Mg basalts, Narracoota Formation, Bryah Group

GSWA sample	*132787*	*132788*	*139131*	*139132*
Easting	*630625*	*630625*	*621200*	*621190*
Northing	*7198600*	*7198600*	*7215100*	*7215090*
		Percent		
SiO_2	50.16	52.36	49.77	50.76
TiO_2	0.37	0.27	0.81	0.77
Al_2O_3	14.06	13.73	14.29	13.56
Fe_2O_3	2.41	2.39	3.29	3.36
FeO	6.47	5.77	8.33	7.94
MnO	0.17	0.16	0.20	0.19
MgO	9.18	8.97	7.18	7.14
CaO	11.26	10.68	9.45	9.96
Na_2O	2.48	2.10	2.55	1.97
K_2O	0.06	0.07	0.18	0.35
P_2O_5	0.03	0.03	0.07	0.06
S	0.00	0.00	0.00	0.00
Total	**96.65**	**96.53**	**96.12**	**96.06**
		Part per million		
As	1.50	1.50	2.00	1.50
Ba	58.12	52.65	104.32	167.05
Ce	2.22	2.10	11.54	10.81
Cr	438.00	491.00	175.00	163.00
Co	53.00	53.00	65.00	55.00
Cu	65.00	162.00	117.00	128.00
Ga	10.00	10.00	13.50	13.50
Ge	438.00	491.00	175.00	163.00
La	0.77	0.86	3.95	3.73
Mn	1 320.00	1 290.00	1 540.00	1 490.00
Nb	0.00	0.00	2.00	1.00
Ni	171.00	196.00	135.00	123.00
Rb	0.00	1.00	3.00	5.50
Sc	54.00	48.00	57.00	54.00
Sn	2.00	0.00	4.00	2.00
Sr	53.00	62.00	75.00	166.00
V	212.00	189.00	290.00	268.00
Y	15.00	13.00	18.00	17.00
Zn	72.00	63.00	104.00	98.00
Zr	19.00	13.00	45.00	43.00
Pr	0.36	0.36	1.74	1.59
Nd	1.94	1.61	8.07	7.72
Sm	0.94	0.78	2.87	2.61
Eu	0.48	0.41	1.19	1.08
Gd	1.90	1.60	4.00	3.65
Tb	0.38	0.39	0.83	0.70
Dy	2.89	2.59	4.96	4.70
Ho	0.71	0.68	1.17	1.07
Er	2.22	2.14	3.28	3.04
Tm	0.34	0.38	0.56	0.46
Yb	2.32	2.21	3.11	2.79
Lu	–	–	0.53	0.42

NOTE: These analyses were carried out by ANUTECH Pty Ltd at the Australian National University INAX Laboratory. Major-element analyses were determined using a PW2400 spectrometer. Samples were fused into glass discs using a lithium borate flux consisting of 12 parts lithium tetraborate to 22 parts lithium metaborate. Apart from this flux change, the method follows that of Norrish and Hutton (1969). Trace-element analyses were carried out using a Phillips PW1400 X-ray fluorescence spectrometer following methods discussed by Chappell (1991) and on a Spectro energy-dispersive X-ray fluorescence spectrometer. The Spectro instrument uses polarized X-rays or monochromatic X-rays from secondary targets to achieve low backgrounds and therefore low detection limits. Instrumental neutron activation was completed using the method of Chappell and Hergt (1989)

Ravelstone Formation (*ⱣAr, ⱣArw*)

The Ravelstone Formation (*ⱣAr*), formerly known as the (western part of the) 'Thaduna Formation' (Gee, 1979, 1987), is poorly exposed in scattered low outcrops over a wide area north of the Fortnum mine. The formation contains turbidites, consisting of medium-grained, lithic and feldspathic wackes with interleaved siltstone. Lithic fragments include massive chlorite(–rutile) fragments derived from mafic precursors, chert, hematite–quartz-rich shale, as well as partly sericitized feldspar grains. Quartz grains are rounded to irregular in shape, and the biotite may be detrital in origin. Quartz, white mica, chlorite, and variable amounts of carbonate are part of the fine-grained matrix. The well-developed foliation is defined by aligned sericite, elongate quartz, and, to a lesser extent, feldspar grains, and mica seams. New muscovite flakes have grown along and across the foliation.

The volcanic rocks of the Narracoota Formation in the Fortnum mine area are overlain by graded bedded, lithic–crystal wacke and siltstone (*ᵽArw*). The wacke contains medium-grained to locally coarse-grained crystals of feldspar (plagioclase, minor K-feldspar) and quartz, as well as various fragments (fine metabasalt and chlorite) derived from mafic volcanic rocks. The feldspar crystals, which are strongly sericitized, dominate over quartz. The matrix consists of sericite–chlorite–quartz with or without carbonate. Other clastic rock types include fragmental layers with fine metabasalt debris, and graded chloritic siltstone containing plagioclase laths. The derivation of the mafic component is easily explained, but the well-preserved feldspar crystals suggest nearby granitic or felsic ?volcanic precursors. The mafic volcanic rocks of the Narracoota Formation contain no, or very few, feldspar phenocrysts. Several authors have suggested that the presence of medium-grained embayed quartz crystals indicates the proximity of felsic volcanic rocks (Hill and Cranney, 1990; Windh, 1992; Cranney, P. J., 1995, pers. comm.). Association of felsic volcanic rocks with the upper part of the Narracoota Formation has been documented at and around the Horseshoe Lights copper–gold mine, 29 km east of the Fortnum mine plant, on JAMINDI.

Horseshoe Formation (*ᵽAh, ᵽAhi*)

The Horseshoe Formation (*ᵽAh*) consists of finely laminated ferruginous (hematitic) shale and siltstone, and fine-grained quartz–feldspar wacke with interleaved iron formation and chert. Relatively high manganese contents are inferred from the abundant manganese oxide staining in weathered and lateritic rocks. Lateritic manganese ore has been mined east (in the Horseshoe Range) and south (at the Mount Padbury mine) of MILGUN. The lower contact with the Ravelstone Formation is gradational.

Gee (1987) recognized three units in the well-exposed hills of the Horseshoe Range on JAMINDI:

1) the lowermost unit consisting of regularly bedded wacke and shale, similar to the underlying Ravelstone succession, but finer grained, more calcareous, and containing less chlorite and more feldspar(–quartz), indicative of a granitic rather than mafic volcanic precursor (Gee, 1987);
2) a middle iron-formation unit with several banded iron-formation (chert–magnetite–stilpnomelane; white chert) horizons (*ᵽAhi*) intercalated with chloritic shale;
3) an upper unit of calcareous manganiferous shale and wacke. The prominent iron formation thins along strike on to MILGUN, but still forms ridges outlining a syncline northwest of Dandy Well. The lowermost unit is exposed on MILGUN in the low hills east of the Fortnum airstrip, where fine-grained, carbonate-cemented wacke and shale contain disharmonic-folded white chert lenses (2–12 cm thick) and more rarely seen discontinuous quartz–magnetite layers (2–3 cm thick).

Padbury Group

The Padbury Group on MILGUN is made up of the Labouchere, Wilthorpe, and Robinson Range Formations (Fig. 6; Table 2). Windh (1992) and Martin (1992, 1994, 1998) suggested that the Labouchere Formation unconformably overlies the Horseshoe Formation of the Bryah Group, basing this opinion on the regional geometry in the Fortnum – Dandy Well area. The regional unconformity is inferred from the low-angle truncation of an iron-formation marker unit in the Horseshoe Formation against the lowermost quartz wacke of the Labouchere Formation in the area south of Yarlarweelor Creek. North of the Fortnum Fault, iron formation within the Horseshoe Formation is nearly parallel to bedding in the Labouchere Formation. Elsewhere in the region, contacts between various formations of the Bryah and Padbury Groups are interpreted as unconformities (Windh, 1992) or, alternatively, as faults or shear zones (Pirajno and Occhipinti, 1998; Occhipinti et al., 1998a). Even at the proposed unconformity south of Yarlarweelor Creek, there is evidence for deformation, marked by highly siliceous rocks with a stretching lineation, although no movement indicators were found (Windh, 1992).

Martin (1994, 1998) proposed a formal stratigraphy for the lower Padbury Group based on detailed sedimentological studies in the southeastern and central parts of MILGUN. This formal stratigraphy replaced previous stratigraphic divisions (Barnett, 1975; Gee, 1979, 1987; Windh, 1992), and has since been expanded only to include two distinct lithostratigraphic units as members within the Wilthorpe Formation (Fig. 6; Occhipinti et al., 1998a). Martin (1998) interpreted the Labouchere and Wilthorpe Formations as an upward-coarsening, deep-water turbidite complex overlain by shales and iron formation of the Robinson Range Formation. The turbidites were derived by erosion from granite gneiss basement (Yilgarn Craton) and reworking of underlying sedimentary and mafic volcanic rocks in the Bryah Basin. The following descriptions are largely based on Martin (1994, 1998).

Labouchere Formation (*ᵽPl, ᵽPla, ᵽPli*)

The Labouchere Formation (*ᵽPl*) consists mainly of medium- to coarse-grained sericitic quartz wacke and sericitic siltstone, with minor conglomerate. Martin's (1994) type section is a composite stratigraphy (about 3500–4000 m thick) based on four separate sections in the southeastern part of MILGUN. Quartz wacke has a matrix-supported framework of variably rounded quartz grains, minor lithic fragments, and feldspar in a sericite–chlorite matrix, whereas laminated shale consists of sericite and chlorite. Wacke and siltstone form numerous upward-fining cycles.

Quartz arenite (*ᵽPla*) contains grain-supported, well-rounded quartz in a sericitic matrix and is extensively silicified. A prominent quartz arenite marker forms the ridge including Mount Labouchere north of the Horseshoe mining centre, and can be traced for many tens of kilometres to the southeast where, gradually, more quartz wacke is interbedded with the arenite. A second quartz arenite marker about halfway up the Labouchere Formation is mapped north of the Fortnum Fault. In the same area, an iron formation – chert layer (*ⱣPli*) is mapped about 250 m above this second quartz arenite marker. Martin (1994) emphasized that the deep-water chemical precipitation of this iron formation indicates a similar depositional environment for the clastic rocks.

Muscovite–quartz schist or slate *(ⱣPl)* has developed from quartz wacke and siltstone in zones of high strain and higher metamorphic grade adjacent to the Narryer Terrane. Strongly foliated quartz wacke and muscovite–quartz schist occupy a 4 km-wide zone between the Labouchere-Nathans mine and Billarra Fault. Another belt of schist and slate exists between the Billarra Fault and Despair Granite in the southwestern part of Milgun. These strongly foliated rocks can be traced northward into recognizable, though strongly foliated, pebbly quartz wacke. The fine-grained schist consists of elongate, polygonal–granoblastic quartz with spaced trails of aligned muscovite flakes. Bedding and cleavage are recognizable in less-deformed areas, whereas in high-strain zones, tectonic layering is present.

Wilthorpe Formation (*ⱣPw, ⱣPws*)

The Wilthorpe Formation (*ⱣPw*), formerly called the ‘Wilthorpe Conglomerate’ by Elias and Williams (1980), consists of quartz-pebble conglomerate, quartz wacke, and siltstone. Martin (1994) measured the type section (about 1300 m thick) along the Talbot Divide in the southern part of Milgun. In this area, the characteristic quartz-pebble conglomerate forms a prominent ridge to the east of hills underlain by the Robinson Range Formation (*ⱣPr*). In the Fortnum–Labouchere area, the exact location of the Labouchere–Wilthorpe Formation transitional boundary is less well defined. Along the western wall of the Nathans Deep South opencut, several upward-fining cycles of quartz-pebble conglomerate grading into quartz wacke and quartz–muscovite siltstone can be seen. These cycles are underlain by fine-grained chloritic shale interleaved with quartz wacke.

The conglomerate contains well-rounded, slightly elongate or faceted vein-quartz clasts, and, less commonly, chert, quartzite, and quartz wacke, as well as rare siltstone–mudstone clasts in a quartz wacke matrix. Clast sizes range from pebbles to boulders. Quartzite pebbles locally contain folded foliation fabrics. Metamorphosed siltstone forms a distinct mappable upper unit *(ⱣPws)* along the gradational contact with the Robinson Range Formation.

Robinson Range Formation (*ⱣPr, ⱣPri*)

The Robinson Range Formation (*ⱣPr*) consists of ferruginous or hematitic shale, with two iron formations (*ⱣPri*) — a well-defined, lower banded unit separated by about 100 m of ferruginous shale from an upper unit with clastic textures as mapped by Gee (1987) on Peak Hill. The upper contact of the Robinson Range Formation is not exposed on Milgun.

Palaeoproterozoic structure and metamorphism

A regional deformation history consisting of four phases has been recognized in the course of regional mapping of the Bryah and Padbury Groups (Table 4). These deformation phases are not developed everywhere with the same intensity. The earliest Capricorn Orogeny deformation events (D_1 and D_2) were defined on Bryah as D_1 subhorizontal, mylonitic thrust faults and recumbent folds, and D_2 upright, easterly striking regional folds (Pirajno and Occhipinti, 1998; Table 4). The D_1 and D_2 deformation events developed under north–south compression, and can be interpreted as successive stages during progressive deformation or, alternatively, as structures developed at the same time at different crustal levels: D_1 in Archaean basement rocks and along the basement–cover contact, and D_2 in the volcano-sedimentary cover succession at higher crustal levels.

On Milgun, small-scale, mostly intrafolial D_1–D_2 folds (overprinted by D_3 folds), are found in BIF and chert layers in the Horseshoe and Robinson Range Formations. Highly disharmonic D_1 and D_2–D_3 fold interference patterns are displayed by discontinuous white chert layers or lenses in the Horseshoe Formation, particularly in the area east of the Fortnum airstrip.

Several regional D_1–D_2 structures are inferred from structural–stratigraphic relationships; these structures were strongly reactivated during D_3 east–west compression. The main contact between the Horseshoe Formation and Labouchere Formation in the area south of the Fortnum mine was interpreted by Martin (1994, 1998) to represent the regional unconformity between the Bryah and Padbury Groups. This interpretation was based on the low-angle truncation of a magnetic unit in the Horseshoe Formation against basal quartz wacke of the Labouchere Formation south of Yarlarweelor Creek. However, chert and chert breccia with strong down-dip mineral lineation close to this contact may suggest at least some tectonic movement. Other contacts between the Bryah and Padbury Groups on Milgun and Padbury show strongly sheared mafic–ultramafic schists of the Narracoota Formation overlain by the Labouchere Formation, Wilthorpe Formation, or even the Robinson Range Formation (Occhipinti et al., 1998b). These contacts, with local interleaving, are interpreted as tectonic in origin and formed during D_1–D_2. The Padbury Group was most likely deposited during basin closure (i.e. during early D_1), and therefore major unconformities are expected. These unconformities were subsequently reactivated during continued D_1–D_2 deformation. Examples on Milgun include the Narracoota Formation – Labouchere Formation contacts near Laurel Well. Similar contacts along the Kinders Fault were strongly reactivated during D_3 (see below). Other smaller scale occurrences of infaulted slices of mafic–ultramafic schist or even

Table 4. Regional compressional deformation history of the Capricorn Orogeny in the Bryah and Padbury Groups as interpreted from the MILGUN, PADBURY, and BRYAH 1:100 000 sheets

MILGUN	*PADBURY* [(a)]	*BRYAH* [(b)]
D_4 east–west sinistral transpression or north-northeast–south-southwest compression; small-scale folds trending between 280° and 310°; shear zones,faults, with quartz blows; subvertical foliation	D_4 as for MILGUN; foliation or cleavage trending between 280° and 310°	–
D_3 east–west compression; north–south trending subvertical foliation — decreasing intensity to east; steep west-dipping faults or shear zones (thrust faults): Kinders Fault; reactivation of Wilthorpe Fault, Billara Fault; tectonic interleaving of Bryah Group and Padbury Group Eastwards: north-northeast to east-northeast trending folds, increasingly disharmonic	D_3 as for MILGUN; north–south to northeast–southwest folds,and west-dipping steep reverse faults	D_3 upright north–south and northeast– folds; southwest folds, intensity increases to west; gentle doming of F_2 folds
D_2 N–S compression; small-scale folds, mostly intrafolial	D_2 north–south compression, as for BRYAH; regional east–west upright folds Millidie Syncline	D_2 north–south compression; upright tight–isoclinal east–west folds; east–west shear zones Robinson Syncline, Peak Hill Anticline Fraser Synclinorium
D_1 tectonic juxtaposition of Padbury and Bryah Groups; tectonic interleaving of Padbury Group and ?Narryer Gneiss Terrane; rootless between Billara and Wilthorpe Faults	D_1 north–south compression, as for BRYAH; early isoclinal folds and microfolds; Fraser Synclinorium; initial juxtaposition Padbury Group over Bryah Group	D_1 north–south compression; subhorizontal east–west mylonites, thrusts, folds; mesoscale tight–isoclinal recumbent folds; mylonites in Peak Hill Schist

SOURCES: (a) Occhipinti et al. (1998a)
(b) Pirajno and Occhipinti (1998)

dolerite within folded, faulted, and strongly foliated Labouchere Formation can be interpreted in the same way (e.g. at the Labouchere-Nathans opencut mine; and east and south of Billarra Well).

Interleaving along the contact between the Palaeoproterozoic basins and Archaean basement, involving fault-bounded slices of strongly foliated Labouchere Formation with Narracoota Formation and the Despair Granite in places, is interpreted to have developed during D_1–D_2 north-to-south tectonic transport (e.g. Wilthorpe and Billarra Faults). This large-scale interleaving implies considerable amounts of tectonic transport.

The D_3 structures are responsible for the overall geometry of the Palaeoproterozoic rocks in the southeastern portion of MILGUN. They include regional folds with north–south axial surfaces (including the so-called Padbury Syncline, and the Horseshoe Syncline–anticline fold pair in the Ravelstone and Horseshoe Formations), a commonly well developed upright foliation, and major faults including the Kinders Fault. These structures indicate east–west compression during the D_3 deformation event. The deformation in the metasedimentary rocks is most intense along the contact with the Narryer Terrane, and is less intense and more disharmonic further away from the Narryer Terrane. On the adjacent JAMINDI, BRYAH, and PADBURY 1:100 000 map sheets, D_3 structures are only weakly developed and show more variable orientations. The formation of D_3 structures is thus related to distinct, areally restricted deformation in the Palaeoproterozoic succession overlying and against the Archaean basement (Myers, 1989, 1990; Gee, 1990; see below).

The Kinders Fault (Elias and Williams, 1980) separates mafic volcanic schists of the Narracoota Formation from the Robinson Range, Wilthorpe, and Labouchere Formation rocks, and lies along the sheared-out axial plane of the so-called Padbury Syncline (Elias and Williams, 1980; Martin, 1994). In fact, only the eastern limb of this syncline is preserved. Martin (1994, 1998) suggested a very steep southerly plunge as also shown by small-scale folds; however, these folds and S_3 cleavage may have formed late in the D_3 east–west shortening after initial tilting of the succession, and may not be representative of the regional fold plunge. Martin (1998) interpreted the Kinders Fault as a D_3 thrust fault along which older Narracoota Formation rocks were stacked up against the Padbury Group. The mafic schist wedge may represent an anticlinal fold-thrust wedge overlain to the west by strongly foliated Labouchere Formation quartz wacke. The mafic schist – wacke contacts can be interpreted as D_3 reactivations of D_1–D_2 faults.

Further west, sericite–quartz schist, locally with recognizable quartz-pebble conglomerate layers, is characterized along the Billarra Fault by a pervasive S_3 fabric, and folds are difficult to trace. East of the Kinders Fault, open to close and, locally, tight to isoclinal folds are outlined by the marker beds in the Labouchere and Horseshoe Formations. These increasingly disharmonic folds may be underlain by a hidden or blind detachment surface. The S_3 foliation and intermediate to steep southerly plunging small-scale folds are well developed in the area of the Horseshoe Syncline and further north. North of the Fortnum Fault, the S_3 foliation is rotated to a more northwesterly trend (e.g. in the lithic wacke of the Ravelstone Formation west of Duffey Well), and refolded into east–west orientations, (e.g. west of Curly Well, AMG 343129), during formation of the Mesoproterozoic Edmund fold belt.

Gee (1990), Gee and Grey (1993), and Martin (1994, 1998) suggested that the Narryer Terrane acted as an indentor block or a thrust sheet moving from west to east against and over the Bryah and Padbury Groups. Gee and Grey (1993) regarded this as a second (north–south) convergence phase associated with dextral movement in the Capricorn Orogeny. In the Gee and Grey (1993) model, the D_3 fold and fault structures were formed at this stage and died out eastwards, away from the thrust front (Table 5). Martin (1994) suggested that the change from north–south movements during D_1 and D_2 to localized east–west movements during D_3 can be interpreted as lateral escape tectonics during overall north–south shortening in the Capricorn Orogeny. Myers (1989, 1990) regarded both the Narryer Terrane and the Palaeoproterozoic volcano-sedimentary rocks as thrust sheets that were placed on the Yilgarn Craton basement. This stacked succession was subsequently folded about east–west axes. For all these models the driving force lies in the presumed collisional tectonics of the Capricorn Orogen. However, none of these models fully explains all observed geometrical constraints.

An alternative model (Fig. 5) is based on a striking regional structural feature. The zone of D_3 north–south folding is restricted to the 'depression' between two 'basement highs or domes', represented by the Narryer Terrane in the Yarlarweelor Dome and the Peak Hill Schist – Marymia Dome in the Peak Hill Anticline (Figs 4 and 5d; Pirajno and Occhipinti, 1998). Both Archaean basement domes have strongly sheared contacts with the Palaeoproterozoic cover succession that, nevertheless, wraps around these domes on a regional scale. The sheared contacts are interpreted to have formed as subhorizontal shear zones during D_1(–D_2) north–south shortening (Fig. 5b). With continued north–south shortening during D_2, the Archaean basement and Palaeoproterozoic succession, together with their D_1 sheared contacts, were deformed into fault-bend anticlines that developed above a mid-crustal frontal thrust ramp (Figs 5b and 5c). The 'depression' between the two basement-cored anticlines or domes was formed because of lateral ramps in the mid-crustal thrust plane. If the lateral ramps are oblique to the movement direction, then with continued movement an easterly compression will result in north–south striking folds (Fig. 5d). The D_3 fold and fault structures are interpreted to have developed in response to such localized east–west shortening through which the Kinders and Wilthorpe Faults developed or were reactivated as D_3 detachment faults. This interpretation is the basis for the cross section shown on MILGUN, where the belt of disharmonic D_3 folds is underlain by a detachment fault formed within ductile mafic schists of the Narracoota Formation.

This model is also consistent with the substantial uplift implied by the regional geology. The low-grade supracrustal rocks of the Bryah and Padbury Groups give way westwards to Archaean gneisses that experienced high-grade metamorphic conditions (up to granulite

Table 5. Compressional deformation histories proposed for different areas of the Yerrida, Bryah, and Padbury Basins

PEAK HILL 1:250 000 (Gee, 1987; Hynes and Gee, 1986)	*Basin-wide (Windh, 1992)*	*MILGUN 1:100 000 (Martin, 1994, after Gee, 1987; Windh, 1992)*	*Tectonic events, basin-wide (Gee and Grey, 1993)*
	D_3 north–south to north-northeast–south-southwest compression; west-northwest to west trending dextral kinks and subvertical small-scale folds; west-northwest trending dextral–reverse faults spatially related to Wilthorpe Fault	D_3 north–south compression; subvertical kinks; west-northwest trending crenulation cleavage; west-northwest trending reverse faults	
	D_2 north–south folds, axial plane foliation; decreasing intensity to east; west-dipping thrusts; uplift and east-directed transport of Gascoyne Complex	D_2 east–west compression, minor; north–south folds; upright axial plane foliation; west-dipping reverse faults	PHASE 3: second convergence (with dextral transcurrent movement) — emplacement of Narryer Gneiss Terrane
D_2 east–west folds, upright; axial plane cleavage; high angle thrusting; reactivation of Marymia Dome	D_1 north–south shortening; tight–isoclinal east–west folds; reverse shear zones; southward transport of Marymia Inlier	D_1 north–south compression; east–west isoclinal, upright folds; east–west reverse faults	PHASE 2: frontal north–south convergence — rise of Marymia Dome
Early recumbent folds (D_1); rise of basement domes predates Padbury Group			
			PHASE 1: early rifting (with sinistral wrench component)

facies) in the late Archaean and early in the Capricorn Orogeny (Williams, 1986; Muhling, 1988). This regional uplift (i.e. the fault-bend anticline now exposed as the Yarlarweelor Dome) occurred during the Capricorn Orogeny because, as demonstrated by Muhling (1988), early and late Capricorn Orogeny structural stages are characterized by granulite- and lower amphibolite-facies conditions respectively.

The D_4 deformation resulted in a variety of mesoscale structures that are found in a wide zone around the Narryer Terrane – Palaeoproterozoic supracrustal contact. This deformation apparently did not greatly influence the regional-scale geometry, although Elias and Williams (1980) suggested a west-northwesterly trending antiform (the 'Fraser Anticline') defined by the Narryer Terrane – Padbury Group contact on PADBURY and MILGUN. The D_4 structures include west-northwesterly trending subvertical foliations, shear zones, zones of small-scale folding, and faults outlined by quartz blows. These structures are commonly developed in the Archaean Despair Granite and other domains of the Narryer Terrane.

The lower to middle greenschist-facies assemblages in the Bryah and Padbury Groups are defined by local biotite-bearing assemblages in the metasedimentary rocks and by tremolite–actinolite(–epidote–chlorite) in the mafic schists. Windh (1992) inferred similar lower to middle greenschist-facies alteration assemblages associated with $(D_3–)D_4$ gold mineralization. The strongly deformed muscovite–quartz schist of the Labouchere Formation along the contact with the Narryer Terrane rocks locally contains staurolite, andalusite, biotite, and later stage (?)chloritoid (Martin, 1994, 1998; Occhipinti et al., 1998a). These upper greenschist- to lower amphibolite-facies assemblages record a higher grade marginal zone adjacent to the Narryer Terrane. Some textures indicate porphyroblast growth before the main contact-parallel foliation (D_2–D_3). These assemblages record probable uplift of the high-grade Narryer Terrane into the lower grade Bryah and Padbury Groups. Structural considerations (see above) suggest final emplacement late during D_2–D_3, but uplift started during early D_2.

Mesoproterozoic geology

Bangemall Group

The Mesoproterozoic Bangemall Group rests unconformably on, or is in faulted contact with, the Bryah and Padbury Groups and the Narryer Terrane. The basic stratigraphic framework (Elias and Williams, 1980; Muhling and Brakel, 1985) in the western part of the Bangemall Basin has not changed (Williams, 1990), and the reader is referred to Muhling and Brakel (1985) for more-detailed descriptions of the regional characteristics of the formations. The rocks in the western part are deformed into zones of tight, upright folding about east–west axes parallel to existing basement faults and intervening zones of broad open folds, forming the Edmund fold belt. A poorly constrained zircon U–Pb SHRIMP date of 1638 ± 14 Ma has been reported for the Tangadee Rhyolite in the lower Edmund Subgroup (or 'western facies') of the Bangemall Group (Williams, 1990; Nelson, 1995).

Formations of both the Edmund and Collier Subgroups (Muhling and Brakel, 1985) are found on MILGUN. The contact between these two subgroups is not exposed, although it appears that the Collier Subgroup unconformably overlies folded rocks of the Edmund Subgroup. Formations belonging to the Edmund Subgroup are exposed in the hills west of Milgun Homestead, at Coolinbar Hill, and in isolated smaller occurrences in the complex, faulted contact zone with the underlying basement rocks of the Narryer Terrane and the Bryah–Padbury Groups. The basal deposits of the Edmund Subgroup include quartz-pebble conglomerate followed by a transgressive marine succession and subsequent deeper water turbidites. Extensive dolerite sills and dykes intruded this succession. Several examples of the basal unconformity between foliated Palaeoproterozoic rocks and flat-lying quartz sandstone or conglomerate of the Tringadee Formation of the Edmund Subgroup are exposed. The succession is deformed into open to tight, upright, easterly trending folds, such as the Mount Arapiles Anticline (Fig. 3) and the anticline at Coolinbar Hill.

Shallowly dipping formations of the Collier Subgroup form the ridges and tableland of the Dunns Range, northeast of the Gascoyne River. Contacts between the Collier and Edmund Subgroups are hidden under the broad Gascoyne River valley. Muhling and Brakel (1985) interpreted the basal formation of the Collier Subgroup, underlying the well-exposed Backdoor Formation, as the Nanular Sandstone. However, this formation is here correlated with the Wonyulgunna Sandstone (*ꝒMw*).

Edmund Subgroup (*ꝒMe, ꝒMi, ꝒMj, ꝒMd, ꝒMv, ꝒMf*)

The Tringadee Formation (*ꝒMe*) is the basal unit containing conglomerate grading into regularly bedded quartz sandstone and wacke. Conglomerate pebbles, cobbles, and (locally) boulders consist of vein quartz, chert, and foliated quartz wacke. The basal unconformity with folded and foliated quartz wacke and siltstone of the Labouchere Formation is exposed in several localities; for example, 1.5 km east-northeast of the Labouchere-Nathans opencut mine and in the area west of Laurel Well.

The Irregully Formation (*ꝒMi*) contains layered dolomite, dolomitic shale, shale, carbonate–quartz sandstone, and local, thin white chert lenses. Small-scale erosional channels and cross-bedding are present. Stromatolites (?*Conophyton* as suggested by Elias and Williams, 1980) are present in the low ridges east of Coolinbar Hill in a succession dominated by quartz–feldspar–carbonate sandstone. Lower contacts are not exposed on MILGUN. South of Kay Bore the transition to the overlying Jillawarra Formation is marked by (?secondary) black chert and cream-coloured silicified shale.

The Jillawarra Formation (*ꝒMj*) consists of finely bedded siltstone, shale, and minor fine-grained sandstone.

This ferruginous, reddish-coloured package of rocks is well exposed in the hills east of Milgun Homestead. The formation grades into the Discovery Chert (*ᵽMd*), which consists of finely laminated light- and dark-coloured cherts and some interbedded shale. This formation, with a thickness of 50 to 80 m, is the best regional marker bed in the western Bangemall Basin and was most likely deposited as a silica gel (Muhling and Brakel, 1985).

The Devil Creek Formation (*ᵽMv*) contains finely bedded dolomite, dolomitic shale, and shale, and has a transitional lower contact with the Discovery Chert. The Nanular Sandstone (*ᵽMf*) is thought to conformably overlie the Devil Creek Formation, but lower contacts are not exposed on MILGUN. The formation is exposed in an open east–west syncline, and contains a thick succession of regularly bedded quartz arenite, feldspar–quartz arenite, poorly sorted feldspar–quartz wacke with minor interbedded quartz siltstone, and reddish-coloured shale.

Collier Subgroup (*ᵽMw, ᵽMb, ᵽMy*)

The exposures of the Collier Subgroup in the Dunns Range, in the northwestern part of MILGUN, represent the westernmost outcrops of this eastern facies. The lowermost unit consists of ripple-marked feldspar–quartz sandstone and minor shale, and is tentatively correlated with the Wonyulgunna Sandstone (*ᵽMw*), rather than with the Nanular Sandstone as suggested by Muhling and Brakel (1985). The outcrop patterns suggest that the sandstone is separated from the Edmund Subgroup succession by a major fault or unconformity underlying the broad valley of the Gascoyne River, and that the sandstone is part of the overlying Collier Subgroup succession.

The Backdoor Formation (*ᵽMb*) unconformably overlies the Wonyulgunna Sandstone elsewhere in the basin (Muhling and Brakel, 1985; Williams, 1990), although the contact is not exposed on MILGUN. The Backdoor Formation consists of mostly light coloured, layered to laminated siltstone, variably siliceous shale, and minor chert. The Backdoor Formation grades into the Calyie Sandstone (*ᵽMy*), which consists of medium-grained, light-grey quartz arenite with minor interbedded siltstone and shale. The resistant quartz arenite forms the high hills and plateau of the Dunns Range in northeastern MILGUN.

Other rock types in the Bangemall Group include unassigned finely layered, dark- and light-coloured chert (*ᵽMc*) and fine-grained gabbro(–dolerite) sills (*ᵽMo*) that are present on several stratigraphic levels within both the Edmund and Collier Subgroups.

Mesoproterozoic structure and metamorphism

Complex fault and fold patterns that are part of the Edmund fold belt mark the boundary between the Capricorn orogenic belt (i.e. the Narryer Terrane and Bryah–Padbury Groups) and the Mesoproterozoic Bangemall Basin. The regionally overlapping Fortnum–Coolinbar and Chalba fault systems are characterized by complex rotational movements. The faults bound blocks within which unconformable contacts between deformed older rocks and little-disturbed basal rocks of the Bangemall Basin are preserved. The Fortnum–Coolinbar fault system juxtaposes the Narryer Terrane against open to tightly folded Bangemall successions in the west, and splits up to the east into distinct separate faults that 'die out' along strike. The faults are thus characterized by rotational or scissor-type displacement to the west. A number of subsidiary faults can be inferred between the Fortnum–Coolinbar and Chalba fault systems on the basis of variations in structural trends such as fold orientations and magnetic trends. One east–west trending branch of the Chalba Fault system at Thomas and Watt Well juxtaposes the Discovery Chert against very strongly foliated granite (tentatively correlated with Archaean granites of the Narryer Terrane, but alternatively possibly of Capricorn Orogen age). A major fault-bounded uplift or horst may underlie the broad Gascoyne River floodplain in northwestern MILGUN. Magnetic signatures suggest deep-seated magnetic anomalies and a central westerly striking major fault within this fault block. The history of fault movements includes early extension during basin formation and contractional, rotational, and strike-slip movement during basin inversion.

Most close to tight folds of the Bangemall Group succession trend approximately east–west with a widely spaced, upright axial planar cleavage, although there are other fold orientations including northwesterly trending axial planes. These folds are all ascribed to the same phase of basin closure or deformation. Variations in fold intensity probably reflect basement fault control in the development of the fold belt (Muhling and Brakel, 1985).

North of the Fortnum–Coolinbar fault system, the Horseshoe–Labouchere Formation succession is folded about tight folds with northeasterly trending fold axes, and with accommodation faults in the hinges. The tight, multiple fold–fault pattern outlined by the quartz arenite marker in the Labouchere Formation is not mimicked in the underlying shale – BIF succession of the Horseshoe Formation, suggesting that a detachment surface developed between the two units during disharmonic folding. The fold geometry developed as part of the Edmund fold belt, but the question is whether the folds, in particular the main syncline, represent rotated F_3 folds of the Capricorn Orogeny or newly formed structures. An inferred, apparently unfolded, north-northwesterly striking unconformity overlying these folds to the west suggests that they are folds of Capricorn age that were reoriented during basin extension and closure (Martin, 1994, 1998).

An uplifted block of Narracoota Formation (Bryah Group) and overlying Labouchere Formation (Padbury Group) is exposed between Laurel Well and 4 Corners Well. The Palaeoproterozoic rocks are strongly foliated and folded, with the main foliation trending approximately east–west, and are overlain unconformably by units of shallowly dipping and open-folded quartz conglomerate of the Tringadee Formation.

Chert pods (ᵽPc), dolerite dykes (ᵽd), and quartz veins (ᵽq, q)

Small chert veins or pods (*#Pc*) are present within rocks of the Labouchere and Horseshoe Formations, and within the Wilthorpe Fault, which separates the Despair Granite from the Labouchere Formation. The origin of this unit is not known, but it may relate to structurally controlled hydrothermal activity, during or after deformation.

A swarm of easterly trending dolerite dykes (*#d*) intruded the granite gneiss of the Narryer Terrane and the Bryah Group in southern MILGUN. They are commonly fine grained, but locally contain small plagioclase phenocrysts. The majority of these dykes are interpreted from aeromagnetic anomalies, but a few outcrop in southwestern MILGUN.

Quartz veins (*#q*) are numerous and present within the area of dolerite dykes in southern MILGUN. Most of these veins intruded granite gneiss and have a northwesterly trend.

Numerous small quartz pods trend northwesterly, and are emplaced within mafic–ultramafic rocks of the Narracoota Formation and metasedimentary rocks of the Labouchere and Horseshoe Formations. One quartz pod (*q*) is associated with the Coolinbar Fault in western MILGUN. These quartz pods are probably the result of late hydrothermal activity related to the deformation events in the region.

Cainozoic geology

Areas of recent and active sedimentation are mapped as Quaternary (*Q*) deposits. Older and significantly dissected sediments are mapped as Cainozoic deposits. Ten Cainozoic units, including five Quaternary units, have been mapped on MILGUN.

Alluvial deposits (*Qa*) consist of silt, sand, and gravel in the main river channels and immediately adjacent floodplains. A few claypans (*Qac*) within the broad floodplains contain mainly clay, silt, and fine sand.

Colluvium (*Qc*) is composed of unconsolidated and consolidated rubble of bedrock, gravel, sand, and silt, and forms scree and thin sheets overlying and surrounding rock outcrops. Loose material overlies conglomeratic or gritty hardpan developed by induration and consolidation. Fine- to medium-grained quartz–feldspar sand derived by weathering and erosion of granite is mainly eluvial. In many localities, colluvium deposits contain considerable volumes of vein quartz debris spread over wide areas. Ferruginized rock rubble in colluvium (*Qcf*) is derived from highly weathered rock and laterite, and may contain ferruginous pisolites, degraded and transported laterite duricrust fragments, and ferruginized rock fragments. Alluvium and colluvium (*Qw*), consisting of unconsolidated sand, silt, and clay, are present in extensive sheetwash fans as part of broad drainage systems.

Sandplain deposits (*Czs*) include overlying low, anastomosing, windblown dune ridges of sand and silt that are commonly covered by low bushes.

Laterite (*Czl*) is a ferruginous pisolitic deposit, including ironstone duricrust and underlying saprolite, which developed in situ by weathering. The laterite commonly forms undulating plateaus representing old weathering surfaces. Laterite (and highly ferruginized zones) developed over rocks of the Horseshoe Formation are characterized by abundant dark-blue, metallic manganese staining. Locally, siliceous caps (*Czu*) have formed over ultramafic rocks northwest of the Nathans group of workings.

Silcrete (*Czz*) is subvitreous siliceous rock with small to large, angular to rounded quartz fragments. Several substantial deposits are found along the Fortnum–Coolinbar fault system. Calcrete sheets (*Czk*) are developed along the main river channels, and contain white carbonate and opaline silica deposits.

Economic geology

MILGUN lies within the Peak Hill Mineral Field and contains the Horseshoe mining centre. Three distinct zones of gold mineralization have been discovered on MILGUN. The Labouchere group (Labouchere and Central Valley deposits) and Nathans group (Labouchere-Nathans, Nathan Bitter, and Nathans Deep South deposits) were mined from the late 1930s to the early 1940s, with additional discoveries in the mid-1980s (Hanna and Ivey, 1990). The Fortnum deposits (Trevs, Starlight, Twilight, Ricks, Toms Hill, Alton, Eldorado, Callies, D39, and Yarlarweelor) were discovered in the early 1980s (Hill and Cranney, 1990). Active opencut mining and associated mineral exploration was being carried out at the Fortnum mine at the time of writing (June 1996).

Gold mineralization is commonly interpreted as epigenetic, and structurally controlled in host rocks of both the Bryah and Padbury Groups (Hill and Cranney, 1990). Windh (1992) concluded from detailed studies at the Labouchere-Nathans, Nathans Deep South, and Fortnum mines that aqueous fluids of high temperature and moderate salinity were responsible for mineralization. Constraints on temperature are derived from the lower to middle greenschist-facies alteration assemblages (muscovite–chlorite–albite(–biotite)) and fluid inclusion trapping temperatures up to 320°C. Based on lead isotope work (galena from the Nathans group of workings), Windh (1992) suggested that the syn-D_4 gold mineralization occurred between 1.9 and 1.8 Ga. The main features of the ore deposits are described below from the available literature.

At the Labouchere-Nathans mine, gold mineralization is hosted by pyritic chert lenses or pods that lie within mafic–ultramafic schist and along the contact with overlying quartz wacke of the Labouchere Formation. Windh (1992) described volcanic breccia (with high Ni and Cr) with fuchsitic ultramafic and chert clasts, similar to the reworked clastic rocks immediately overlying the mafic–ultramafic volcanic rocks in the Narracoota Formation, at the Fortnum mine. The mafic–ultramafic schist lies in the core of a southerly plunging anticline (Hanna and Ivey, 1990), and is here interpreted as part of the Narracoota Formation. The Narracoota–Labouchere Formation contact is interpreted as an early (D_1–D_2) fault or shear zone that was tightly folded during D_3. The structure is crosscut and slightly offset by west(-northwest) trending D_4 faults, including a shear zone that forms the southern limit to the mineralization (Hanna and Ivey, 1990). Gold is associated with quartz veining and pyrite in the altered chert, with siderite–muscovite–pyrite alteration around the veins (Windh, 1992). Production figures are only known for the combined output of the Labouchere-Nathans and Nathans Deep South opencuts (nearly 7 t of gold over five years; Table 6).

At the Nathans group of workings, the Nathan Bitter shafts within the upper Labouchere or lower Wilthorpe Formation have a recorded production of about 8 kg over the period 1943–50 (Table 6). About 500 m to the north-northwest, shallow shafts lie along the Kinders Fault between coarse and pebbly quartz wacke to the east, and ultramafic schist of the Narracoota Formation to the west. The Nathans Deep South mineralization lies about 1 km south-southeast of Nathan Bitter and was only discovered in 1986 (Hanna and Ivey, 1990). The mineralization is hosted by finely laminated, chloritic shale interbedded with coarse-grained quartz wacke and overlain by coarse units grading from quartz-pebble conglomerate to quartz–sericite shale. The entire succession is here described as part of the Wilthorpe Formation, including the chloritic shale, which is most likely derived from mafic volcanic precursors (Hanna and Ivey, 1990; Windh, 1992). The westerly younging succession contains a northerly trending S_3 foliation, axial planar to a few small-scale, parasitic D_3 folds plunging steeply south, and is overprinted by west-northwesterly trending F_4 microfolds and kinks. Gold mineralization is within pyrite, which has replaced finely bedded chlorite shale near crosscutting D_4 quartz–ankerite veins. The highest grades are found adjacent to D_4 faults. These and other structural observations led Windh (1992) to infer a syn-D_4 timing of mineralization. However, small quartz-vein networks, possibly related to low-grade mineralization, in the overlying coarse graded units are deformed by D_4 microfolds.

The gold mineralization at the Fortnum mine is hosted by the Ravelstone and Narracoota Formations; the latter is truncated to the north against the Fortnum Fault, and wedges out to the south. The package contains mafic–ultramafic schist with overlying reworked fragmental and volcaniclastic rocks, including rocks with a supposed felsic volcanic derivation, overlain by the Ravelstone Formation (Hill and Cranney, 1990).

Mineralization at Trevs (and closely associated orebodies, including a recent discovery named Starlight) is hosted by quartz-vein systems in a westerly dipping succession of graded sericitic siltstone and coarse wacke with medium- to coarse-grained feldspar, quartz, and lithic fragments, at least partly derived from the underlying mafic–ultramafic volcanic rocks. The Yarlarweelor mineralization is hosted by ovoid lenses of jasperoidal chert within variably schistose mafic–ultramafic volcanic rocks, including interleaved fine ?tuffaceous and coarse fragmental layers (Hill and Cranney, 1990). The chert lenses are within a westerly dipping reverse D_3 shear zone characterized by quartz–chlorite–sericite alteration. Gold-bearing quartz(–pyrite) veins within the chert pods and within magnetite-bearing chlorite schist trend east-southeasterly, dip steeply to the north, and are parallel to small, sinistral D_4 faults (D_3 in Windh, 1992). Windh (1992) also reported a minor set of east-northeasterly trending (dextral) faults crosscutting the D_3 shear zones. This may suggest a conjugate fault set recording east–west compression, possibly late during D_3 rather than during north-northeast–west-southwest D_4 compression.

Mining at the Fortnum group of workings from 1990 to 1998 yielded 11 928 kg of gold from 4.685 Mt of ore, with an average recovered grade of 2.54 g/t gold (Table 6). Remaining measured and indicated resources at Fortnum,

Table 6. Gold production recorded on Milgun

Mine/Group (Year)	AMG location Northing	AMG location Easting	Alluvial (g)	Dollied (g)	Production Ore (t)	Production Gold (g)	Total (kg)
Nathan Bitter (1943–50)	7199850	631200			776.22	8 213	8.21
Labouchere main lode	7204850	627800	484.27	395.32	3 958.34	16 862	17.74
Labouchere and Nathans Deep South (1989–94)	7199889	631696			2 886 025	6 936 064	6 936.06
Fortnum group (1990–98)	7197627	636372			4 685 224	11 928 462	11 928.46
Total			**484.27**	**395.32**	**7 575 983.6**	**18 889 601**	**18 890.5**

NOTES: All mines lie within the Horseshoe mining centre of the Peak Hill Mineral Field. Data are from the Department of Minerals and Energy including Trevs and Starlight, contain an additional 17 970 kg of gold, with a further 4340 kg of gold estimated within inferred resources (Perilya Mines NL, 1998).

Several manganese occurrences formed by enrichment in laterite overlying rocks of the Horseshoe Formation. No manganese production occurred on MILGUN, although several mines were developed on the adjacent PADBURY and JAMINDI sheet areas. MacLeod (1970) interpreted these deposits as fossil bog manganese ores formed from replacement of infillings in old drainage lines.

A minor malachite (copper) occurrence was noted by Elias and Williams (1980) in mafic rocks of the Narracoota Formation, west of Milgun Homestead.

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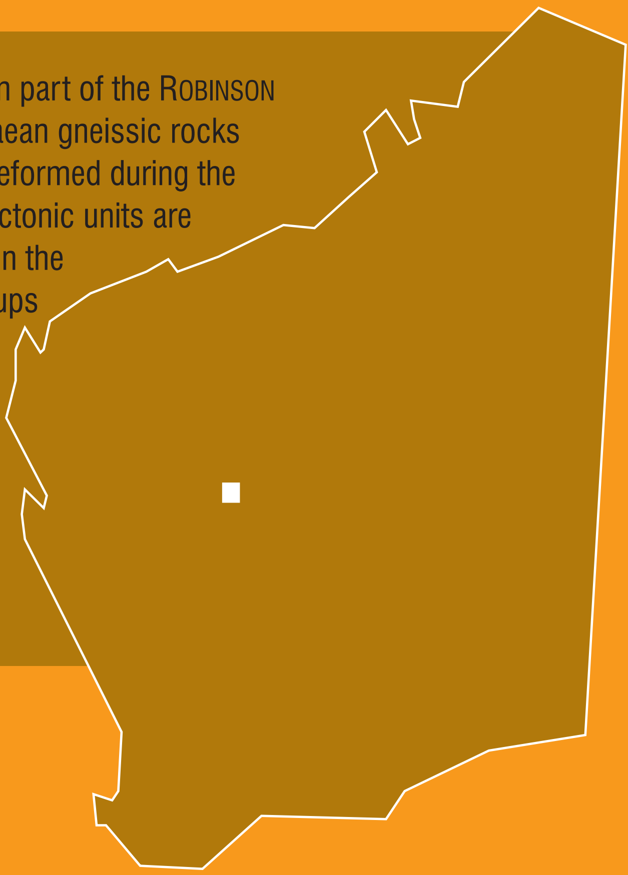
Appendix

Gazetteer of localities

Locality	*AMG coordinates* *Easting*	*Northing*
Alarm Well	621700	7198420
Alton opencut	636372	7197627
Billarra Bore	625240	7187240
Callies prospect	636193	7196552
Camel Bore	614600	7184520
Carlyon Bore	626480	7194820
Central Valley prospect	627680	7204110
Coolinbar Hill	601300	7210840
Curly Well	634180	7212960
D39	636663	7195962
Dandy Well	646400	7188740
Duffey Well	644100	7202800
Eldorado prospect	636800	7197280
Fortnum mine/plant	636372	7197627
Gigbywabby Well	644400	7188620
Kays Bore	618780	7229300
Kinders Bore	628770	7299700
Labouchere opencut	627730	7204710
Labouchere-Nathans mine	631696	7199889
Laurel Well	623940	7217520
Milgun Homestead	630700	7224200
Minnieritchie Well	605600	7196100
Mount Arapiles	625600	7222300
Mount Labouchere	630360	7212620
Nathan Bitter mine	631100	7199820
Nathans Deep South opencut	631713	7198812
O'Brien Well	606640	7215680
Ricks gold prospect	636266	7198305
Starlight/Twilight opencut	636693	7198914
Thomas (and) Watt Well	609330	7213940
Toms Hill opencut	637162	7198357
Trevs opencut	636412	7198887
Yarlarweelor (D43) opencut	636723	7196423
4 Corners Well	617730	7216030

The MILGUN 1:100 000 sheet covers the northeastern part of the ROBINSON RANGE 1:250 000 map sheet. MILGUN contains Archaean gneissic rocks and Palaeoproterozoic volcano-sedimentary rocks deformed during the Palaeoproterozoic Capricorn Orogeny. Three main tectonic units are represented: Archaean rocks of the Narryer Terrane in the west; the Palaeoproterozoic Bryah and Padbury Groups in the central and southern parts; and the overlying Mesoproterozoic Bangemall Group in the north. These Notes complement the 1:100 000 map sheet, and describe the geology, structural relationships, and metamorphic history of the area. Epigenetic gold mineralization is found at the Fortnum, Labouchere, and Nathans mining localities.



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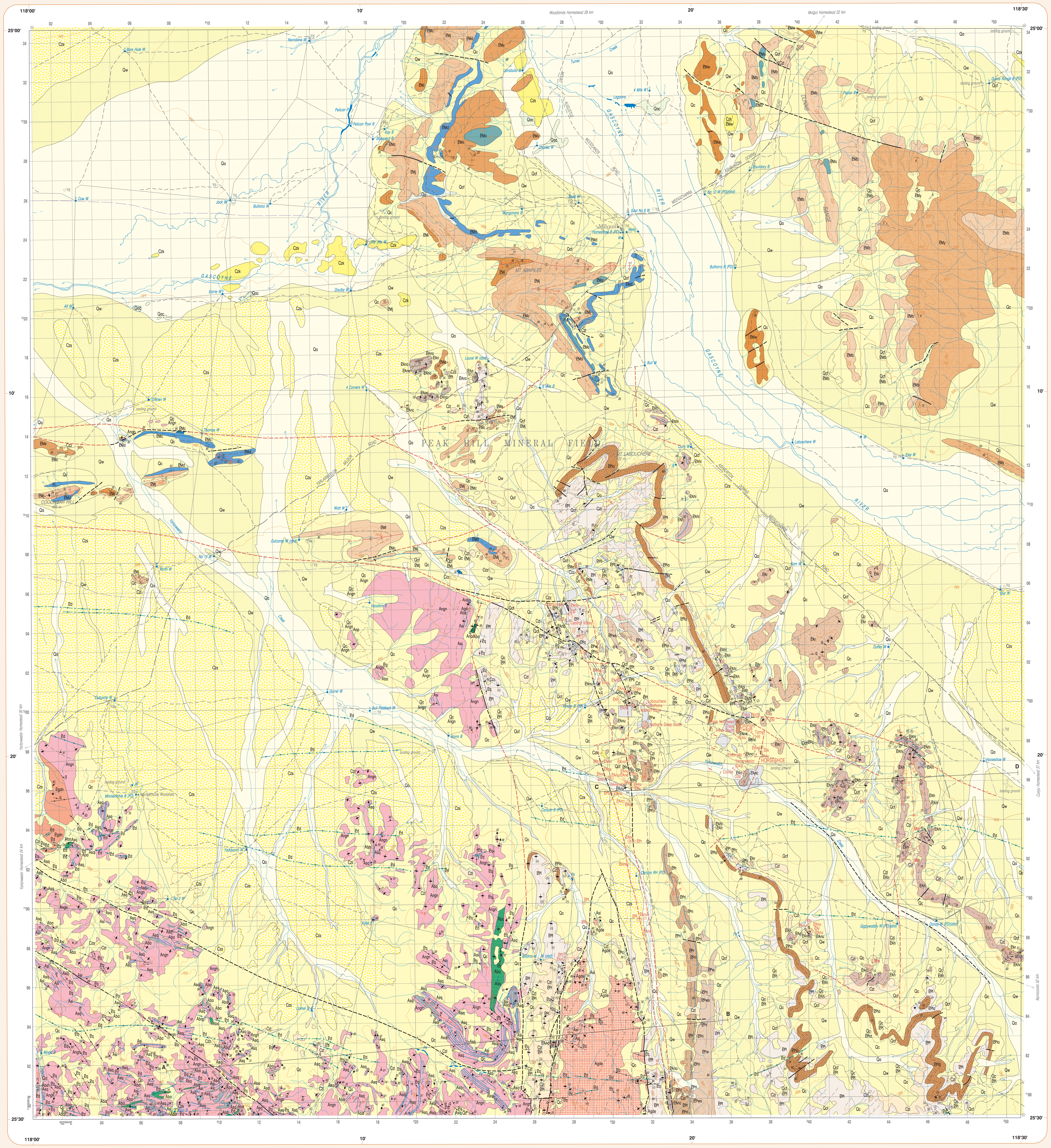
MILGUN

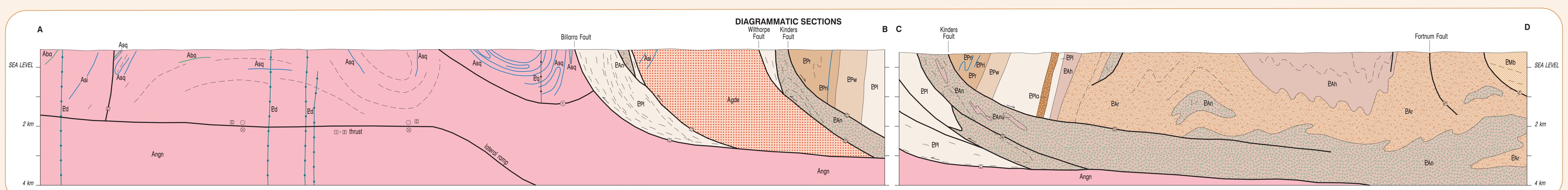
AUSTRALIA 1 : 100 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

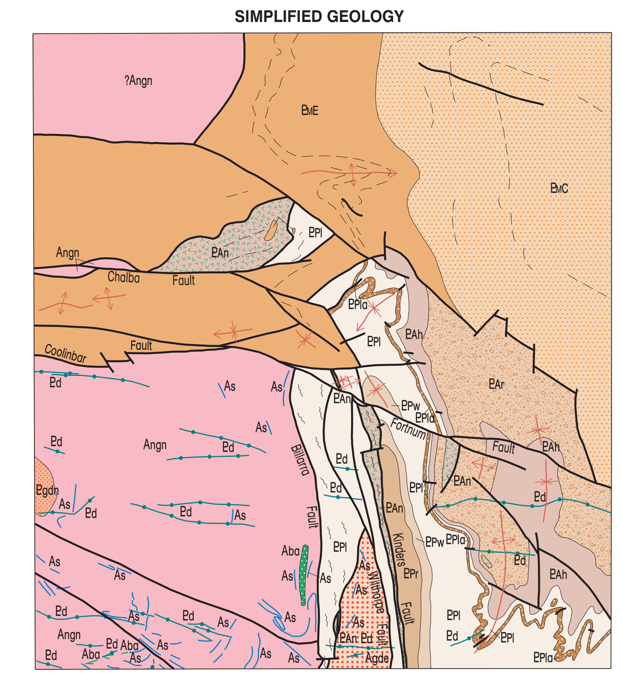
SHEET 2547



DIAGRAMMATIC SECTIONS



SIMPLIFIED GEOLOGY



Legend

PHANEROZOIC — CAINOZOIC — QUATERNARY

Qa Alluvium—gravel, sand, and silt in channels and floodplains
Qac Clay and silt in claypans
Qw Alluvium and colluvium—unconsolidated clay, silt, and sand as extensive sheetwash fans

Qc Colluvium—unconsolidated gravel, sand, and silt with extensive quartz vein debris; overlying rock or consolidated colluvium; includes quartz-feldspar sand over granite
Qcf Ferruginized rubble and colluvium, ferruginous pisolite, ferruginized rock, and degraded and transported laterite duricrust rubble

Czk Calcrete
Czl Laterite; ironstone duricrust and saprolite; duricrust debris overlying saprolite
Czs Sandplain deposits—sand; minor silt and clay; includes low, vegetated dunes
Czu Silica caprock over ultramafic rock
Czz Silcrete

PROTEROZOIC

q Quartz vein

Ᵽd Dolerite dyke, locally with small plagioclase phenocrysts; dashed where interpreted from aeromagnetic data: + positive magnetic anomaly, - negative magnetic anomaly

MIDDLE PROTEROZOIC — BANGEMALL BASIN

ᵽMc Chert, marker bed; unassigned

ᵽMo Dolerite-gabbro sill

Bangemall Group — Collier Subgroup

CALYIE SANDSTONE: quartz arenite; fine- to medium-grained

BACKDOOR FORMATION: grey to brown shale, with cream to grey laminated chert

WONYULGUNNA SANDSTONE: quartz arenite and feldspar-quartz arenite; minor shale

Bangemall Group — Edmund Subgroup

NANULAR SANDSTONE: feldspar-quartz sandstone with interbedded siltstone and shale

DEVIL CREEK FORMATION: bedded dolomite, minor shale and laminated chert

DISCOVERY CHERT: cream to black chert, finely bedded

JILLAWARRA FORMATION: siltstone and shale; minor chert, ferruginous

IRREGULLY FORMATION: dolomitic shale and dolomite, locally stromatolitic; quartz-carbonate sandstone

TRINGADEE FORMATION: pebbly quartz sandstone, conglomerate and siltstone

EARLY PROTEROZOIC

c. 1800 Ma

Granitic dyke; includes muscovite-bearing leucogranite and pegmatite

DISCRETION GRANITE: medium-grained, porphyritic biotite monzogranite; tabular phenocrysts of K-feldspar

Quartz vein, ranging from massive to foliated; associated with faults and shear zones

Padbury Group — PADBURY BASIN

< c. 2000 Ma

Chert, unassigned; metamorphosed

ROBINSON RANGE FORMATION: metamorphosed finely bedded ferruginous shale, siltstone, banded iron-formation, and chert

Metamorphosed banded iron-formation

WILTHORPE FORMATION: quartz pebble to boulder conglomerate; clasts include vein quartz and minor chert; quartz wacke and granite; quartz wacke and finely bedded siltstone, locally chloritic; graded beds; metamorphosed

Metamorphosed siltstone, finely bedded

LABOUCHERE FORMATION: metamorphosed quartz wacke and siltstone with local quartz pebble conglomerate beds; zones of pervasive foliation comprising quartz schist, muscovite-quartz schist, and minor biotite-muscovite schist locally with chloritoid, staurolite, andalusite or garnet

Metamorphosed banded iron-formation and ferruginous chert

Quartz arenite; minor interbedded quartz wacke and siltstone; metamorphosed

Bryah Group — BRYAH BASIN

< c. 2015 Ma

HORSESHOE FORMATION: metamorphosed ferruginous chloritic shale and quartz-feldspar wacke, partly manganiferous and calcareous; iron-formation and chert

Metamorphosed iron-formation, quartz-magnetite(-stilpnomelane); white chert lenses

RAVELSTONE FORMATION: metamorphosed lithic wacke and siltstone; chloritic fragments; graded beds (coeval and interbedded with NARRACOOTA FORMATION)

Lithic quartz-feldspar wacke; interbedded siltstone; thinly bedded, chloritic matrix; metamorphosed

NARRACOOTA FORMATION: metabasalt and mafic schist; locally plagioclase-phyric; includes metamorphosed mafic volcaniclastic rock (coeval and interbedded with RAVELSTONE FORMATION)
Dolerite, metamorphosed
Ultramafic and mafic schist; talc-chlorite(-quartz-carbonate) schist and actinolite-chlorite schist
Jasperoidal metachert, in lenses; contains irregular quartz veins
Grey to black slate, local biotite-chlorite slate; as interflow layers

ARCHAEAN — YILGARN CRATON — Narryer Terrane

c. 2650 Ma

Agde DESPAIR GRANITE: biotite granite, foliated to locally massive, with lenses of biotite schist, quartzite, banded iron-formation, and amphibolite

Angn Granitic gneiss derived from c. 3400–3000 Ma and c. 2700 Ma biotite monzogranite (both deformed by Late Archaean D_1–D_3), intruded by sheets and veins of granite and pegmatite (deformed by Late Archaean D_3)
Agd Granodiorite to diorite; heterogeneously foliated

Aci Metamorphosed banded iron-formation, quartz-magnetite rock
Aqq Quartzite, with minor cordierite and sillimanite
Aba Amphibolite; locally with clinopyroxene, mafic schist
Amp Clinopyroxene-amphibole-quartz-feldspar gneiss, amphibole-clinopyroxene gneiss, and calc-silicate gneiss, derived from mafic rocks
Au Metamorphosed ultramafic rock; undivided
Aup Peridotite, serpentinized

Symbols

Geological boundary
- exposed
- concealed
- interpreted, partly based on aeromagnetic data

Structural symbols are numbered according to their age of formation where known
(Archaean fabrics are unlabelled, except in sections)
- Middle Proterozoic
  - Edmund fold belt; unspecified
- Early Proterozoic
  - Capricorn Orogeny; unspecified
  - D_2, D_3, D_4
- Archaean
  - Yilgarn Orogeny; unspecified (sections only)

Fault or shear
- exposed
- concealed
- concealed, position uncertain
- concealed, interpreted from aeromagnetic data
- strongly foliated rock
- shear sense indicator; dextral, sinistral

Fold, showing direction of plunge
- anticline; exposed, concealed
- overturned anticline; exposed, concealed
- syncline; exposed, concealed
- minor fold, showing plunge
  - asymmetric, showing sense of vergence,
    - Z-vergence
    - S-vergence
    - fold axis

Small-scale fold axial surface, showing strike and dip
- inclined
- vertical

Small-scale fold axis, showing trend and plunge
- Z-vergence
- M-vergence

Bedding, showing strike and dip
- inclined
- vertical
- horizontal
- overturned

Way-up indicator
- pillow structure
- predominantly graded bedding, minor cross-bedding

Foliation, showing strike and dip
- inclined
- vertical

Cleavage, showing strike and dip
- inclined
- vertical

Lineation, showing trend and plunge direction
- mineral lineation
  - inclined
  - horizontal
- intersection lineation; inclined
- unspecified lineation

Fracture or joint, showing strike and dip
- inclined
- vertical

Airphoto lineament
- bedding or foliation trend

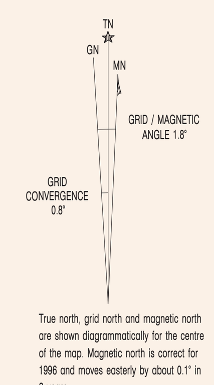
Aeromagnetic lineament
Stromatolite locality

Formed road
Track
Fence, generally with track
Homestead — Milgun
Building
Yard — Yd
Microwave repeater station
Horizontal control; major
Contour line, 20 metre interval — 420

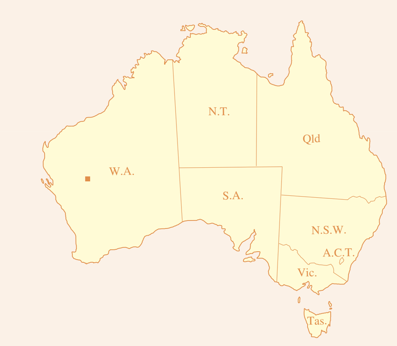
Watercourse, ephemeral
Pool — P
Rockhole — RH
Bore — B
Well — W
Windpump
Abandoned — (abd)
Position doubtful — (PD)

Mining centre — HORSESHOE
Mine (Gold, unless otherwise indicated)
Major opencut
Opencut
Prospect
Mining area
- opencut
- made ground
- tailings, slime dump

Mineral exploration drillhole, costean or pit showing subsurface data — ᵽPl
Mineral exploration drillhole line showing subsurface data — ᵽAnu
Mineral occurrence
- Copper — Cu
- Manganese — Mn



SHEET INDEX



CANDOLLE 2348	MOUNT EGERTON 2448	MULGUL 2548	CALYIE 2648	CARDAWAN 2748	WONYULGUNNA 2648
ERRABIDDY 2347	MARQUIS 2447	MILGUN 2547	JAMINDI 2647	THREE RIVERS 2747	MARYMIA 2847
GOULD 2346	MOORARIE 2446	PADBURY 2546	BRYAH 2646	DOOLGUNNA 2746	THADUNA 2846

ROBINSON RANGE SG 50-7 — PEAK HILL SG 50-8

1:100 000 maps shown in black
1:250 000 maps shown in brown

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SCALE 1:100 000

1000 Metres 0 1 2 3 4 5 6 7 8 9 10 Kilometres

TRANSVERSE MERCATOR PROJECTION
Grid lines indicate 1000 metre interval of the Australian Map Grid Zone 50

The Map Grid Australia (MGA) is based on the Geocentric Datum of Australia 1994 (GDA94)
GDA94 positions are compatible within one metre of the datum WGS84 positions

Reference points to align maps based on the previous datum, AGD84, have been placed near the map corners

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Cartography by D. Ladbrook
Topography from the Department of Land Administration Sheet SG 50-7, 2547, with modifications from geological field survey
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