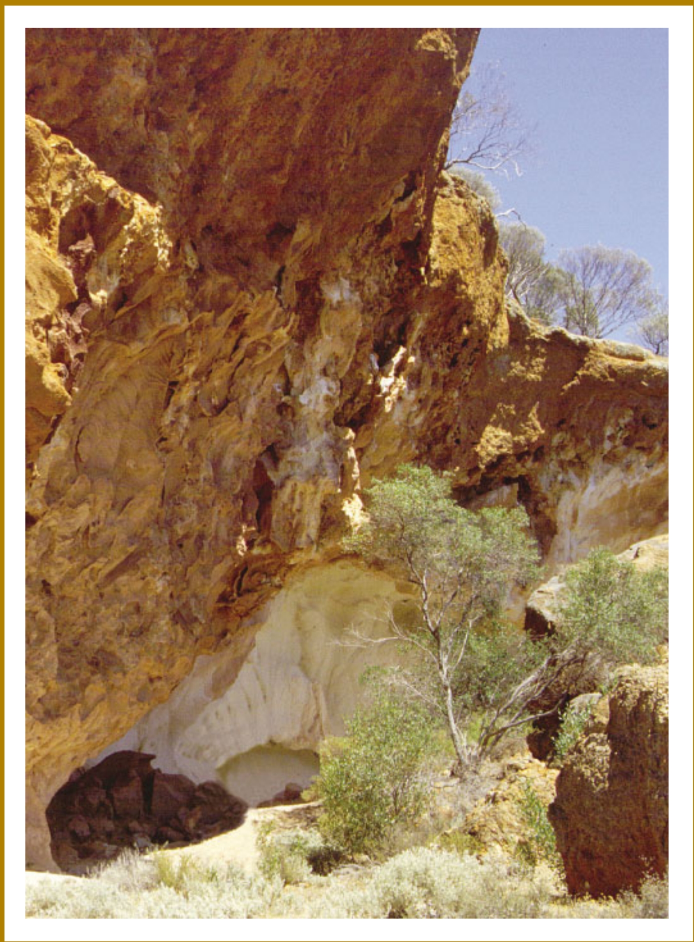
EXPLANATORY NOTES

Department of
Mineral and Petroleum Resources

GEOLOGY OF THE BARLEE 1:100 000 SHEET

by A. Riganti

1:100 000 GEOLOGICAL SERIES



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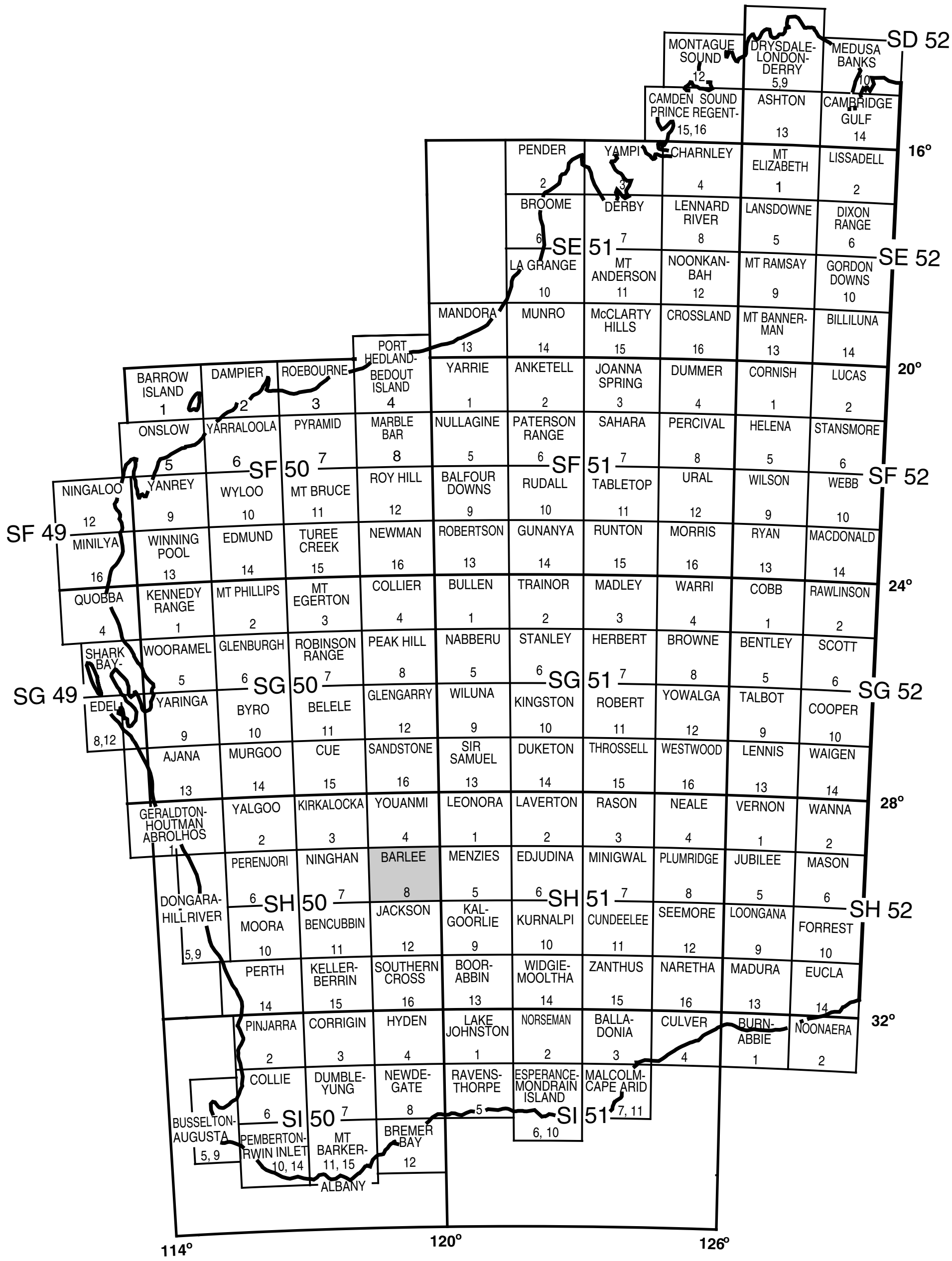
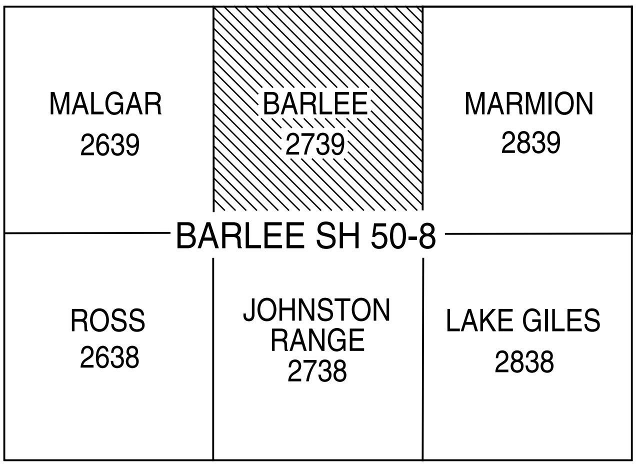

MONTAGUE SOUND
12
DRYSDALE-LONDON-DERRY
5,9
MEDUSA BANKS
10
SD 52
CAMDEN SOUND PRINCE REGENT-
15,16
ASHTON
13
CAMBRIDGE GULF
14
PENDER
2
YAMPI
3
CHARNLEY
4
MT ELIZABETH
1
LISSADELL
2
16°
BROOME
DERBY
LENNARD RIVER
8
LANSDOWNE
5
DIXON RANGE
6
6
SE 51
7
SE 52
LA GRANGE
10
MT ANDERSON
11
NOONKAN-BAH
12
MT RAMSAY
9
GORDON DOWNS
10
MANDORA
13
MUNRO
14
McCLARTY HILLS
15
CROSSLAND
16
MT BANNER-MAN
13
BILLILUNA
14
BARROW ISLAND
1
DAMPIER
2
ROEBOURNE
3
PORT HEDLAND-BEDOUT ISLAND
4
YARRIE
1
ANKETELL
2
JOANNA SPRING
3
DUMMER
4
CORNISH
1
LUCAS
2
20°
ONSLOW
5
YARRALOOLA
6
SF 50
PYRAMID
7
MARBLE BAR
8
NULLAGINE
5
PATERSON RANGE
6
SF 51
SAHARA
7
PERCIVAL
8
HELENA
5
STANSMORE
6
SF 52
NINGALOO
12
YANREY
9
WYLOO
10
MT BRUCE
11
ROY HILL
12
BALFOUR DOWNS
9
RUDALL
10
TABLETOP
11
URAL
12
WILSON
9
WEBB
10
SF 49
MINILYA
16
WINNING POOL
13
EDMUND
14
TUREE CREEK
15
NEWMAN
16
ROBERTSON
13
GUNANYA
14
RUNTON
15
MORRIS
16
RYAN
13
MACDONALD
14
QUOBBA
4
KENNEDY RANGE
1
MT PHILLIPS
2
MT EGERTON
3
COLLIER
4
BULLEN
1
TRAINOR
2
MADLEY
3
WARRI
4
COBB
1
RAWLINSON
2
24°
SHARK BAY-
WOORAMEL
5
GLENBURGH
6
SG 50
ROBINSON RANGE
7
PEAK HILL
8
NABBERU
5
STANLEY
6
SG 51
HERBERT
7
BROWNE
8
BENTLEY
5
SCOTT
6
SG 52
SG 49
EDEL
8,12
YARINGA
9
BYRO
10
BELELE
11
GLENGARRY
12
WILUNA
9
KINGSTON
10
ROBERT
11
YOWALGA
12
TALBOT
9
COOPER
10
AJANA
13
MURGOO
14
CUE
15
SANDSTONE
16
SIR SAMUEL
13
DUKETON
14
THROSSELL
15
WESTWOOD
16
LENNIS
13
WAIGEN
14
GERALDTON-HOUTMAN ABROLHOS
1
YALGOO
2
KIRKALOCKA
3
YOUANMI
4
LEONORA
1
LAVERTON
2
RASON
3
NEALE
4
VERNON
1
WANNA
2
28°
PERENJORI
NINGHAN
BARLEE
8
MENZIES
5
EDJUDINA
6
MINIGWAL
7
PLUMRIDGE
8
JUBILEE
5
MASON
6
DONGARA-HILL RIVER
5,9
6
SH 50
7
SH 51
SH 52
MOORA
10
BENCUBBIN
11
JACKSON
12
KAL-GOORLIE
9
KURNALPI
10
CUNDEELEE
11
SEEMORE
12
LOONGANA
9
FORREST
10
PERTH
14
KELLER-BERRIN
15
SOUTHERN CROSS
16
BOOR-ABBIN
13
WIDGIE-MOOLTHA
14
ZANTHUS
15
NARETHA
16
MADURA
13
EUCLA
14
PINJARRA
2
CORRIGIN
3
HYDEN
4
LAKE JOHNSTON
1
NORSEMAN
2
BALLA-DONIA
3
CULVER
4
BURN-ABBIE
1
NOONAERA
2
32°
COLLIE
DUMBLE-YUNG
NEWDE-GATE
RAVENS-THORPE
5
ESPERANCE-MONDRAIN ISLAND
6, 10
MALCOLM-CAPE ARID
7, 11
6
SI 50
7
8
SI 51
BUSSELTON-AUGUSTA
5, 9
PEMBERTON-IRWIN INLET
10, 14
MT BARKER-
11, 15
ALBANY
BREMER BAY
12
114°
120°
126°


MALGAR
2639
BARLEE
2739
MARMION
2839
BARLEE SH 50-8
ROSS
2638
JOHNSTON RANGE
2738
LAKE GILES
2838

AR38

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Cover photograph:
Breakaway in weathered granite, capped by ferruginized silcrete (MGA 733600E 6752900N).

Contents

Appendix

Figures

Table

Geology of the Barlee 1:100 000 sheet

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Abstract

The BARLEE 1:100 000 sheet lies within the Southern Cross Granite–Greenstone Terrane in the central part of the Archaean Yilgarn Craton. Granitoid rocks are dominant on BARLEE, with greenstones of the Marda–Diemals greenstone belt confined to the southwestern quadrant of the sheet. Greenstones comprise metamorphosed basalt, high-Mg basalt, mafic tuff, gabbro, banded iron-formation, shale, and minor peridotite and tremolite schist. All greenstones have undergone greenschist- to amphibolite-facies metamorphism.

A depositional age of 3.0 Ga is inferred for the greenstones from adjacent areas of the belt. Several episodes of granitoid magmatism are recognized on BARLEE. The oldest identified granitoid rocks (c. 2710 Ma) consist of granitoid gneiss, locally with abundant mafic and sedimentary enclaves. These gneiss exposures are enveloped by later, largely monzogranite intrusions that range in age from 2.69 to 2.63 Ga.

The first deformation event recorded on BARLEE (D_1) produced an easterly trending schistosity that was later folded by upright, northerly trending, mesoscopic to megascopic folds (D_2). Regional-scale faults and shear zones (e.g. the Yuinmery Shear Zone) were developed during the D_3 event. Subsequent deformation included the development of easterly faults and fractures, some of which are infilled by quartz veins and intruded by possibly Proterozoic mafic and ultramafic dykes.

KEYWORDS: Archaean, granite, greenstone, Southern Cross, Barlee, Diemals.

Introduction

The BARLEE* 1:100 000 geological map sheet (SH 50-8, 2739) occupies the north-central part of the BARLEE 1:250 000 map sheet, and is bound by latitudes 29°00'S and 29°30'S, and longitudes 119°00'E and 119°30'E (Fig. 1). BARLEE derives its name from Lake Barlee, one of the largest playa lakes in Western Australia, the western part of which dominates the map sheet (Fig. 2). The lake was named by John Forrest in 1869, after the then Colonial Secretary of Western Australia (Feeken et al., 1970).

Mapping of BARLEE was carried out between September and November 1999 using 1:24 700-scale colour aerial photography flown for the Western Australian Department of Land Administration (DOLA) in 1998. Map compilation used Landsat TM5 (Thematic Mapper) images and 400-m line-spaced aeromagnetic data collected by Kevron Geophysics Pty Ltd in 1997 (available for purchase from Geoscience Australia).

Access to BARLEE is provided by the formed Lake Barlee – Youanmi Road (Fig. 2), which joins the town of Menzies (about 200 km to the east-southeast) with the Youanmi–Sandstone region (about 130 km to the north). Most of the map sheet can be reached via station tracks and a few mineral exploration gridlines, although some are degraded and inaccessible during wet periods. BARLEE is covered by three leasehold pastoral stations (Lake Barlee, Diemals, and Cashmere Downs) and some vacant Crown land, but the only permanent settlement is the Lake Barlee Homestead†, at the western edge of the sheet (Figs 1 and 2). The main commercial activities in the area are cattle grazing and licensed sandalwood collection.

Previous investigations

The earliest published geological descriptions of the area were those of Talbot (1912) and Woodward (1912), and the first systematic regional mapping of BARLEE was completed by the Geological Survey of Western Australia (GSWA) as part of the BARLEE 1:250 000 sheet mapping project (Walker and Blight, 1983). BARLEE lies within the

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

† MGA coordinates of localities mentioned in the text are listed in the Appendix.

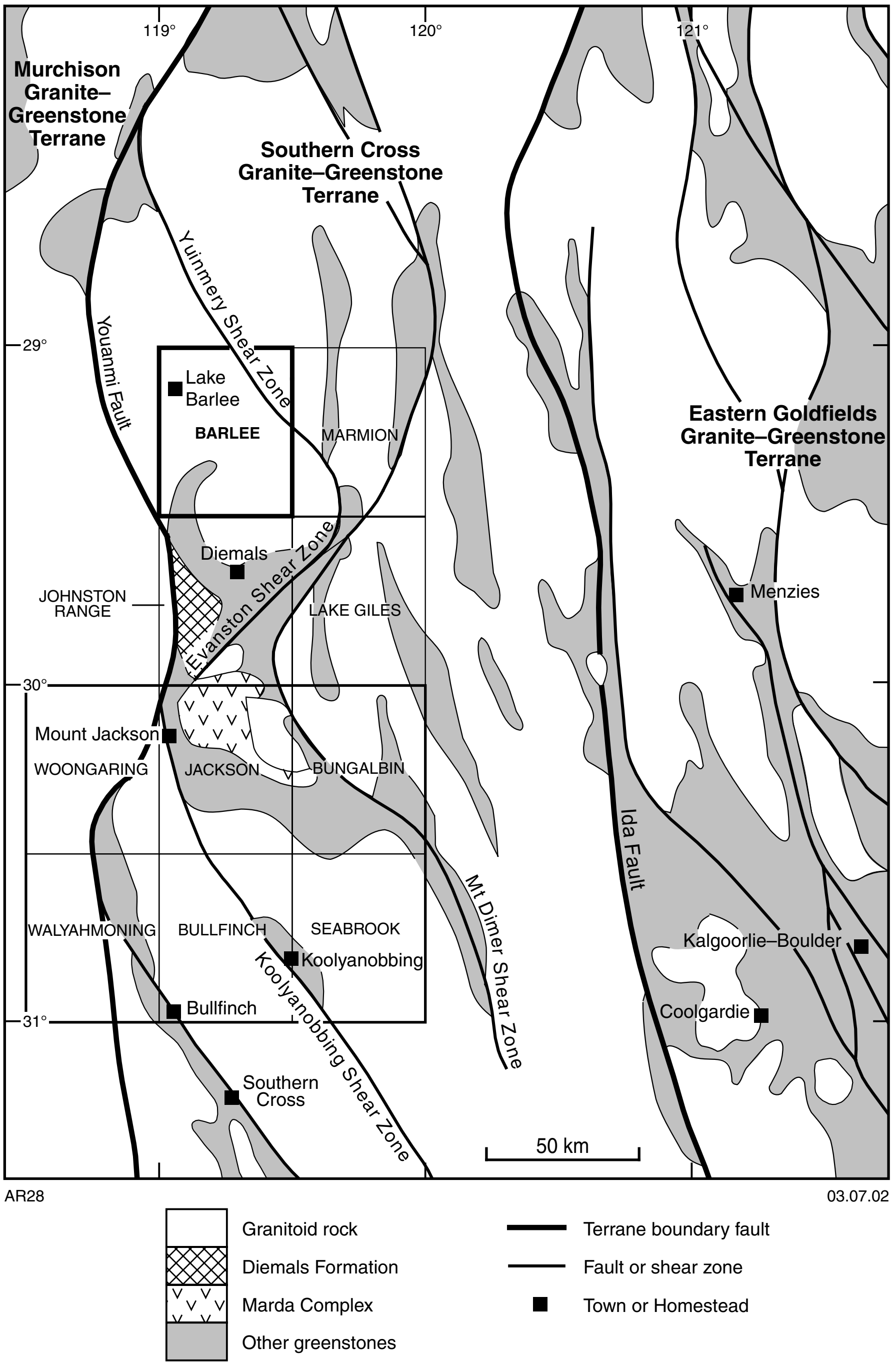

Figure 1. Regional geological setting of BARLEE (adapted from Myers and Hocking, 1998)

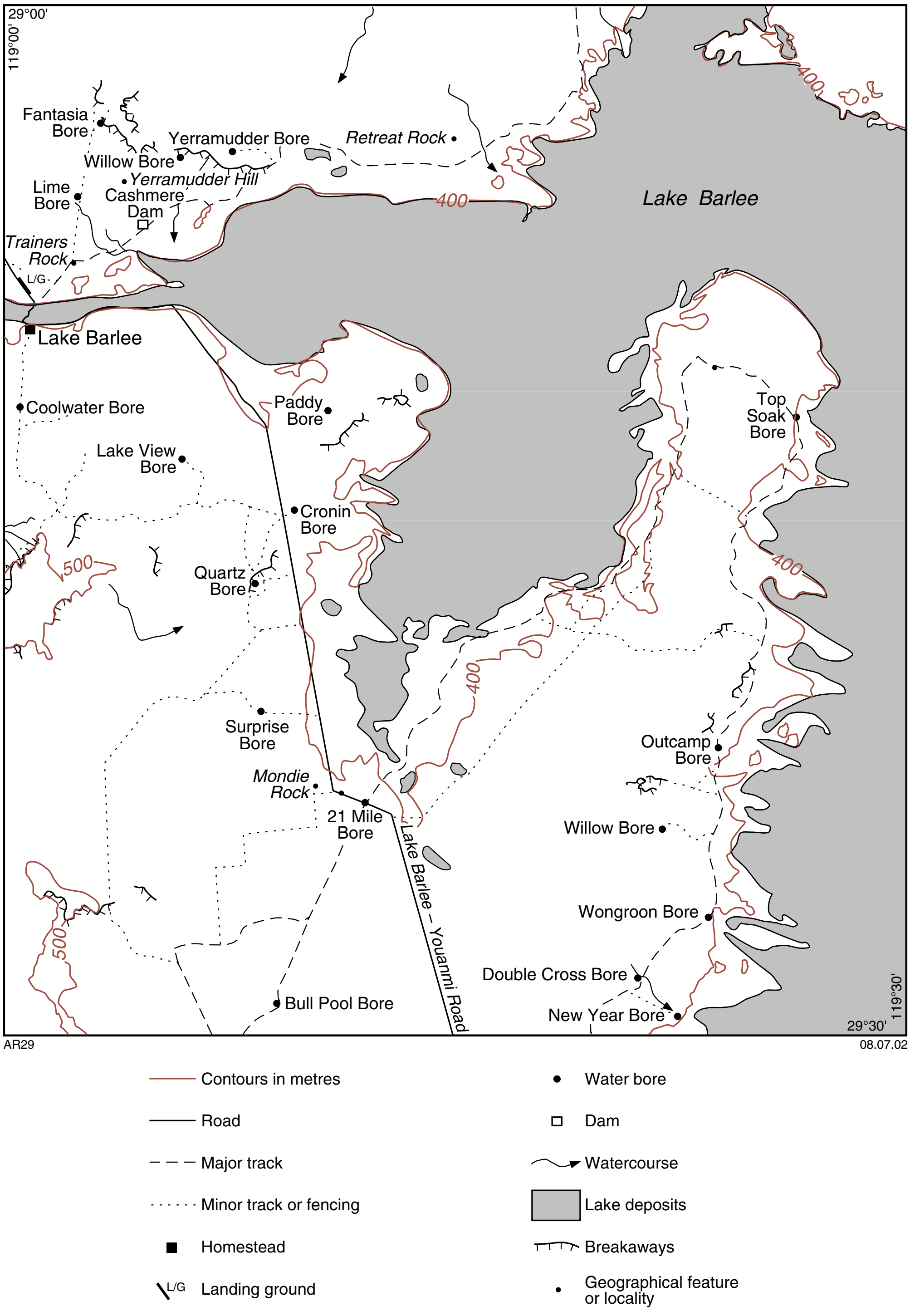

Figure 2. Principal localities, roads, and physiographic features on Barlee

area covered by the regional study of the distribution of metamorphic grades by Ahmat (1986). The southwestern corner of BARLEE was included in a regional metamorphic, structural, and mineralization study of the Southern Cross – Diemals region (Dalstra, 1995; Dalstra et al., 1999), and all of BARLEE was included in a regional laterite and ferricrete sampling program discussed by Grunsky (1998). An interpretation of the geology for the BARLEE 1:250 000 area based on geophysical data is given by Mackey (1999). Sensitive high-resolution ion microprobe (SHRIMP) geochronological data for the area are presented by Nelson (2001, 2002). Information and data collected by mineral exploration companies in statutory reports can be accessed through the Western Australian mineral exploration (WAMEX) open-file database in the Department of Mineral and Petroleum Resources' (MPR) library in Perth and Kalgoorlie. Summaries of the reports are on the MPR website (www.mpr.wa.gov.au).

Climate, physiography, and vegetation

The region that includes BARLEE has a semi-arid climate, characterized by dry weather, with mild to cold winters and hot summers. Rainfall data are not available for BARLEE, but the 250 mm (mean) isohyet, which approximately separates arid (<250 mm of rain) from semi-arid regions, crosscuts the northeastern corner of the map sheet (Payne et al., 1998). Rain falls predominantly in winter, although remnants of southeasterly moving cyclonic systems can cause heavy falls in summer months. Heavy rain may cause local flooding and filling of the large salt lakes with ephemeral water up to 30 cm deep (Biological Surveys Committee, 1985).

BARLEE falls within the Salinaland Plateau physiographic division of the Yilgarn Plateau Province, which is a region characterized by sandplains and lateritic breakaways, granitic and alluvial plains, ridges of greenstones, granite hills and rises, calcrete flats, large salt lakes, and dunes along valleys (Jennings and Mabbut, 1986). The most conspicuous physiographic element on the map is Lake Barlee, which is part of an endorheic salt-lake chain that drains southeasterly through the Raeside Palaeoriver (van de Graaff et al., 1977; Hocking and Cockbain, 1990).

The area has only gentle topography. Lake Barlee is 400 m above sea level, and the greatest topographic relief is provided by sandplains that rise to about 520 m along the western edge of the map. Greenstones form subdued hills, with more-rugged banded iron-formation (BIF) ridges, in the southwestern corner of the sheet. Elsewhere granitoid monoliths or flat pavements alternate with extensive undulating sandplains and flat sheetwash areas. The sandplains are punctuated by bedrock highs capped by ferricrete and silcrete, and erosional escarpments (breakaways) that are typically only a few metres high.

BARLEE lies entirely within the Austin Botanical District (or Murchison Region) of the Eremaean Botanical Province (Beard, 1990). The vegetation in the region is typically mulga, a tall shrubland of dominant *Acacia aneura* mixed with other species of *Acacia*, with a lower layer of occasional *Eremophila* and *Cassia* species, and herbaceous annuals in season. Sandplains are characterized by spinifex-hummock grassland, with scattered mallee and *Acacia* scrub. Granitoid exposures and surrounding areas support complexes of shrubs, perennial grasses, and herbaceous plants, with tall shrubland of *Acacia* spp. (e.g. *Acacia quadrimarginea*). Hills of greenstones are characterized by low woodlands of *Casuarina* and tall shrubs of *Eremophila*, with patches of *Eucalyptus* woodland on the surrounding colluvial flats. Along the edges of Lake Barlee a succulent steppe of scattered to dense samphires and other salt-tolerant plants is developed. Detailed descriptions of the ecosystems on BARLEE are given by Beard (1976, 1990), Payne et al. (1998), and the Biological Surveys Committee (1985).

Precambrian geology

Regional geological setting

BARLEE lies entirely in the central part of the Southern Cross Granite–Greenstone Terrane (Fig. 1), one of the major geological subdivisions of the Archaean Yilgarn Craton (Tyler and Hocking, 2001), which broadly corresponds to the Southern Cross Superterrane of Myers (1997) and the Southern Cross Province of Gee et al. (1981). The Southern Cross Granite–Greenstone Terrane is bound to the west and east by the Murchison and Eastern Goldfields Granite–Greenstone Terranes respectively.

Less than 5% of BARLEE is occupied or underlain by greenstones, the remainder consisting of granitoid rocks (Fig. 3). The exposed greenstones on BARLEE are the northernmost outcrops of the Marda–Diemals greenstone belt (Greenfield and Chen, 1999; Chen et al., 2001), which combines the Marda and Diemals belts of Griffin (1990). Aeromagnetic images suggest that some greenstones also underlie the southwestern arm of Lake Barlee (Figs 2, 3, and 4). The main exposures of the Marda–Diemals greenstone belt are south of BARLEE, on JOHNSTON RANGE (Wyche et al., 2001), and on JACKSON (Riganti and Chen, 2002; Fig. 1). The regional stratigraphy of the belt comprises a mafic- and BIF-dominated lower greenstone succession unconformably overlain by an upper greenstone succession that includes the felsic volcanic rocks of the Marda Complex and the clastic sedimentary rocks of the Diemals Formation (Table 1; Hallberg et al., 1976; Walker and Blight, 1983; Chin and Smith, 1983; Griffin, 1990). Only the lower greenstone succession has been recognized on BARLEE. The lower greenstone succession is inferred to have a depositional age of 3 Ga (Wyche et al., 2001), based on SHRIMP U–Pb zircon (Wang et al., 1996; Nelson, 1999) and Sm–Nd (Fletcher et al., 1984) geochronology. The age of the upper greenstone succession is well constrained at c. 2730 Ma by conventional and SHRIMP U–Pb zircon dating (Pidgeon and Wilde, 1990; Nelson, 2001). Granitoid intrusions in the Marda–Diemals region range in age from c. 2730 to c. 2635 Ma (Bloem et al., 1997; Dalstra et al., 1998; Wang et al., 1998; Nelson, 1999, 2000, 2001; Qiu et al., 1999).

Figure 3. Simplified geological map of Barlee

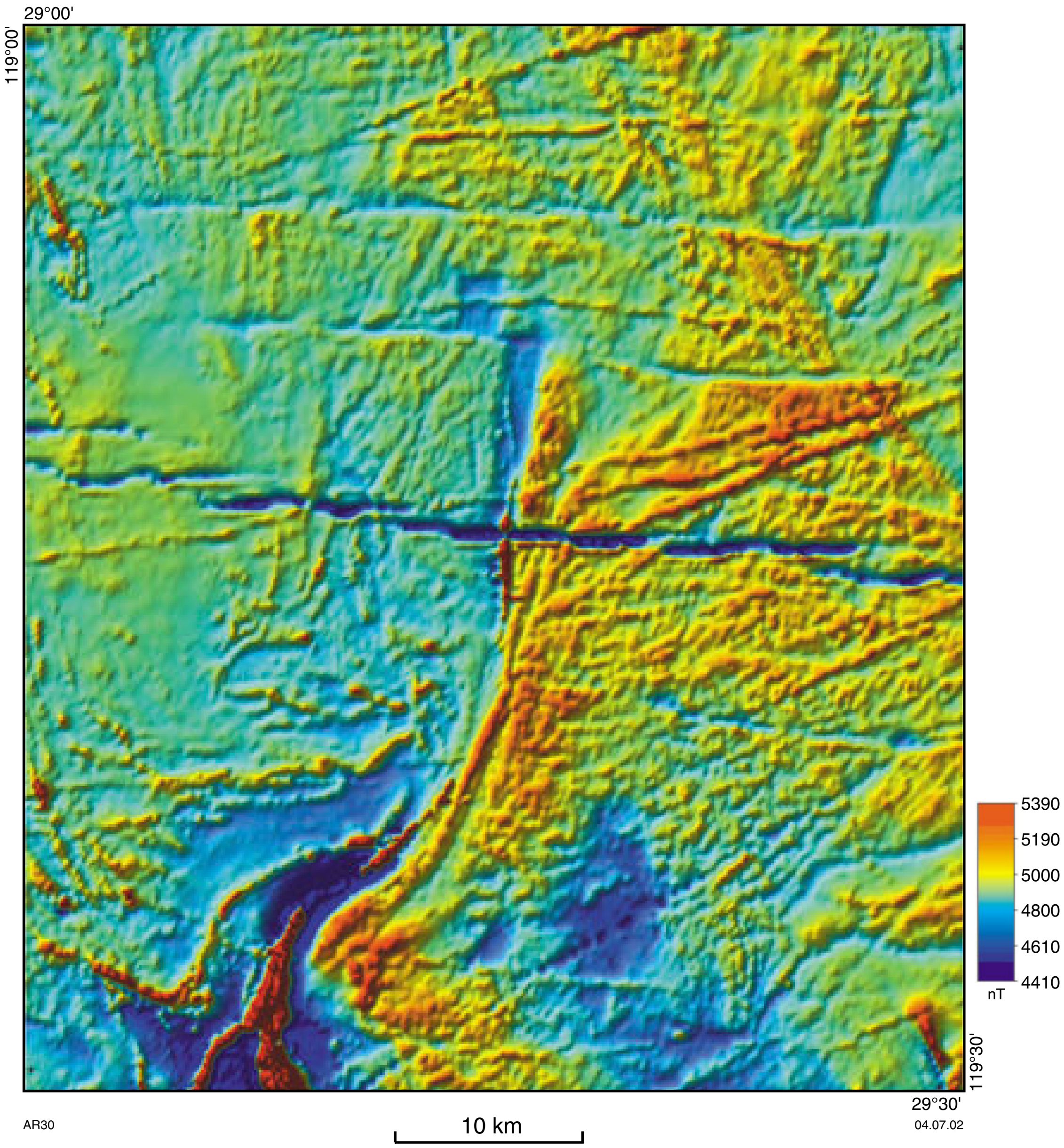

Figure 4. Aeromagnetic map of total magnetic intensity for Barlee (based on 400-m line-spaced data)

Various deformation schemes have been proposed for the Marda–Diemals region (Chin and Smith, 1983; Walker and Blight, 1983; Griffin, 1990; Dalstra, 1995; Dalstra et al., 1999; Greenfield and Chen, 1999; Chen et al., 2001). Most schemes involve a north–south compressional stage followed by a phase of east–west compression. Recent interpretations describe an early north–south compressional stage (D_1), characterized by low-angle thrusting and tight to isoclinal folding, that affected only the lower greenstone succession (Chen et al., 2001). Prolonged east–west regional compression produced large-scale, north-trending upright folds (D_2) that overprinted D_1 structures (Chen et al., 2001). North-trending gneissic banding and foliation in some of the granitoids suggest that most were probably intruded pre- to syn-D_2. The upper greenstone succession was also probably partly emplaced during D_2 (Chen et al., in prep.). Ongoing east–west shortening during D_3 resulted in the development of arcuate structures and regional-scale shear zones (e.g. the Yuinmery Shear Zone that crosscuts the northwestern part of Barlee; Chen et al., 2001). Later easterly to north-easterly trending faults and fractures were locally intruded by mafic to ultramafic dykes of probable Proterozoic age.

Archaean rock types

All Archaean rocks described in these notes were subjected to low- to medium-grade metamorphism, but primary textures are commonly preserved and protoliths can be inferred in most instances. For ease of description the prefix 'meta' is commonly omitted in the following descriptions.

Greenstone outcrops are confined to the southwestern part of Barlee, but the aeromagnetic image (Fig. 4) suggests that a narrow belt of greenstones extends to the central part of the map sheet. Metamorphic grade ranges from greenschist to amphibolite facies (see **Structural geology and metamorphism**), with the highest grades near granite–greenstone contacts.

Metamorphosed ultramafic rocks (*Au, Aup, Aur, Aus*)

Ultramafic rocks form only a small proportion of the lower greenstone succession on BARLEE (Fig. 3). Undivided ultramafic rocks (*Au*) are only preserved as cuttings from mineral exploration drillholes (e.g. MGA 702730E 6736860N). They are typically deeply weathered, but can be identified by their tremolite, talc, and chlorite contents. Serpentinized peridotite (*Aup*) with associated minor gabbro is poorly exposed in a north-northeasterly segment, 2 km west of Bull Pool Bore. Peridotite has a relict granular texture with olivine grains up to 2 mm, now completely pseudomorphed by serpentine or tremolite and minor talc, in a finer grained groundmass of Mg-rich hornblende with minor interstitial plagioclase and quartz. Tremolite–chlorite(–talc) schist (*Aur*) is in gradational contact with foliated mafic rocks southwest of 21 Mile Bore. The schist has a northeast-trending foliation that is commonly crenulated and complexly folded, with subhorizontal to vertical intersection lineations (see **Structural geology and metamorphism**). Rock chips of serpentinite (*Aus*) were recovered from mineral exploration drillholes 7.5 km northwest of Bull Pool Bore (MGA 702150E 6740070N).

Metamorphosed fine- to medium-grained mafic rocks (*Aba, Abf, Abg, Abm, Abmf, Abr, Abt, Abv*)

Metamorphosed fine- to medium-grained mafic rocks are the dominant component of the lower greenstone succession on BARLEE.

Amphibolite (*Aba*) outcrops 7 km northwest of Bull Pool Bore. It is a fine- to medium-grained, black to dark-grey rock, with a strong foliation and a variably plunging, pronounced lineation. Intercalations of thin BIF units are common, as are small, crosscutting quartz, granitic, and feldspar-phyric veins. In thin section, hornblende, plagioclase and minor quartz form a granoblastic assemblage crosscut by later veinlets containing epidote and clinozoisite.

Strongly foliated mafic rocks (*Abf*) form a fault-bounded, northeasterly trending 6 km-long segment 2.5 km south of Mondie Rocks. This package is characterized by metre-scale intercalations of very fine and fine-grained mafic volcanic rocks, fine- to medium-grained gabbro, chlorite schist, and BIF. Tremolite schist units predominate over chlorite schist intercalations in the northeast. The mafic rocks have a strong, broadly northeasterly trending foliation with a vertical to steep southeasterly dip, but with local variations due to small-scale folding. The more schistose units are crenulated, with the crenulation locally folded.

Table 1. Geological evolution of the Marda–Diemals greenstone belt

Age	*Deformation event*	*Geology*
3 Ga		Deposition of the lower greenstone succession; burial or seafloor metamorphism
	D_1	North–south compression: layer-parallel foliation and thrusting; tight to isoclinal folding
c. 2.73 Ga		Deposition of upper greenstone succession: Marda Complex (felsic volcanism) Granitoid intrusion (e.g. Butcher Bird Monzogranite; Pigeon Rocks Monzogranite)
	D_2	Initiation of east–west compressional regime Upright to inclined folding (e.g. Watch Bore Syncline, Diemals Anticline) Deposition and deformation of upper greenstone succession: Diemals Formation (clastic sedimentation)
c. 2.71 – c. 2.65 Ga		Granitoid intrusion (external granitoids); peak metamorphism Development of gneissic banding (e.g. Willow Bore; Yacke Yackine Dam)
Pre-c. 2656 Ma	D_3	Development of major northeasterly and northwesterly trending shear zones; reorientation of D_2 structures
c. 2635 Ma		Late- to post-kinematic granitoid intrusion (e.g. porphyritic granite at Retreat Rock; Millars Monzogranite)
	Post-D_3	North-northeasterly and easterly to east-southeasterly brittle faults
		Intrusion of easterly to northeasterly trending mafic and ultramafic dykes and quartz veins along crosscutting fractures

NOTE: Modified after Riganti and Chen (2002)

Strongly foliated mafic, ultramafic, and metasedimentary rocks interleaved with subordinate foliated granitoid rock (*Abg*) is typical of areas adjacent to tectonic granite–greenstone contacts on BARLEE. About 1 km south of Mondie Rocks metre-scale slivers and lenses of fine-grained amphibolite, banded magnetite–grunerite quartzite, and tremolite and tremolite–talc schist are intercalated with granitoid gneiss and some quartz veins. Banding in the gneiss and layering in the magnetite–grunerite quartzite are parallel to a strong, northeasterly trending, steep to vertical foliation. Lineations dip moderately to the southwest, and schists are commonly crenulated. Intercalations of mafic and ultramafic schist, and minor biotite paragneiss with foliated biotite-rich monzogranite are common about 9 km northwest of Bull Pool Bore (MGA 699750E 6739240N). At this locality quartz veins parallel an east-southeast, generally vertical foliation, and contain small enclaves of weathered mafic and ultramafic schist that are characterized by a folded foliation.

Metamorphosed high-Mg basalt with relict pyroxene-spinifex and/or variolitic textures (*Abm*) only outcrops along the southern edge of BARLEE (MGA 705600E 6734800N), where it represents the northernmost extension of a unit, a few hundred metres thick, intermittently exposed along the eastern limb of the Watch Bore Syncline on JOHNSTON RANGE (Wyche et al., 2000, 2001). Small outcrops of strongly foliated, locally variolitic high-Mg basalt (*Abmf*) 6 km west-southwest of Bull Pool Bore are considered the strike extension of strongly foliated, tremolite- and chlorite-rich rocks (*Abr*) exposed farther west and southwest, in which spinifex textures were most probably obliterated by intense deformation. These rocks now consist of felty tremolite and chlorite, with patches of saussuritized plagioclase and very minor interstitial quartz, indicating a Mg-rich basaltic composition. Locally developed knobbly weathered surfaces suggest the presence of varioles in some exposures (e.g. MGA 700270E 6736230N).

Metamorphosed mafic tuff and tuffaceous sedimentary rock (*Abt*) form rubbly exposures within a sequence of metabasalt and subordinate gabbro between 5 and 7.5 km west of Bull Pool Bore. These rocks are medium to dark grey and fine to very fine grained, and typically form thinly to very thinly bedded units. Individual layers are 1 to 4 cm thick, have sharp contacts, and may contain parallel laminations. In places, black, elongate lithic fragments are set in a very fine grained matrix. North-northwesterly trending, vertical beds in one of the westernmost exposures (MGA 701080E 6736590N) contain grading that faces south-southwest. In thin section, grading is suggested by variable concentrations of actinolite, chlorite, plagioclase, opaque oxides, and minor quartz. The tuffaceous units are commonly a few metres in thickness, except for an area (centred around MGA 701000E 6736300N) where tuffaceous units become volumetrically predominant over basaltic rocks. The attitude of bedding, younging directions, and high-angle bedding–cleavage intersections at several localities suggest that the tuffaceous units are folded around a south-plunging anticline (see **Structural geology and metamorphism**). The distribution of outcrops also suggests that the tuffaceous units may be stratigraphically equivalent to similar tuffaceous intervals described from south and south-southwest of Diemals Homestead on JOHNSTON RANGE (Wyche et al., 2001; see **Stratigraphy**).

Metabasalt (*Abv*) is the dominant mafic lithotype on BARLEE. It is typically a dark- to medium-grey, fine-grained, massive to moderately foliated rock, with local rounded quartz amygdales up to 4 mm in diameter. Metabasalt is commonly associated with subordinate laminated mafic tuffs and volcaniclastic metasedimentary rocks, high-Mg basalt, gabbro, and chlorite schist, as well as chert and BIF units. The typical mineral assemblage for the metabasalt consists of tremolite–actinolite amphibole, plagioclase extensively altered to sericite or saussurite, chlorite, epidote, clinozoisite, opaque oxides, and minor quartz. Sulfide minerals are locally abundant.

Metamorphosed medium- to coarse-grained mafic rocks (*Aog, Aogf*)

Metagabbro (*Aog*) forms low hills about 3 to 5 km west-southwest of Bull Pool Bore. The gabbro is medium to coarse grained, with extensively sericitized plagioclase. Quartz veinlets are subparallel to a weak foliation in places, and there is local silicification (e.g. MGA 704580E 6734970N). The foliation becomes more pronounced from west to east in these exposures. Gabbroic intercalations are common within the basaltic units exposed farther to the west, and there are suboutcrops of gabbro between BIF units about 4.5 km north-northwest of Bull Pool Bore. Strongly foliated metagabbro (*Aogf*), 7 km north of Bull Pool Bore, is a more deformed variety of the same poorly outcropping gabbro units.

Metamorphosed sedimentary rocks (*Ash, Asi, Aci*)

Metamorphosed sedimentary rocks are less common than mafic rock types on BARLEE.

Metamorphosed shale and siltstone (*Ash*) is represented by a unit of metamorphosed, greenish to grey and black shale about 4 km west-southwest of Bull Pool Bore. Although exposure is poor, the distribution of the shale is clearly outlined on aerial photos and Landsat images by a change in vegetation from the underlying and overlying gabbros, and on the ground by the conspicuous absence of gabbro debris. This shale unit represents a distinct marker horizon that helps to define the Watch Bore Syncline, and can be followed intermittently along the limbs of this structure for about 4 km on JOHNSTON RANGE (Wyche et al., 2001).

Metasedimentary rocks including shale, siltstone, and BIF (*Asi*) are typically preserved on the flanks of BIF ridges, with the most extensive outcrop 2 km southwest of Bull Pool Bore. They comprise metamorphosed shale and thin-bedded siltstone, with minor fine-grained sandstone and interleaved chert and BIF, and are typically deeply ferruginized and poorly exposed.

Metamorphosed BIF and ferruginous banded chert (*Aci*) form distinct ridges 2 km west and 4 km north-northwest of Bull Pool Bore. The same units extend farther northeast, but become progressively more fragmented and topographically subdued. Banded iron-formation is typically a steel-grey to blue, black, and locally red (jaspilitic) rock, with alternating laminae and layers of quartz and magnetite or hematite. Tight to isoclinal, and locally chaotic, folding of beds within the BIF units is common. Ridges of BIF are strongly lateritized in places.

Gneissic rocks (*An, Ang, Angx, Anm, Anmx*)

Gneissic rocks, although not well exposed, are extensive in the central and northern parts of BARLEE. A few exposures are within or adjacent to strongly deformed areas (e.g. northeast of Retreat Rock and at Mondie Rocks), but most gneissic areas are surrounded by undeformed granite.

Undivided gneissic rock (*An*) is typically deeply weathered, with relict banding, granular texture, and quartzofeldspathic mineralogy. Many of these exposures are at the bases of breakaways (e.g. north of Yerramudder Hill), and commonly grade into more distinctly banded granitoid gneiss.

Granitoid gneiss (*Ang*) is the most common type of gneiss on BARLEE, with the best exposures at Mondie Rocks, east of Paddy Bore, near Yerramudder Hill, east and northwest of Retreat Rock, and in the north-eastern corner of the map sheet. The rock is typically medium to coarse grained with alternating mesocratic and leucocratic bands ranging in thickness from 1 to 20 cm, and locally up to 2 m. The bands are granitic to grano-dioritic and quartz dioritic in composition, with minor tonalite and pegmatitic or aplitic layers. Most phases are even grained, with some feldspar-phyric layers. Gneissic banding and a generally coplanar foliation have a typically northerly trend, with the only significant deviation at Mondie Rocks, where the banding trends east-northeasterly. Intrusion of dykes during the late stages of gneissic banding formation is indicated at several localities by crosscutting relationships and a foliation within the dykes parallel to the banding. For instance, at Mondie Rocks, narrow pegmatite and aplite dykes crosscut the gneissic banding, but are isoclinally folded (Fig. 5) with fold-axial traces parallel to the gneissic banding and foliation. About 3.3 km southeast of Willow Bore (MGA 706760E 6779780N) a melanocratic biotite-rich, sparsely feldspar-phyric dyke crosscuts the gneissosity at a low angle and contains a foliation parallel to the gneissosity.

Granitoid gneiss in the Yuinmery Shear Zone, about 7 km east-northeast of Retreat Rock, has a poorly defined, sinistral S–C fabric with the main foliation parallel to the gneissosity (see **Structural geology and metamorphism**). This gneiss has a cataclastic texture, with augen of microcline and plagioclase up to 6 mm in diameter in an inequigranular, recrystallized matrix of quartz, feldspar, and biotite, with various-sized laths, lamellae, and filaments of mica defining the foliation.

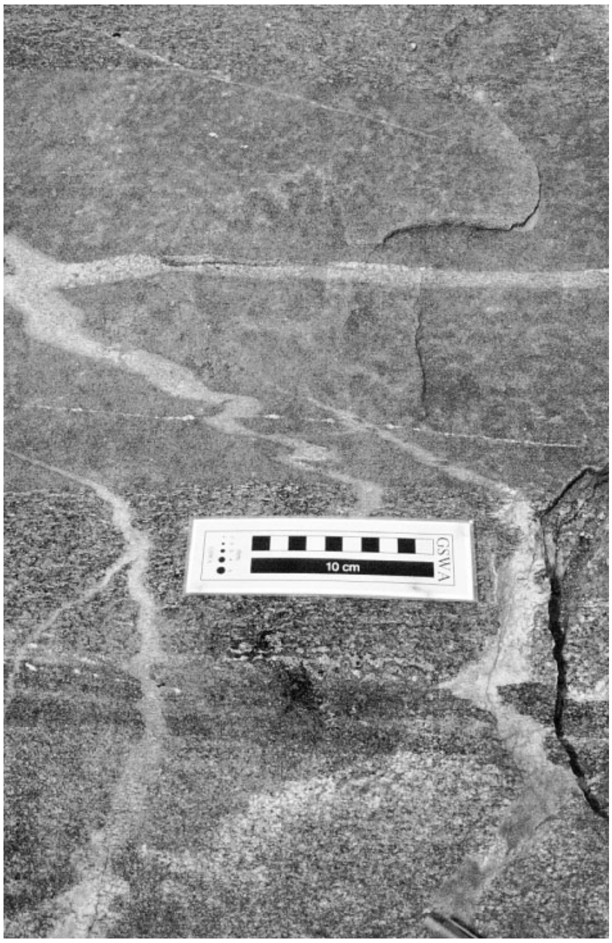

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Figure 5. Granitoid gneiss with crosscutting aplitic and pegmatitic veins at Mondie Rocks (MGA 710870E 6747580N). Isoclinal folds in the aplitic veins have axial planes with the same orientation as the layer-parallel foliation

Away from zones of intense deformation, granitoid gneiss consists of a granoblastic assemblage of plagioclase, microcline, and quartz, with varying amounts of biotite and local myrmekite. Magnetite, apatite, muscovite, and titanite are accessory phases. A quartz monzodiorite phase from a gneiss pavement 3.3 km southeast of Willow Bore (MGA 706760E 6779780N) yielded a SHRIMP U–Pb zircon crystallization age of 2714 ± 10 Ma (Nelson, 2002), which is similar to the age of a granitoid gneiss at Yacke Yackine Dam on JACKSON (Nelson, 2001). Zircons from a tonalite band from Mondie Rocks have a younger SHRIMP U–Pb crystallization age of 2694 ± 6 Ma (Nelson, 2002).

Granitoid gneiss with numerous enclaves of medium- to high-grade metasedimentary, mafic, and ultramafic rocks (*Angx*) outcrops in a 14 km-long northeasterly trending segment, from Surprise Bore to northeast of Cronins Bore. In this gneiss millimetre- to centimetre-scale bands are largely granitic in composition, with granoblastic assemblages of plagioclase, K-feldspar, quartz, and varying concentrations of lepidoblastic biotite. Biotite may form 'books' up to 4 cm across (e.g. northeast of Surprise Bore, MGA 708420E 6751790N). Compositional banding is not as continuous along strike as in other granitoid gneiss outcrops, and commonly grades into irregular patches with lensoidal and sigmoidal bands, and disharmonic folding. The rock contains abundant pegmatites at varying angles to the gneissosity. Enclaves within the granitoid gneiss are typically lensoidal to irregular in shape, and range from a few tens of centimetres to a few tens of metres in size, but can be up to a few hundred metres across. Metasedimentary rocks are the most common enclaves and include:

- locally laminated, fine- to medium-grained, grey quartzite with beds up to 3 cm;
- thinly bedded magnetite quartzite;
- commonly ferruginized pelite consisting of muscovite and minor quartz, with locally preserved grading and parallel laminations;
- banded hornblende–plagioclase–biotite rocks that may represent mafic metasedimentary rock types.

Bedding in the quartz-rich enclaves and schistosity in the pelitic lenses are commonly folded. Other enclaves include tremolite-rich rocks (with possible relict spinifex texture), quartz and pegmatitic veins, and amphibolite. A large ultramafic enclave, consisting mainly of silica caprock with talc–tremolite schist remnants, forms a distinctive hill just west of the Lake Barlee – Youanmi Road (MGA 709520E 6760020N). The mineral assemblages indicate that the enclaves have been metamorphosed to amphibolite facies (see **Structural geology and metamorphism**). The enclave-rich granitoid gneiss is intruded by an undeformed, pegmatite-poor monzogranite, with the best relationships exposed about 1.5 km southeast of Quartz Bore. Although direct contacts are not exposed, isolated pavements of granitoid gneiss are surrounded by outcrops of medium- to fine-grained, equigranular biotite monzogranite (e.g. MGA 708970E 6757960N and MGA 708910E 6757260N). A few undeformed pegmatite and tonalite dykes crosscut the gneiss xenoliths.

Isolated exposures of migmatitic gneiss (*Anm*) about 9 km west of Mondie Rocks consist of a granitic to tonalitic palaeosome and a granitic to granodioritic neosome. In the palaeosome irregularly folded gneissic banding is defined by biotite-enriched parts. The banding is crosscut at various angles by dykes of medium-grained equigranular granodiorite and leucocratic granite, which represent the more voluminous products of anatexis of the palaeosome. Locally, the neosome phase is enriched in zoisite and titanite.

Heterogeneous migmatitic gneiss (*Anmx*) is exposed near Top Soak Bore, with the most complex relationships a few kilometres northwest of the bore (e.g. MGA 735520E 6769920N, and around a small claypan at MGA 734370E 6770040N). The main phase in these exposures is a medium-to coarse-grained gneissic monzogranite, characterized by prominent north-northeasterly trending schlieric banding and nebulitic textures. Schlieric banding is defined by concentrations of mafic silicate minerals (amphibole, biotite) and magnetite, with commonly irregular schlieren varying considerably in thickness and length (Fig. 6a). The granite contains sparse to locally abundant tonalitic and granodioritic inclusions that have irregular to lensoidal shapes (Fig. 6b), are typically elongated in the same direction as the schlieric banding, and have diffuse contacts with the granite host. Concentrations of magnetite are common at the edges of these phases, which are also characterized by abundant zoisite and titanite. Isolated magnetite and subordinate biotite lenses, typically a few centimetres across, are also commonly elongated parallel to the schlieric banding, and are locally abundant (Fig. 6b). Some tonalite blocks are intruded by granite apophyses (Fig. 6c), with both phases crosscut by irregular pegmatitic veins (Fig. 6d). All these phases are interpreted as the remnants of a largely assimilated gneiss (diffuse nebulitic textures are common in the granite; Fig. 6b,d) from which the diatexitic granitic melt was anatectically derived.

Granitoid rocks (*Ag, Aga, Agf, Agm, Agmf, Agmp, Agn*)

Granitoid rocks comprise almost 90% of BARLEE (Fig. 3). Outcrop is sparse, but exposed granitoids range in composition from syenogranite to granodiorite, with monzogranite by far the most abundant. Where weathering or difficult access prevent a more precise classification, the granitoid outcrop is shown as undivided (*Ag*).

Fine- to medium-grained leucocratic monzogranite with abundant aplite and pegmatite (*Aga*) forms pavements and sparse, low-lying bouldery outcrops near Trainers Rocks. The granite is commonly equigranular, and locally contains a weak northerly foliation. Microcline, plagioclase, and quartz are the dominant phases, with muscovite locally very abundant, and commonly predominant over biotite. Randomly oriented aplite and pegmatite veins comprise up to 70% of the outcrop, their proportion increasing from north to south. Coarse-grained pegmatites commonly have a graphic texture. Locally exposed enclaves of banded gneiss, several tens of centimetres across (e.g. MGA 698260E 677920N), are crosscut by irregular pegmatite veins.

Strongly foliated, deeply weathered granitoid rock (*Agf*) outcrops in an intensely deformed area immediately southwest of Mondie Rocks. The original composition is difficult to determine, but these rocks are juxtaposed with strongly foliated monzogranite.

The most common granite type on BARLEE is a massive to weakly foliated monzogranite (*Agm*) that is medium to coarse grained and commonly equigranular, containing local porphyritic patches with K-feldspar (generally microcline) megacrysts up to 2 cm long. Biotite is a ubiquitous primary phase, but its abundance varies. Monzogranite may have a large pegmatoid component, with veins characterized by graphic textures in places (e.g. around MGA 695500E 6737400N). Biotite-rich schlieren, locally with magnetite concentrations at their edges (e.g. MGA 729320E 6737140N, MGA 730920E 6739920N), mark the transition to gneissic granitoid outcrops in places.

Strongly foliated monzogranite (*Agmf*) mineralogically resembles the massive monzogranite, but is texturally distinguished by a steeply dipping to vertical foliation defined by aligned biotite flakes and 'books', and strings of strained quartz and feldspar. In areas of intense

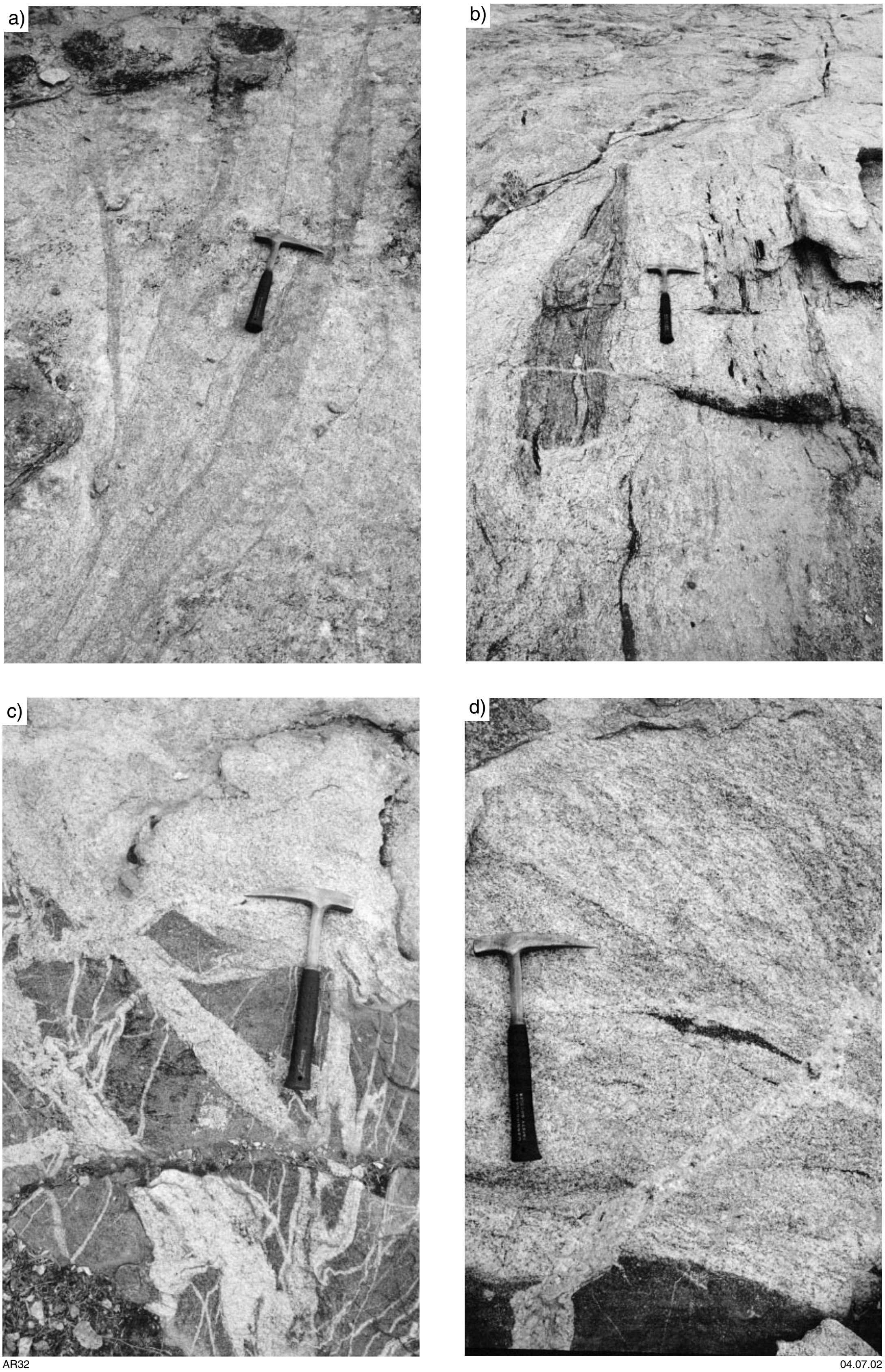

Figure 6. Heterogeneous migmatitic gneiss northwest of Top Soak Bore: a) schlieric banding in a medium-grained leucocratic monzogranite is defined by irregular concentrations of biotite (MGA 735520E 6769920N); b) remnants of assimilated granitoid gneiss (left) and residual lenses of magnetite (right) in a medium-grained monzogranite host with nebulitic texture (MGA 734370E 6770040N); c) tonalite block invaded by granitic veins (MGA 734370E 6770040N); d) detail of the same tonalite block, showing nebulitic textures in the invading granite and a pegmatite vein crosscutting both phases

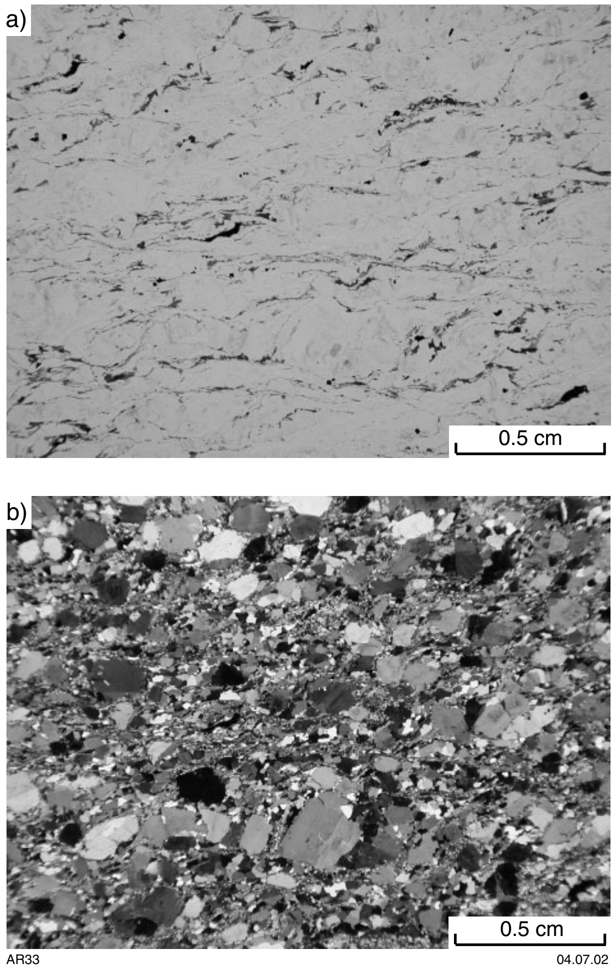

Figure 7. Cataclastic texture in strongly foliated monzogranite, 3 km southwest of Mondie Rocks, showing feldspar and quartz porphyroclasts with mortar edges enclosed by a granoblastic quartzofeldspathic groundmass; GSWA 164872, plane-polarized light (a) and crossed nicols (b)

deformation (e.g. 3 km southwest of Mondie Rocks, around MGA 709300E 6745400N), the foliation is folded and the granite is characterized by a cataclastic texture (Fig. 7). There are strongly deformed enclaves of metamorphosed mafic and sedimentary rocks, several metres in length and a few metres across, near the tectonized contact with greenstones (e.g. MGA 699880E 6739280N). Pegmatite and aplite within the foliated granite are commonly deformed, but later veins also cut across the foliation (e.g. MGA 700190E 6740440N).

Medium- to coarse-grained porphyritic monzogranite (*Agmp*) forms small prominent hills near Retreat Rock and a few kilometres east-southeast and south of Lake Barlee Homestead. Microcline commonly forms large tabular megacrysts, up to 6 cm long (e.g. MGA 696400E 6767350N) but typically only 1 to 2 cm wide (Fig. 8a), that are surrounded by a granular, grey, quartzofeldspathic groundmass. Microcline crystals are aligned in a north–south direction near Retreat Rock, probably as a result of igneous flow, whereas they are more randomly oriented near the homestead. In places, the abundance of microcline megacrysts results in a syenogranitic composition. The microcline megacrysts contain inclusions of plagioclase (commonly with concentric zoning, and varying from fresh to strongly sericitized), fresh to chloritized biotite, titanite, opaque oxides, and minor quartz (Fig. 8b). In several grains microcline grades into perthite (Fig. 8b), suggesting that these megacrysts originally formed as orthoclase from which plagioclase exsolved to form perthite, with the orthoclase partly inverting to microcline. Myrmekite patches are common between plagioclase and microcline (Fig. 8c). Microcline also forms smaller grains in a groundmass consisting mainly of plagioclase and polycrystalline patches of quartz with sutured boundaries. The contacts between porphyritic monzogranite and adjacent granitoid rocks are not exposed. However, the lack of deformation and a SHRIMP U–Pb zircon crystallization age of 2635 ± 8 Ma obtained for a sample near Retreat Rock (Nelson, 2001) indicate that the porphyritic granite intruded the adjacent gneissic rocks. The age obtained for this porphyritic granite is one of the youngest reported for this part of the Southern Cross Granite–Greenstone Terrane.

Gneissic granitoid rock (*Agn*) on BARLEE is a weakly to strongly foliated heterogeneous monzogranite, characterized by coarse-grained, equigranular, biotite-poor bands alternating with medium-grained, equigranular, biotite-rich granite. Bands vary from irregular to strongly aligned and parallel to the foliation, have sharp to gradational contacts, and range in thickness from a few centimetres to 30 cm. Bands range in composition from granodiorite to biotite monzogranite, with a later biotite-poor granite crosscutting all other phases (e.g. MGA 731860E 6740780N). Gneissic granitoids east of Retreat Rock are adjacent to the Yuinmery Shear Zone, whereas exposures in the southern part of BARLEE are isolated and appear spatially unrelated to intensely deformed areas, having a gradual transition to undeformed homogeneous monzogranite (e.g. west of Wongroon Bore).

Veins and dykes (*q, p*)

Quartz veins (*q*) are widespread on BARLEE and crosscut both granitoids and greenstones. They have a dominantly easterly trend, but may be parallel to granite–greenstone contacts. For example, east-northeasterly trending, locally brecciated quartz veins are intercalated with chlorite–tremolite schist and foliated granite 2 km south of Mondie Rocks. The most prominent system outcrops for a total of about 10 km east and west of Yerramudder Hill, and consists of one main quartz reef flanked by numerous long, parallel lenses of quartz. The quartz in the vein is milky to finely crystalline, pale grey to greenish, and is typically crosscut by a network of millimetre- to centimetre-wide white quartz veins. A similar quartz vein system is exposed 4 km north of Top Soak Bore. Both large quartz vein systems coincide with strong easterly trending magnetic lineaments (Fig. 4) interpreted as faults with an apparent sinistral displacement (Fig. 3; see **Structural geology and metamorphism**). Smaller, but similarly oriented, quartz veins outcrop a few hundred metres east-southeast and 7 km west of Quartz Bore, and about 1 km south of Trainers Rocks.

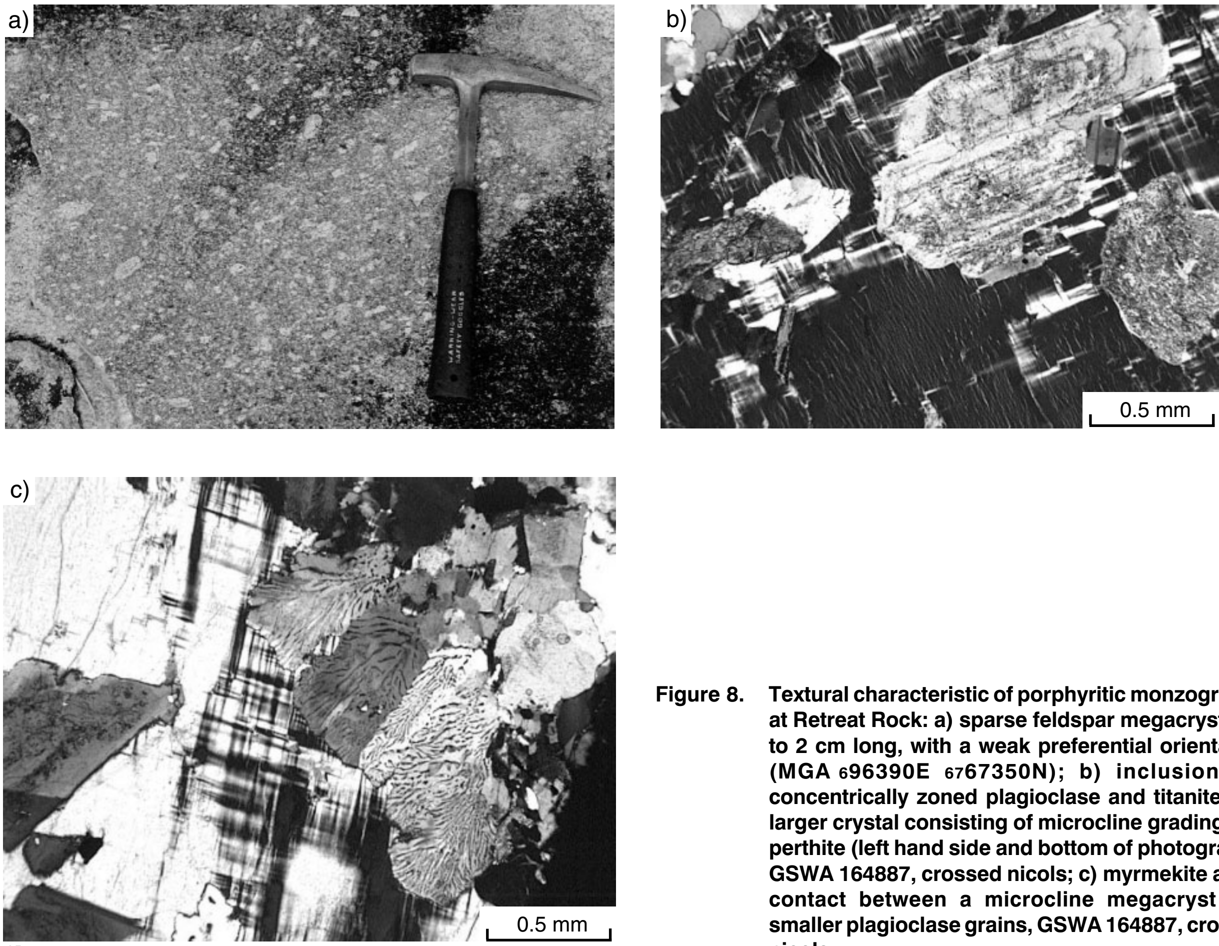

Figure 8. Textural characteristic of porphyritic monzogranite at Retreat Rock: a) sparse feldspar megacrysts up to 2 cm long, with a weak preferential orientation (MGA 696390E 6767350N); b) inclusions of concentrically zoned plagioclase and titanite in a larger crystal consisting of microcline grading into perthite (left hand side and bottom of photograph), GSWA 164887, crossed nicols; c) myrmekite at the contact between a microcline megacryst and smaller plagioclase grains, GSWA 164887, crossed nicols

Coarse-grained pegmatite (*p*) forms resistant outcrops within granitic residual material about 5.5 km northwest of Outcamp Bore. Smaller, irregular pegmatite veins are commonly associated with granitoid rocks elsewhere on the map sheet.

Porphyritic felsic dykes in the southwestern quadrant of BARLEE are too small to be mapped individually. These dykes typically have plagioclase and subordinate quartz phenocrysts up to 3 mm across in a medium- to dark-grey, aphanitic, crystalloblastic, quartzofeldspathic groundmass. The phenocrysts have corroded outlines and are enclosed by a foliation defined by biotite and minor actinolite, strings of opaque oxides, and the elongation of quartz and feldspar grains in the groundmass. The porphyritic dykes typically crosscut different greenstone and granite lithotypes (e.g. amphibolite at MGA 702400E 6739970N, foliated metabasalt at MGA 712780E 6746430N, chlorite–tremolite schist at MGA 710980E 6746790N, and foliated granite at MGA 725630E 6785380N). At the last locality debris from porphyritic dykes is associated with dolerite clasts, with the latter possibly chilled against the felsic dyke. In this example the porphyritic felsic component contains resorbed crystals of plagioclase and granoblastic quartz in a quartzofeldspathic groundmass, suggesting derivation by thermal erosion from a granitoid precursor.

Mafic dykes (*Pdy*)

Prominent easterly and northeasterly magnetic lineaments that cut across all other structural trends on BARLEE (Fig. 4) have been interpreted as fractures filled by mafic and ultramafic dykes (*Pdy*).

Of the very few dykes with a surface expression the most notable are north and northeast of Retreat Rock. Here the dykes are represented by scattered debris of gabbroic and doleritic material, commonly with plagioclase phenocrysts up to a few millimetres across in a felty groundmass of plagioclase and mafic and opaque phases. Although poorly outcropping, the position of these dykes is clearly outlined on aerial photos by linear features that are typically darker brown and have denser vegetation than the surrounding granitoid rocks.

The dyke exposed discontinuously 2 km north of Retreat Rock crosscuts a porphyritic granite dated at 2635 ± 8 Ma (Nelson, 2001). This and similarly interpreted dykes were probably emplaced along tensional fractures during Proterozoic tectonic activity after cratonization of the Yilgarn Craton. This activity was concentrated along the margins of the craton (cf. Hallberg, 1987).

Stratigraphy

The greenstones exposed on BARLEE are part of the Diemals section of the Marda–Diemals greenstone belt. This belt has been shown to comprise lower and upper greenstone successions (Griffin, 1990). The lower greenstone succession is dominated by mafic rocks and abundant BIFs with minor ultramafic rocks, for which a depositional age of 3 Ga is suggested by a Sm–Nd model age of 3050 ± 100 Ma for metabasalts near Diemals (Fletcher et al., 1984). The Deception Hill Porphyry on Johnston Range is a possible intrusive into the lower greenstone succession, but the SHRIMP U–Pb age of 3023 ± 10 Ma (Nelson, 1999) may have been obtained on xenocrystic zircons. The upper greenstone succession comprises the c. 2733 Ma felsic volcanic rocks of the Marda Complex (Hallberg et al., 1976; Chin and Smith, 1983; Nelson, 2001), and the clastic sedimentary rocks of the Diemals Formation (Walker and Blight, 1983) for which detrital zircons have indicated a maximum depositional age of 2729 ± 9 Ma (Nelson, 2001). Only the lower greenstone succession has been recognized on BARLEE.

Within the lower greenstone succession, three informal stratigraphic associations (lower, middle, and upper) have been distinguished on the basis of their distinct lithologies and positions relative to the major BIF units within the Marda–Diemals greenstone belt (Chen and Wyche, 2001; Chen et al., in prep.). The three associations are particularly well exposed on JOHNSTON RANGE in the Diemals – Kim Bore area (Wyche et al., 2001) just south of BARLEE, and extend north onto BARLEE west of Bull Pool Bore (Fig. 9). The lower and middle associations have relatively uniform characteristics across the Marda–Diemals region, and are interpreted to have been deposited in a widespread extensional basin, whereas the upper association contains different rock types in different areas, suggesting that it might have been deposited in separate sub-basins (Chen and Wyche, 2001).

The lower association is best exposed in the core of the Diemals and Horse Well Anticlines on JOHNSTON RANGE (Fig. 9). It is dominated by tholeiitic basalts with subordinate ultramafic schist in the lowest part, and gabbro and mafic tuff intercalations at higher levels. On BARLEE the lower association is poorly preserved, except in the westernmost greenstone exposures where mafic tuffaceous rocks about 7 km west of Bull Pool Bore are regarded as stratigraphically equivalent to similar lithological intervals exposed south and southwest of Diemals Homestead.

The middle association is exposed in the limbs of the Diemals and Horse Well Anticlines (Fig. 9), and is dominated by BIF and chert with minor shale and siltstone. Banded iron-formation and chert are extensively intruded by gabbro sills that are typically concordant with bedding, but discontinuous along strike. On BARLEE the main BIF interval is exposed on the eastern limb of the Watch Bore Syncline, from where it extends farther northeast towards 21 Mile Bore. In addition to the gabbro sills, a poorly exposed peridotite is intercalated with the BIF unit just north of the boundary with JOHNSTON RANGE. Banded iron-formation of the middle association is also interpreted, from aeromagnetic images, stratigraphically above metabasaltic rocks in the westernmost greenstone exposures (Figs 3 and 4).

The upper association is well exposed in the Watch Bore Syncline (Fig. 9), where it includes tremolite–chlorite schist, high-Mg basalt, and gabbro at the base; two discontinuous shale units separated by a gabbro sill in the middle; and high-Mg basalt with gabbro sills at the top (Chen and Wyche, 2001). Only the lowermost part of this association is preserved on BARLEE in the core of the Watch Bore Syncline, where gabbro is exposed below and above a poorly outcropping shale unit (Fig. 9).

Structural geology and metamorphism

Due to the paucity of greenstone outcrops on BARLEE, a comprehensive structural interpretation for this map sheet draws heavily on observations on the adjacent JOHNSTON RANGE sheet, where structural and overprinting relationships are better exposed (Wyche et al., 2001). The regional structural evolution of the Marda–Diemals greenstone belt was discussed further by Dalstra (1995), Dalstra et al. (1999), Greenfield and Chen (1999), and Chen et al. (2001).

Like their counterparts exposed to the south, rocks on BARLEE were subjected to three major deformation events, which were followed by at least one further deformation stage (Table 1). An early deformation event (D_1) affected only the 3 Ga lower greenstone succession, producing tight to isoclinal folds and thrusts, as well as an easterly trending, layer-parallel foliation (Wyche et al., 2001; Chen et al., 2001). Schistosity in tremolite–chlorite and mafic schist southwest of 21 Mile Bore (e.g. MGA 712750E 6746320N, MGA 712880E 6746370N, MGA 708860E 6744720N) has been folded into small-scale, symmetric, tight to open folds with wavelengths of 10 to 20 cm. These folds have subvertical axial planes that trend northerly, with hinges plunging steeply north or south. This geometry suggests that the folds formed during D_2 (see below), with schistosity a product of D_1. Megascopic folds with wavelengths of up to 300 m that are attributed to D_1 are exposed in a BIF unit on JOHNSTON RANGE in the hinge areas of the Horse Well and Diemals Anticlines (Wyche et al., 2001; Fig. 9). This BIF unit extends north onto BARLEE.

The early deformation was followed by a prolonged period of east–west compression (Table 1) that was largely responsible for the present-day configuration of the greenstones and granitoids in the Marda–Diemals region (Libby et al., 1991; Dalstra, 1995; Dalstra et al., 1999; Greenfield and Chen, 1999; Chen et al., 2001; Wyche et al., 2001). This long-lived compressional event comprised an initial phase (D_2) characterized by northerly trending, open to tight upright folds and a north-trending regional foliation, followed by the development of regional-scale shear zones (D_3; Wyche et al., 2001; Chen et al., 2001). On BARLEE structures assigned to D_2 are represented by the northernmost part of the Watch Bore Syncline and by an unnamed anticline exposed farther to

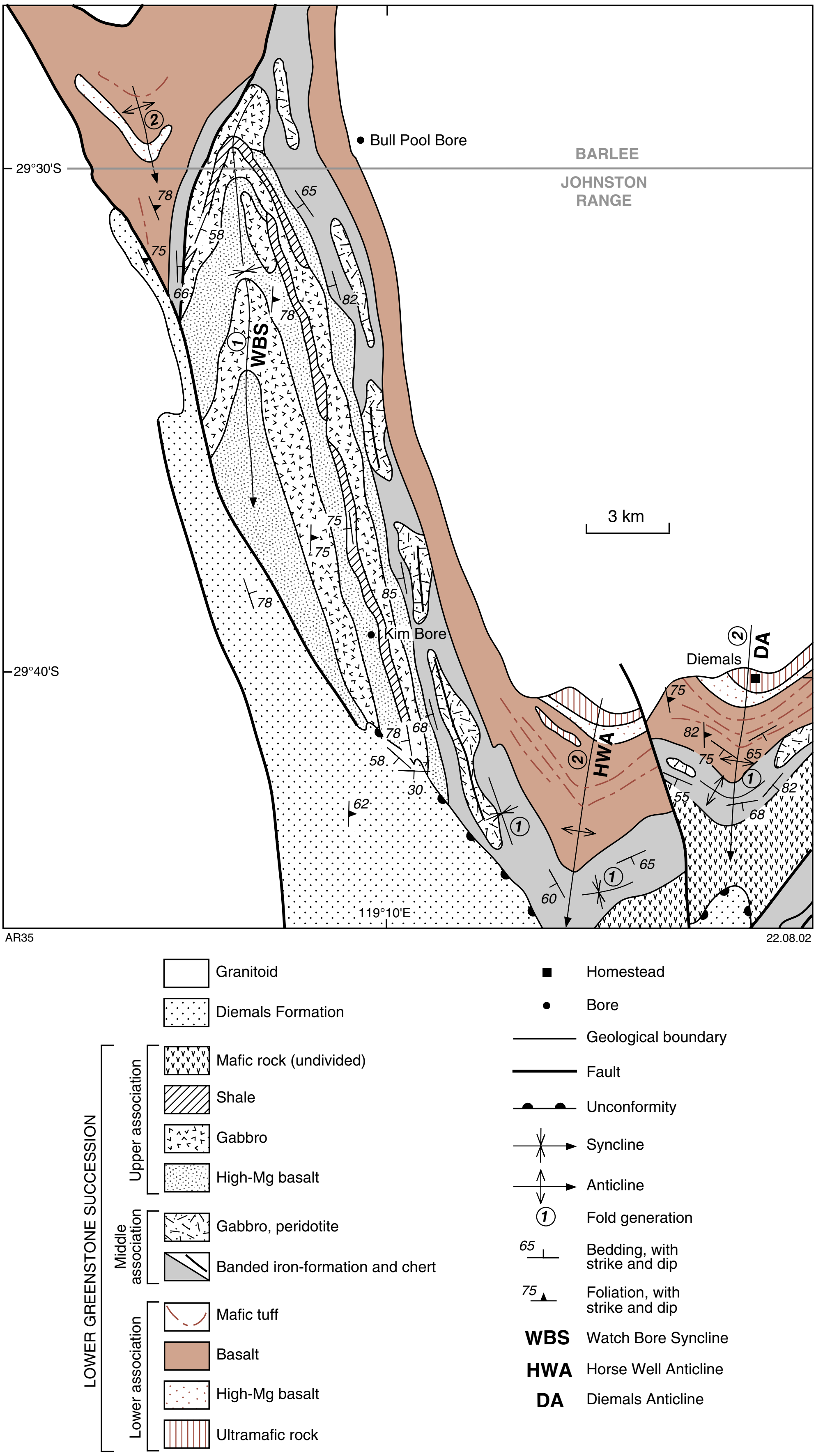

Figure 9. Simplified geological map showing the lithostratigraphic distribution and structure of the Diemals – Bull Pool Bore area

the west (Fig. 9), both of which plunge to the south. The mafic and ultramafic schist exposed southwest of 21 Mile Bore contain small-scale, north-trending F_2 folds. The unconformable deposition of the Diemals Formation over the lower greenstone succession just south of BARLEE may have commenced during early D_2, whereas emplacement of the Marda Complex and associated granitoids farther south on JACKSON probably began before the start of the east–west compression (Riganti and Chen, 2002; Table 1). Voluminous granitoids were emplaced synkinematically, mainly during D_2, resulting in the development of gneissic banding and foliation in the earliest intrusions (Wyche et al., 2001; Riganti and Chen, 2002). On BARLEE the most strongly deformed granitoid rocks are represented by the granitoid gneiss southeast of Willow Bore, which is dated at 2714 ± 10 Ma (Nelson, 2002). This age is similar to the 2711 ± 4 Ma age (Nelson, 2001) of granitoid gneiss at Yacke Yackine Dam on JACKSON, which is interpreted as an early gneissic component enveloped by subsequent granite intrusions (Riganti and Chen, 2002). An intrusive relationship between an undeformed monzogranite and granitoid gneiss that may represent the southern extension of the gneiss exposed at Willow Bore is southeast of Quartz Bore (see **Gneissic rocks**, *Angx*).

With ongoing east–west compression, impingement of large, rigid granitoid bodies into the greenstones resulted in the reorientation of the earlier D_2 structures and development of regional-scale shear zones (D_3; Chen et al., 2001). These shear zones form arcuate structures, which characteristically consist of northwesterly sinistral and northeasterly dextral shear zones, linked by a north-trending contractional zone in the apex regions (Chen et al., 2001). The most prominent D_3 structure on BARLEE is the southern part of the Yuinmery Shear Zone, which crosscuts the northeastern quadrant of the map sheet. The shear zone is largely covered by lake deposits, but a 2 to 5 km-wide tectonized zone, is evident on aeromagnetic images (Fig. 4). Near the northern shore of Lake Barlee, granitoid gneiss and strongly foliated monzogranite within the shear zone contain shallow (<20°), southeasterly dipping mineral lineations. In these rocks S–C fabrics are defined by north-northwesterly trending (around 342°), vertical S planes parallel to the gneissosity that are sinistrally displaced by northwest-trending (320°), vertical C planes. The Yuinmery Shear Zone is better exposed north of BARLEE, on RAYS ROCK and WINDIMURRA, where the shear zone is defined by mylonite in the Yuinmery gneiss (Stewart et al., 1983; Eisenlohr et al., 1993). Kinematic indicators (e.g. asymmetric porphyroclasts, S–C fabrics, and small-scale restraining jogs) are consistent with sinistral movement on the Yuinmery Shear Zone (Chen et al., 2001).

A small D_3 shear zone south of Mondie Rocks is characterized by a 3 km-wide zone of strongly deformed, in places intimately interleaved, greenstone and granitoid rocks. In this zone mafic and ultramafic schist are characterized by a northeast-trending, vertical to steeply southeasterly dipping foliation that is commonly crenulated and folded, with steeply plunging, Z-shaped asymmetric folds indicative of dextral movement (e.g. MGA 709850E 6744640N, MGA 712750E 6746320N).

Post-D_3 deformation on BARLEE is best seen on aeromagnetic images, where large-scale, linear, easterly trending, low-magnetic anomalies cut across greenstones, granitoid rocks, and D_3 structures (Figs 3 and 4). The most prominent set crosscuts the Yuinmery Shear Zone and unexposed greenstones in the northeastern and central-northern parts of the map sheet, in both cases with apparent sinistral offsets up to 2.5 km. These anomalies are interpreted as brittle faults and fractures that are locally infilled by prominent quartz veins (e.g. at Yerramudder Hill and north of Top Soak Bore). Some easterly trending, linear magnetic anomalies correspond to tension fractures that were infilled by Proterozoic mafic and ultramafic dykes (Hallberg, 1987; see **Mafic dykes**).

Greenstones on BARLEE are typically metamorphosed to greenschist facies, with mineral assemblages comprising actinolite, albitic plagioclase, and epidote, with minor opaque oxides (ilmenite, magnetite) and quartz. Higher grade, upper greenschist- and amphibolite-facies metamorphism is evident in greenstones near the contacts with granite, and is indicated by biotite in mafic and ultramafic schists (MGA 702150E 6740070N), hornblende in amphibolite (MGA 702380E 6739940N), and grunerite in magnetite quartzite (MGA 710910E 6746940N). Assemblages of hornblende–plagioclase–clinopyroxene (–garnet), indicative of upper amphibolite- and possibly granulite-facies conditions, were reported by Stewart et al. (1983) in mafic enclaves within granitoid gneiss 2.5 km northeast of Quartz Bore. These observations are consistent with the distribution of metamorphic grades in the regional studies of Binns et al. (1976), Ahmat (1986), and Dalstra (1995).

Cainozoic geology

BARLEE is covered by extensive Cainozoic regolith deposits as a result of prolonged weathering. Mapping of the regolith is based on field observations and interpretations of aerial photos and Landsat images. Regolith units have been subdivided into relict (residual) and depositional regimes, following the Residual–Erosional–Depositional (RED) scheme of Anand et al. (1993), with modifications by Hocking et al. (2001). A review of the regolith geology of the Yilgarn Craton is given by Anand and Paine (2002).

Relict units (*Rd, Rf, Rz, Rzi, Rzu, Rg, Rgm_g, Rgp_g*)

Undivided duricrust (*Rd*) on BARLEE is developed over extensive areas that are largely underlain by granitoid rocks, and is typically covered by a layer of probably residual yellow sand with minor pisolitic laterite, silt, and clay (*Sl*). The profile of the duricrust is best developed at breakaways, which are erosional surfaces with gentle (10–15°) scree slopes and bluff faces that can be up to 10 m high (see cover photo). The duricrust profile consists of siliceous to ferruginous duricrust underlain by saprolite and granitoid saprock. Ferruginous or lateritic duricrust (*Rf*) consists of nodular, pisolitic or massive ferricrete developed over both greenstones (particularly iron formations) and granitoid rocks. The geochemistry of ferruginous duricrust developed over the greenstones in southwestern BARLEE was presented by Grunsky (1998) as part of a regional study of lateritic deposits in the central Yilgarn Craton. Silcrete (*Rz*) forms areas of siliceous duricrust over granitoid rocks, and is typically represented by either massive chalcedony or, more commonly, angular, millimetre-sized quartz clasts set in cryptocrystalline siliceous duricrust. Siliceous duricrust with intergranular cement impregnated by iron oxides and hydroxides (*Rzi*) has been mapped separately. On aerial photos these areas are characterized by medium-brown colours, intermediate between the dark red-brown typical of ferricrete and the pale-brown to creamy hues of silcrete. Contacts between ferruginous duricrust, silcrete with ferruginous cement, and silcrete are commonly gradational. Pale- to dark-brown opaline silica caprock over ultramafic rocks (*Rzu*) is developed over a large ultramafic enclave within granitoid gneiss, and forms a prominent hill just west of the Lake Barlee – Youanmi Road (MGA 709520E 6760020N).

Residual quartzofeldspathic sand over granitoid rock (*Rg*) is characterized by a few scattered, weathered (granitoid) outcrops, and locally abundant quartz-vein and silcrete pebbles. It is common at the base of breakaways and in the peripheral aprons surrounding granitoid exposures, where the sand can be up to 2 m thick (Biological Surveys Committee, 1995). In many cases the preservation of scattered outcrops within the residual sand adjacent to fresh exposures allows a distinction between quartzofeldspathic residual sand developed over granite (Rgp_g) and over granitoid gneiss (Rgm_g). Scattered debris of metamorphosed sedimentary and mafic enclaves typically associated with gneiss also assists in the distinction between different types of residual sand.

Depositional units (C, Cf, Clc_i, Cq, W, Wf, A, A_p, L_l, L_d1, L_d2, L_m, S, Sl)

The depositional regime on BARLEE is largely controlled by the Lake Barlee playa-lake system (*L*), with large areas of sheetwash (*W*) and broad alluvial channels (*A*) around the lake margins. The intervening parts contain mainly sandplain (*S*), whereas undivided colluvial deposits (*C*) are close to rock outcrops, and include poorly sorted rock fragments, gravel, sand, and silt from mixed erosional sources. Dominantly ferruginous colluvium (*Cf*) is derived from reworked ferruginous duricrust and iron-rich metasedimentary rocks, whereas coarse angular debris of BIF and chert (Clc_i) is typical of the flanks of prominent BIF ridges. Colluvium composed predominantly of angular quartz clasts (*Cq*) lies adjacent to conspicuous quartz veins.

Sheetwash units (*W*) consist of well-sorted red sand, silt, and clay material, typical of floodplains and areas of very gentle slope gradational between colluvial and alluvial units. Abundant fine ferruginous grit (*Wf*) characterizes areas adjacent to ferruginous colluvial units. Areas of channelized flow (as opposed to sheetflow) can be distinguished on aerial photos and Landsat images. These alluvial deposits (*A*) consist of poorly sorted, fine- to coarse-grained sand, with lenses of silt and gravel, in which distinct channels can be identified and are marked as watercourses. Claypans (A_p) are located within active alluvial systems.

Lacustrine deposits on BARLEE form the western part of Lake Barlee, which is a major lake system that is part of the southeasterly flowing Raeside palaeodrainage (van de Graaff et al., 1977; Hocking and Cockbain, 1990). Lake surfaces (L_l) are characterized by flat and unvegetated expanses of mud and clay, saturated by brine and covered by a thin veneer of evaporitic halite and gypsum. There are dune systems on the fringes of, and within, the lake. Two generations of dunes have been distinguished. Active dunes (L_d1) with minimal topographic expression are barren or have very minor halophytic vegetation, whereas stabilized dunes (L_d2) rise a few metres above the lake level and are characterized by encrusted gypsiferous sediments with red sand in shallow pockets. The latter are colonized by samphire and locally scattered shrubland or rare *Eucalyptus* woodlands with a saltbush understorey. Stabilized dunes are older than the active dunes, although the absolute age of these deposits is unknown. The flat to gently undulating margins of the playa lakes contain a mixture of eolian, evaporite, lacustrine, and alluvial deposits (L_m).

Variably thick sandplain deposits (*S*) on BARLEE are characterized by well-sorted, quartz-rich sand that may represent a mixture of eolian sand and residual material from a quartzofeldspathic bedrock. On aerial photos and false-colour Landsat images yellow sand distinguished by areas of abundant pisolitic and nodular gravel, silt, and clay (*Sl*) has darker tones than the quartz-rich sand. It is probably derived from ferruginous or siliceous duricrust developed over a granitoid substrate, possibly with a minor eolian component.

Economic geology

Although there is no recorded mineral production on BARLEE, surface and near-surface exploration for gold, base metals, and diamonds has been carried out by soil sampling, rotary air-blast (RAB) and reverse circulation (RC) drilling, and magnetic surveys. The results of mineral exploration on BARLEE are presented in open-file statutory reports in the MPR library in Perth and Kalgoorlie.

Gold exploration on BARLEE focused on the south-western part of the sheet, in areas with exposed or ferruginized greenstones. Gold mineralization is typical of zones of alteration marginal to quartz veins. Quartz veins with intersected widths of up to 16 m (but mostly up to 3 m) are surrounded by gold-bearing alteration zones consisting of fine-grained, sheared, silicified, and sericitized mafic and ultramafic rocks with grades up to 7.7 g/t Au (Doepel, 1990). Areas of competency contrast, such as fold hinges in BIFs and shear zones, were also targeted (Schwebel, 1991).

Exploration for base metals in shale and tuffaceous beds within the greenstone sequence has not located economic mineralization (Tredger, 1974). Copper traces in the form of dense siliceous gossans cut by stringers of malachite and azurite on JOHNSTON RANGE are within the same shale unit that is exposed on BARLEE (Marston, 1979).

Exploration for diamonds focused in the area east and west of Mondie Rocks, but interpretation of magnetic surveys and heavy mineral sampling did not locate any kimberlite rocks (Dalton, 1997).

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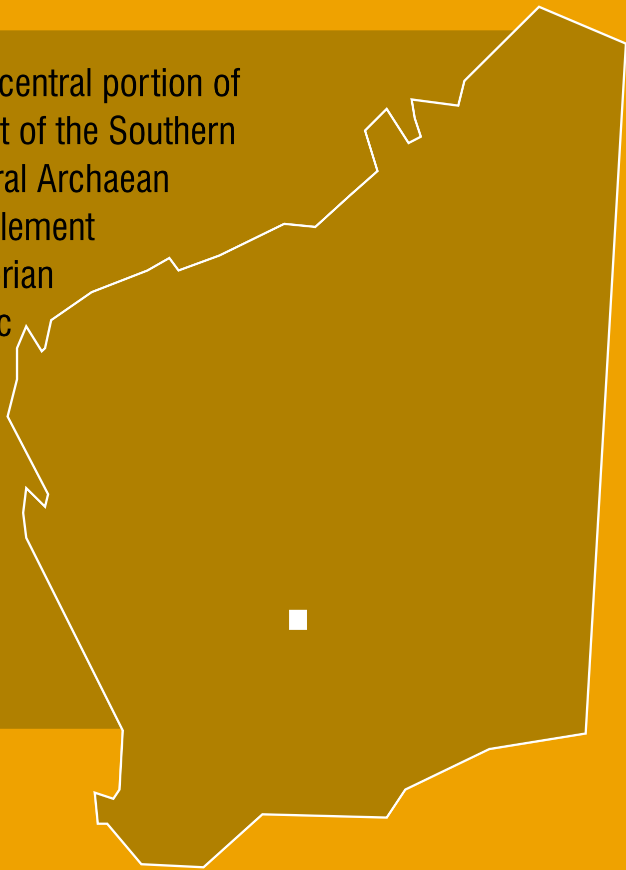
Appendix

Gazetteer of localities on Barlee

Locality	MGA coordinates Easting	Northing
21 Mile Bore	713400	6746950
Bull Pool Bore	708450	6736200
Cronins Bore	710070	6762950
Diemals Homestead (on Johnston Range)	723000	6715800
Kim Bore (on Johnston Range)	709300	6717900
Lake Barlee Homestead	696140	6773000
Mondie Rocks	710800	6747900
Outcamp Bore	732700	6749700
Paddy Bore	712050	6782260
Quartz Bore	707950	6759100
Retreat Rock	719100	6783200
Surprise Bore	707850	6751700
Top Soak Bore	737300	6767600
Trainers Rocks	697750	6775800
Willow Bore	704270	6782260
Wongroon Bore	732000	6740500
Yacke Yackine Dam (on Jackson)	693630	6644630
Yerramudder Hill	701250	6780900

The BARLEE 1:100 000 sheet covers the north-central portion of the BARLEE 1:250 000 sheet in the western part of the Southern Cross Granite–Greenstone Terrane, in the central Archaean Yilgarn Craton. These Explanatory Notes complement the 1:100 000 map, and describe the Precambrian rock types, and the structural and metamorphic geology of the Archaean granite–greenstone terrain. The greenstone stratigraphy and constraints on the age of granitoid intrusion are discussed. The Notes also contain descriptions of the extensive Cainozoic regolith cover.



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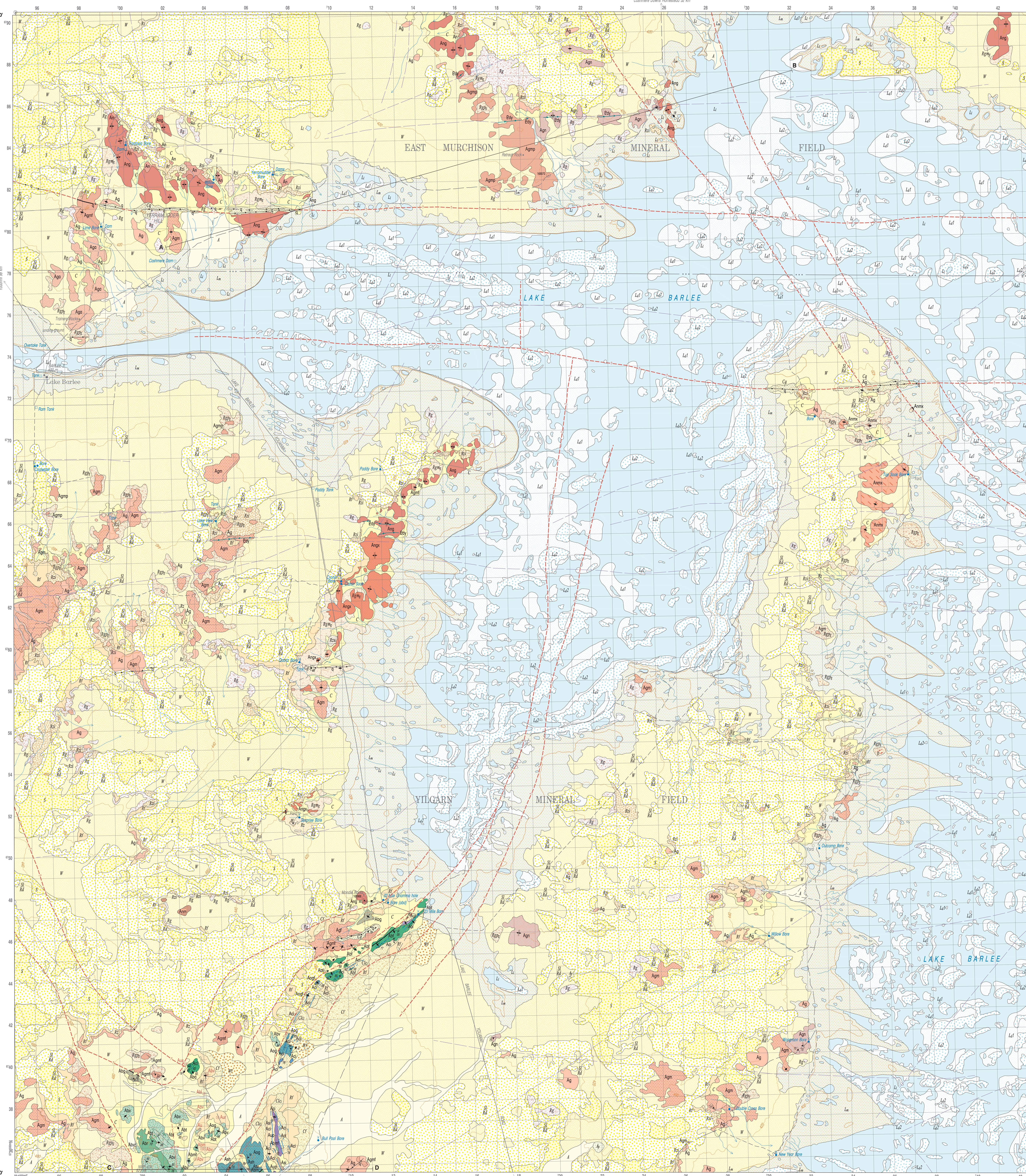
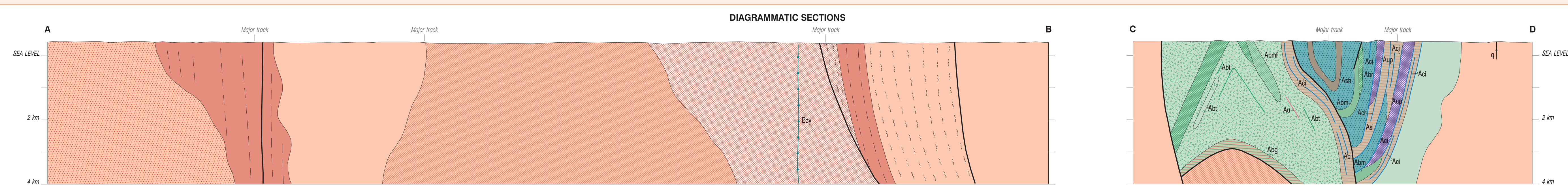
RIGANTI
Geology of the Barlee 1:100 000 sheet
EXPLANATORY NOTES

BARLEE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



DIAGRAMMATIC SECTIONS



PHANEROZOIC — CAINOZOIC

C, Cf, Clc, Cq, W, Wf, A, Ap, Ll, Ld1, Lm

Colluvial units
- *C* — Mixed gravel from different rock types as proximal talus; includes sand and silt; locally ferruginous
- *Cf* — Ferruginous gravel and reworked duricrust
- *Clc* — Talus from banded iron-formation and chert; locally cemented
- *Cq* — Quartz-vein debris

Sheetwash units
- *W* — Clay, silt, and sand in extensive fans; locally ferruginous
- *Wf* — Deposits with abundant ferruginous grit

Alluvial units
- *A* — Clay, silt, sand, and gravel in channels and floodplains
- *Ap* — Clay and silt in claypans

Lacustrine units
- *Ll* — Saline playa lake deposits
- *Ld1* — Dune and lake deposits; active systems within and adjacent to playa lakes; unvegetated or poorly vegetated
- *Lm* — Mixed dune, evaporite, and alluvial deposits adjacent to playa lakes

Ld2, S, Sl

Lacustrine unit
- *Ld2* — Dune deposits; stabilized dunes within and adjacent to playa lakes; vegetated

Sandplain units
- *S* — Residual and eolian sand
- *Sl* — Yellow sand with minor pisolitic laterite, ferruginized silcrete, silt, and clay

Rd, Rf, Rg, Rgmg, Rgpg, Rz, Rzi, Rzu

Relict units
- *Rd* — Siliceous and ferruginous duricrust, undivided
- *Rf* — Lateritic duricrust; includes iron-cemented reworked products
- *Rg* — Quartzofeldspathic sand over granitoid rock
- *Rgmg* — Quartzofeldspathic sand over gneissic rock; sparse gneiss outcrop
- *Rgpg* — Quartzofeldspathic sand over granitic rock; sparse granite outcrop
- *Rz* — Silcrete, predominantly over granitoid rock
- *Rzi* — Silcrete with ferruginous cement
- *Rzu* — Silica caprock over ultramafic rock

PROTEROZOIC

- Ꝑdy — Mafic dyke
- q — Quartz veins and dykes
- p — Pegmatite veins and dykes

ARCHAEAN — YILGARN CRATON

Ag, Aga, Agf, Agm, Agmf, Agmp, Agn

- Ag — Granitoid rock, undivided; includes deeply weathered rock
- Aga — Fine- to medium-grained leucocratic monzogranite with abundant aplite and pegmatite
- Agf — Strongly foliated granitoid rock; typically deeply weathered
- Agm — Monzogranite; locally weakly foliated
- Agmf — Strongly foliated monzogranite
- *c.* 2635 Ma — Agmp — Medium- to coarse-grained monzogranite with aligned microcline megacrysts
- Agn — Gneissic granitoid rock; weakly to strongly foliated granitoid rock, locally becoming gneissic

An, Ang, Angx, Anm, Anmx

- An — Gneissic rock, undivided; commonly deeply weathered
- 2694 Ma — Ang — Granitoid gneiss
- Angx — Granitoid gneiss, with numerous enclaves of medium- to high-grade metasedimentary, mafic, and ultramafic rocks
- Anm — Migmatitic gneiss, with granitic to granodioritic neosome and quartz–feldspar–biotite orthogneiss palaeosome
- Anmx — Heterogeneous migmatitic gneiss, complex mixing of anatectically derived granitoid diatexite and assimilated gneissic rocks; prominent schlieric banding

Ash, Asi, Aci

- Ash — Shale and siltstone, metamorphosed
- Asi — Metasedimentary rock, includes shale, siltstone, and banded iron-formation; deeply weathered and ferruginized
- Aci — Banded iron-formation and minor banded chert; local jaspilite; metamorphosed

Aog, Aogf

- Aog — Metagabbro; medium- to coarse-grained
- Aogf — Strongly foliated metagabbro

Aba, Abf, Abg, Abl, Abm, Abmf, Abt, Abv

- Aba — Amphibolite; fine- to medium-grained; commonly strongly foliated and lineated
- Abf — Strongly foliated metamorphosed mafic rock; local amphibolite
- Abg — Strongly foliated mafic, ultramafic, and metasedimentary rocks interleaved with subordinate foliated granitoid rock
- Abl — Chlorite(–talc–tremolite) schist (subsurface only)
- Abm — High-Mg basalt with relict pyroxene-spinifex and/or variolitic textures; metamorphosed
- Abmf — Strongly foliated high-Mg basalt, locally variolitic; metamorphosed
- Abr — Strongly foliated tremolite- and chlorite-rich rock; probably after high-Mg basalt
- Abt — Mafic tuff and tuffaceous sedimentary rock; metamorphosed
- Abv — Metabasalt; massive to weakly foliated

Aup, Aur

- Au — Metamorphosed ultramafic rock; typically deeply weathered (subsurface only)
- Aup — Serpentinized peridotite
- Aur — Tremolite–chlorite(–talc) schist
- Aus — Serpentinite (subsurface only)

SYMBOLS

Geological boundary
- exposed

Structural symbols are labelled according to the sequence of deformation events, where known
- Yilgarn
  - D_2 — ②

Fault or shear
- exposed
- concealed, interpreted from aeromagnetic data

Strongly foliated rock

Fold, showing axial trace and generalized plunge direction
- anticline; exposed, concealed
- syncline; exposed, concealed

Bedding, showing strike and dip
- inclined — 74
- vertical

Way-up indicator
- graded bedding

Foliation, showing strike and dip
- inclined — 78
- vertical

Gneissic banding, showing strike and dip
- inclined — 80
- vertical

Stretching lineation, showing trend and plunge — 18

Axis of crenulation, showing trend and plunge — 40

Fracture, joint, or extension vein, showing strike and dip
- inclined — 65
- vertical

Airphoto lineament

Aeromagnetic lineament

Isotopic age determination site with identification number — 168970

Formed road

Major track

Track

Fence, generally with track

Homestead — Lake Barlee

Building

Yard — Yard

Horizontal control; major, minor

Breakaway

Contour line, 20 metre interval — 480

Watercourse

Gnamma hole — *Gnamma hole*

Soak — *Soak*

Bore — *Bore*

Windpump

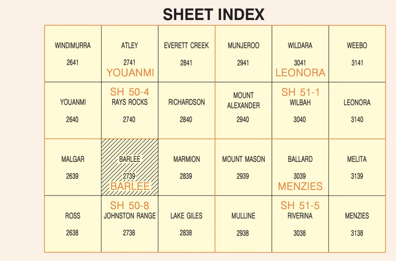
Dam, tank — *Dam* *Tank*

Abandoned — *(abd)*

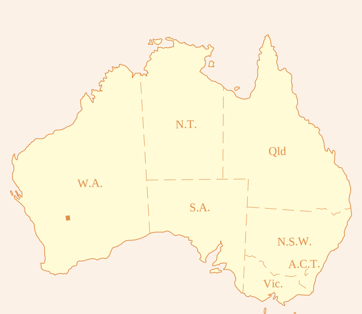
Mineral field boundary

Subsurface data from drillhole, costean, shallow shaft, or pit — Abv

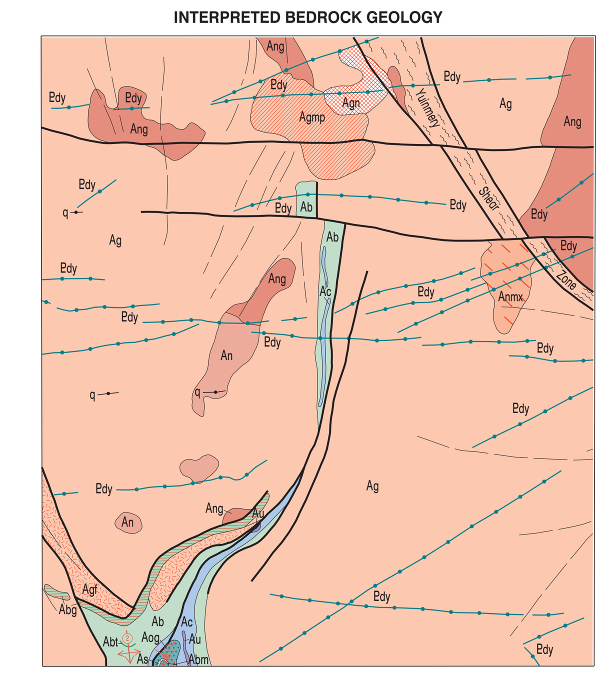
SHEET INDEX



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



INTERPRETED BEDROCK GEOLOGY



YILGARN CRATON

- Ꝑdy — Mafic and ultramafic dykes
- q — Quartz veins and dykes

Ag, Agf, Agmp, Agn, An, Ang, Anmx

- Ag — Granitoid rock
- Agf — Foliated granitoid rock
- Agmp — Porphyritic monzogranite
- Agn — Gneissic granitoid rock
- An — Gneiss
- Ang — Granitoid gneiss
- Anmx — Heterogeneous migmatitic gneiss with prominent schlieric banding

As, Ac

- As — Metasedimentary rock
- Ac — Metamorphosed banded iron-formation, chert, and shale with associated mafic rock

- Ab — Metagabbro

Abg, Abm, Abt

- Ab — Metabasalt dominant
- Abg — Foliated mafic, ultramafic, and metasedimentary rock with minor granitoid rock
- Abm — Metamorphosed high-Mg basalt
- Abt — Metamorphosed mafic tuffaceous rock

- Au — Metamorphosed ultramafic rock

Structural trend

Geology by A. Riganti 1999

Geochronology by D. R. Nelson, in prep., GSWA Record 2001/2

Edited by N. Tetlaw and G. Loan

Cartography by A. Francois and K. Greenberg

Topography from the Department of Land Administration Sheet SH 50-8, 2739, with modifications from geological field survey

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This map is also available in digital form

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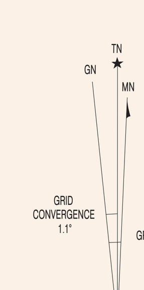

True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 2000 and moves easterly by about 0.1° in 2 years.

Department of Mineral and Petroleum Resources

Geological Survey of Western Australia

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MINISTER FOR STATE DEVELOPMENT

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DIRECTOR GENERAL

TIM GRIFFIN
DIRECTOR

SCALE 1:100 000

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

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

Grid lines indicate 1000 metre interval of the Map Grid Australia Zone 50

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

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

BARLEE

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