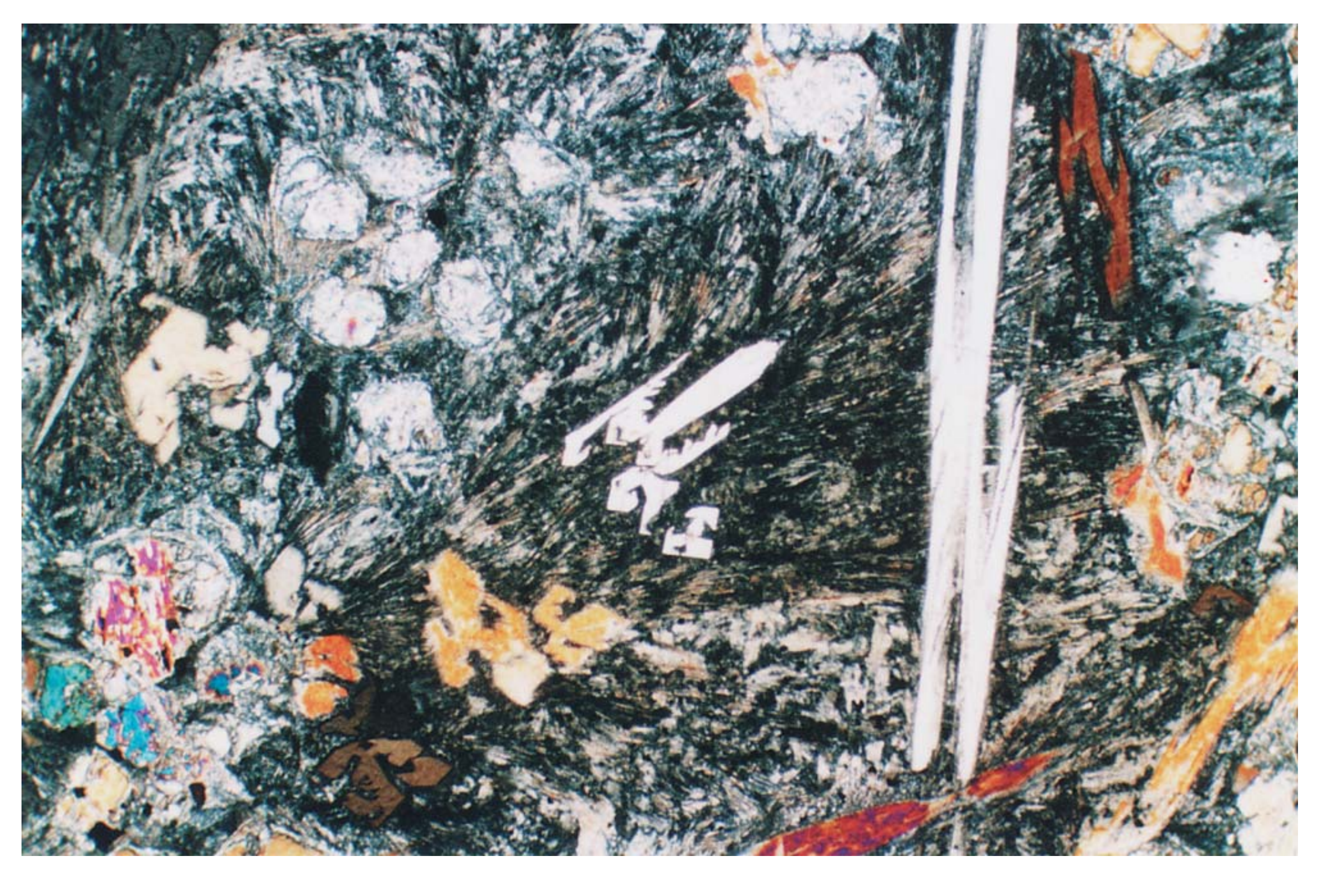
EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

GEOLOGY OF THE PADBURY 1:100 000 SHEET

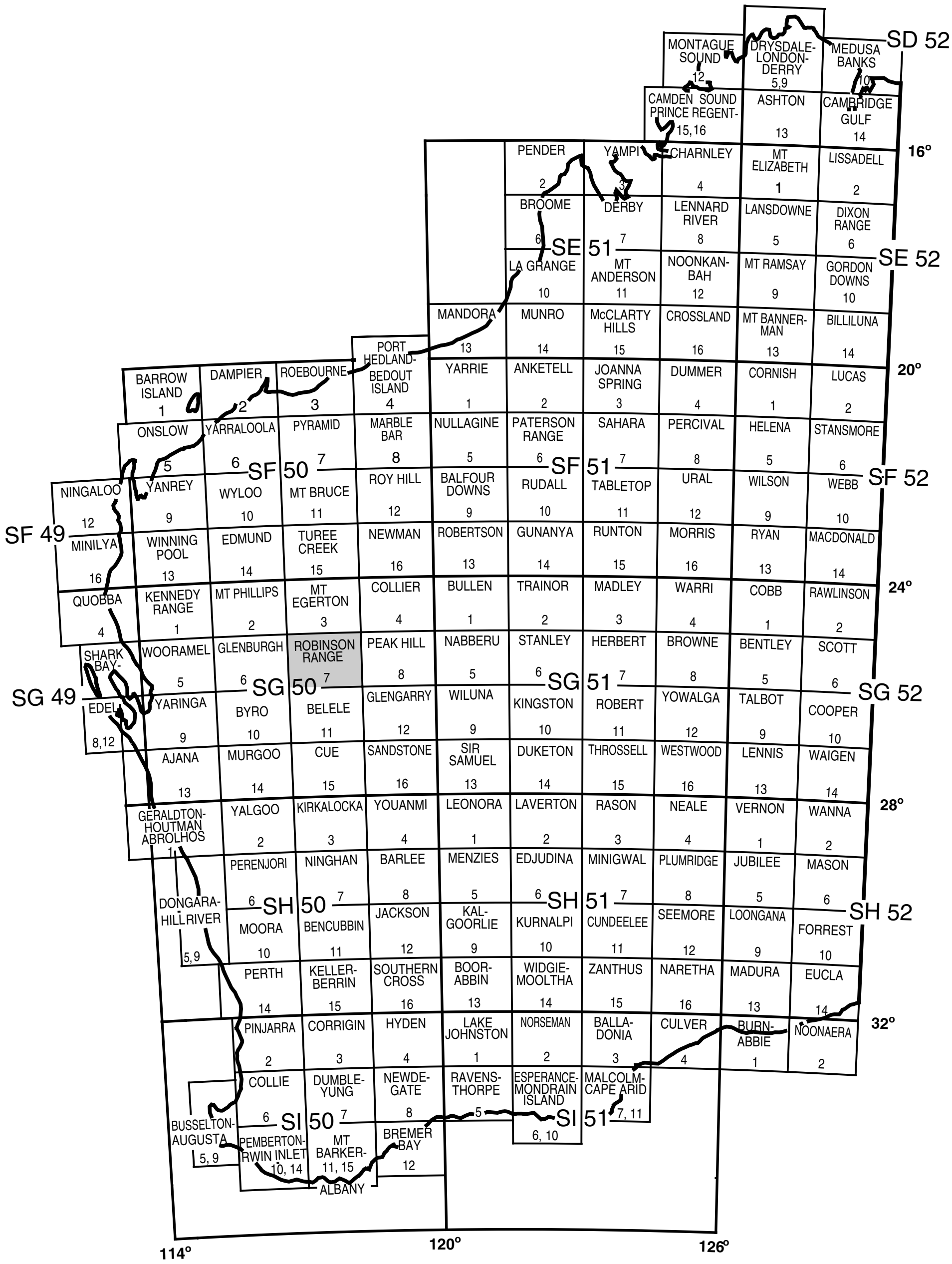
by S. A. Occhipinti, J. S. Myers, and C. P. Swager

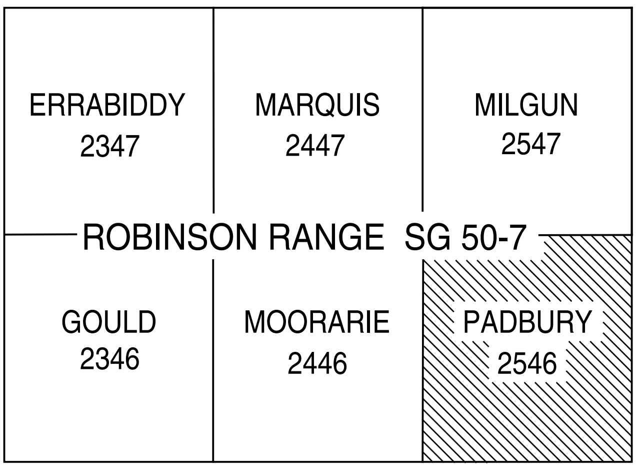
1:100 000 GEOLOGICAL SERIES



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY





CAS51

06.03.98

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF THE PADBURY 1:100 000 SHEET

by
S. A. Occhipinti, J. S. Myers, and C. P. Swager

Perth 1998

MINISTER FOR MINES
The Hon. Norman Moore, MLC

DIRECTOR GENERAL
L. C. Ranford

ACTING DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
David Blight

Copy editor: K. A. Blundell

The recommended reference for this publication is:

OCCHIPINTI, S. A., MYERS, J. S., and SWAGER, C. P., 1998, Geology of the Padbury 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 29p.

National Library of Australia Card Number and ISBN 0 7309 6585 6

ISSN 1321–229X

Cover photograph:

Photomicrograph (cross-polarized light) of komatiitic pyroxenite with skeletal amphibole prisms after a quench-textured pyroxene matrix.

Contents

Appendix

Figures

Tables

Geology of the Padbury 1:100 000 sheet

by

S. A. Occhipinti, J. S. Myers, and C. P. Swager

Introduction

The PADBURY[1] 1:100 000 sheet (SG 50-07, 2546) occupies the southeastern part of the ROBINSON RANGE 1:250 000 sheet and is bounded by latitudes 26°00'S and 25°30'S and longitudes 118°00'E and 118°30'E (Fig. 1).

PADBURY includes components of the Palaeoproterozoic Padbury, Bryah, and Yerrida Basins, the northern part of the Archaean Murchison Terrane (granites and greenstones of the Yilgarn Craton), the eastern part of the Archaean Narryer Terrane (high-grade[2] gneiss of the Yilgarn Craton), and a few isolated outliers of the Mesoproterozoic Bangemall Basin (Fig. 2).

The mapping of PADBURY is part of a mapping project that has subdivided the former Glengarry Group (Gee and Grey, 1993) into three distinct groups of rocks — the Yerrida, Bryah, and Padbury Groups — that formed in three separate basins: the Yerrida, Bryah, and Padbury Basins (Pirajno et al., 1996). The name Glengarry Group has therefore been abandoned. The Yerrida Group rests unconformably on the Archaean Yilgarn Craton and is in faulted contact with the Bryah Group. The relative age of the Yerrida and Bryah Groups is unknown. The Padbury Group is both unconformable on, and in faulted contact with, the Bryah Group.

The geology of PADBURY was previously described by Elias and Williams (1980). The general geology of the region was also discussed by Maitland (1898), Montgomery (1910), Johnson (1950), Cleverly (1965), Elias and Williams (1980), Gee (1979), Hynes and Gee (1986), Myers (1989), Windh (1992), and Martin (1994).

The nearest town to PADBURY is Meekatharra, located 82 km south-southeast of where the Mount Clere[3] – Meekatharra Road intersects the southern border of the map sheet. The unsealed, but well maintained, Mount Clere – Meekatharra Road connects with the Great Northern Highway and provides excellent access to the area. Station tracks provide good to reasonable access away from the main roads.

[1] Capitalized names refer to standard map sheets.
[2] In these Notes the terms 'high grade' and 'low grade' refer to the grade of metamorphism undergone by the rocks.
[3] Mount Clere is incorrectly spelt as 'Mount Clare' on the printed map.

Climate and vegetation

The PADBURY area has an arid climate, with a mean annual rainfall ranging between 190 and 240 mm. Cyclones and thunderstorms occurring between November and April provide summer rainfall. During the winter months, rain is associated with strong cold fronts from the southwest that are either combined with low pressure cells or interactive with tropical cloud bands from the north-northwest (Curry et al., 1994).

Vegetation in the area is diverse and depends on the condition of the pastoral land and proximity to drainage systems, and in some cases it is related to rock type. In the year of mapping, annual species of mulla mulla (*Ptilotus aervoides, Ptilotus exaltatus, Ptilotus macrocephalus, Ptilotus polystachyus*) and everlasting daisies (*Rhodanthe floribunda*) were abundant, particularly on flat floodplains. The purple mulla mulla (*Ptilotus exaltatus*) was also common on the scree slopes of Mount Padbury. Perennials such as flannel bush (*Solanum lasiphyllum*) were present, particularly in the northern and northwestern parts of PADBURY. Red grevillea (*Grevillea deflexa*), ghost gums, river red gums, and mulga (*Acacia aneura*) are locally abundant along drainage systems. Gidgee (*Acacia pruinocarpa*), miniritchie (*Acacia grasbyi*), and various other types of acacia are also abundant in the area (Mitchell and Wilcox, 1988).

Physiography and regolith

The Murchison River and its major tributaries, including Mount Fraser Creek, Dimble Creek, and several unnamed creeks, form the main drainage system on PADBURY. Mount Fraser Creek flows southward from the northern part of PADBURY. The creek is steep sided and contains pools in the vicinity of Beatty Park Bore.

Hills formed by Palaeoproterozoic iron-formations are prominent features of PADBURY. The main ridges incorporate Mount Padbury and Mount Fraser, to the west and east of Mount Fraser Creek respectively. Outcrops of the gneissic Narryer Terrane and the Murchison granite–greenstone rocks form rolling hills that rise above the flat landscape of colluvium and alluvium that surrounds them.

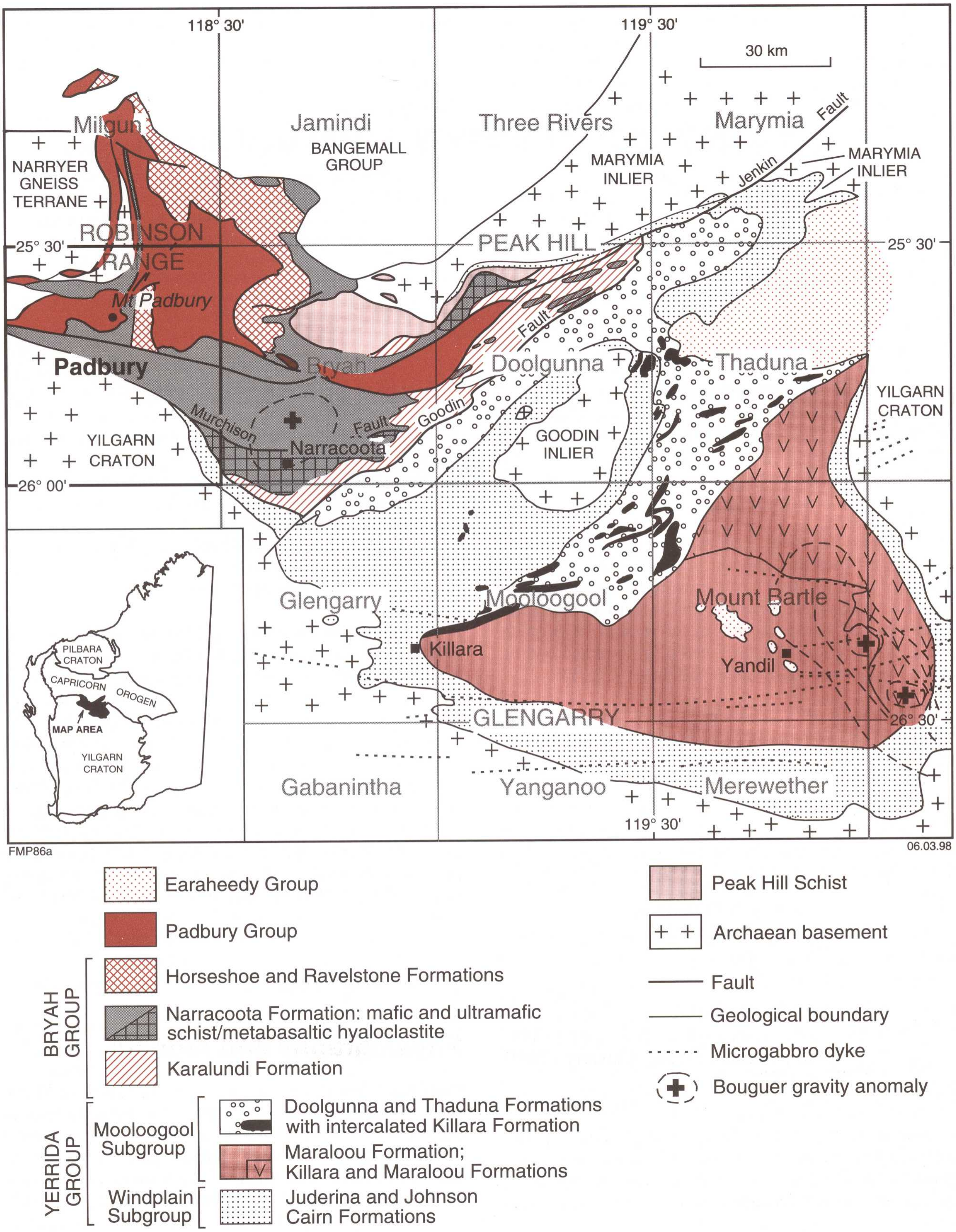


Figure 1. **Simplified geology of the Palaeoproterozoic basins showing the distribution of the Yerrida, Bryah, and Padbury Groups, and the 1:250 000 and 1:100 000 map sheets. Modified from Pirajno et al. (1996)**

Alluvial deposits (*Qa*) consist of sand, gravel, and silt in the main river channels and on floodplains. Colluvium (*Qc*) is prominent around the iron-formation hills and other rock outcrops. In flat areas and on gentle slopes, most colluvium forms a thin veneer, of angular or rounded rock fragments within sand or silt, over rock or consolidated colluvium (referred to as *Czc*).

Sheetwash deposits of alluvium and colluvium (*Qw, Cza*) comprise sand, silt, and clay. Where colluvium is dominated by quartz vein debris it is referred to as *Qcq* or *Czcq*.

Laterite (*Czl*) mainly consists of ironstone duricrust. Over manganese-rich rocks, such as those around the Elsa Mary manganese mine, this duricrust typically contains high concentrations of manganese. Ironstone rubble (*Qcf, Czf*) has developed over iron-rich rocks and is especially abundant in the southeastern part of PADBURY. This rubble comprises highly ferruginized and weathered rock (including laterite) and transported fragments of lateritic duricrust.

Claypans (*Qac*) and calcrete (*Czk*) are well developed along the Murchison River and some of its tributaries. Calcrete is particularly well developed over amphibolite and calcium-rich rocks. Chalcedony caps ultramafic rocks (*Czu*) in the western part of PADBURY. In the central part of PADBURY, siliceous and chalcedonic materials are adjacent to manganiferous sedimentary rocks and have developed as a cap to either the sedimentary rocks or buried ultramafic rocks.

Geological setting

PADBURY covers the southernmost part of the 400 km-wide Palaeoproterozoic Capricorn Orogen that resulted from the collision and amalgamation of the Archaean Pilbara and Yilgarn Cratons (Tyler and Thorne, 1990; Myers 1993).

Prior to the episode of continental collision marked by the Capricorn Orogen, Palaeoproterozoic shelf deposits were laid down on the rifted continental margins of the Pilbara and Yilgarn Cratons. These shelf deposits constitute the lower part of the Wyloo Group on the margin of the Pilbara Craton and the lower part of the Yerrida Group on the margin of the Yilgarn Craton. Other Palaeoproterozoic sedimentary and mafic rocks that were deposited on the northern part of the Yilgarn Craton include the Bryah and Padbury Groups. These groups were deposited in rift- and foreland-basin settings respectively. The Palaeoproterozoic rocks were deformed in fold-and-thrust belts during the Capricorn Orogeny.

The centre of the orogen, northwest of PADBURY, is dominated by granite plutons and high-grade granitic gneiss with interleaved supracrustal rocks (collectively known as the Gascoyne Complex — Williams, 1986).

Further south, at the margin of the Yilgarn Craton on PADBURY, autochthonous supracrustal rocks (Yerrida Group) were overridden by high-angle thrusts carrying the supracrustal rocks of the Bryah Group and overlying parautochthonous rocks of the Padbury Group (Figs 1 and 2). In the northern part of PADBURY, tectonic slices of basement are interleaved with the supracrustal rocks of the Bryah Group.

The northwestern part of the Yilgarn Craton, which forms the basement to these Palaeoproterozoic supracrustal rocks, is composed of two terranes: the Murchison and Narryer Terranes. These terranes represent parts of two different rafts of continental crust that were amalgamated at c. 2650 Ma (Myers, 1993, 1995). The Murchison Terrane mainly consists of low-grade granites and greenstones that formed between 3000 and 2650 Ma. In contrast, the Narryer Terrane contains extensive remnants of 3730–3300 Ma granitic gneisses that are interleaved with late Archaean supracrustal rocks and extensively intruded by sheets of granite. The Narryer Terrane was subjected to intense deformation and high-grade metamorphism during late Archaean amalgamation with the Murchison Terrane.

Archaean geology

Narryer Terrane

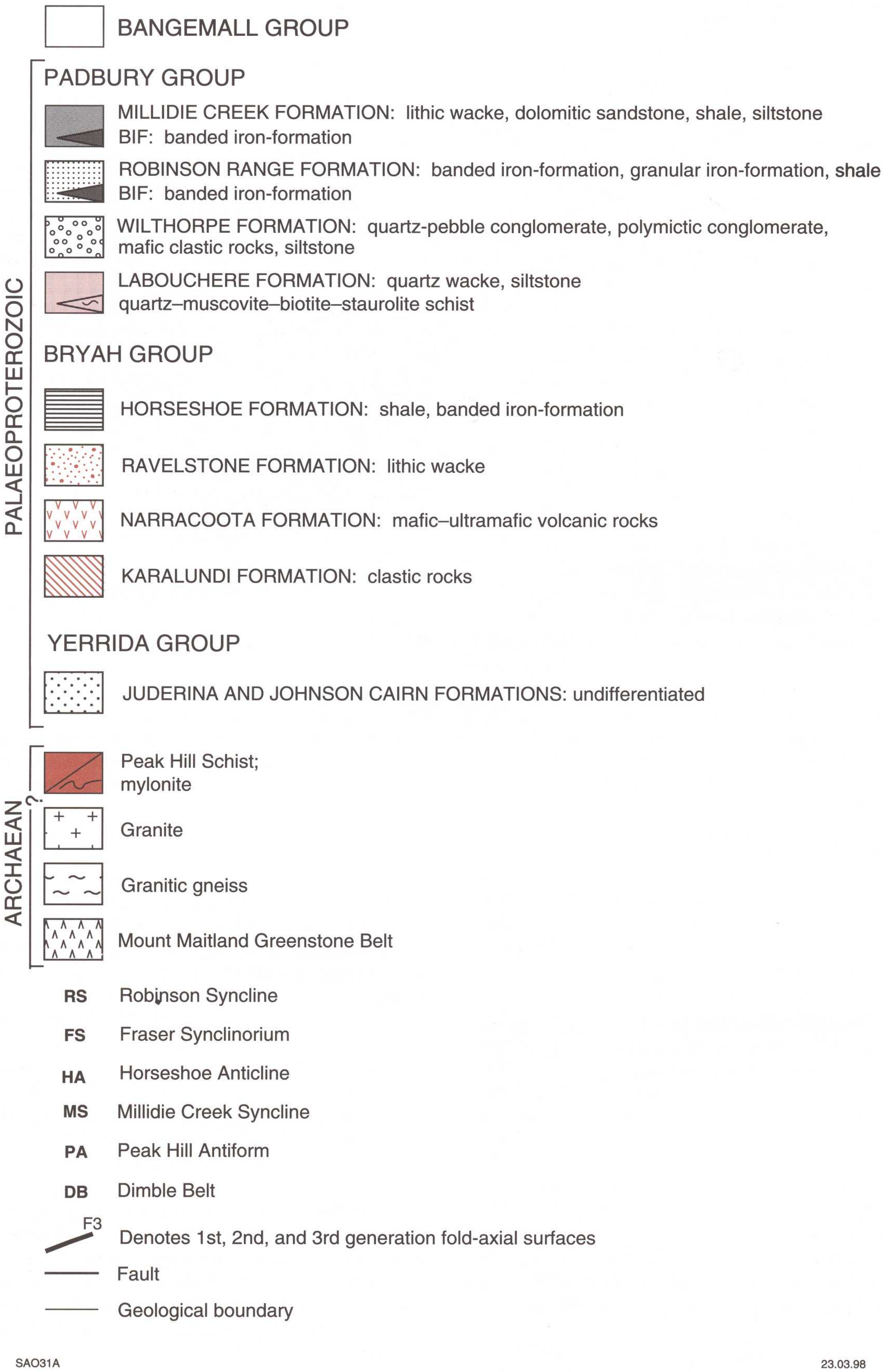
The Narryer Terrane in the northwestern part of PADBURY largely consists of late Archaean granite (Le Maitre, 1989) and granitic gneiss containing numerous thin layers of supracrustal rocks. The granite and granitic gneiss are mostly monzogranitic in composition. The rocks were repeatedly subjected to deformation and high-grade metamorphism during the late Archaean. No isotopic ages have been determined on PADBURY, and the inferred age of these rocks is based on extrapolation from similar rocks to the west and southwest, where limited Sensitive High-Resolution Ion Microprobe (SHRIMP) U–Pb isotopic dating of zircons has been carried out (Kinny et al., 1988, 1990; Nutman et al., 1991; Weidenbeck, 1992).

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

On PADBURY, supracrustal rocks of the Narryer Terrane lie within granite and granitic gneiss as layers ranging from a few centimetres to a few hundred metres in thickness. 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 (the oldest known traces of terrestrial rocks) to c. 3100 Ma (Froude et al., 1983; Compston and Pidgeon, 1986; Nutman et al., 1991). These quartzites and spatially associated supracrustal rocks are therefore thought to be late Archaean deposits.

Quartzite (*Asq*) is the most abundant supracrustal rock of the Narryer Terrane on PADBURY. It is most abundant in a zone that stretches from about 4 km northwest of Paddy Bore to about 500 m north of Ti Tree Bore*. Most

* Ti Tree Bore is incorrectly spelt as 'Tritree Bore' on the printed map.


BANGEMALL GROUP
PALAEOPROTEROZOIC
PADBURY GROUP
MILLIDIE CREEK FORMATION: lithic wacke, dolomitic sandstone, shale, siltstone
BIF: banded iron-formation
ROBINSON RANGE FORMATION: banded iron-formation, granular iron-formation, shale
BIF: banded iron-formation
WILTHORPE FORMATION: quartz-pebble conglomerate, polymictic conglomerate, mafic clastic rocks, siltstone
LABOUCHERE FORMATION: quartz wacke, siltstone
quartz–muscovite–biotite–staurolite schist
BRYAH GROUP
HORSESHOE FORMATION: shale, banded iron-formation
RAVELSTONE FORMATION: lithic wacke
NARRACOOTA FORMATION: mafic–ultramafic volcanic rocks
KARALUNDI FORMATION: clastic rocks
YERRIDA GROUP
JUDERINA AND JOHNSON CAIRN FORMATIONS: undifferentiated
ARCHAEAN
?
Peak Hill Schist;
mylonite
Granite
Granitic gneiss
Mount Maitland Greenstone Belt
RS Robinson Syncline
FS Fraser Synclinorium
HA Horseshoe Anticline
MS Millidie Creek Syncline
PA Peak Hill Antiform
DB Dimble Belt
F3 Denotes 1st, 2nd, and 3rd generation fold-axial surfaces
Fault
Geological boundary
SAO31A
23.03.98

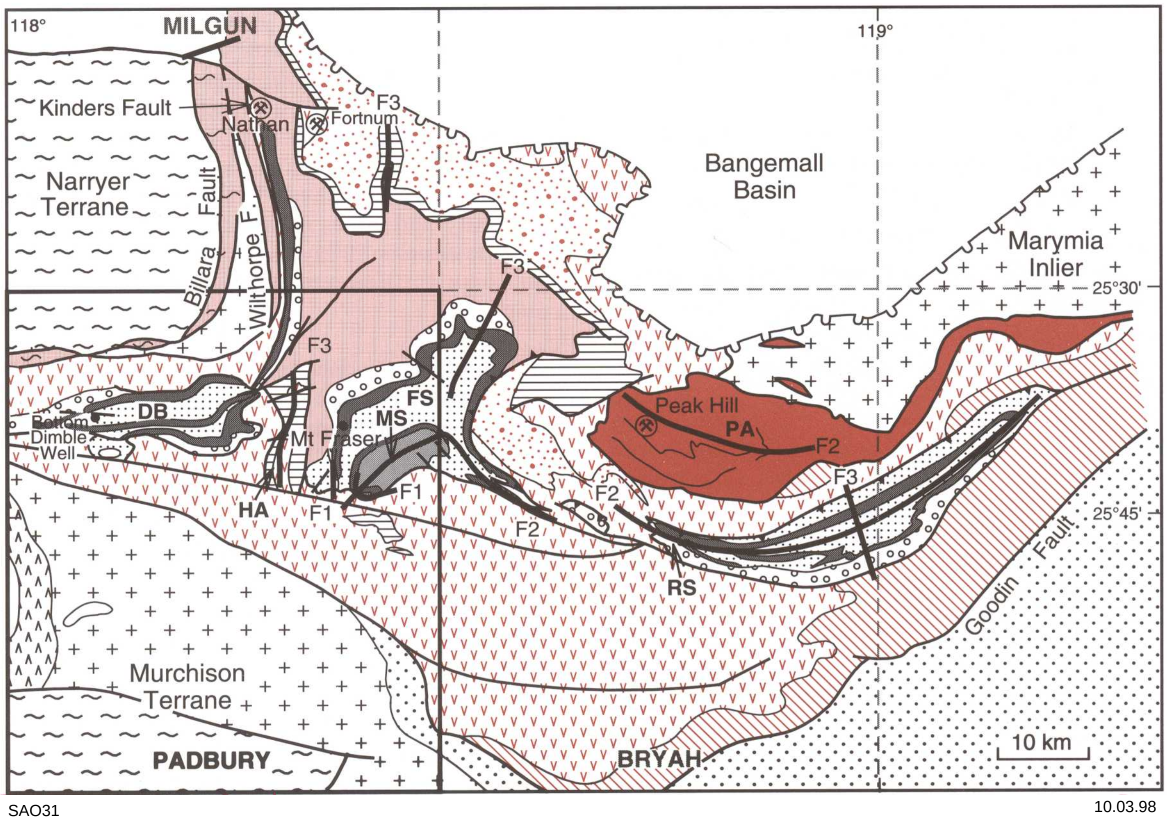


Figure 2. Simplified solid geology map of the Bryah and Padbury Groups including the Archaean Narryer and Murchison Terranes and the Marymia Inlier (legend is on opposite page). This solid geology map was produced by combining field data with aeromagnetic data and Landsat thematic mapping. Modified from Occhipinti et al. (1996)

quartzites are fairly homogenous quartz-rich rocks, but some contain compositional layering a few centimetres thick marked by alternations of pure quartz with quartz–cordierite–sillimanite and quartz–amphibole. The quartzite is composed of predominantly coarse-grained aggregates of quartz, with granoblastic textures overprinting older planar tectonic fabrics. Most quartzites contain large clusters of cordierite or micas after cordierite, and some contain radiating clusters of sillimanite or relict sillimanite within the main schistosity or compositional banding.

Metamorphosed banded iron-formation (BIF — *Asi*) forms a very minor component of the supracrustal rocks and is much less abundant relative to quartzite than is typical elsewhere in the Narryer Terrane. The BIF lies close to the tectonic contact with the Palaeoproterozoic Narracoota Formation (Bryah Group) at locations 5.3 km west of Kelly Bore, 2.3 km northeast of Kelly Bore, and 1.5 km northwest of Relief Bore. These rocks are finely banded and intensely deformed and comprise alternations of quartz and quartz–magnetite.

Amphibolite (*Aba*) is the second most abundant component of the Narryer Terrane supracrustal rocks. It is widespread as layers, ranging from a few metres to a few hundred metres in thickness, within granitic gneiss or interlayered with quartzite. Most amphibolite is relatively massive hornblende–clinopyroxene–plagioclase rock with a coarse-grained granoblastic texture. In some places this can be seen to overprint the compositional layering modified by intense Archaean deformation. Some amphibolites have been further modified to schistose hornblende–plagioclase rocks by later deformation and associated metamorphism. Some amphibolites are interlayered with the quartzite, suggesting that the mafic protoliths to the amphibolites may have been either intrusive into the quartzite or extrusive.

Ultramafic rocks (*Au*) form a minor component of the supracrustal sequence. Most of the ultramafic rocks outcrop in two narrow discontinuous belts within the granitic gneiss in the northwestern corner of PADBURY. The ultramafic rocks mainly consist of pyroxene, amphibole, and serpentine and appear to have been derived from pyroxenites and peridotites.

Granitic gneiss (*Angn*)

Granitic gneiss (*Angn*) is widespread throughout the Narryer Terrane in the northern part of PADBURY. It forms sheets that separate the thin layers of supracrustal rocks and contains tectonic fabrics that parallel the layers of supracrustal rocks. Locally, the protolith to the granitic gneiss has intruded the supracrustal rocks, cross-cutting compositional layering.

The granitic gneiss mainly consists of strongly deformed monzogranite intruded by pegmatite veins. The pegmatite veins have been rotated into parallelism and attenuated and the rock converted into a pegmatite-banded gneiss. This main tectonic fabric formed during late Archaean deformation. Peak metamorphic conditions reached granulite facies during and after deformation, resulting in the development of granoblastic textures.

The intensity of the early deformation was heterogeneous; however, it was most intense along boundaries with more competent rocks, such as quartzite and ultramafic rock. The Archaean fabric of the granitic gneiss was modified during Palaeoproterozoic deformation and retrograde recrystallization to amphibolite facies. During Palaeoproterozoic deformation, the Narryer Terrane was also cut by faults and shear zones, and the Archaean rocks were converted to mylonites and schists by greenschist facies metamorphism.

Granite cuts across the early tectonic structures and fabrics of the granitic gneiss and supracrustal rocks, and in some places it forms large sheet-like bodies within the older layering of these rocks. The granites range in thickness from thin veins, to sheets that are hundreds of metres thick. Due to the range in thickness of these granite sheets, and because the boundaries are typically diffuse, they are indistinguishable at map scale and are included in the granite gneiss (*Angn*) unit.

The granite consists of coarse-grained monzogranite that has been heterogeneously deformed and recrystallized to amphibolite facies. In many places it is weakly deformed and thus is distinct from most granitic gneiss, but in some places it is strongly deformed to pegmatite-banded gneiss.

Structure

The Narryer Terrane on PADBURY is dominated by complex fold-interference structures. Late Archaean structures are prominent in the supracrustal rocks. They consist of canoe-shaped antiforms and synforms defined by two sets of folds (D_2 and D_3) that have axial surfaces at high angles to each other. The folds were superimposed on granitic gneiss and supracrustal rocks that were interleaved during D_1 deformation. The D_3 structures and fabrics (together with D_1 and D_2 structures and fabrics rotated into D_3 orientations) were refolded by Palaeoproterozoic structures. This resulted in the main tectonic grain, which is generally easterly trending — except in the northeast (between the areas 1.5 km northwest of Paddy Bore and north of Ti Tree Bore), where it is northerly trending due to further Palaeoproterozoic refolding.

The maximum intensity of deformation was immediately below a major décollement that separated the Archaean gneiss from the Palaeoproterozoic sedimentary rocks. The results of this deformation are best seen between 1 and 2 km north of Kelly Bore. In this area the intensity of this deformation gradually increases over a distance of about 1 km in the gneiss towards the now vertical décollement. The Archaean foliation is progressively rotated into parallelism with the major décollement surface and is overprinted by a new schistosity and zones of mylonite. The schistosity and mylonite develop in layers that parallel the décollement, and close to the contact are themselves folded and crenulated.

Away from the décollemont zone the Narryer Terrane was cut by faults and shear zones, and the gneiss was locally converted to mylonite and schist by greenschist facies metamorphism.

Despair Granite (*Agde*)

The Despair Granite (*Agde*) is a massive to gneissic (but typically foliated) biotite monzogranite that outcrops in the northeastern part of PADBURY. This granite was informally named the Wilthorpe granite by Windh (1992), but here it is formally named the Despair Granite to avoid confusion with the Wilthorpe Formation, which also outcrops on PADBURY. The Despair Granite is named after Despair Bore (AMG 252698*) in the northwestern part of PADBURY. Where strongly deformed, the Despair Granite is a quartz–feldspar–muscovite schist. Although it contains lenses of quartzite, biotite schist, metamorphosed BIF, and amphibolite, the granite is relatively uniform compared to the adjacent Archaean granitic gneiss of the Narryer Terrane and has one main tectonic fabric. This suggests that it may not be part of the Narryer Terrane but may be part of the Murchison Terrane or another late Archaean terrane.

The contact between the Despair Granite and the Narryer Terrane is a fault that formed as a thrust during the Capricorn Orogeny when a slice of metasedimentary rock was tectonically interleaved between the Narryer Terrane (below) and the Despair Granite (above).

The part of the Despair Granite around the Wilthorpe gold mine was interpreted by Elias and Williams (1980) as an Archaean granite that had been reworked by one or more Proterozoic tectonic events. Myers (1989) further interpreted it as a thrust slice of c. 2700 Ma granite that was emplaced over the Narryer Terrane during the Capricorn Orogeny. The granite was also shown to be overlain by folded thrust sheets carrying mafic and ultramafic rocks of the Palaeoproterozoic Trillbar complex and metasedimentary rocks of the Padbury and Glengarry (now Bryah) Groups.

The contact between the Archaean gneiss and granite basement (including the Despair Granite) and the Palaeoproterozoic cover (Padbury Group) was named the

* Localities are specified by the Australian Map Grid (AMG) standard six-figure reference system whereby the first group of three numbers (eastings) and the second group (northings) together uniquely define position, on this sheet, to within 100 m.

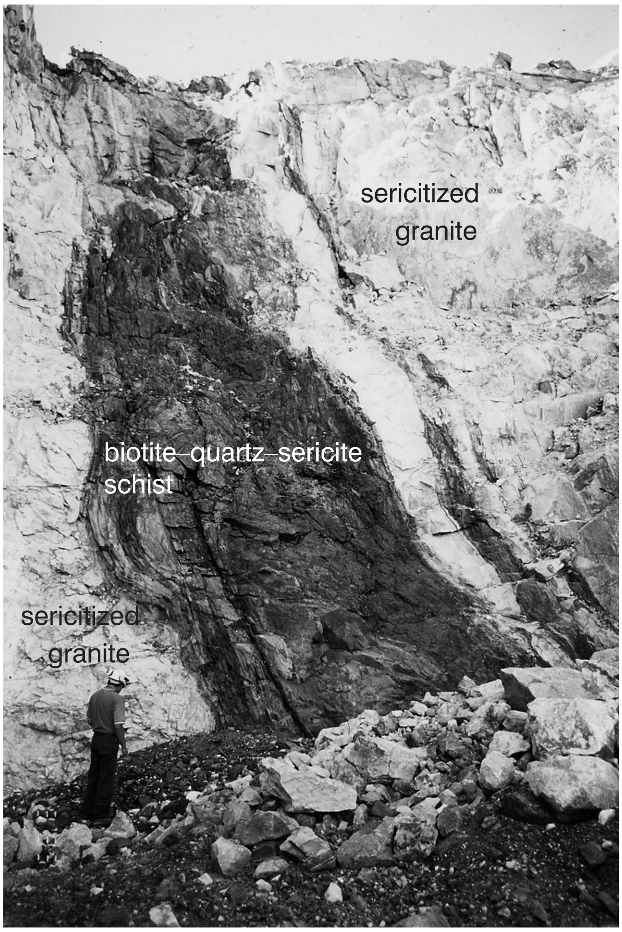
Wilthorpe Lineament by Elias and Williams (1980). They interpreted it to be partly an unconformity and partly a fault. Windh (1992), however, considered that the contact between the Despair Granite and Proterozoic rocks was intrusive, based on the observation that unfoliated granite abuts foliated siltstone, which forms an irregular body within the granite. Nutman (Windh, 1992) also reported zircons with SHRIMP U–Pb ages of c. 2650 Ma from massive Despair Granite. Windh (1992) considered these zircons to be xenocrysts and interpreted the age of the Despair Granite as Proterozoic.

Recent mapping on PADBURY indicates that the Despair Granite is in faulted contact with the Labouchere Formation of the Padbury Group and that the granite is Archaean rather than Proterozoic in age. The Wilthorpe Lineament of Elias and Williams (1980) is here renamed the Wilthorpe Fault. On MILGUN, north of PADBURY, the Labouchere Formation becomes increasingly deformed and strongly foliated towards its contact with the Despair Granite, and in places it is difficult to distinguish it from that granite. Large-scale tectonic interleaving has also been observed between the Labouchere Formation, Despair Granite, and Narryer Terrane.

Tectonic interleaving of the Despair Granite and Proterozoic metasedimentary rocks, which may be equivalents of the Labouchere Formation, has also been observed at the Wilthorpe gold mine and about 2 km southeast of the mine. Biotite–sericite–quartz schist is exposed within the Wilthorpe gold mine (Fig. 3). The schist shows evidence of bedding, and hence formed from a sedimentary protolith. This biotite–sericite–quartz schist outcrops parallel to steeply dipping faults and its contact with the Despair Granite is fault bounded. Just outside the mine, a metasedimentary rock showing cross-bedding and upward-fining beds is also in tectonic contact with the Despair Granite. In places this metasedimentary rock is so extremely sheared and foliated that the original bedding is difficult to recognize. Features of the contact between the metasedimentary rock and the Despair Granite in the vicinity of the Wilthorpe mine include:

- sharp breaks, locally with quartz veins striking parallel to the contact;
- a lack of evidence for contact metamorphism;
- foliations in the metasedimentary rock that are subparallel to those in the granite in close proximity to the contact, but which die out with distance from the contact until bedding is the dominant fabric;
- pervasive foliation in the granite that has been crenulated with axial surfaces subparallel to a crenulation cleavage in the metasedimentary rock, indicating that the granite contains an earlier foliation.

Thus, in the vicinity of the Wilthorpe mine, both the metasedimentary rock and the granite show evidence of the same two folding events, and the granite also contains a pervasive foliation that is absent in the metasedimentary rock. The first set of fold structures in the area are isoclinal and upright, and axial surfaces are parallel to the dominant south-southwesterly trending regional foliation. The axial surfaces of the second-generation folds trend east-southeast and the folds are open. The oldest fabric in the Despair Granite is late Archaean in age and developed during middle greenschist facies conditions. This fabric is cut by the faults that tectonically interleave the granite and the Labouchere Formation and is deformed into upright isoclinal folds. Locally, where the granite was not affected by Archaean deformation, a foliation subparallel to the isoclinal upright folds was developed. Therefore the dominant structural grain of the Despair Granite is considered to reflect Palaeoproterozoic reorientation of a late Archaean fabric.



SAO 32 23.3.98

Figure 3. The Wilthorpe opencut mine illustrating the contact between the biotite–sericite–quartz schist and deformed Despair Granite

Windh (1992) described the Despair Granite as a weakly foliated granite. Regional mapping has shown that, for the most part, the granite contains at least one strong foliation and in some places two or three distinct foliations. In some areas, such as 1 km west of Wilthorpe gold mine, the granite is unfoliated. These massive domains are continuous with deformed zones and reflect heterogeneous deformation. They are interpreted as large lens-shaped bodies with late Archaean low strain.

Murchison Terrane

On PADBURY the Archaean rocks south of the Murchison River comprise both low-grade granite–greenstone terrane and high-grade gneiss terrane (Fig. 2). These rocks are bounded by Palaeoproterozoic faults to the north, along the Murchison River, and to the south by the Yalgar Fault. The latter is an east-trending, steep, dextral transcurrent fault just to the south of PADBURY along the Yalgar River.

Sharp boundaries between the high- and low-grade terranes within the Murchison Terrane on PADBURY were not recognized during mapping. The boundary marked on the map separates dominantly low-grade granite–greenstone terrane in the north from high-grade rocks in the south. Although late Archaean granites are present in both terranes and many of these rocks are weakly deformed and recrystallized during low-grade metamorphism, high-grade granitic, mafic, and ultramafic gneisses are abundant in the southern part of PADBURY. The present situation could reflect tectonic interleaving of high- and low-grade slices of the Murchison Terrane during late Archaean or Palaeoproterozoic tectonism.

Granite–greenstone terrane

Granite (*Agf*)

The low northwest-trending ridge to the south of the Murchison River largely consists of late Archaean biotite monzogranite (*Agf*). The granite ranges from massive to foliated or gneissic and is locally mylonitic. These fabrics largely constitute a single foliation that swings in orientation from northerly in the west to north-northeasterly in the east. The granite is typically medium grained, but locally contains K-feldspar phenocrysts and minor amounts of biotite. In some places the feldspar and biotite are partly replaced by sericite.

Quartz veins are abundant along and adjacent to high-strain zones and are known to host gold mineralization (e.g. Anne-Marie* mine about 1 km east of Deep Well).

Mount Maitland Greenstone Belt

The Mount Maitland Greenstone Belt forms prominent low ridges south of the Murchison River on the western edge of PADBURY (Fig. 2). The belt consists of a 3 km-thick succession of ultramafic, mafic, and felsic volcanic rocks and interleaved sedimentary rocks metamorphosed to upper greenschist facies. This succession may be part of the Luke Creek Group, defined by Watkins and Hickman (1990), which consists of a similar succession of rocks.

High-grade gneisses such as those in the southwestern part of PADBURY are not present in the Mount Maitland Greenstone Belt, although it is likely that the precursor rocks to the high-grade mafic and ultramafic slices were greenstones. The rocks of Mount Maitland are the only known low-grade greenstones on PADBURY.

* Anne-Marie is incorrectly spelt 'Anne-Mary' on the printed map.

Ultramafic volcanic rocks (*Aup, Aur, Auz*)

Ultramafic volcanic rocks form a prominent unit close to the western margin of the greenstone belt and are also interleaved with several other rock types in the eastern part of the belt. Serpentinized peridotite (*Aup*) consists of serpentine (antigorite), tremolite, chlorite, and magnetite. Olivine is replaced by serpentine and magnetite. Tremolite schist (*Aur*) is dominated by tremolite with additional chlorite, epidote, zoisite, feldspar, and quartz. Where these ultramafic rocks are lateritized, they are capped by a distinctive brownish silica caprock (*Auz*).

The western ultramafic succession contains, from west to east, serpentinite with associated talc schist (*Aup*), tremolite schist with dolerite-textured metamorphosed high-Mg basalt (*Aur*), and a zone of pyroxene spinifex-textured basalt (*Abm;* see below) with coarse tremolite schists.

Mafic volcanic rocks (*Ab, Abd, Abm*)

Three main types of basalts have been differentiated on a textural and/or mineralogical basis. Fine-grained foliated basalt (*Ab*) typically comprises actinolite–tremolite, feldspar, epidote, quartz, sphene, and opaque minerals. Alteration associated with regional metamorphism has resulted in the formation of small epidosite bodies, consisting mainly of epidote, quartz, and tremolite. Coarser grained basalt (*Abd*) has partly preserved subophitic textures and typically consists of tremolite–actinolite, quartz, epidote, and sphene. The doleritic lenses may be synvolcanic intrusive bodies; the lenses are thin, contacts with finer grained basalt are sharp, and the grain size of the rock does not appear to increase towards the centre of the lenses. The dolerite shows abundant 'spotted' textures, which are caused by amphibole replacing pyroxene phenocrysts. High-Mg or komatiitic basalt (*Abm*) is characterized by pyroxene spinifex textures; however, the pyroxene is now completely replaced by amphibole. The high-Mg basalt contains various amounts of tremolite, talc, and chlorite.

Other rock types (*Afs, As, Aci*)

Felsic schists (*Afs*) outcrop in a thin discontinuous lens within the Mount Maitland Greenstone Belt. These rocks are well foliated and comprise quartz, chlorite, feldspar, sericite (after feldspar), and minor amounts of epidote and biotite. Accessory minerals include rutile, titanite, and tourmaline. One distinct unit of quartz-phyric felsic schist can be traced for 4–5 km in the central part of the belt and appears to have a highly strained or mylonitic contact with slate on its eastern margin. Another unit directly east of the main BIF-bearing interval is up to 400 m wide and contains both feldspar and quartz porphyroclasts. This unit encloses 4–5 m-wide lenses of tremolite schist.

Fine-grained metasedimentary schist or slate (*As*) is poorly exposed and deeply weathered. Banded iron-formation (*Aci*) consists of finely banded (black–white) quartz–magnetite rocks associated with less-ferruginous chert. They show intrafolial folding, typically bounded by bedding-parallel detachments, as well as a younger generation of small-scale folds. In the eastern part of the belt, BIF layers and lenses are interleaved with tremolite–chlorite schist and grey slate. These rocks are cross-cut at low angles by quartz veins that are locally associated with gold mineralization. Banded iron-formation also lies within and along the eastern contact of the westernmost basalt–dolerite unit.

High-grade metamorphic gneiss terrane (*Ags, Adm, Ap, Anm, Anu*)

High-grade metamorphic gneiss terrane is dominated by banded granitic gneiss (*Ags*) in which the banding is defined by variations in strain intensity, abundance of biotite, and grain size, as well as the abundance of pegmatite veins (*Ap*), aplite veins, or dykes. While most granitic gneisses show granoblastic textures indicative of high-grade metamorphism, some typically foliated to gneissic granites in the area do not appear to have been subjected to high-grade metamorphism and may represent younger late Archaean granites.

The main foliation and banding are folded into variously sized and oriented folds. The axial surfaces of the youngest folds range in strike from east to northwest and have steep to moderate dips. About 1.5 km south of Old Camp Well and in the area between Beefwood Bore* and Dog Rocks, there are complex patterns of folded foliation and arcuate dolerite (now amphibolite) dyke swarms. North of Beefwood Bore, fine-grained dolerite dykes (*Adm*) are folded into a broad arcuate pattern. Some of the dykes have retained primary textures and mineralogy, and others have been deformed and partly converted to amphibolite or garnet–hornblende–plagioclase schist.

The gneiss comprises quartz–feldspar–white mica–biotite(–hornblende). While such assemblages offer little information regarding peak conditions of metamorphism, the presence of gneissic banding and the high metamorphic grade of the associated mafic and ultramafic layers suggest that these rocks were metamorphosed at amphibolite to granulite facies. Archaean dolerite dykes in the south-central part of PADBURY contain hornblende–plagioclase–garnet assemblages, indicating that they have been metamorphosed to amphibolite facies.

In the southwestern part of PADBURY, the granitic gneiss contains slices of high-grade mafic gneissic granulite (*Anm*) and ultramafic granulite and amphibolite (*Anu*). The mafic granulite comprises an assemblage of diopside–hypersthene–plagioclase. In these rocks, amphibolite facies assemblages appear to be retrogressive from granulite facies and related to rehydration. These partially to completely retrogressed mafic granulite assemblages range from augite–hypersthene–plagioclase–hornblende to hornblende–plagioclase–actinolite–sericite. Ultramafic granulite (*Anu*) consists of olivine–clinopyroxene–orthopyroxene, with serpentine and magnetite as retrograde phases, and olivine–serpentine rocks in which serpentine replaces metamorphic olivine. In some thin sections it is apparent that the original granulite facies assemblage is partly broken down to amphibolite facies assemblages with hornblende and oligoclase. Amphibolite typically contains hornblende–plagioclase with actinolite and sericite as retrograde minerals. These high-grade mafic–ultramafic rocks are vertically dipping and trend north-northwest or north-northeast. The banded gneissic granite that surrounds them has been folded and typically contains a fabric that is easterly trending. The high-grade mafic–ultramafic rocks do not appear to have been affected by this folding, and the northerly trend of these slivers of rock may reflect the orientation of this high-grade terrane prior to large-scale, east-trending folding or further syn- to post-tectonic interleaving of the mafic–ultramafic rocks with the gneissic granite.

Mesoscopic isoclinal to tight folds are seen in the banded gneissic granites in the southwestern part of PADBURY. The trends of these folds show a wide range in orientations, perhaps as a result of later deformation events. Folds observed in the southern part of PADBURY can be broadly divided into the following three groups:

1) isoclinal folds with axial surfaces that trend north-northwest and fold axes that plunge steeply in that direction;
2) folds with axial surfaces that strike east;
3) broad arcuate folds with north-striking axial surfaces, which fold late Archaean amphibolite dykes.

Palaeoproterozoic geology

The main Proterozoic rocks on PADBURY are sedimentary and comprise three groups: the Yerrida, Bryah, and Padbury Groups. These rocks were involved in the Palaeoproterozoic Capricorn Orogeny and are unconformably overlain by the Mesoproterozoic Bangemall Group.

The rocks of the Yerrida, Bryah, and Padbury Groups were formerly assigned to the Glengarry Sub-basin of the Nabberu Basin (Gee, 1990). The Glengarry Sub-basin was subsequently raised to basin status and the rocks were divided into the Glengarry and Padbury Groups by Gee and Grey (1993). It has recently been recognized that the Glengarry Group comprises two tectonically juxtaposed groups having different stratigraphic successions and geological histories (Pirajno et al., 1996). These two groups are now referred to as the Yerrida and Bryah Groups and are assigned to separate basins — the Yerrida and Bryah Basins respectively (Tables 1 and 2). For example, igneous rocks have been divided on the basis of geochemical signatures into two main types, indicative of oceanic (Narracoota Formation of the Bryah Group) and mixed continental–oceanic (Killara Formation of the Yerrida Group) origin (Pirajno et al., 1995; Pirajno and Davy, 1996). Clastic units within the Bryah and Yerrida Groups are different. For instance, the basal unit within the Yerrida Group is a quartz arenite (Finlayson Member), whereas the basal unit within the

* Beefwood Bore is incorrectly spelt 'Bufurood Well' on the printed map.

Table 1. Stratigraphy of the Yerrida, Bryah, and Padbury Basins

Basin/Group	*Formation/Member*	*Rock types*
PADBURY BASIN (peripheral foreland basin)		
Padbury Group	Millidie Creek	sericitic siltstone, chloritic siltstone, BIF, dolomitic arenite
	Robinson Range	ferruginous shale, BIF
(< c. 2000 Ma)	Wilthorpe	quartz-pebble conglomerate
	Beatty Park Member	mafic siltstone/wacke
	Heines Member	polymictic conglomerate
	Labouchere	turbidite sequence (quartz wacke, siltstone)
~ ~ ~ *Unconformable contact — in places tectonized* ~ ~ ~		
BRYAH BASIN (rift succession)		
Bryah Group	Horseshoe	BIF, wacke, shale
(< c. 2000 Ma)	Ravelstone	quartz-lithic wacke
	Narracoota	mafic–ultramafic volcanic rocks and dykes, tuffs, and intercalated sedimentary rocks
	Karalundi	conglomerate, quartz wacke
~ ~ ~ *Faulted contact* ~ ~ ~		
YERRIDA BASIN		
Yerrida Group		
Mooloogool Subgroup	Maraloou	black shale, siltstone, carbonate
(rift succession)	Killara	aphyric mafic lavas and intrusives
Intercalated	Doolgunna	diamictite, arkosic sandstone, siltstone, shale
	Thaduna	lithic wacke, siltstone, shale, minor arkose
Windplain Subgroup	Johnson Cairn	siltstone, shale, carbonate, minor lithic wacke
(sag-basin succession) (< c. 2200 Ma)	Juderina	arenite, conglomerate, minor carbonate
	Bubble Well Member	silicified carbonate with evaporite units
	Finlayson Member	arenite
~ ~ ~ *Unconformity on Yilgarn Craton* ~ ~ ~		

NOTE: Modified from Pirajno et al. (1996)

Bryah Group includes lithic wacke, sublitharenite, and shale (Karalundi Formation; Fig. 1 — Pirajno et al., 1996). Hence, the name Glengarry Group has been abandoned.

The Bryah Group is in faulted contact with the Yerrida Group, the eastern part of the Narryer Terrane, and the southern part of the Marymia Inlier. On PADBURY the Bryah Group is in tectonic contact with the Padbury Group. On MILGUN and BRYAH, however, the contact between the Bryah Group and the basal unit of the Padbury Group is considered to be unconformable (Martin, 1994; Martin, in prep.; Pirajno and Occhipinti, 1998). The Padbury Group developed in the Padbury Basin over the Bryah Group (Windh, 1992; Martin, 1994; Martin, in prep.; Occhipinti et al., 1996).

Yerrida Group

The Yerrida Group consists of the Windplain and Mooloogool Subgroups, but only the former is exposed on PADBURY. The Windplain Subgroup is interpreted as the initial sag-basin succession, which probably underlies the entire Mooloogool rift-basin succession. The subgroup contains the Juderina and Johnson Cairn Formations (Occhipinti et al., in prep.). These two formations are exposed in the southeastern part of PADBURY, where they are characterized by a well-developed north-northeasterly trending foliation. The basal unconformity with foliated granites of the Murchison Terrane is well exposed in several localities and is outlined by ridges of a distinct basal quartz arenite unit defined by Gee and Grey (1993) as the Finlayson Sandstone Member, but now referred to as the Finlayson Member due to its heterolithic character (Occhipinti et al., 1997).

The age of the Yerrida Group is poorly constrained between 2250 and 1900 Ma by a Pb–Pb isochron of 2258 ± 180 Ma on stromatolitic carbonate from the Bubble Well Member (Occhipinti et al., 1997) of the Juderina Formation near the base of the Yerrida Group (Russell et al., 1994) and the 1900–1800 Ma age of the overlying Earaheedy Group (Nelson, 1996; Grey, 1994).

Juderina Formation (*ꝒYj, ꝒYjf, ꝒYjp*)

The basal quartz arenite, or orthoquartzite, forms the Finlayson Member (*ꝒYjf*). This unit is characterized by cross-bedding and ripple marks and is intercalated with sericite–quartz siltstone, shale, and quartz wacke and locally deformed into quartz–muscovite schist along the basal unconformity. The thickness of the Finlayson Member does not exceed 30 m on PADBURY; however, Gee and Grey (1993) reported a maximum thickness of 50 m on GLENGARRY (1:250 000).

Table 2. Historical evolution of terminology for the Palaeoproterozoic sedimentary basins

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

The remainder of the Juderina Formation (*ⱣYj*) comprises shale, siltstone, quartz wacke, and several chert, quartz arenite, and quartz-pebble to quartz-cobble conglomerate beds. Cross-bedding and channel structures are abundant in the coarser grained intervals. The main clastic components are quartz and sericite, but small lithic fragments and some feldspar grains are found in medium-grained wacke. Quartz arenite layers are fine to medium grained, typically representing original grain sizes despite recrystallized grain boundaries. Spotted textures in quartz arenite are ascribed to tremolite (Crane and Dunn, 1979) or chlorite that is now replaced by kaolinite. Chert and chert breccia, found mostly as rubble above the Finlayson Member, may be correlated with the Bubble Well Member on GLENGARRY (1:250 000; Pirajno et al., 1995).

The Juderina Formation includes several pebble- to cobble-conglomerate layers (*ⱣYjp*) consisting of a lithic quartz wacke matrix with minor elongate slate fragments, locally with textures resembling angular chert breccia. The elongate and locally flat pebbles of vein quartz and some chert are commonly aligned.

The rocks of the Juderina Formation on PADBURY are well foliated, and the finely bedded siltstone and shale sequences are folded on several scales. The total thickness of the Juderina Formation is therefore difficult to estimate but may be about 700 m.

Johnson Cairn Formation (*ⱣYc*)

The Johnson Cairn Formation (*ⱣYc*) comprises vari-coloured, finely bedded and laminated ferruginous shale and slate, and is extensively lateritized. The entire sequence is pervasively foliated or cleaved so that the original rock types were transformed into slate and fine-grained quartz–muscovite schist. Fragmental structures have developed from folded, boudinaged, and disrupted thin quartz veins and/or chert lenses. The main pervasive cleavage trends north-northeast to northeast and dips at 80–90°E, as in the underlying Juderina Formation. This cleavage is locally overprinted by a northerly to north-northwesterly trending crenulation cleavage that dips moderately to the east.

This unit appears to conformably overlie the Juderina Formation. The upper contact with mafic rocks of the overlying Narracoota Formation (Bryah Group) is not exposed but is inferred to be a fault on the basis of fault structures mapped on GLENGARRY (1:250 000) and PEAK HILL (Pirajno et al., 1995; Pirajno and Occhipinti, 1998).

Bryah Group

The Bryah Group comprises deformed and metamorphosed mafic–ultramafic volcanic rocks and chemical and siliciclastic sedimentary rocks. These rocks make up four formations (Pirajno et al., 1996), two of which, the Narracoota and Horseshoe Formations, are present on PADBURY.

The age of the Bryah Group is unclear, but the depositional age may be between 2650 Ma (the age of the Yilgarn Craton; Myers, 1990) and the 1785 ± 11 Ma age of the Mount Leake Formation of the Earaheedy Group, which unconformably overlies the Bryah Group (Nelson, 1996). Age determinations on detrital zircons give a maximum age for the Ravelstone Formation (Bryah Group) of 2014 ± 22 Ma (Nelson, 1996). Windh (1992) also obtained a Pb–Pb isochron age of 1920 ± 35 Ma on inferred syngenetic pyrite from the Narracoota Formation. This age and Pb–Pb ages of 1.7 Ga (Pirajno and Occhipinti, 1998) from galena from the Mikhaburra mine (Narracoota Formation on BRYAH) may represent one of the mineralizing events of the Bryah Group.

Narracoota Formation (*ⱣAn, ⱣAnd*)

The Narracoota Formation consists largely of meta-basaltic rocks that occupy most of the southern half of BRYAH and extend westward onto PADBURY, where they are in tectonic contact with the Padbury Group. The nature of the metabasaltic rocks of the Narracoota Formation is discussed in detail by Hynes and Gee (1986) and more recently by Pirajno and Occhipinti (1995, 1998). New whole-rock geochemical data for this formation on PADBURY are presented and discussed later in **Whole-rock geochemistry**.

On BRYAH the Narracoota Formation is overlain by lithic wacke of the Ravelstone Formation, which grades upward into the clastic, argillaceous, and chemical sedimentary rocks (BIF) of the Horseshoe Formation. On PADBURY these relationships are not exposed, and the Narracoota Formation is inferred to be in faulted contact with the Horseshoe Formation and various formations of the Padbury Group.

Pirajno and Occhipinti (1998) suggested that the Narracoota Formation can be subdivided, based on geochemistry and petrology, into two main metabasite lithotypes: mafic and ultramafic schists, and metabasaltic hyaloclastite.

The mafic and ultramafic schists (*ᵽAn)* typically contain a pervasive schistosity, although metadolerite dykes and sills (*ᵽAnd)*, metabasaltic breccia, and minor metapyroxenite lenses within these mafic schists on BRYAH are not internally deformed.

The metabasaltic hyaloclastite is relatively undeformed but is locally strongly lateritized. It is spilitic and has been metasomatized to epidosite.

According to Hynes and Gee (1986), the mafic rocks of the Narracoota Formation have fairly uniform chemistry and are of mid-ocean-ridge basalt (MORB) affinity, although the original mafic materials may have been emplaced through rifted continental crust. Hynes and Gee (1986) also noted the presence of ultramafic members (high-Mg basalt or komatiite).

Carbonated mafic rocks previously described as carbonate intrusives (Lewis, 1971; Elias and Williams, 1980) are mostly interpreted to be part of the Narracoota Formation and outcrop in the Horseshoe anticlinal block (Fig. 2). Cuttings from rotary air-blast (RAB) drilling on PADBURY suggest that much of the area is underlain by mafic and ultramafic schists interpreted as part of the Narracoota Formation (Occhipinti et al., 1996).

Metabasaltic hyaloclastite (*ᵽAnh*)

Metabasaltic hyaloclastite (*ᵽAnh*) outcrops sporadically in an extensively lateritized area on the eastern edge of PADBURY, south of the Murchison River and is partly covered by reworked lateritic materials, colluvium, and alluvium. Much better outcrops lie further east on BRYAH. These rocks probably represent a substantial thickness of mafic lava. A total thickness of 4–6 km was estimated by Hynes and Gee (1986) and Gee (1987).

Whilst extensive lateritization obscures most textures of the metabasaltic hyaloclastite on PADBURY, outcrops on BRYAH are typically unfoliated, massive, and have a characteristic jigsaw-fit texture outlined by epidote, carbonate, prehnite, and/or quartz.

Mafic and ultramafic schists (*ᵽAns, ᵽAnu*)

Mafic and ultramafic schists have been identified from RAB drill cuttings on the flat floodplains along, and just north of, the Murchison River and on the eastern side of Mount Padbury. The schists are derived from protoliths that range in composition from mafic to ultramafic. The mafic schists (*ᵽAns*) contain an assemblage of actinolite chlorite–epidote–sericite–titanite with minor amounts of quartz. Ultramafic schists (*ᵽAnu*) typically contain actinolite–tremolite, talc, and chlorite. In zones of more intense metamorphism, epidosites locally consist of massive epidote–clinozoisite(–chlorite) and minor amounts of tremolite, titanite, and quartz. This alteration developed due to strong magnesium and calcium metasomatism as a result of circulation of H_2O–CO_2 fluids (Pirajno et al., 1995).

Well-foliated mafic–ultramafic schists are also exposed in a prominent belt between Despair Bore and Haystack Well. Both northern and southern contacts are strongly foliated and interpreted as faults. The northern contact juxtaposes the Narracoota Formation, with well-foliated quartz wacke of the Labouchere Formation in the west and deformed Archaean granites in the east. The southern contact is characterized by apparent tectonic interleaving of mafic schist with pebbly quartz wacke of the Wilthorpe Formation. The original volcanic textures of the schist are preserved, despite the well-developed foliation and complete metamorphic recrystallization to actinolite–tremolite, epidote(–zoisite), relict plagioclase, chlorite, and leucoxene(–titanite) after iron–titanium oxides. White mica has locally replaced plagioclase and has also grown at a late stage at the expense of chlorite. Fragmental textures (e.g. at the road-metal quarry 4 km north of Haystack Well), finely bedded hyaloclastic or tuffaceous textures including possible plagioclase clasts, and sheaf or plumose textures of tremolite–actinolite (after pyroxene) are locally recognizable in hand specimen. Pervasively foliated schists also contain doleritic textures with up to 20 volume percent interstitial plagioclase.

Tremolite–actinolite and chlorite are the main constituents of light-green ultramafic schist. Original textures are not preserved and local acicular amphibole crystals are interpreted to be metamorphic in origin.

*Peridotite and high-Mg basalt** (*ᵽAnp*)

Massive, layered volcanic flows (*ᵽAnp*) are preserved in prominent hills between Top Dimble Well and Despair Bore. Hynes and Gee (1986) described these rocks as komatiitic basalt with up to 20% MgO and included them as part of the Narracoota Formation. The rocks are metamorphosed, but their protoliths include olivine cumulate (peridotite), high-Mg basalt, komatiitic pyroxenite with plumose and harrisitic textures, and

* High-Mg basalt is referred to as 'basaltic komatiite' on the printed map.

medium-grained basalt. Compositional layering is mainly defined by massive olivine-cumulate layers up to 20 m thick and plumose-textured basalt layers up to 5 m thick. Locally, large sheaves of skeletal amphibole (after pyroxene) are arranged at right angles to the layering, forming a harrisitic-like texture (Fig. 4a). Unequivocal pillows, as mentioned by Hynes and Gee (1986), were not observed.

Peridotite layers typically consist of 70–80% fine- to medium-grained tremolite(–talc) after olivine, skeletal amphiboles after pyroxene, and 20–30% fine-grained matrix of plumose-textured amphibole. High-Mg basalt has up to 30% locally glomeroporphyritic olivine (now tremolite) and some acicular pyroxene in a 60–70% amphibole plumose-textured matrix (Fig. 4b). One particular sample contains 35% olivine (partly altered to talc), fresh skeletal (‘swallow-tail’) orthopyroxene, and some acicular, skeletal amphibole prisms (possibly after clinopyroxene — Fig. 4c). This sample is transitional to picritic basalt and contains about 20% MgO. The high-Mg basalt layers are characterized by well-developed spinifex-like textures with acicular tremolite–actinolite after pyroxene and interstitial plagioclase (replaced by epidote or zoisite). They are interlayered with medium-grained basalt layers of similar mineralogy and composition, with 8–9% MgO (further discussed in **Whole-rock geochemistry**).

Carbonated and silicified ultramafic rocks (*ꝒAnk*)

Carbonated and silicified ultramafic rocks (*ꝒAnk*), interpreted to be part of the Narracoota Formation, outcrop in the Horseshoe anticlinal block (Fig. 2). These rocks are compositionally heterogeneous. Petrographic descriptions of some of these rocks are given in Table 3.

These rocks both underlie and are intercalated with rocks of the Horseshoe Formation. Elsewhere in the Bryah Group the Horseshoe Formation was not observed to be in direct contact with the Narracoota Formation (see below), suggesting that such contacts are tectonic (Occhipinti et al., in prep.).

If sample GSWA 133038 (Table 3) from the Horseshoe anticlinal block is a metaleucogabbro, then it is probably part of a layered mafic intrusion within the Narracoota Formation.

Horseshoe Formation (*ꝒAh*)

The type area of the Horseshoe Formation (*ꝒAh*) is the Horseshoe Range on PEAK HILL, where Gee (1979) estimated a thickness of 1000 m. The Horseshoe Formation on PADBURY comprises ferruginized quartz wacke, manganiferous shale, and irregularly banded iron-formation. On PADBURY the Horseshoe Formation forms an isolated fault-bounded block between Mount Fraser and Mount Fraser Creek, where it was previously assigned to the Labouchere Formation by Elias and Williams (1980), and outcrops in the eastern part of PADBURY in the vicinity of Brunsden Well, where it was previously an ‘unassigned’ unit (Elias and Williams, 1980).

On PADBURY the Horseshoe Formation is in faulted contact with both the Narracoota and Labouchere Formations. These contacts are inferred from regional mapping (the adjacent stratigraphy is different on each side of the Horseshoe anticlinal block — Fig. 2) and interpretation of aeromagnetic data. In the type area, on PEAK HILL, the Horseshoe Formation overlies the Ravelstone Formation with a gradational and conformable contact (Occhipinti et al., in prep.). Martin (1994) suggested that there is a regional unconformity between the Horseshoe Formation (Bryah Group) and the lowermost unit of the Padbury Group (Labouchere Formation). This relationship is not observed on PADBURY.

Padbury Group

The Padbury Group comprises the Labouchere, Wilthorpe, Robinson Range, and Millidie Creek Formations and a strongly deformed, fault-bounded (unassigned) metasedimentary unit that may be a correlative to the Labouchere Formation. The Beatty Park Member of the Wilthorpe Formation has its type area on PADBURY, in the vicinity of Beatty Park Bore at the eastern foothills of Mount Padbury. Windh (1992) and Martin (1994) suggested that the Labouchere Formation unconformably overlies the Horseshoe Formation of the Bryah Group. This proposition was based on regional mapping in the Fortnum – Dandys Well area on MILGUN, where an apparent low-angle truncation of an iron-formation marker unit in the Horseshoe Formation was observed against the quartz wacke of the Labouchere Formation. Elsewhere, contacts between the Bryah and Padbury Groups have variously been described as unconformities (Gee 1979, 1987; Windh, 1992) or faults and shears (Pirajno and Occhipinti, 1998; Occhipinti et al., 1996).

The age of the Padbury Group is very poorly constrained. Windh (1992) reported U–Pb ages of 2.0 and 1.9 Ga from detrital zircons of the Labouchere Formation on PADBURY.

Martin (1994, in prep.) proposed a formal stratigraphy for the lowermost parts of the Padbury Group (Labouchere and Wilthorpe Formations) based on sedimentological studies on MILGUN. Regional mapping on PADBURY and MILGUN supports this formal stratigraphy, which is adopted here in favour of the previous stratigraphic divisions proposed by Barnett (1975), Gee (1987), and Windh (1992). In addition to the stratigraphy described by Martin (1994), two members, the Heines Member (Pirajno and Occhipinti, 1998) and the Beatty Park Member, are recognized within the Wilthorpe Formation of the Padbury Group.

Labouchere Formation (*ꝒPl, ꝒPls*)

The Labouchere Formation is dominantly composed of coarse-grained sericitic quartz wacke (*ꝒPl*), sericitic siltstone and shale (*ꝒPls*), and minor amounts of conglomerate. Martin (1994) proposed a composite type section based on four separate sections with a total stratigraphic thickness of 3500–4000 m. The quartz wacke consists of partly rounded quartz grains and

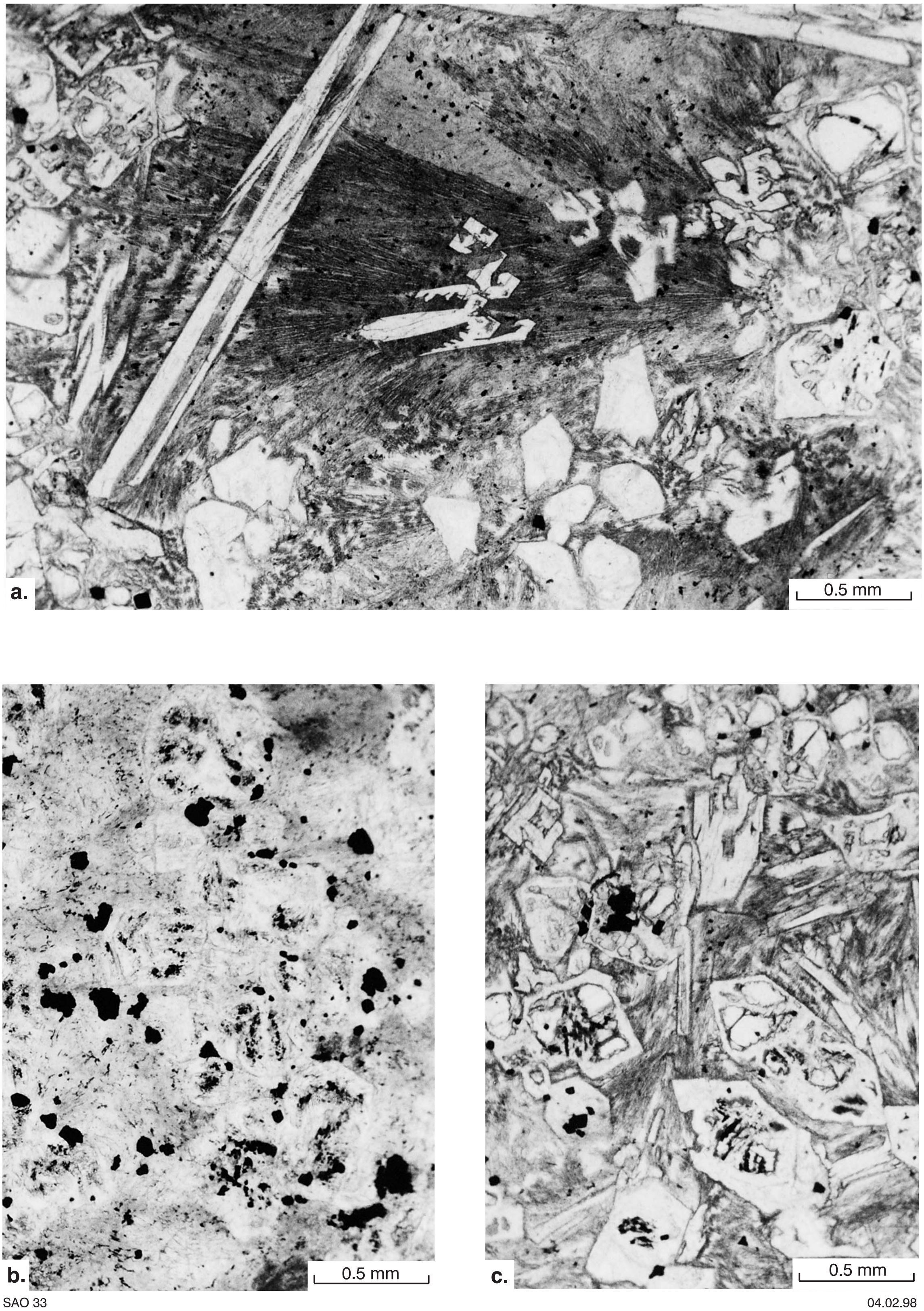


Figure 4. Photomicrographs (plane-polarized light) of mafic–ultramafic Narracoota Formation volcanic rocks from the Dimble Belt:

a) komatiitic pyroxenite with skeletal amphibole prisms after a quench-textured pyroxene matrix;

b) peridotite with glomeroporphyritic olivine aggregates (now largely replaced by tremolite and talc) in a matrix of tremolite;

c) peridotite with olivine phenocrysts, partly altered to talc around the edges, and pyroxene in a fine-grained tremolite matrix

Table 3. Petrographic descriptions of altered mafic rocks

GSWA sample no.	*Petrographic description*	*Veining/ alteration*	*Interpreted precursor*
133033	**Fine-grained quartz, chlorite, talc, iron oxides**	silicified	?mafic rock
133038	**Plagioclase, chlorite, iron oxides, carbonate** This rock contains greater than 50% feldspar. Much of the plagioclase has recrystallized to andesine or albite; however, fresh grains appear to be almost pure anorthosite. It contains an igneous texture unmodified by tectonism and has boxworks of iron oxides (after pyrite) and carbonate. Carbonate is also present as veinlets and around the interstices of plagioclase grains. This rock may have originally been an anorthosite, and with carbonate metasomatism much of the original anorthosite recrystallized to andesine	carbonate	leucogabbro
133049	**Chlorite, quartz, sericite, feldspar, carbonate, iron oxide** Foliated and ferruginized rock. Feldspar is locally replaced by sericite	carbonate, ?silicified	mafic rock
133051	**Carbonate, iron oxide** Layered rock, where layers are defined by relative abundance of iron oxide	carbonate, iron oxide	–

minor amounts of lithic fragments and feldspar in a sericite–chlorite matrix. Shale is partly ferruginized and consists of sericite and chlorite. On MILGUN, the quartz wacke and siltstone form numerous upward-fining cycles (Martin, 1994, in prep.; Swager and Myers, in prep.).

Well-foliated rocks of the Labouchere Formation outcrop about 4 km west of Kelly Bore and are in tectonic contact with both the Narracoota Formation to the south and strongly foliated to gneissic granites of the Narryer Terrane to the north. Regularly bedded quartz wacke (locally with small quartz pebbles) and siltstone are folded about west-southwesterly trending axial surfaces. The rocks have well-developed upright axial-planar foliation and related small quartz-vein systems. With increasing strain, the rocks were converted into muscovite–quartz schist with a pervasive east-striking regional foliation. Pelitic layers locally contain staurolite and andalusite porphyroblasts that enclose an early fabric. Fine-grained muscovite and local small chloritoid prisms have developed along this regional cleavage. The quartz schist is most deformed close to its contacts, where primary textures are obliterated.

About 4 km west of Kelly Bore and about 2 km northeast of Ti Tree Bore, narrow strips of strongly foliated schist are inferred to be part of the Labouchere Formation. This unit is fault bounded against heterogeneous gneiss and granite of the Narryer Terrane to the west and Despair Granite to the east. The unit wedges out to the southwest but widens northward as it extends onto MILGUN. In these higher grade metamorphic rocks, two foliations can be recognized in staurolite–andalusite–biotite–sericite–quartz schist (Fig. 5). Staurolite, biotite, and quartz appear to form an equilibrium assemblage, with andalusite having developed by the partial breakdown of staurolite, whereas sericite is a later stage retrograde mineral formed by the breakdown of biotite, staurolite, or andalusite. Sericite forms rims between andalusite and staurolite where the andalusite appears to have crystallized in cracks in the staurolite grains. Weathered schists from this area also contain kaolinite, illite, and abundant fine-grained sericite. The mineral assemblages suggest low-pressure (less than 4 kbar) metamorphic conditions with temperatures of up to 500°C (Spear, 1993).

Wilthorpe Formation (*ⱣPw, ⱣPws, ⱣPwc*)

The Wilthorpe Formation — formerly called the Wilthorpe Conglomerate by Elias and Williams (1980) and Gee (1987) — has been defined as a sequence of quartz-pebble conglomerate, quartz wacke, and siltstone (Windh, 1992; Martin, 1994). The type area, described by Martin (1994, in prep.), is in the Talbot drainage divide along the MILGUN–PADBURY boundary. Two distinct members are now recognized in the formation: the Heines Member, which outcrops on BRYAH and contains polymictic conglomerate, sandstone, and shale (Pirajno and Occhipinti, 1998); and the Beatty Park Member, which outcrops on PADBURY and contains a distinctive sequence of chlorite–quartz wacke.

Quartz-pebble conglomerate, quartz wacke, and siltstone (*ⱣPw*) are well exposed in the hills to the east of Haystack Well. The uppermost unit within the formation contains fine-grained quartz wacke, siltstone, and phyllite, but lacks any coarser grained rocks or pebbly layers and has been mapped as a separate unit (*ⱣPws*).

A quartz–chloritoid–sericite–chlorite rock unit (*ⱣPwc*) previously interpreted to be a carbonate intrusion (Lewis,

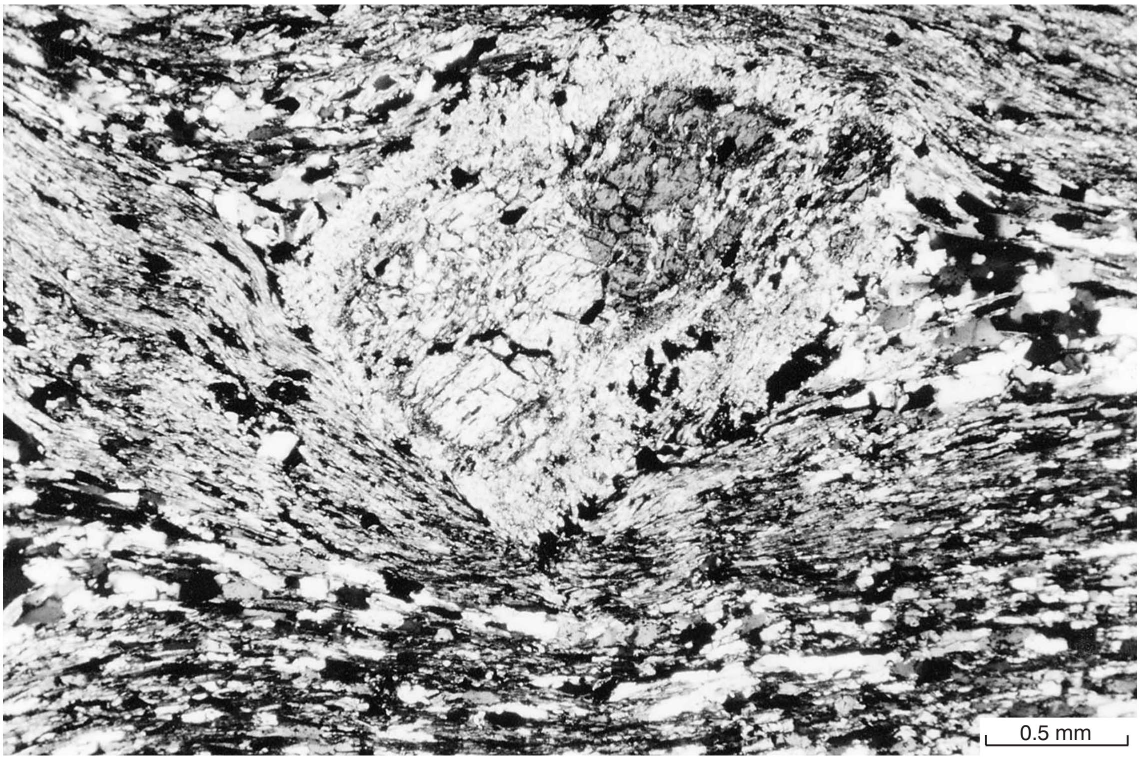


Figure 5. Photomicrograph of staurolite–andalusite–biotite–sericite–quartz schist of the Labouchere Formation, sampled from 5 km east of Kelly Bore. Cross-polarized light

Figure 6. Photomicrograph of chloritic siltstone from the Beatty Park Member comprising quartz, chlorite, and muscovite. Plane-polarized light

1971; Elias and Williams, 1980) has also been assigned to the Wilthorpe Formation. This rock comprises quartz, chloritoid, sericite, chlorite, and sulfide. The chloritoid has crystallized as sprays and displays a 'bow-tie' texture. The presence of abundant chloritoid indicates that this rock has a high-alumina content, implying either a pelitic precursor or an extensively metasomatized protolith.

Beatty Park Member (ꝐPwb)

The Beatty Park Member (*ꝐPwb*) is characterized by 'mafic' clastic rocks dominated by metamorphosed chlorite–quartz shale, siltstone and wacke, several conglomeratic or breccia lenses, and some finely laminated chert layers (Occhipinti et al., in prep.).

The shale and siltstone layers (Fig. 6) are well bedded to finely laminated and consist of quartz and chlorite with minor amounts of sericite, epidote, feldspar, titanite, and detrital hornblende. The fine laminations in shale beds are defined by variations in quartz and chlorite content and the amount of fine euhedral magnetite and/or anhedral hematite. These layers are accompanied by very fine grained recrystallized white chert beds in the upper part of the member. West of the Fraser Syncline (Fig. 2), sedimentary structures such as bedding-parallel laminations, flame structures (Fig. 7a), contorted bedding (Fig. 7b), and scour (Fig. 7c) can be observed within chloritic siltstone.

The wacke units commonly contain quartz, carbonate, chlorite, feldspar, sericite, epidote, sphene, and opaque minerals (either magnetite or pyrite). Lithic fragments in wacke layers include various metabasaltic and mafic schists in which leucoxene pseudomorphs of iron oxides can still be recognized. Lenses of coarse-grained lithic wacke and conglomerate comprise rock fragments (basalt, mafic schist, chert, and chlorite–quartz wacke) and coarse-grained crystals (quartz and feldspar) in a sericite–chlorite–quartz matrix. Coarse clastic rocks containing abundant rip-up clasts were formed from channel-fill deposits produced by channel erosion. This suggests that the Beatty Park Member, at least in part, was deposited proximally to the source region. Locally, white chert lenses are continuous across such erosional contacts, indicating that the chert is diagenetic or epigenetic.

Within all rocks of the Beatty Park Member, sericite and muscovite are of metamorphic origin. They replace chlorite in the fine-grained chloritic shale–siltstone layers and feldspar clasts in the wacke units. In several examples fine-grained muscovite has grown along late cleavage planes.

The contact between the Beatty Park Member and overlying Robinson Range Formation is gradational, with chloritic siltstone and chert layers grading into sericite–quartz siltstone. The lower contact of the Beatty Park Member with the Labouchere Formation appears to be gradational in the area west of the Fraser Syncline, where ferruginized kaolinitic siltstone and quartz wacke grade into chloritic siltstone. In this area, a minimum thickness of 470 m is implied because the upper part of the Beatty Park Member is not exposed. Windh (1992) recognized chloritic siltstone below the Wilthorpe Conglomerate in the openpit at Nathans mine on MILGUN and suggested that it was derived from the Narracoota Formation (Bryah Group). This siltstone is probably a correlative to the more extensively developed Beatty Park Member.

Robinson Range Formation (*ꝐPr, ꝐPri, ꝐPrg*)

The Robinson Range Formation (*ꝐPr*) consists of a sequence of BIF, siltstone, shale, and iron-rich shale. Granular iron-formation (*ꝐPrg*) forms abundant irregular lenses. The BIF (*ꝐPri*) consists of laminae up to 3 cm thick. These laminations comprise various amounts of quartz, iron oxide (hematite or magnetite), biotite, and (locally) ferro-actinolite. Granular iron-formation is characterized by a granular texture and comprises microcrystalline chert outlined by rims of iron oxides. The shale and siltstone consist of fine-grained sericite, quartz, chlorite, iron oxides, and (in some places) minor amounts of sphene.

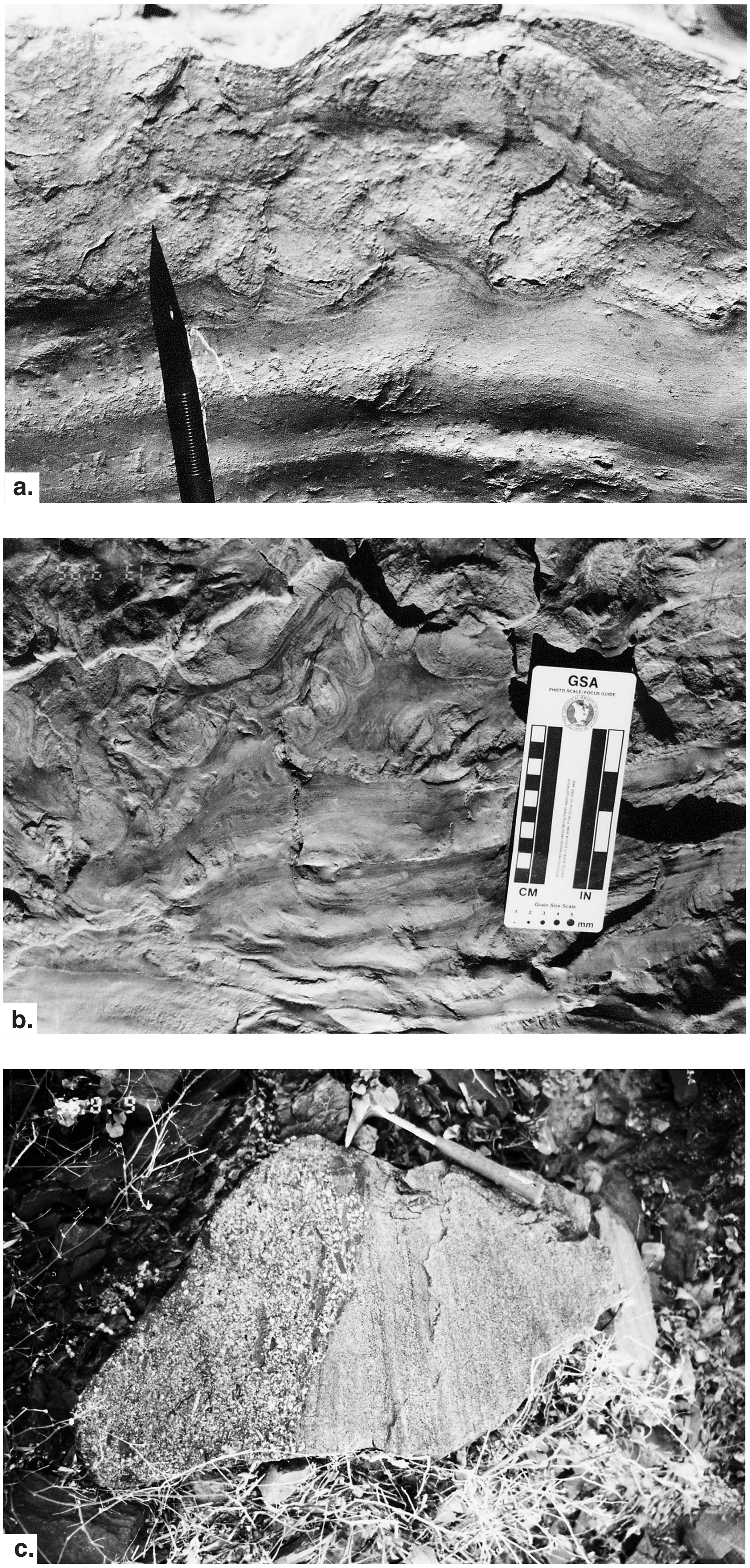
Millidie Creek Formation (*ꝐPm, ꝐPmi, ꝐPmc, ꝐPms*)

On PADBURY the Millidie Creek Formation consists of metamorphosed iron-rich shale and siltstone (*ꝐPm*), irregularly banded manganiferous iron-formation (*ꝐPmi*), chloritic siltstone (*ꝐPms*), and a unit of sericitic shale, dolomitic sandstone, and ferruginous quartz wacke (*ꝐPmc*).

Ferruginous shale and siltstone, intercalated with irregularly banded manganiferous iron-formation (*ꝐPmi*) and chloritic siltstone (*ꝐPms*), form the basal part of the formation. The iron- and manganese-rich units are locally lateritized and host many manganese deposits, such as those mined at the Elsa Mary mine. The banded manganiferous iron-formation (*ꝐPmi*) typically forms low ridges.

The quartz wacke within the dolomitic sandstone and quartz wacke unit (*ꝐPmc*) is well bedded and matrix supported and typically contains subangular to subrounded quartz grains. The matrix is composed of randomly oriented fine-grained biotite and includes late sphene and minor amounts of sericite. The dolomitic sandstone comprises carbonate, quartz, and muscovite. The dolomitic sandstone and quartz wacke unit includes a finely bedded micaceous siltstone with interbedded quartz–dolomite siltstone that was previously assigned to the Labouchere Formation (Elias et al., 1980). This unit outcrops in low hills 3 km north of 5 Mile Well. These rocks are folded about northwest-trending D_4 fold axes, contain S_4 foliation, and are unconformably overlain by subhorizontal to shallowly dipping basal quartz arenite of the Bangemall Group.

Chloritic siltstone (*ꝐPms*) of the Millidie Creek Formation is compositionally similar to siltstone of the Beatty Park Member (*ꝐPwb*). It comprises quartz, feldspar, lithic fragments of sericite–quartz schist, and detrital cordierite grains, all in a foliated matrix of chlorite.



SAO 35 04.02.98

Figure 7. Chloritic siltstone from the Beatty Park Member showing a) flame structures, b) contorted bedding, and c) conglomeratic sandstone scour

Unassigned rock unit (*PPs*)

Metasedimentary rocks comprising biotite–muscovite–quartz schists (*PPs*), which outcrop within the Despair Granite in the vicinity of the Wilthorpe gold mine, were previously referred to as chlorite–muscovite–quartz schist and were not assigned to any group (Elias et al., 1980). Here these units are assigned to the Padbury Group and may be part of the Labouchere Formation; however, as their stratigraphic relationship with other units within the Labouchere Formation is unknown, they are left unassigned. Two main outcrops are observed: one in the Wilthorpe gold mine and the other just outside the mine as a fault-bounded inclusion within the granite.

Sedimentary rock found as lenses within the Despair Granite is heterogeneously deformed and metamorphosed. Sedimentary structures such as cross-bedding (Fig. 8) and bedding-parallel laminations are present. This rock consists of alternating layers of very fine grained biotite, quartz, sericite, and feldspar, with accessory opaque minerals. In a few places, this rock contains a foliation parallel to faults or fold-axial planes (see **Despair Granite**). Opaques typically cross-cut the dominant fabric (bedding). The preservation of the primary sedimentary textures suggests that strong deformation did not accompany low-grade (greenschist facies) metamorphism of these rocks.

Within the Wilthorpe gold mine, the metasedimentary rocks are in faulted contact with the sericitized Despair Granite and contain a slightly different mineralogy. For instance, one sample shows two distinct layers: one consisting of sericite, quartz, biotite, and opaque minerals and the other of biotite, sericite, quartz, and minor amounts of opaque minerals. This variation in bedding composition is consistent with that observed in the metasedimentary rocks that outcrop outside the mine; however, those within the mine are more deformed and metamorphosed, possessing two foliations and a shear fabric with a dextral shear sense. The rocks within the mine are also coarser grained and comprise quartz, biotite, sericite, and andalusite. The foliation in the rock is overprinted by sericite and biotite.

Palaeoproterozoic structure

The regional geology on PADBURY is divided into three structural domains: the Palaeoproterozoic Padbury–Bryah domain, the Murchison Terrane, and the Narryer Terrane (Fig. 2). The Murchison and Narryer Terranes share a common late Archaean history of deformation and metamorphism. However, during the Palaeoproterozoic Capricorn Orogeny, the Murchison Terrane was disrupted as a relatively rigid basement and only locally deformed in fault and mylonite zones, whereas on PADBURY the Narryer Terrane was extensively reworked. The Padbury–Bryah domain comprises Palaeoproterozoic rocks that have been repeatedly folded.

Contacts between these domains are faults. The northern part of the Murchison Terrane is separated from the Padbury–Bryah domain by a steep east-trending fault.

SAO 37 04.02.98

Figure 8. Cross-bedding in a sericite–biotite–quartz–feldspar–hematite metasedimentary lens in the Despair Granite. Pencil is 14 cm long

On PADBURY the Murchison River follows this structure. Another east-trending fault, north of this terrane boundary, cuts rocks of the Bryah and Padbury Groups on both PADBURY and BRYAH. This fault appears to change direction from easterly trending to north-northeasterly trending on MARYMIA, where it has been referred to as the Jensen fault by Bagas (in prep.). Another major fault zone on PADBURY is the boundary between the Padbury–Bryah domain and the Narryer Terrane. This boundary is marked by large-scale tectonic interleaving between the two domains and is therefore not represented by one fault, but rather a series of faults (e.g. the Billara and Wilthorpe faults).

Padbury–Bryah domain

Major fold structures in the Padbury–Bryah domain are the Fraser Synclinorium, Horseshoe Anticline, and Millidie Syncline. The Fraser Synclinorium is interpreted to be a refolded fold; its basin-like structure being the result of at least three folding events (D_{P1}, D_{P2}, and D_{P3}*). The Millidie Syncline is also a refolded fold and is partly enclosed by the Fraser Synclinorium, although its southern boundary appears to be faulted. The Horseshoe Anticline appears to be a D_{P3} fold and is contained within the fault-bounded Horseshoe anticlinal block. This fault-bounded block also appears to be cut by southeast-trending faults.

D_{P1} structures

The first Palaeoproterozoic deformation event (D_{P1}) produced layer parallel folds, a locally pervasive S_{P1} schistosity, and faults. However, because these structures were pervasively overprinted by D_{P2} structures, they are rarely observed. First-generation (F_{P1}) folds are locally observed in the Fraser Synclinorium in an area 5 km northeast of Mount Fraser and in the Millidie Syncline. They are small-scale isoclinal folds that plunge gently towards the east-northeast or west-southwest. In addition, metre-scale F_{P1} folds are observed in the vicinity of Mount Padbury within the BIF and shale of the Robinson Range Formation. These folds are tight to isoclinal and plunge gently north or south. First-generation folds within the Millidie Syncline and Fraser Synclinorium (Fig. 2) are also inferred from aeromagnetic data.

On BRYAH the F_{P1} folds are interpreted as originally being subhorizontal (Pirajno and Occhipinti, 1998). This is partly in agreement with Hynes and Gee (1986), who suggested that the Glengarry Group (now the Yerrida and Bryah Groups — Pirajno et al., 1996) may have developed recumbent folds before the major, more-open folds that dominate the regional geology. Although Hynes and Gee (1986) recognized this early folding event, they did not suggest that it also affected the Padbury Group.

Zones of high strain and mylonite developed locally during D_{P1}, mainly in the Peak Hill Schist on BRYAH (Pirajno and Occhipinti, 1998). These mylonite zones are not observed on PADBURY, possibly suggesting that a deeper crustal level may be reflected within the Peak Hill Schist on BRYAH.

* The subscript ‘P’ refers to ‘Palaeoproterozoic’ deformation during the Capricorn Orogeny.

D_{P2} structures

The second deformation event (D_{P2}) produced large-scale upright F_{P2} folds. On BRYAH the Robinson Syncline is a steeply inclined, tight to isoclinal fold that trends east (Fig. 2). On PADBURY it is more difficult to define the D_{P2} folds. At Mount Padbury the easterly trending syncline may be a D_{P2} fold; an axial-planar foliation strikes east and is subvertical. The Millidie Syncline appears to be a D_{P2} fold structure that was reoriented northeasterly during D_{P3} (Fig. 2).

Second deformation event structures also include faults and shear zones. The D_{P1} structures were refolded and locally overprinted by S_{P2} schistosity (e.g. in the vicinity of Mount Padbury). Faults and shear zones that developed during D_{P2} may be inferred from regional mapping, missing sections in stratigraphy, and aeromagnetic data. Near Mount Padbury the Narracoota Formation of the Bryah Group is in contact with the Wilthorpe Formation of the Padbury Group due to the removal of the Ravelstone, Horseshoe, and Labouchere Formations. A D_{P2} fault or a reactivated D_{P1} fault lies along the contact between the Narracoota Formation and the Padbury Group, from BRYAH to the area north of the Mount Maitland Greenstone Belt (Fig. 2). This fault continues onto MARYMIA, where it is called the Jensen fault. Bagas (in prep.) suggests that the Jensen fault may have continued to be active on MARYMIA until at least the Mesoproterozoic, because it has displaced the Bangemall Group.

The relative age of other faults in the area — for example, the faults between the Narracoota Formation of the Bryah Group and the Robinson Range and Wilthorpe Formations of the Padbury Group in the area east of the Despair Granite — are contentious. These faults may be D_{P3} structures that developed during tectonic interleaving of the Padbury and Bryah Groups and the Narryer Terrane or may be earlier structures reactivated during D_{P3}.

D_{P3} structures

The third deformation event (D_{P3}) was a regional faulting and folding event that involved the late juxtaposition or further interleaving of the Narryer Terrane with the Padbury–Bryah domain during the later stages of the Capricorn Orogeny. Although there is uncertainty about the mechanism, the distribution and intensity of the D_{P3} structures is closely related to the contact between the Narryer Terrane and Padbury and Bryah Groups. Isoclinal F_{P3} folds are observed throughout PADBURY and MILGUN, but eastward on BRYAH these folds range from open to closed (Occhipinti et al., in prep.; Pirajno and Occhipinti, 1998; Fig. 2). On MILGUN the folds and associated faults trend north, whereas on PADBURY they trend north to northeast. Third-generation (F_{P3}) folds have steeply plunging fold axes with fold-axial surfaces trending north or northeast. No pervasive S_{P3} cleavage is evident. During D_{P3}, older folds were refolded, leading to the development of complex fold-interference structures such as the Fraser Synclinorium.

D_{P4} structures

On PADBURY, the fourth-deformation-event (D_{P4}) structures include mesoscopic chevron folds, kinks, shear zones, and faults and were locally accompanied by the development of a foliation. These D_{P4} structures developed locally throughout the Padbury–Bryah domain, the Narryer Terrane, and in the northernmost part of the Murchison Terrane. Most structures trend between 280 and 300° in the northern and northwestern parts of PADBURY, but these trends were not observed in other parts of PADBURY due to the localized development of D_{P4} structures. The development of such structures suggests a northeast–southwest compression. This compressional event may represent the last deformation episode of the Capricorn Orogeny in this region. The fourth deformation event may also be responsible for the apparent reorientation of the typically north-trending structures on MILGUN to east-trending structures in the northeastern part of PADBURY. This reorientation could be related to late shearing and faulting in response to north-northeast–south-southwest compression. Elias and Williams (1980) suggested that this reorientation reflected late large-scale folding and called this structure the Fraser Anticlinorium.

Discussion

Martin (1994) suggested that the Padbury Group was deposited in a foreland basin in the northwestern part of the Glengarry Basin. A foreland basin is an asymmetric subsiding trough that forms in response to loading of the lithosphere by thrust sheets in an active fold-and-thrust belt (Price, 1973; Flemings and Jordan, 1990). These basins are separated from the unflexed foreland by a peripheral arch, or forebulge (Martin, 1994). Sedimentation within such basins is dependent on a number of factors, including the relief of the mountain belt that supplies the sediment and whether or not the thrust belt is active. The denudation rate increases when the thrust belt is active and is greater in areas where the relief of the mountain belt is high (Flemings and Jordan, 1990).

Martin (1994) suggested that continued convergence of the fold-and-thrust belt and the forebulge led to the formation of isoclinal folds. These folds are the east-trending, steeply dipping F_{P2} folds on PADBURY and BRYAH (Pirajno and Occhipinti, 1998). It is probable that the F_{P1} folds, faults, and shear zones in the Padbury–Bryah domain, interpreted to have originally been shallow-dipping structures, developed during this initial stage of thrusting. Continued convergence may have led to the closing of the basin and development of the large-scale D_{P2} structures.

Field evidence suggests that the Padbury Group was deposited on the Narracoota Formation (Bryah Group). The presence of mafic epiclastic rocks (Beatty Park Member, Millidie Creek Formation) within the Padbury Group indicates a hinterland that included mafic rocks. Possible sources include fault blocks of Narracoota Formation that were uplifted during convergence. Later tectonic movements modified the contacts between the Padbury and Bryah Groups and the Narryer Terrane, perhaps after the closing of the foreland basin during D_{P3}. This model suggests that deformation and interleaving of parts of the Padbury and Bryah Groups was at least partly synchronous with the deposition of the Padbury Group. Although structural overprinting relationships are readily observed between different generations of folds, it is more difficult to distinguish repeated movements on faults or to relate these movements to a particular deformation event. It is probable that major faults, which developed early in the history of the deformation or even during basin development, were reactivated (Occhipinti et al., 1996). These faults may have formed during north–south convergence (D_{P1}, D_{P2}) or later, during further tectonic interleaving of the Padbury and Bryah Groups and the Narryer Complex (D_{P3}). One such fault zone extends from near Bottom Dimble Well, east to Mount Padbury and then north onto MILGUN. In this zone, Elias and Williams (1980) suggested that a major refolded syncline was present. They called this the Padbury Syncline and suggested that it had been refolded by the Fraser Antiform (Elias and Williams, 1980, fig. 1). Recent mapping suggests that the Padbury Syncline, as outlined by Elias and Williams (1980), is not a simple synclinal structure, but has been cross-cut in many places by faults and shear zones. The unusual orientation of the Padbury Syncline suggests that its orientation has been modified by shearing and faulting, possibly during D_{P3} and D_{P4}.

Palaeoproterozoic metamorphism

Padbury–Bryah domain

The Palaeoproterozoic Padbury and Bryah Groups on PADBURY are mainly metamorphosed at lower to middle greenschist facies and generally still preserve their original clastic or volcanic textures. However, original textures have been locally obliterated through weathering and/or pervasive metasomatism and deformation. In the western part of PADBURY, the Padbury and Bryah Groups are metamorphosed up to lower amphibolite facies along contacts with the Narryer Terrane.

The timing of metamorphism in the region is difficult to ascertain as pervasive crystallization of metamorphic minerals in foliation planes is not observed everywhere. Evidence based on regional observations suggests that the Padbury Group was mostly metamorphosed to lower greenschist facies during D_{P1} and D_{P2}.

In the northwestern part of PADBURY, where the Labouchere Formation is tectonically interleaved with the Narryer Terrane and Despair Granite, staurolite–andalusite–biotite–muscovite–quartz(–chloritoid) schist displays at least two deformation fabrics. The pervasive fabric (D_{P2}–D_{P3}) is defined by a differentiated schistosity and, in places, by a crenulation cleavage. An earlier folded fabric (D_{P1}) is defined by the alignment of biotite and muscovite. Trails of minute inclusions (probably sericite) within staurolite grains are rotated in some places, indicating that staurolite may have crystallized during or after the early deformation event (D_{P1}). Andalusite appears to have crystallized at the same time as staurolite.

Biotite and muscovite recrystallized during D_{P2} or D_{P3} to form the dominant pervasive schistosity and are often wrapped around andalusite and staurolite porphyroclasts. These assemblages indicate that lower amphibolite facies metamorphism accompanied early deformation of these rocks. Late-stage retrogression, which does not appear to be linked with any deformation event, includes the breakdown of staurolite and andalusite to sericite and kaolinite–illite. During D_2–D_3, biotite, muscovite, and (more rarely) chloritoid crystallized to form a pervasive cleavage, indicating metamorphism at greenschist facies.

The difference in metamorphic grade between Palaeoproterozoic rocks in the eastern and western parts of PADBURY suggests that the rocks in these two regions were at different structural levels during the early stages of metamorphism. This can be explained in terms of thrust tectonics, where rocks in the western part of PADBURY were at lower structural levels during early north–south convergence. With continued movement this area may have been uplifted to a higher structural level.

Greenschist facies metamorphism in the Narracoota Formation is marked by pervasive crystallization of actinolite–tremolite(–talc–chlorite) assemblages, particularly in the mafic and ultramafic schists. From structural relationships, Pirajno and Occhipinti (1998) suggest that this greenschist facies assemblage may have developed during D_{P2}. In the Dimble Belt (Fig. 2), where the Narracoota Formation is least sheared and original volcanic textures are still preserved, the original mineral assemblages are only recrystallized to greenschist facies. In some regions, carbonate metasomatism appears to have accompanied deformation, particularly in the Horseshoe anticlinal block, where mafic–ultramafic volcanic rocks have been pervasively altered (see below).

Whole-rock geochemistry

Thirty-three samples of mafic volcanic rocks (Narracoota Formation) and clastic sedimentary rocks (Beatty Park Member) from PADBURY were analysed for major, trace, and rare-earth elements. The mafic volcanic rocks were analysed to compare their geochemical characteristics to those of mafic volcanic rocks of the Narracoota Formation (Hynes and Gee, 1986; Pirajno et al., 1995; Pirajno and Davy, 1996; Pirajno and Occhipinti, 1998). The mafic clastic rocks of the Beatty Park Member were analysed in an attempt to identify possible source rocks.

Narracoota Formation

Hynes and Gee (1986) described the main basaltic sequence of the Narracoota Formation as MORB-like tholeiites. The mafic volcanic rocks associated with ultramafic schists are very low in Ti and Zr and were considered to be boninites. The mafic and ultramafic schists between Haystack Well and Despair Bore on PADBURY also have low concentrations of Ti and Zr and were therefore correlated with the Narracoota Formation defined further east. Hynes and Gee (1986) also regarded the high-Mg basalt near Top Dimble Well as an integral part of the Narracoota Formation.

Pirajno and Occhipinti (1998) and Pirajno et al. (1996) redefined the Narracoota Formation and restricted it to the Bryah Group. Metabasalt and mafic schist were described as high-Fe–Mg tholeiites characterized by low rare-earth element (REE) abundances, light rare-earth element (LREE) enrichment, and high Cr and Ni contents. The ultramafic schists were interpreted as subvolcanic and volcanic cumulates and are characterized by very low REE abundances and slight heavy rare-earth element (HREE) enrichment.

Recently, other occurrences of Narracoota Formation rocks have been mapped or discovered by exploration drilling on MILGUN, JAMINDI, and PADBURY. On PADBURY, extensive areas underlain by heterogeneously altered (carbonated or silicified) mafic to ultramafic schists are interpreted as part of the Narracoota Formation, including the main belt of mafic schist (*ℙAns*) and komatiitic flows (*ℙAnp*) between Haystack Well and Despair Bore.

Mafic–ultramafic volcanic rock samples analysed from PADBURY are divided into two groups: altered (carbonated and silicified) and unaltered. Unaltered mafic–ultramafic volcanic rocks were sampled from the Dimble Belt between Despair Bore and Kelly Bore, and altered mafic–ultramafic rocks were sampled from the Horseshoe anticlinal block.

The major-element geochemical data for altered mafic–ultramafic rocks were not considered, owing to pervasive metasomatism. In contrast to the major elements, the REEs do not appear to have been affected by metasomatism. High Cr and Ni concentrations and REE patterns indicate low REE abundances, and slight LREE enrichment suggests that these altered rocks can be correlated with the Narracoota Formation (Figs 9a,e).

Hynes and Gee (1986) suggested that the mafic rocks of the Dimble Belt (i.e. between Top Dimble Well and Relief Bore) were part of the Narracoota Formation. They based their correlation on chemical similarities to the mafic volcanic rocks of the Narracoota Formation that outcrop on BRYAH. Here the whole-rock geochemistry of the unaltered mafic volcanic rocks of the Dimble Belt is studied in detail and further comparisons with the Narracoota Formation are made.

The Dimble Belt mafic–ultramafic volcanic rocks plot in the low-potassium tholeiite field (Fig. 9b). On a Jensen (1976) diagram the unaltered samples plot in the fields for komatiite (ultramafic komatiite and high-Mg basalt) and high-Mg tholeiite (Fig. 9c). These rocks also have high Cr and Ni concentrations (Fig. 9d).

The komatiitic rocks and high-Mg tholeiites all display flat HREE patterns; however, the high-Mg tholeiites display LREE enrichment while the komatiitic rocks are depleted in LREEs (Fig. 9e).

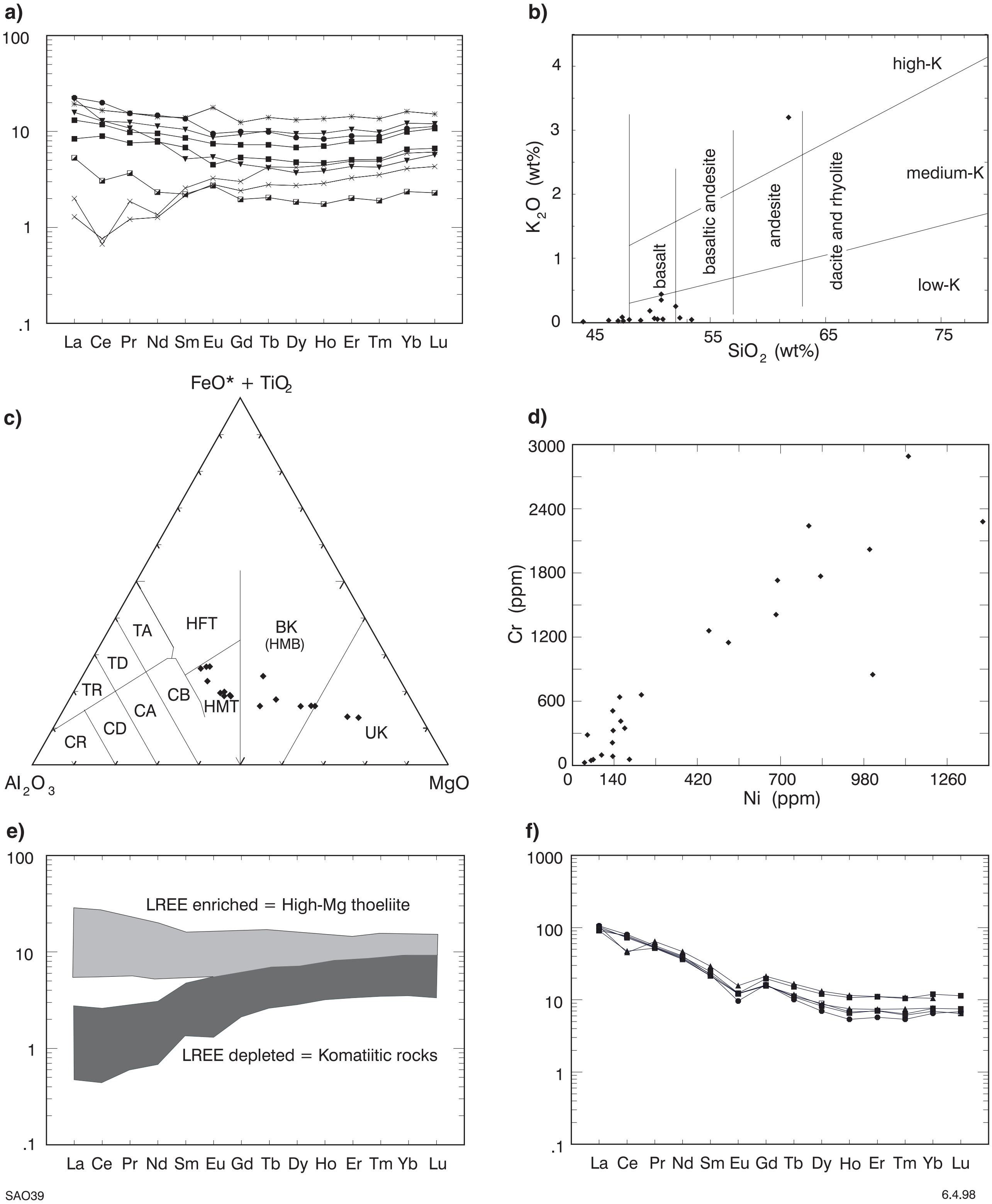


Figure 9. Geochemical diagrams of the Narracoota Formation and the Beatty Park Member of the Wilthorpe Formation:

- **a) chondrite-normalized REE plot for carbonated and silicified (altered) mafic rocks of the Narracoota Formation (normalizing factors after Sun, 1982);**
- **b) K_2O versus SiO_2 plot (after Le Maitre, 1989) for the unaltered mafic–ultramafic volcanic rocks of the Narracoota Formation from the Dimble Belt illustrating that these rocks are tholeiitic;**
- **c) Jensen (1976) cationic plot for Narracoota Formation mafic–ultramafic rocks from the Dimble Belt. UK: ultramafic komatiite, BK: basaltic komatiite, HMB: high-Mg basalt, HMT: high-Mg tholeiite, HFT: high-Fe tholeiite. Refer to Jensen (1976) for description of other fields;**
- **d) Cr versus Ni plot illustrating the Ni and Cr contents of Narracoota Formation rocks on from the Dimble Belt;**
- **e) chondrite-normalized REE plot for unaltered mafic–ultramafic Narracoota Formation volcanic rocks from the Dimble Belt (normalizing factors after Sun, 1982);**
- **f) chondrite-normalized REE plot for the Beatty Park Member mafic epiclastic rocks (normalizing factors after Sun, 1982)**

The Dimble Belt mafic–ultramafic rocks are characterized by low REE abundances and typically flat REE patterns, high Ni and Cr contents (Table 4), and high magnesium numbers (Mg#, defined as Mg/(MgO+FeO^{2+})). Such features are typical of basalts found in a mid-ocean-ridge setting and support the correlation of these rocks with the Narracoota Formation.

Wilthorpe Formation, Beatty Park Member

The Beatty Park Member of the Wilthorpe Formation (Padbury Group) is characterized by 'mafic' clastic rocks mostly consisting of metamorphosed chlorite–quartz shale, siltstone and wacke, several conglomeratic or breccia lenses, and some finely laminated chert layers. The SiO_2 content of these rocks ranges between 61.18 and 69.01 wt%. The REE patterns show slight enrichment in LREEs (Fig. 9f) and are similar to the REE patterns of the Narracoota Formation presented by Pirajno et al. (1995). These results suggest that the source of the mafic component is the underlying Narracoota Formation. This indicates likely tectonic activity, with the uplift and exposure of mafic volcanic rocks before, or during, the deposition of the Beatty Park Member.

Table 4. Averages of major- and trace-element analyses of Narracoota Formation mafic–ultramafic rocks, Dimble Belt

Major and trace elements	*High-Mg tholeiites (8)[a]*	*High-Mg basalts (6)*	*Komatiitic pyroxenites (3)*
	Weight percentage		
SiO_2	50.78	48.07	44.67
TiO_2	0.62	0.39	0.16
Al_2O_3	13.49	11.75	8.30
Fe_2O_3	2.58	1.81	2.28
FeO	7.15	7.22	6.49
MnO	0.17	0.16	0.14
MgO	8.77	13.95	23.47
CaO	10.10	9.74	6.85
Na_2O	2.68	2.09	0.41
K_2O	0.17	0.04	0.02
P_2O_5	0.06	0.04	0.01
S	0.004	0.00	0.00
Total	**96.574**	**95.26**	**92.80**
	Parts per million		
As	1.00	2.17	2.50
Ba	81.07	57.54	66.50
Ce	9.87	5.03	0.87
Cr	472.78	1 375.00	2 313.33
Co	58.22	73.33	99.67
Cu	100.56	58.33	23.67
Ga	12.11	10.00	6.17
Ge	472.78	1 375.00	2 313.33
La	3.80	2.06	0.52
Mn	1 330.00	1 251.67	1 068.33
Nb	1.78	1.00	0.00
Ni	201.44	479.00	1 115.00
Pb	0.22	0.33	0.00
Rb	2.17	0.08	0.33
Sc	50.00	45.17	35.00
Sn	2.22	2.00	0.67
Sr	111.22	98.33	16.50
Th	0.33	0.17	0.00
U	0.11	0.00	0.00
V	236.78	184.17	124.67
Y	15.22	11.67	6.33
Zn	77.11	59.00	49.00
Zr	37.00	20.50	6.67

NOTES: (a) Numbers in parentheses denote number of samples

These analyses were carried out by ANUTECH Pty Ltd at the Australian National University INAX Laboratory. Major-element analyses were completed using a PW2400 spectrometer. Samples were fused with lithium borate mixed with lanthanum oxide as the heavy absorber. The method follows that of Norrish and Hutton (1969). Trace-element analyses were carried out using a Phillips PW1400 X-ray spectrometer following methods discussed by Chappell (1991). Instrumental neutron activation was completed using the method of Chappell and Hergt (1989)

Mesoproterozoic geology

Bangemall Group (₽*Ma*, ₽*Ms*)

Several small isolated outliers of clastic rocks belonging to the basal part of the Bangemall Group unconformably overlie the Padbury Group in a belt about 2 km northeast of Fish Pond Bore. A further outlier overlies the foliated Archaean granite of the Murchison Terrane between 4 Corners Well and Ross Bore. These rocks include quartz arenite to subarkose (₽*Ma*) and siltstone and shale (₽*Ms*), which are probably correlatives with the Tringadee Formation — the basal unit in the western Bangemall Group (Muhling and Brakel, 1985).

The basal unconformity of the Bangemall Group is well exposed at several localities in the low hills 3–4 km north of 5 Mile Well where it cuts across the Millidie Formation. Subhorizontal to very gently dipping quartz arenite layers with well-developed ripple marks, cross-bedding, and, in some layers, rip-up clasts overlie strongly foliated and folded micaceous siltstone. The quartz arenite only forms a thin veneer, except in the southern outcrops, where the arenite grades into siliceous siltstone with some sandstone layers.

In areas about 1.5 and 3 km south-southwest of Wandarrie Well, quartz arenite and subarkose (about 15% feldspar) are associated with quartz-pebble conglomerate layers. Further east at Middle Bore, finely laminated, slightly ferruginous shale (₽*Ms*) is folded into a gently west-plunging open syncline. No basal unconformity is observed at these localities.

Further south, about 3–4 km northeast of 4 Corners Well, gently dipping quartz arenite (₽*Ma*) overlain by shale–siltstone (₽*Ms*) unconformably overlies foliated granite of the Murchison Terrane.

The age of the Bangemall Group is constrained by a Pb-model age from the Abra prospect of 1.64 Ga and a SHRIMP U–Pb zircon age of 1.63 Ga from the Tangadee Rhyolite in the lower part of the succession on COLLIER (Nelson 1995).

Quartz veins, dolerite dykes, and chert pods (*q*, ₽*q*, ₽*d*, ₽*c*)

Quartz veins (₽*q*, *q*) intrude faults throughout PADBURY. These faults are interpreted to have developed in the Palaeoproterozoic.

Table 5. Historical gold production on PADBURY

Mining centre	*Name*	*Northing (AMG)*	*Easting (AMG)*	*Ore treated (t)*	*Gold production (g)*	*Year/s*
Wilthorpe	Wilthorpe	7177192	630636	47.8	651	1904
	Sundry claims	–	–	90.4	800	1904
Mount Fraser	Mount Fraser	7164733	645289	118.9	3 516	1900–02
				144.8	4 625	1907–08
				132.1	1 842	1904
Mount Maitland	Maitland North	7150600	602650	89.4	2 492	1933
				245	1 186	1981–82
	Maitland	7148350	601400	60	47	1983
	Deep Well (Anne-Marie)	7148925	616931	9.7	476	1960

Dolerite dykes (*Pd*) intrude the Labouchere Formation (Padbury Group) in the northeastern part of PADBURY. They are typically fine grained but locally contain small phenocrysts of plagioclase.

Small chert pods (*Pc*) are present within the Horseshoe Anticline (Fig. 2) and appear to have developed later than the deposition of the Horseshoe Formation, perhaps during Palaeoproterozoic deformation of the region.

Economic geology

Gold

PADBURY lies in the Peak Hill and Murchison Goldfields. Gold was discovered in the area in 1892 and was mined at Mount Fraser between 1900 and 1908 and in 1960, and from the Wilthorpe mining group (in the vicinity of the Wilthorpe gold mine) in 1904 and the early 1990s (Table 5). Currently, the only active gold workings on PADBURY, are at Anne-Marie (AMG 169490) in Archaean granite gneiss of the Murchison Terrane.

The Wilthorpe mining group is located within the late Archaean Despair Granite, in which gold was mined from quartz veins and shear zones. In the small opencut gold mine (AMG 306769), gold was recovered from a Proterozoic fault zone between the Despair Granite and what is thought to be metasedimentary rock of the Palaeoproterozoic Padbury Group. Some lithological contacts that were previously thought to be conformable, but are now interpreted as faults, may be good targets for gold exploration.

Manganese

Manganese was discovered in the Peak Hill district in 1905 (Table 6). It is directly related to manganiferous and hematitic shales and BIFs of the Padbury and Bryah Groups. The Horseshoe Formation (Bryah Group) and Millidie Creek Formation (Padbury Group) host manganese mineralization on PADBURY. Manganese mines in the area include the Mount Padbury mine and the Elsa Mary, Elsa, and Elsa Two mines (collectively referred to as the Mount Fraser mine). The ore is lateritic, locally pisolitic or botryoidal, and forms caps over manganese-rich sedimentary rock from which it was derived (by supergene processes). On PADBURY, the ore was last mined in 1982 at Mount Padbury. Here, and at Mount Fraser, the ore was found to be of metallurgical grade with an average manganese content of 48% and 47% respectively.

Gee (1987) suggested that the manganese deposits are lateritic enrichments of manganiferous parent rocks. Likewise, Pirajno and Occhipinti (1998) described the manganese mineralization as being of supergene origin related to the manganiferous shale units beneath them.

Base metals

For the most part, mineral exploration in the region has concentrated on gold; however, some base-metal exploration was carried out in the 1970s. Minor base-

Table 6. Historical manganese production on PADBURY

Mining centre		*Production (t)*	*Mn ore (t)*	*Year*
Mount Fraser		5 074	2 730	1949
		5 132	2 510	1950
		2 201	1 139	1951
		918	445	1952
		29 989	14 403	1965
		21 562	10 027	1966
		8 964	4 124	1967
		16	8	1979
		212	100	1980
	Total	**74 068**	**35 486**	
Mount Padbury		2 267	1 099	1977
		922	438	1978
		1 379	654	1979
		1 481	704	1980
		1 196	568	1981
		74	35	1982
	Total	**7 319**	**3 498**	

metal anomalies — mainly Cu, Ni, and Cr — have been reported within the mafic–ultramafic rocks of the Narracoota Formation (Bryah Group).

Iron

Iron deposits of the Robinson Range Formation were first recorded by McLeod (1970), who reported occurrences of high-grade ore in scattered localities along the Robinson Range. Sofoulis (1970) concluded that the Fraser and Robinson Synclines were host to iron-ore deposits consisting of hematite and goethite. He suggested that these resulted from supergene enrichment of the Robinson Range iron formation and that some ores contained up to 65% iron. Even though he found the iron-ore deposits to be scattered, Sofoulis (1970) concluded that collectively they could provide up to 36 Mt of ore with an average grade of 50% iron. Gee (1987) noted that no drilling had been undertaken in the iron-ore patches identified by Sofoulis (1970). He also suggested that the deposits were probably subeconomic in grade and would not compare with the resources in the Hamersley Iron Province.

Gemstones

Variscite has been found 13 km east of Kelly Bore on PADBURY. It is a green hydrated aluminium phosphate (Al $PO_4.2H_2O$) used as a gemstone. On PADBURY, it is found in deeply weathered high-Mg basalt of the Narracoota Formation as green encrustations (Elias and Williams, 1980); however, no production of this mineral occurrence is recorded.

Phosphate

On Padbury, an occurrence of concentrated phosphate was reported by Elias et al. (1980) in the Narracoota Formation about 3 km east of Kelly Bore.

Construction material

Narracoota Formation metamafic rocks are used for road metal and taken from an area about 1 km east of the Mount Clere – Meekatharra Road in the northwestern part of PADBURY.

Acknowledgements

We would like to thank the pastoralists on PADBURY for their support during our field mapping program.

References

BAGAS, L., in prep., Geology of the Marymia 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes.

BARNETT, J. C., 1975, Some probable Lower Proterozoic sediments in the Mount Padbury area: Western Australia Geological Survey, Annual Report 1974, p. 52–54.

CHAPPELL, B. W., 1991, Trace element analysis of rocks by x-ray spectrometry: Advances in X-Ray Analysis, v. 34, p. 263–276.

CHAPPELL, B. W., and HERGT, J. M., 1989, The use of known Fe content as a flux monitor in neutron activation analysis: Chemical Geology, v. 78, p. 151–158.

CLEVERLY, W. H., 1965, The field occurrence of the Mt. Padbury meteorite: Royal Society of Western Australia, Journal, v. 48, p. 55–59.

COMPSTON, W., and PIDGEON, R. T., 1986, Jack Hills, evidence of more very old detrital zircons in Western Australia: Nature, v. 321, p. 766–769.

CRANE, D. T., and DUNN, P. R., 1979, Geological report on Temporary Reserve 6905H, Judges Patch area, near Meekatharra, Western Australia: Western Australia Geological Survey, M-series, Item 1105 (unpublished).

CURRY, P. J., PAYNE, A. L., LEIGHTON, K. A., HENNIG, P., and BLOOD, D. A., 1994, An inventory and condition survey of the Murchison River catchment, Western Australia: Western Australia Department of Agriculture, Technical Bulletin, no. 84, 430p.

ELIAS, M., BARNETT, J. C., and WILLIAMS, S. J., 1980, Robinson Range, W.A. Sheet SG 50-07: Western Australia Geological Survey, 1:250 000 Geological Series.

ELIAS, M., and WILLIAMS, S. J., 1980, Robinson Range, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 32p.

FLEMINGS, P. B., and JORDAN, T. E., 1990, Stratigraphic modeling of foreland basins — interpreting thrust deformation and lithosphere rheology: Geology, v. 18, p. 430–434.

FROUDE, D. O., IRELAND, T. R., KINNY, P. D., WILLIAMS, I. S., COMPSTON, W., WILLIAMS, I. R., and MYERS, J. S., 1983, Ion microprobe identification of 4,100 – 4,200 Myr-old terrestrial zircons: Nature, v. 304, p. 616–618.

GEE, R. D., 1979, The geology of the Peak Hill area: Western Australia Geological Survey, Annual Report 1978, p. 55–62.

GEE, R. D., 1987, Peak Hill, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 24p.

GEE, R. D., 1990, Nabberu Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 202–210.

GEE, R. D., and GREY, K., 1993, Proterozoic rocks on the Glengarry 1:250 000 sheet — stratigraphy, structure and stromatolite biostratigraphy: Western Australia Geological Survey, Report 41, 33p.

GREY, K., 1994, Stromatolites from the Palaeoproterozoic Earaheedy Group, Earaheedy Basin, Western Australia: Alcheringa, v. 18, p. 187–218.

HALL, W. D. M., and GOODE, A. D. T., 1978, The Early Proterozoic Nabberu Basin and associated iron formations of Western Australia: Precambrian Research, v. 7, p. 129–184.

HYNES, A., and GEE, R. D., 1986, Geological setting and petrochemistry of the Narracoota Volcanics, Capricorn Orogen, Western Australia: Precambrian Research, v. 31, p. 107–132.

JENSEN, L. S., 1976, A new cation plot for classifying subalkalic volcanic rocks: Ontario Division of Mines, Miscellaneous Paper, no. 66, 22p.

JOHNSON, W., 1950, A geological reconnaissance survey of part of the area included between the limits lat. 24º0'S. and lat. 29º0'S. and between long. 115º30'E. and long. 118º30'E. including parts of the Yalgoo, Murchison, Peak Hill and Gascoyne Goldfields: Western Australia Geological Survey, Bulletin 106, 103p.

KINNY, P. D., WILLIAMS, I. S., FROUDE, D. O., IRELAND, T. R., and COMPSTON, W., 1988, Early Archaean zircon ages from orthogneisses and anorthosites at Mount Narryer, Western Australia: Precambrian Research, v. 38, p. 325–341.

LE MAITRE, R. W., 1989, A classification of igneous rocks and glossary of terms: Oxford, Blackwell Scientific Publications, 193p.

LEWIS, J. D., 1971, The geology of some carbonate intrusions in the Mount Fraser area, Peak Hill Goldfield, Western Australia: Western Australia Geological Survey, Annual Report 1970, p. 50–56.

MacLEOD, W. N., 1970, Peak Hill, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 21p.

MAITLAND, A. G., 1898, The country between Northampton and Peak Hill Goldfield: Western Australia Geological Survey, Annual Report 1897, p. 14–19.

MARTIN, D. McB., 1994, Sedimentology, sequence stratigraphy, and tectonic setting of a Palaeoproterozoic turbidite complex, Lower Padbury Group, Western Australia: University of Western Australia, PhD thesis (unpublished).

MARTIN, D. McB., in prep., Lithostratigraphy and structure of the Palaeoproterozoic lower Padbury Group, Milgun 1:100 000 sheet, Western Australia: Western Australia Geological Survey, Report 62.

MITCHELL, A. A., and WILCOX, D. G., 1988, Arid shrubland plants of Western Australia: Perth, W.A., University of Western Australia Press, 325p.

MONTGOMERY, A., 1910, Report on the state of mining progress in certain centres in the Murchison and Peak Hill Goldfields: Perth, W.A., Western Australia Department of Mines, Government Printer, 88p.

MUHLING, P. C., and BRAKEL, A. T., 1985, Geology of the Bangemall Group — the evolution of an intracratonic Proterozoic basin: Western Australia Geological Survey, Bulletin 128, 265p.

MYERS, J. S., 1989, Thrust sheets on the southern foreland of the Capricorn Orogen, Robinson Range, Western Australia: Western Australia Geological Survey, Report 26, Professional Papers, p. 127–130.

MYERS, J. S., 1990, Precambrian tectonic evolution of part of Gondwana, southwestern Australia: Geology, v. 18, p. 537–540.

MYERS, J. S., 1993, Precambrian history of the West Australian Craton and adjacent orogens: Annual Reviews in Earth and Planetary Science, v. 21, p. 453–485.

MYERS, J. S., 1995, The generation and assembly of an Archaean supercontinent — evidence from the Yilgarn Craton, Western Australia, *in* Early Precambrian Processes *edited by* M. P. COWARD and A. C. RIES: Geological Society of London, Special Publication, no. 95, p. 143–154.

NELSON, D. R., 1995, Compilation of SHRIMP U–Pb zircon geochronology data, 1994: Western Australia Geological Survey, Record 1995/3, 244p.

NELSON, D. R., 1996, Compilation of SHRIMP U–Pb zircon geochronology data, 1995: Western Australia Geological Survey, Record 1996/5, 168p.

NORRISH, K., and HUTTON, J. T., 1969, An accurate X-ray spectrographic method for the analysis of a wide range of geological samples: Geochimica et Cosmochimica Acta, v. 33, p. 431–453.

NUTMAN, A. P., KINNY, P. D., COMPSTON, W., and WILLIAMS, I. S., 1991, Shrimp U–Pb zircon geochronology of the Narryer Gneiss Complex, Western Australia: Precambrian Research, v. 52, p. 275–300.

OCCHIPINTI, S. A., GREY, K., PIRAJNO, F., ADAMIDES, N. G., BAGAS, L., DAWES, P., and LE BLANC SMITH, G., 1997, Stratigraphic revision of Palaeoproterozoic rocks of the Yerrida, Bryah and Padbury Basins (former Glengarry Basin): Western Australia Geological Survey, Record 1997/3, 57p.

OCCHIPINTI, S. A., SWAGER, C. P., and PIRAJNO, F., 1996, Structural and stratigraphic relationships of the Padbury Group, Western Australia — implications for tectonic history: Western Australia Geological Survey, Annual Review 1995–96, p. 88–95.

OCCHIPINTI, S. A., SWAGER, C. P., and PIRAJNO, F., in prep., Structural–metamorphic evolution of the Palaeoproterozoic Bryah and Padbury Groups during the Capricorn Orogeny, Western Australia: Precambrian Research.

PIRAJNO, F., ADAMIDES, N. G., OCCHIPINTI, S., SWAGER, C. P., and BAGAS, L., 1995, Geology and tectonic evolution of the Early Proterozoic Glengarry Basin, Western Australia: Western Australia Geological Survey, Annual Review 1994–95, p. 71–80.

PIRAJNO, F., BAGAS, L., SWAGER, C. P., OCCHIPINTI, S. A., and ADAMIDES, N. G., 1996, A reappraisal of the stratigraphy of the Glengarry Basin: Western Australia Geological Survey, Annual Review 1995–96, p. 81–87.

PIRAJNO, F., and DAVY, R., 1996, Mafic volcanism in the Palaeoproterozoic Glengarry Basin, Western Australia, and implications for its tectonic evolution: Geological Society of Australia; 13th Australian Geological Convention, Canberra, 1996, Abstracts, no. 41.

PIRAJNO, F., and OCCHIPINTI, S. A., 1995, Base metal potential of the Palaeoproterozoic Glengarry and Bryah Basins, Western Australia: Australian Institute of Geoscientists, Bulletin, no. 16, p. 51–56.

PIRAJNO, F., and OCCHIPINTI, S. A., 1998, Geology of the Bryah 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 41p.

PRICE, R. A., 1973, Large-scale gravitational flow of supracrustal rocks, southern Canadian Rockies, *in* Gravity and Tectonics *edited by* K. A. de JONG and R. SCHOLTEN: New York, John Wiley, p. 491–502.

RUSSELL, J., GREY, K., WHITEHOUSE, M., and MOORBATH, S., 1994, Direct Pb/Pb age determination of Proterozoic stromatolites from the Ashburton and Nabberu Basins, Western Australia: 8th International Conference on Geochemistry, Geochronology and Cosmochronology, Berkeley, USA, 1994, Abstracts, p. 8.

SOFOULIS, J., 1970, Iron ore deposits of the Robinson Range, Peak Hill Goldfield: Western Australia Geological Survey, Record 1970/6, 10p.

SPEAR, F. S., 1993, Metamorphic phase equilibria and pressure–temperature–time paths: Mineralogical Society of America, Monograph, 799p.

SUN, S-S., 1982, Chemical composition and origin of the Earth's primitive mantle: Geochimica et Cosmochimica Acta, v. 46, p. 179–192.

SWAGER, C. P., and MYERS, J., in prep., Geology of the Milgun 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes.

TYLER, I. M., and THORNE, A. M., 1990, The northern margin of the Capricorn Orogen, Western Australia — an example of an early Proterozoic collision zone: Journal of Structural Geology, v. 12, p. 685–701.

WATKINS, K. D., and HICKMAN, A. H., 1990, Geological evolution and mineralization of the Murchison Province, Western Australia: Western Australia Geological Survey, Bulletin 137, 267p.

WEIDENBECK, M. G., 1992, U–Pb dating of zircons by ion microprobe — case studies from the northwestern Yilgarn Craton, Western Australia: Canberra, Australian National University, PhD thesis (unpublished).

WILLIAMS, S. J., 1986, Geology of the Gascoyne Province, Western Australia: Western Australia Geological Survey, Report 15, 85p.

WINDH, J., 1992, Tectonic evolution and metallogenesis of the early Proterozoic Glengarry Basin, Western Australia: University of Western Australia, PhD thesis (unpublished).

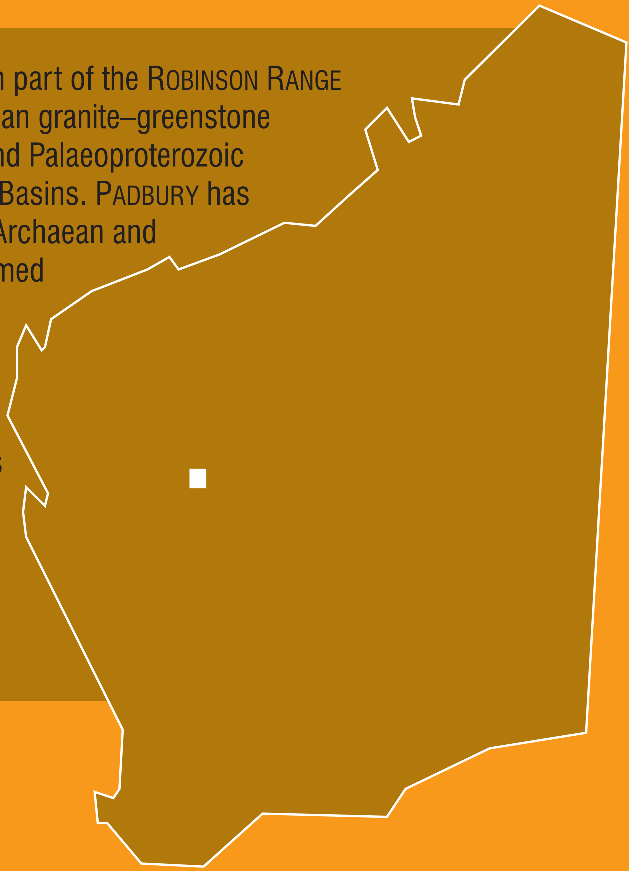
Appendix

Gazetteer of localities

Locality	*Latitude(S)*	*Longitude(E)*	*AMG (E)*	*AMG (N)*
Anne-Marie[(a)] prospect	25°46'24"	118°09'52"	616750	7148900
Beatty Park Bore	25°40'13"	118°17'36"	629800	7160200
Beefwood[(b)] Bore	25°59'38"	118°14'31"	624300	7124400
Bottom Dimble Well	25°38'01"	118°07'55"	613650	7164400
Brunsden Well	25°46'16"	118°26'38"	644800	7148850
Deep Well	25°46'04"	118°09'01"	615350	7148600
Despair Bore	25°35'02"	118°14'47"	625200	7169800
Dog Rocks	25°54'53"	118°15'40"	626300	7133150
Fish Pond Bore	25°40'45"	118°07'01"	612100	7159350
Haystack Well	25°37'54"	118°02'13"	604100	7164700
Kelly Bore	25°34'21"	118°04'29"	607950	7171200
Middle Bore	25°40'07"	118°03'04"	605500	7160600
Mount Fraser	25°38'29"	118°23'12"	639200	7163300
Mount Maitland	25°47'04"	118°00'52"	601700	7147800
Mount Padbury	25°38'07"	118°16'09"	627400	7164100
Mount Padbury Homestead	25°41'43"	118°04'47"	608300	7157600
Mount Pabdury mine	25°37'32"	118°20'44"	635100	7165100
Old Camp Well	25°56'59"	118°07'02"	611850	7129400
Paddy Bore	25°32'13"	118°08'17"	614350	7175100
Relief Bore	25°33'53"	118°10'11"	617500	7172000
Ross Bore	25°48'31"	118°08'21"	614200	7145000
Ti Tree[(c)] Bore	25°32'20"	118°13'56"	623800	7174800
Top Dimble Well	25°36'11"	118°09'37"	616500	7167750
Wandarrie Well	25°39'35"	118°00'26"	601100	7161600
Wilthorpe mining centre	25°31'00"	118°17'00"	629000	7177200
4 Corners Well	25°51'25"	118°05'45"	609800	7139700
5 Mile Well	25°41'25"	118°09'40"	616500	7158100

NOTES: (a) Anne-Marie is incorrectly spelt ‘Anne-Mary’ on the printed map
(b) Beefwood is incorrectly spelt ‘Bufurood’ on the printed map
(c) Ti Tree is incorrectly spelt ‘Tritree’ on the p rinted map

The PADBURY 1:100 000 sheet covers the southeastern part of the ROBINSON RANGE 1:250 000 sheet. The geology is dominated by Archaean granite–greenstone terrane and supracrustal rocks of the Yilgarn Craton and Palaeoproterozoic sedimentary rocks of the Yerrida, Bryah, and Padbury Basins. PADBURY has a complex history of deformation, and as a result the Archaean and Palaeoproterozoic rocks are commonly strongly deformed and tectonically interleaved. A number of prominent faults and folds are recognized in the area. There is a long history of small-scale gold and manganese mining in the Peak Hill and Murchison Goldfields, and the abundance of quartz veins, shear zones, and faults provide numerous targets for gold exploration. These Notes examine the geology and stratigraphic relationships of the formations in the area, with an emphasis on Palaeoproterozoic structure and metamorphism that took place during the Capricorn Orogeny.



Further details of geological publications and maps produced by the Geological Survey of Western Australia can be obtained by contacting:

Information Centre
Department of Minerals and Energy
100 Plain Street
East Perth WA 6004

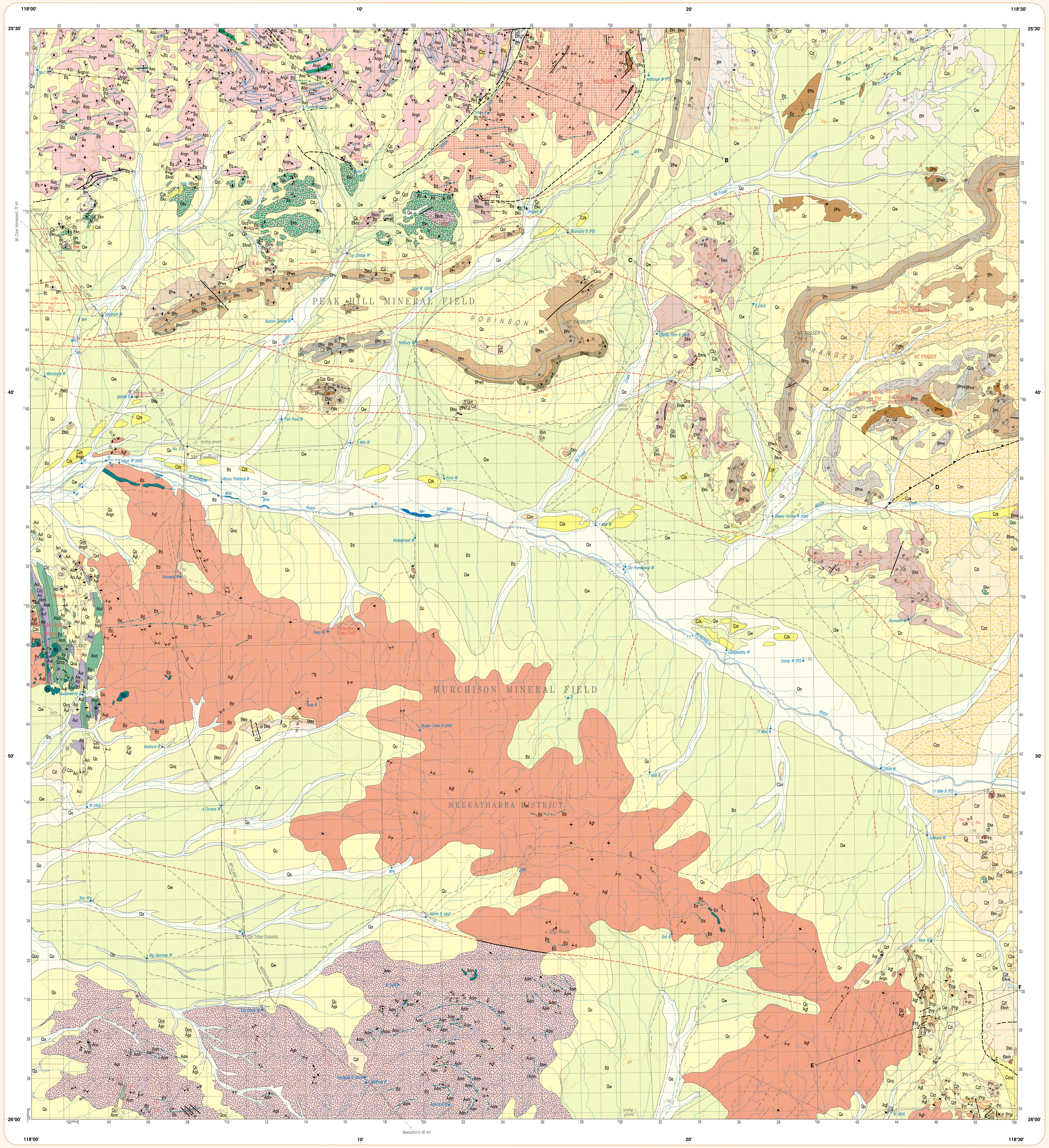
Phone: (08) 9222 3459   Fax: (08) 9222 3444

AUSTRALIA 1 : 100 000 GEOLOGICAL SERIES

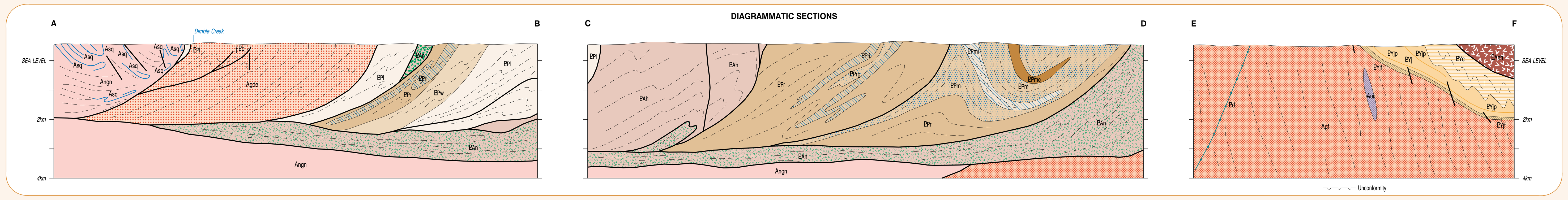
PADBURY

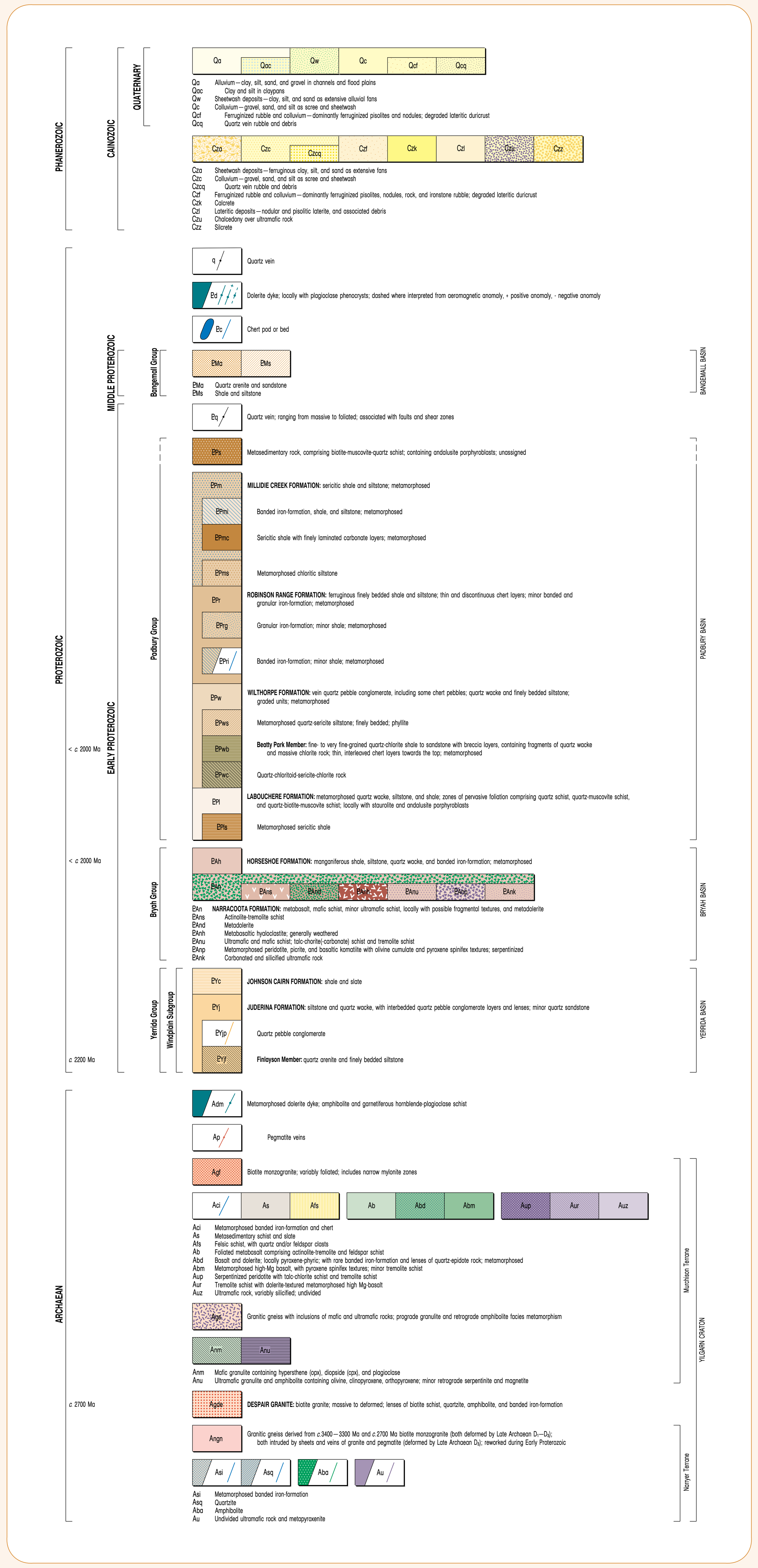
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

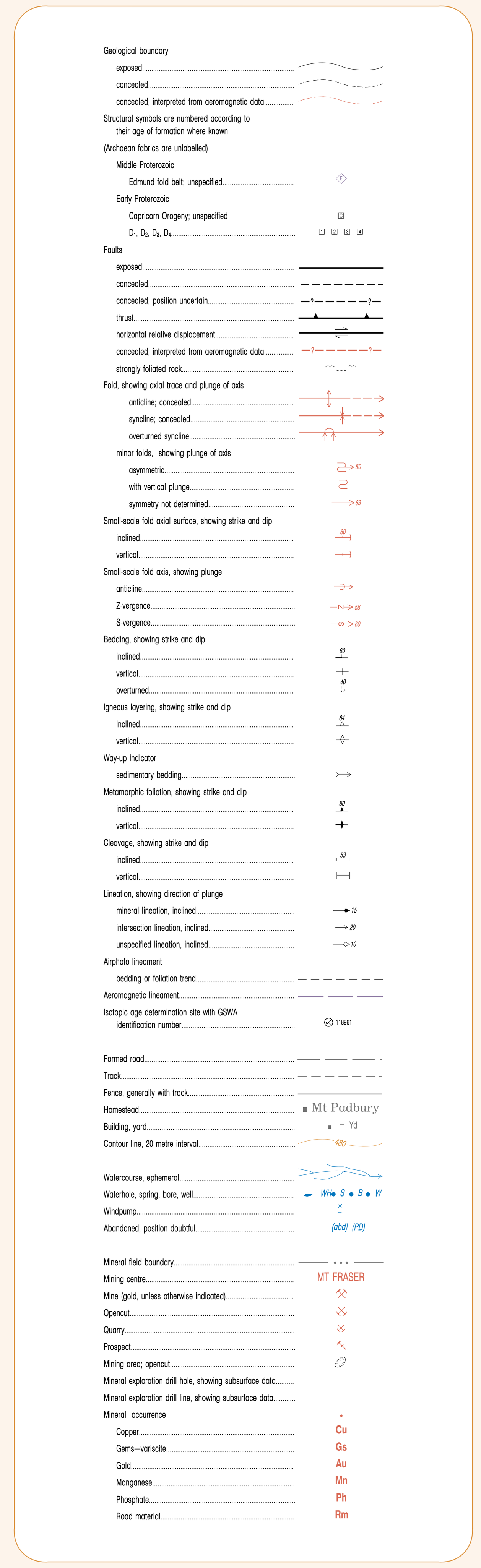
SHEET 2546



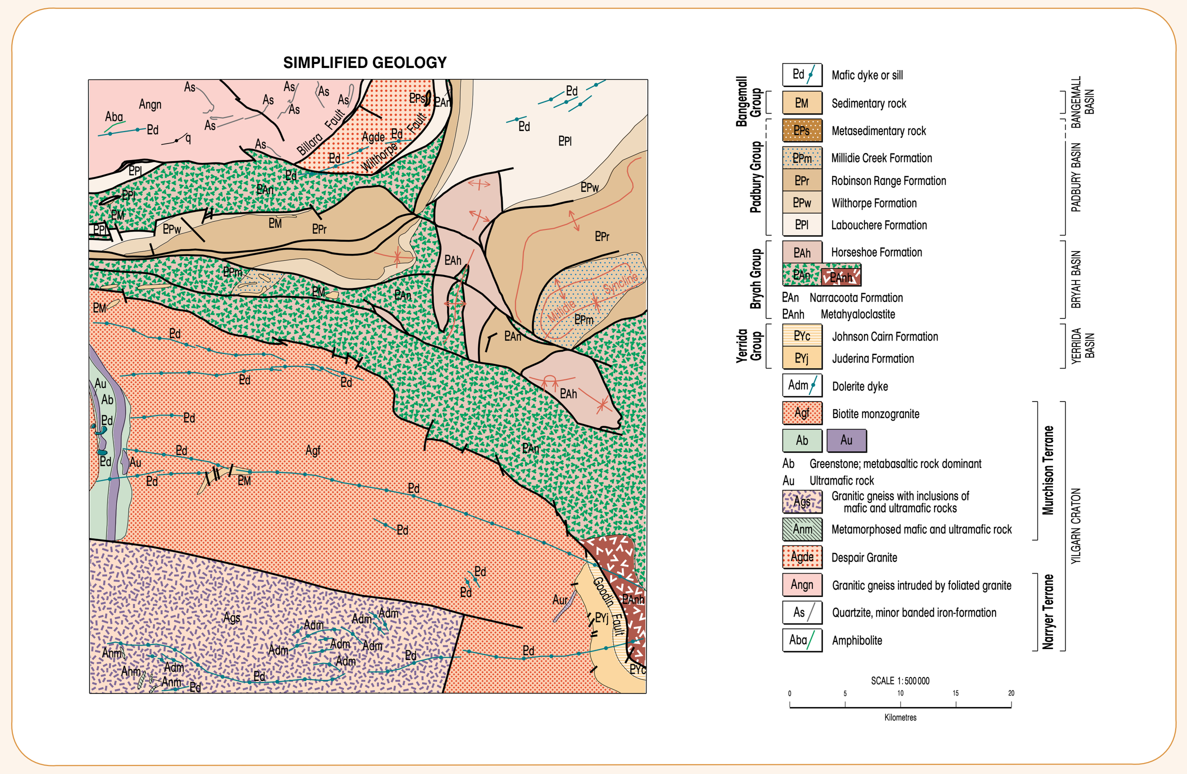
DIAGRAMMATIC SECTIONS



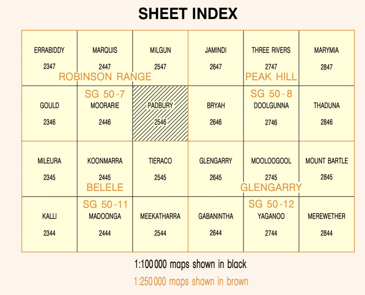


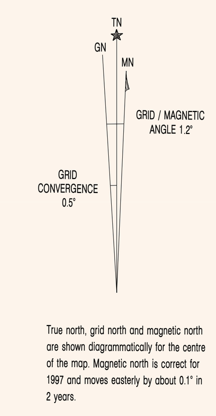


SIMPLIFIED GEOLOGY



SHEET INDEX





DEPARTMENT OF MINERALS AND ENERGY
L.C. RANFORD, DIRECTOR GENERAL

GOVERNMENT OF WESTERN AUSTRALIA
HON. NORMAN MOORE, M.L.C.
MINISTER FOR MINES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
PIETRO GUJ, DIRECTOR

SCALE 1:100 000

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

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

Geology by S.A. Occhipinti, C.P. Swager, and J.S. Myers 1996

Edited by D. Ferdinando and G. Loan

Cartography by C. Bartlett, B. Williams, C. Brien, E. Green, and P. Taylor

Topography from the Department of Land Administration Sheet SG 50-7, 2546, with modifications from geological field survey

Published by the Geological Survey of Western Australia. Copies available from the Mining Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, WA, 6004. Phone (08) 9222 3459, Fax (08) 9222 3444

This map is also available in digital form

Printed by the Sands Print Group, Western Australia

The recommended reference for this map is: OCCHIPINTI, S.A., SWAGER, C.P., and MYERS, J.S., 1997, Padbury, W.A. Sheet 2546: Western Australia Geological Survey, 1:100 000 Geological Series

PADBURY

SHEET 2546 FIRST EDITION 1997