

**EXPLANATORY  
NOTES**



# **GEOLOGY OF THE MERRIE 1:100 000 SHEET**

by **N. G. Adamides**

**1:100 000 GEOLOGICAL SERIES**



**GEOLOGICAL SURVEY OF WESTERN AUSTRALIA**  
**DEPARTMENT OF MINERALS AND ENERGY**



**GEOLOGICAL SURVEY OF WESTERN AUSTRALIA**

# **GEOLOGY OF THE MERRIE 1:100 000 SHEET**

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**N. G. Adamides**

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Cover photograph:  
General view of granite tors in the area 6 km east of the Canning Stock Route (AMG 427317).

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# Geology of the Merrie 1:100 000 sheet

by

N. G. Adamides

## Abstract

MERRIE is located at the junction between the northern extension of the Archaean Eastern Goldfields Province and the Palaeoproterozoic Yerrida and Earahedy Basins. The Archaean rocks contain a poorly exposed greenstone belt (Merrie greenstone belt) composed of metabasalt, amphibolite, and metamorphosed felsic volcanoclastic and sedimentary rocks. The greenstone belt is metamorphosed to lower greenschist facies with higher metamorphic grades adjacent to the granite. Three periods of deformation have affected the Archaean rocks and resulted in the present synclinal structure of the Merrie greenstone belt. A major linear structure, the Merrie Range Fault, is associated with the third deformation event ( $D_3$ ) and is the northerly continuation of the Celia Lineament. The Yerrida Group is unconformable on Archaean basement and represented by shallow-water sandstones and siltstones (Juderina Formation) intruded by sills of the Killara Formation. The Earahedy Group is unconformable on both the Yerrida Group and Archaean basement, and is represented by clastic sedimentary and chemical rocks of the Yelma, Frere, Windidda, and Chiall Formations. Deformation during the Capricorn Orogeny is indicated by the presence of easterly trending structures within the granite and folding of the Earahedy Group rocks. Overprinting of these structures suggests a later (?Bangemall) deformation event associated with northwest-directed compression. Displacement of rocks of the Earahedy Group along the Merrie Range Fault also suggests late rejuvenation of this structure with a strong sinistral displacement. The Yelma Formation contains the Sweetwaters Well Member, which is a dolomite sequence with lead–zinc mineralization. The Frere Formation is predominantly a granular, Superior-type iron-formation, with potential for significant iron ore mineralization. The Windidda Formation (Karri Karri Member) shows, in places, black-shale affinities suggesting the possibility of base metal mineralization.

**KEYWORDS:** Archaean, Merrie greenstone belt, Palaeoproterozoic, Yerrida Group, Earahedy Group, mineralization, base metals, iron, gold

## Introduction

### Location and access

The MERRIE\* 1:100 000 map sheet (SG 51-5, 2946) occupies the southwestern corner of the NABBERU (1:250 000) map sheet and is bounded by latitudes 25°30' and 26°00'S and longitudes 120°00' and 120°30'E (Fig. 1). It is located in the northern extension of the Eastern Goldfields Province of the Yilgarn Craton (Griffin, 1990) and includes part of the eastern extension of the Palaeoproterozoic Yerrida Basin (Pirajno et al., 1996), and the western extension of the Earahedy Basin (Bunting, 1986). The area is located 90 km north of Wiluna†

(population 260; 1996 census) and 150 km northeast of Meekatharra (population 1270). Access from these towns is via the unsealed Wiluna North Road, which leads to Neds Creek Homestead and then joins the Great Northern Highway 83 km to the northwest of MERRIE. Access to the northeastern parts of MERRIE is along the Canning Stock Route, and to the north via the Vermin-proof fence. Both of these access routes are rendered impassable after heavy rain. A privately maintained track starts from the Wiluna North Road about 9 km north of the southern edge of MERRIE and reaches the northeastern part of the area through Doyle Well, Joe Bore, and Nabberu Tank. A number of other tracks, typically passable only by four-wheel drive vehicles, provide access to other parts of the area.

Geological mapping was carried out using 1:50 000-scale monochrome photography (Project number WA3594, 1995) available from the Department of Land

\* Capitalized names refer to standard 1:100 000 map sheets. Where 1:100 000 and 1:250 000 sheets have the same name, the 1:100 000 is implied unless otherwise indicated.

† Coordinates of localities mentioned in text are shown in Appendix 1.

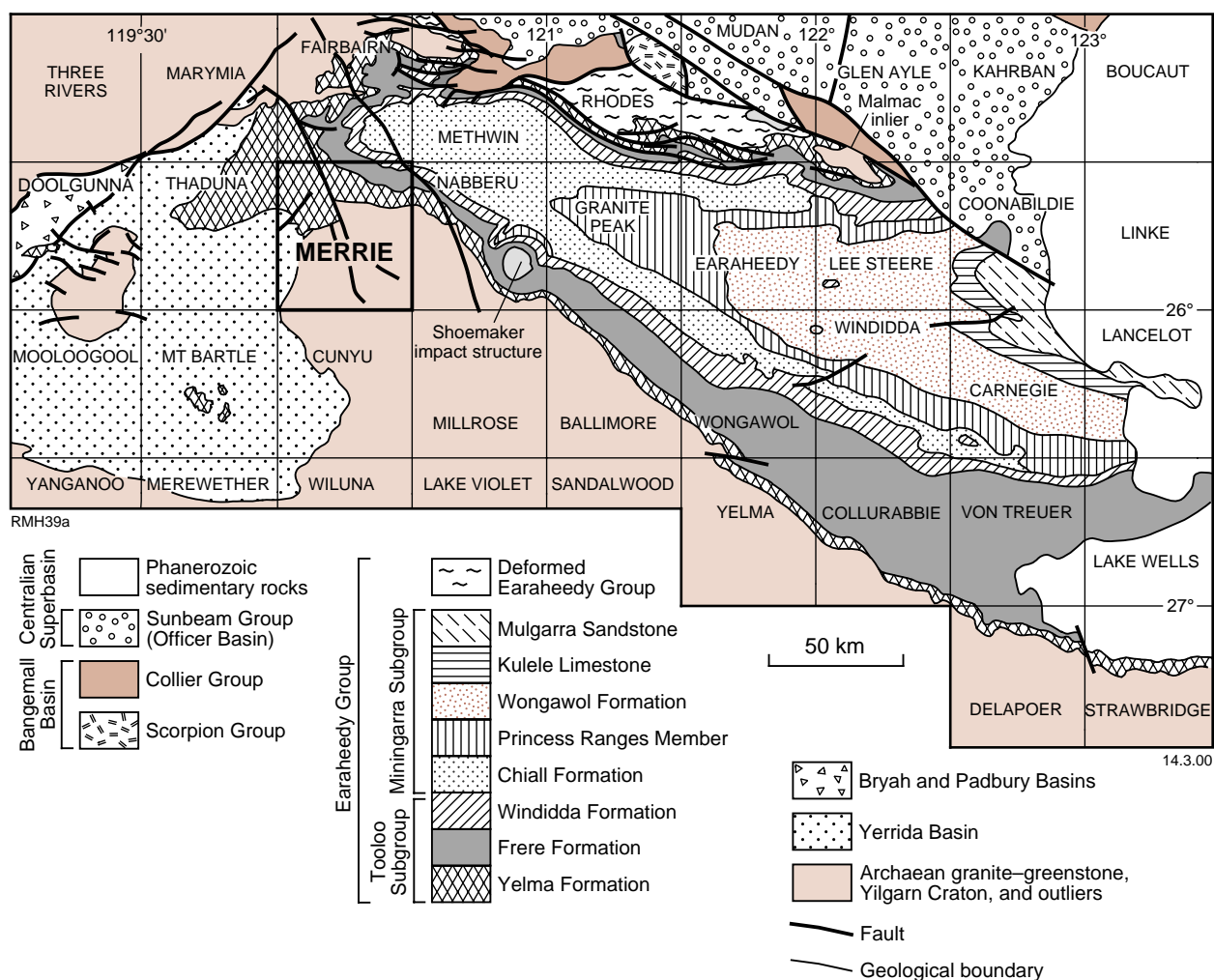


Figure 1. Map showing the Earaheedy Basin and location of the MERRIE 1:100 000 sheet

Administration (DOLA). Landsat Thematic Mapper (TM) images plotted at photo scale, and 400-m line-spaced aeromagnetic data (flown by Australian Geological Survey Organisation (AGSO) in 1996) were used in the field and to interpret geological features beyond localities visited. A Trimble (Ensign XL) navigation aid was used for the determination of Australian Map Grid (AMG) coordinates of outcrops and localities mentioned in the text.

## Climate and vegetation

The climate of the area is semi-arid to arid with long, hot summers and mild winters. Mean daily maximum summer temperatures are between 35 and 40°C and minimum temperatures between 20 and 23°C (Bunting, 1986). In winter, average maximum temperatures are around 20°C and minimum temperatures 6°C with frosts common on clear nights. Mean annual rainfall is in the range of 200 to 240 mm and is unreliable, related to both summer cyclones and winter depressions. Potential annual evaporation may average between 2400 and 3000 mm.

MERRIE lies within the eastern extension of the Gascoyne subprovince of the Eremaean Botanical District (Beard, 1990). The subprovince includes the Carnegie Salient — the system of lakes that includes Lake Nabberu, Lake Wells, and Lake Carnegie. The vegetation of the salt-lake regions is dominated by samphire communities at the lowest topographic levels, followed by *Frankenia*–*Atriplex* communities at higher levels. Acacia shrub dominates the sandhills that surround the lakes. Mulga (*Acacia aneura*) is the commonest shrub in all the other habitats, accompanied by other acacia species (*A. quadrimanginea*, *A. grusbyi*) on areas of iron formation. Low shrubs of the *Eremophila* and *Cassia* families are widespread and, together with a variety of grasses, form the understorey to the taller shrubs. A characteristic slender-branched species of *Eremophila* is particularly prolific on outcrops of granular iron-formation; sandstone outcrops of the Juderina Formation are vegetated with wattle and mulga. Vegetation on granite outcrops is typically sparse, and represented by mulga, isolated yellow cassia (*C. luerseii*), and turpentine bush (*E. fraseri*). River channels are commonly lined with tall river red gum (*Eucalyptus camaldulensis*) and sandplains are mostly covered by spinifex (*Triodia* sp.).



## Physiography

The physiography of MERRIE is dominated by the Nabberu Lake system, which occupies much of the northern part of the sheet (Fig. 2). This easterly trending system of playa lakes is part of a major palaeodrainage that joins with the southward-draining Lake Carnegie system. This palaeodrainage dates back to the early Tertiary and is commonly preserved on the relict duricrusted surface (the 'Old Plateau' of Jutson, 1934). Palaeodrainage preservation is related to a change, at that time, from a humid to a typically arid climate (van de Graaff et al., 1977). The radial arrangement of drainage on MERRIE is governed by the presence of this playa system, and its association with extensive calcrete suggests that recent drainage probably follows the old channels with little modification.

A second major physiographic feature is the extensive sandplain, which dominates the southeastern part of MERRIE. The sand overlies duricrust over granite. The duricrust, consisting of lateritized, kaolinitized, and silcretized granite, fringes the areas of sandplain in the form of shallow breakaways, with fresher granite exposed as low whalebacks and tors (see cover photograph) where present drainage cuts through the old surface. The transition from granite to the overlying sand is commonly marked by a mottled facies in the form of ferruginous and bleached fragments locally exposed in creeks, as in the area 5.6 km east-southeast of Bungarra Bore (AMG 293226\*; Fig. 3). Recent studies (Morris et al., 1997; Pell et al., 1999) on the genesis of desert sands confirm their derivation from local sources with little eolian transport.

The topography of MERRIE is typically subdued, with highest elevations (620 m) in the southeastern part of the area, and lowest (540 m) around Lake Nabberu. The topographic expression of the various rock types varies with their resistance to erosion. The granular iron-formations of the Frere Range in the northeastern part of MERRIE form resistant ridges rising several tens of metres above the surrounding plain. Associated siltstones and shales form recessive units occupying the low ground. The Merrie Range area in the central part of the sheet is characterized by mesas where resistant sandstone caps granite. Verscher Range to the west, consisting of sandstones of the Juderina Formation intruded by sills of the Killara Formation, is characterized by a hilly topography with elevations up to 60 m above the surrounding plain.

## Previous investigations

The earliest reports on the geology of the area were by explorers, and their work is described in Feeken et al. (1970). In 1874, John Forrest traversed the area in a journey that started south of the Kimberley Range, and passed through the Frere Range to Weld Spring. However, the first detailed geological investigation of the area was by Talbot (1920, 1928) who accompanied A. W. Canning

in a preliminary survey of the stock route between Wiluna and Halls Creek, and subsequently covered the area in more detail. Talbot's interpretations were accepted until the early 1960s when regional investigations by Sofoulis and Mabbutt (1963) resulted in the inclusion of all Proterozoic rocks under one unit.

MERRIE includes part of the Nabberu Basin as initially defined by Hall and Goode (1975, 1978) and Bunting et al. (1977). These authors correctly identified the unconformity between the Archaean granite-greenstone basement and younger rocks, and an unconformity between older Proterozoic rocks and the Bangemall Group. The older rocks were included in a Nabberu Supergroup deposited in the Nabberu Basin. Rocks on MERRIE were included in a regional synthesis by Horwitz and Smith (1978) and Gee (1990). Sanders and Harley (1971) carried out a regional survey of the hydrogeology of the area around MERRIE.

The Nabberu Basin was initially subdivided from east to west into the Earacheedy, Glengarry, and Padbury Sub-basins; all these sub-basins were later elevated to basin status (Gee and Grey, 1993), with the Glengarry Basin later partitioned into the Bryah and Yerrida Basins (Pirajno et al., 1996). MERRIE straddles the boundary between the Yerrida and Earacheedy Basins.

Systematic mapping of NABBERU (1:250 000) was carried out in 1975–76 and the results presented in Bunting et al. (1982). Bunting (1986) presented a detailed account of the geology of the Earacheedy Basin. Recently, Morris et al. (1997) presented an account of regolith geochemistry on NABBERU (1:250 000).

## Stratigraphic nomenclature

The Proterozoic stratigraphic sequence on MERRIE is shown in Table 1. The stratigraphy of the Yerrida Group follows the terminology of Occhipinti et al. (1997). Exposed rocks belong to the Windplain Subgroup (Juderina Formation) and are locally intruded by sills of the Killara Formation (Mooloogool Subgroup).

The nomenclature of the Earacheedy Group was initially established by Hall et al. (1977) and the group was subdivided into the basal Tooloo Subgroup and an upper Miningarra Subgroup based on deposition in two distinct cycles. The Tooloo Subgroup included the Yelma, Frere, and Windidda Formations. The Miningarra Subgroup included the Wandiwarras Formation, Princess Ranges Quartzite, Wongawol Formation, Kulele Creek Limestone, and Mulgarra Sandstone. This nomenclature was adopted by Bunting et al. (1982) for the description of NABBERU (1:250 000).

As a result of recent mapping, there has been some modification of the stratigraphy of the Earacheedy Group: the upper sandy part of the Wandiwarras Formation and Princess Ranges Quartzite have been downgraded to members of the new Chiall Formation; the lower, shaly part of the Wandiwarras Formation is now the Karri Karri Member of the Windidda Formation. The dolomite and associated chert breccia at the contact with the Frere

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



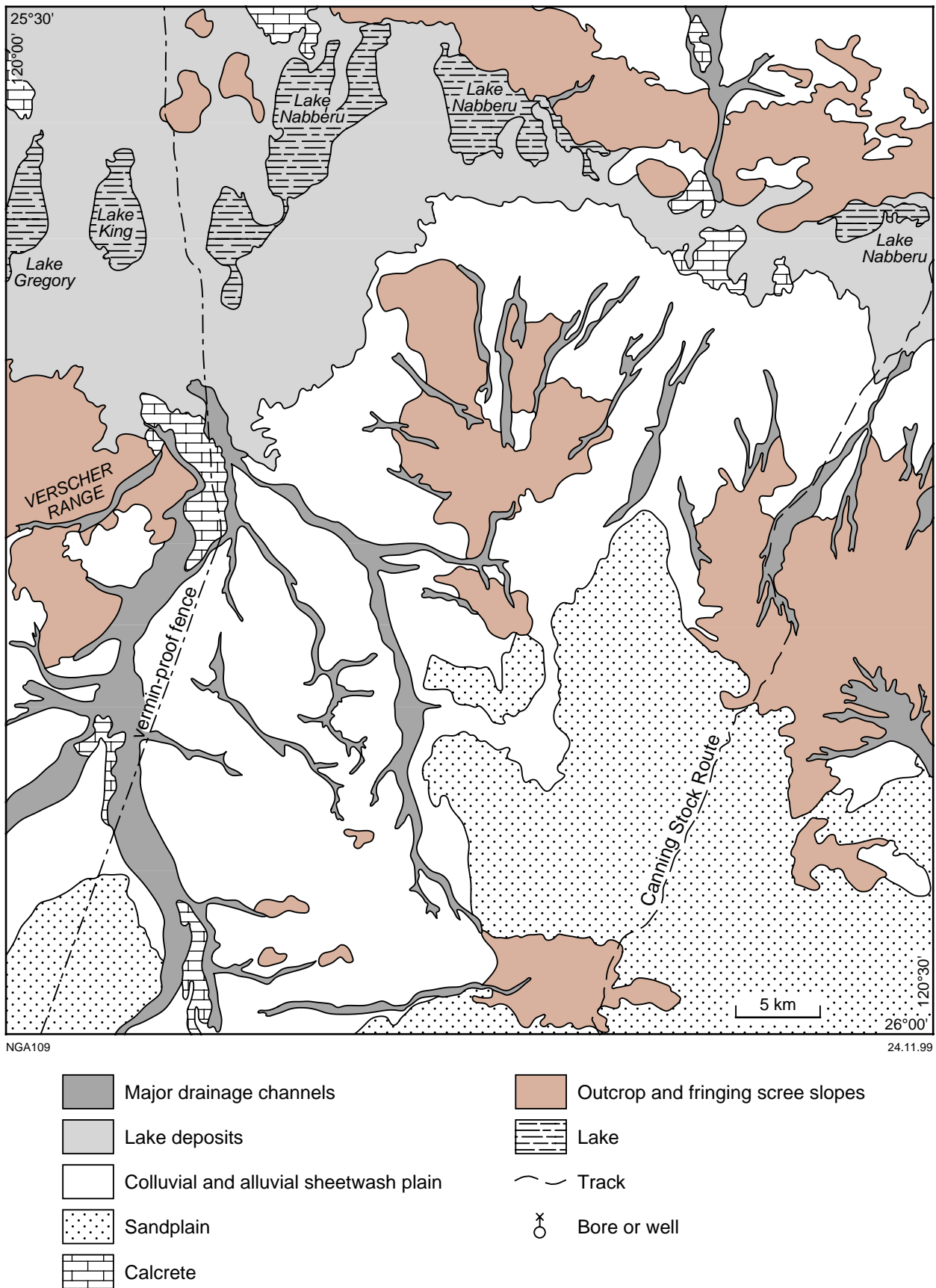
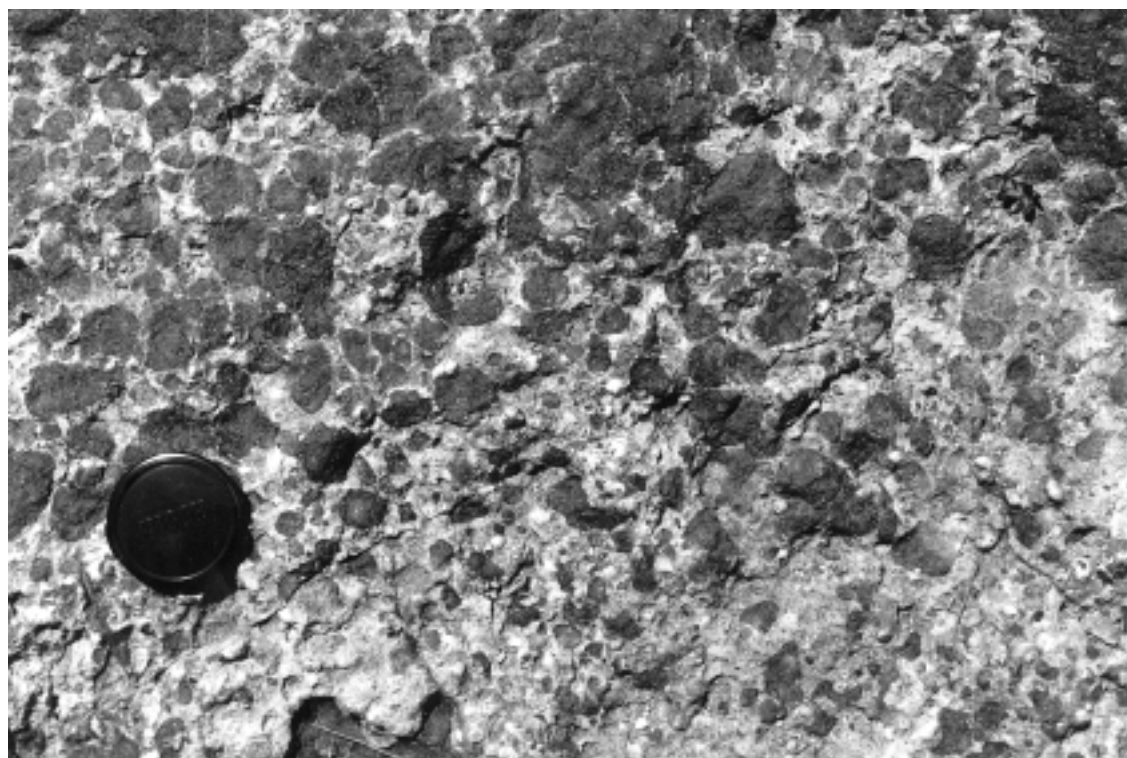


Figure 2. Physiographic map of MERIE



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**Figure 3.** Mottled saprolitic granite at the boundary between lateritic duricrust and underlying weathered granite. From an outcrop 5.3 km east-southeast of Bungarra Bore (AMG 293226). The diameter of the lens cap is 5.5 cm

**Table 1. Proterozoic stratigraphy of MERRIE**

<i>Group/Subgroup</i>	<i>Formation</i>	<i>Lithology</i>	<i>Approximate thickness (m)</i>	<i>Depositional environment</i>
<b>Earaheedy Group</b>	Chiall Fomation Wandiwarra Member	Thin-bedded quartz arenite and interbedded shale	?500	Shallow-marine, transgressive
	Windidda Formation Karri Karri Member	Laminated siltstone and shale with sandstone lenses	?500	Deposition below wave-base, rare interbedded, storm-derived sandstones
	Frere Formation	Granular and banded iron-formation, shale, chert, minor carbonate	1 200	Shallow marine. Transgressive
	Yelma Formation	Quartz arenite, shale, minor carbonate, chert, and conglomerate	1 500	Shallow marine, locally fluvial near base. Transgressive
~~~~~ <i>unconformity</i> ~~~~~				
<b>Yerrida Group</b> Mooloogool Subgroup	Maralooou Formation	Thin-bedded siltstone, shale, minor marl	?100	Deposition below wave-base
	Killara Formation	Fine- to medium-grained mafic intrusive rocks; sills	200	Preliminantly sills of continental affinities intruding Juderina Formation
Windplain Subgroup	Juderina Formation	Quartz sandstone, subordinate siltstone, and chert breccia	500	Shallow marine to intertidal

Formation from the new Sweetwaters Well Member of the Yelma Formation. On MERRIE, only the basal members of the Earraheedy Group are present, and the Wandiwarras Member of the Chiall Formation is the youngest outcropping unit.

## Regional geological setting

MERRIE is located at the northwestern extension of the Eastern Goldfields Province (Griffin, 1990) of the Yilgarn Craton and contains, at its northern and western parts, rocks of the Yerrida and Earraheedy Groups. The groups are part of the Capricorn Orogen (Gee, 1979; Myers, 1990; Tyler et al., 1998), an assemblage of sedimentary basins and associated metamorphic and igneous rocks, which resulted from the collision and fusion of the Yilgarn and Pilbara Cratons between 2000 and 1800 Ma. The Capricorn Orogeny includes the Gascoyne Complex and the Ashburton Basin (Thorne and Seymour, 1991), in addition to the Earraheedy, Yerrida, and Bryah Basins. Collision between the two cratons is thought to have been oblique; it commenced at the southeastern parts of the Pilbara Craton and migrated northwestwards, whereas the Ashburton Basin evolved as a foreland basin (Tyler and Thorne, 1990). The orogen is about  $800 \times 300$  km in exposed dimensions and is elongated east–west. Both its eastern and western extensions are covered by Phanerozoic sedimentary rocks. The suture between the Yilgarn and Pilbara Cratons is interpreted, on geophysical evidence (Drummond et al., 1981), to be located 80 km

south of Newman. The basement to the Proterozoic rocks on MERRIE is therefore, part of the Yilgarn Craton.

The Archaean rocks on MERRIE are part of the Eastern Goldfields Province and in the western end of the sheet form a basement high called the Wiluna Arch (Gee, 1990). The north-northwesterly orientation of this feature matches that of major folds, faults, greenstone belts, and shear zones in the region (Griffin, 1990; Wyche et al., 1997). The Wiluna Arch was probably a positive feature during sedimentation in the Proterozoic, and is covered to the northwest by sandstone and dolerite of the Juderina and Killara Formations of the Yerrida Group, and to the north by the chemical and clastic sedimentary rocks of the Earraheedy Group.

## Geochronology

A summary of geochronology data relevant to rock units exposed on MERRIE is presented in Table 2. Data from the granite basement, which underlies the Proterozoic units, suggest ages of crystallization around 2624–2648 Ma (Nelson, 1996, 1998). The age of the basal units of the Yerrida Group (Juderina Formation) is probably around 2200 Ma, as suggested from Pb–Pb isochron data from stromatolitic carbonate of the Bubble Well Member (Woodhead and Hergt, 1997).

The geochronology of the Earraheedy Group is constrained by the age of the Bangemall Group, which unconformably overlies it. Historical data from the

Table 2. Geochronology data relevant to rock types on MERRIE

Age (Ma)	Lithological unit	Dating method	Interpretation	Source
1638 ± 14	Bangemall Group, Coobarra Formation	SHRIMP U–Pb zircon	Age of emplacement of porphyritic rhyolite, lower Bangemall Group	Nelson (1995)
1700	Earraheedy Group, Yelma Formation	K–Ar (glauconite)	Minimum age of deposition	Preiss et al. (1975)
1590–1710	Earraheedy Group, Yelma Formation	Rb–Sr (glauconite)	Minimum age of deposition	Preiss et al. (1975)
1688 ± 72	Earraheedy Group, Wandiwarras Formation	Glauconite	Minimum age of deposition	Horwitz (1975)
1700	Earraheedy Group, Yelma Formation (Sweetwaters Well Member)	Pb isotope (galena)	Age of lead mineralization	Johnston and Hall (1980), Richards and Gee (1985)
1785 ± 11	Earraheedy Group, Mount Leake Formation	SHRIMP U–Pb zircon	Maximum depositional age based on detrital zircons	Nelson (1996)
2173 ± 80	Juderina Formation, Bubble Well Member	Pb–Pb isochron	Depositional age	Woodhead and Hergt (1997)
2624 ± 8	Goodin Inlier	SHRIMP U–Pb zircon	Crystallization age of granite	Nelson (1996)
2648 ± 19	Yilgarn Craton (CUNYU)	SHRIMP U–Pb zircon	Minimum crystallization age of granite	Nelson (1998)

Bangemall Group (Compston and Arriens, 1968) suggest a minimum age of 1100 Ma. Recent dating of porphyritic rhyolite intercalated with rocks of the Coobarra Formation (basal Bangemall Group) suggests a maximum age of  $1638 \pm 14$  Ma for the emplacement of the rhyolite (Nelson, 1995).

Samples of glauconite from the basal units of the Earraheedy Group on the DUKETON (1:250 000) sheet gave minimum K–Ar ages of around 1700 Ma and minimum Rb–Sr ages of between 1590 and 1710 Ma (Preiss et al., 1975). Horwitz (1975) reported an age of  $1688 \pm 72$  Ma from glauconite in sandstone of the Wandiwarra Formation. Richards and Gee (1985) reported lead isotope ages of 1700 Ma from galena within stromatolitic dolomite of the Sweetwaters Well Member (Yelma Formation). Recently, Nelson (1997) obtained a sensitive high-resolution ion microprobe (SHRIMP) age of  $1785 \pm 11$  Ma on detrital zircons from the Mount Leake Formation on BRYAH, which is tentatively correlated with the basal Earraheedy Group. The age of the Earraheedy Group is, therefore, constrained by that of the Bangemall Group, probably around 1650 Ma, and that of the Yerrida Group (2100–2200 Ma), with an age around 1800 Ma being the most likely.

Stromatolite biostratigraphy fails to provide a more precise determination of age: Grey (1995) commented on the lack of correlation between the taxa of the Earraheedy Group and taxa of presumably similar age (1500–1800 Ma) from the McArthur Basin (Northern Territory), and highlighted the similarities between two of the Earraheedy Group taxa (*Asperia digitata* and *Pilbaria deverella*) to taxa in older (1840–1890 Ma) successions, such as the Duck Creek Dolomite. On the basis of this evidence, Grey (1995) suggested that the age of the Earraheedy Group may lie between 1800 and 1900 Ma.

## Archaean geology

The Archaean rocks on MERRIE belong to the Eastern Goldfields Province of the Yilgarn Craton (Griffin, 1990). The province is an assemblage of granitoid and greenstone rocks that probably formed between 2780 and 2630 Ma as a result of intense volcanic, plutonic, and metamorphic activity (Myers and Swager, 1997).

## Merrie greenstone belt

Outcrops of greenstones on MERRIE are sparse, invariably deeply weathered, and confined to the central-western and southwestern part of the sheet. They form the northerly continuation of similar outcrops on CUNYU. The Cunyu greenstone belt (Adamides et al., 1999) is thus the southern extension of the Merrie greenstone belt. Due to lack of surface outcrop, most of the information is derived from petrographic examination of drillhole samples.

The aeromagnetic image of the greenstone belt (Fig. 4a) outlines a major north-northwesterly trending fold bounded to the east by the Merrie Range Fault. The

core of the structure is occupied by metamorphosed felsic volcanoclastic and sedimentary rocks, weathered outcrops of which, with well-developed subvertical cleavage, are present 3.5 km west-southwest of the abandoned 6 Mile Well (AMG 156497).

A synclinal structure has been considered likely for the Merrie greenstone belt on the basis of the local presence of poorly preserved, vaguely defined, subvertical pillow forms, as in the area 600 m southeast of Doyle Well (AMG 167410), with westerly facing consistent with their location on the eastern limb of a syncline. Furthermore, neighbouring greenstone belts, such as the Yandal and Lake Violet belts (Phillips et al., 1998; Stewart, 1997), are also synclinal in form. However, the most conclusive evidence for a synclinal structure is provided by geophysical modelling of magnetic features (Fig. 4b). This interpretation is at variance with that of Liu (1997) and Myers and Hocking (1998), who interpreted the structure of the belt as anticlinal.

Deformation of the rocks in the Merrie greenstone belt is strongly heterogeneous, with undeformed types juxtaposed against strongly schistose types. In the latter, the schistosity is defined by an alignment of phyllosilicates, commonly chlorite. Cleavages are locally affected by crenulation, defined by the bending of chlorite flakes, indicating a later period of deformation.

Alteration has affected the rocks to varying degrees, with the main minerals being quartz, chlorite, epidote, biotite, and carbonate. Many of these alteration minerals are also members of the metamorphic assemblage. Distinction between the two modes of genesis is made on the basis of crosscutting vein assemblages and replacement of the matrix by alteration minerals. Biotite alteration is strongly evident in some samples and interpreted as evidence of potassium metasomatism. Similarly, epidotization is interpreted as evidence of CO<sub>2</sub> metasomatism. Carbonate alteration, commonly indicating strong CO<sub>2</sub> metasomatism, has been identified only in one drillhole 1 km north of Doyle Well (GSWA 152707, AMG 162423). The alteration assemblages observed in the Merrie greenstone belt have been interpreted by Farrell and Adamides (1999) as indicative of temperatures around 410–430°C, under low fluid CO<sub>2</sub> concentrations (XCO<sub>2</sub> < 0.18), and net addition of potassium. Carbonate alteration is a common feature of assemblages proximal to gold-bearing veins in some deposits in the surrounding region, such as the Bulletin deposit at Wiluna (Chanter et al., 1998), and the Nimary deposits of the Yandal greenstone belt (Byass and MacLean, 1998); its scarcity in the locations studied to date in the Merrie greenstone belt is interpreted as indicating that XCO<sub>2</sub> in the fluids was too low for the deposition of carbonate.

## Ultramafic rocks (Au, Auf)

Outcrops of ultramafic rock are very sparse on MERRIE and mainly represented by laterite. The interpretation of the presence of ultramafic units is based on subsurface information associated with linear magnetic anomalies.

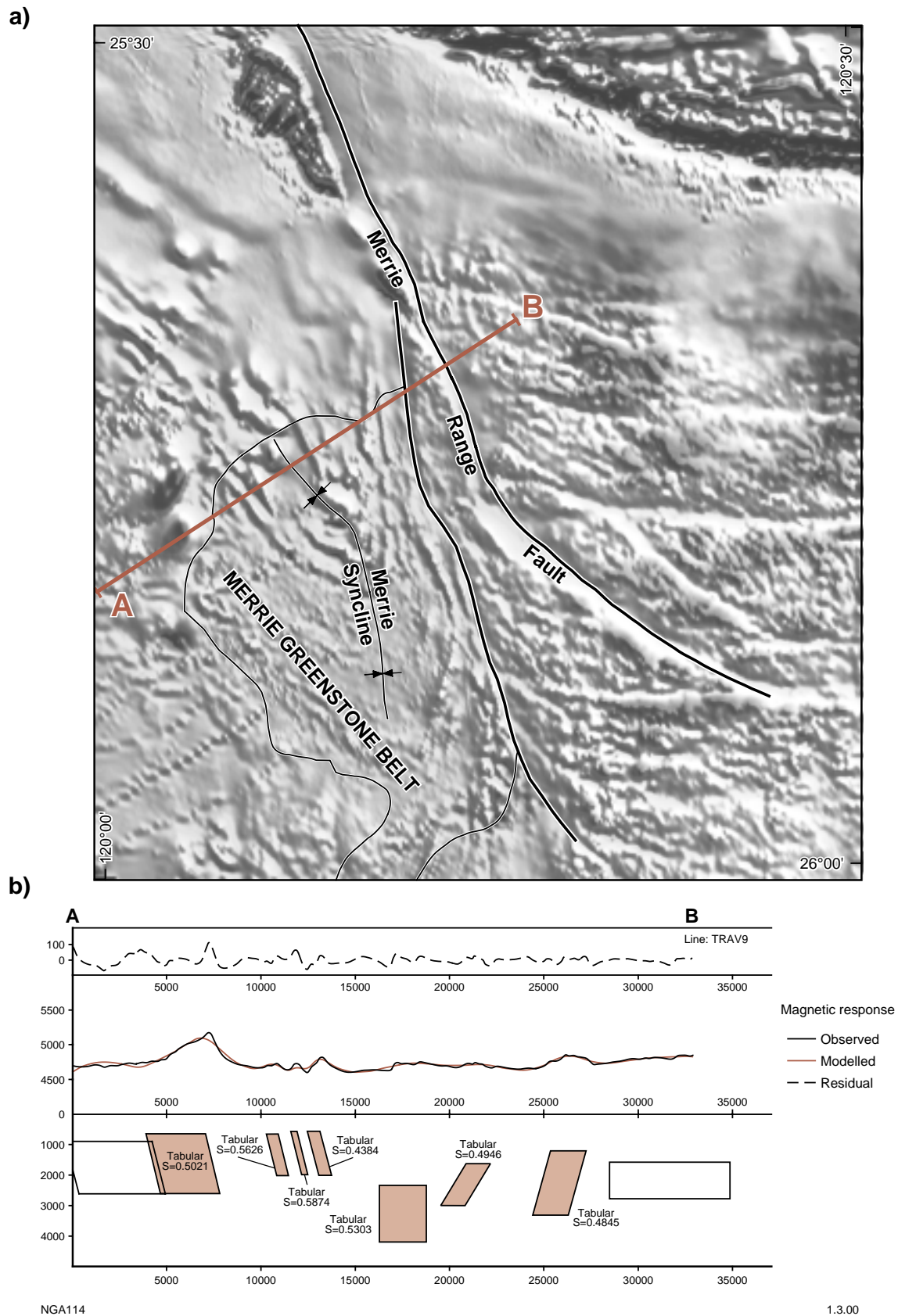


Figure 4. Modelling of magnetic features in the Merrie greenstone belt:  
 (a) Total Magnetic Intensity image of MERRIE showing location of modelling traverse (data used with permission from AGSO), with 400 m spacing between flight lines. Outcropping part of the Merrie greenstone belt is shown;  
 (b) Profile of geophysical traverse and associated interpretation of features, which suggest a synclinal form for the Merrie greenstone belt. Modelling performed by D. Bui

Interpreted ultramafic rocks (*Au*) and their foliated equivalents (*Auf*) are typically represented by an association of chlorite and lath-like crystals of talc in interlocking aggregates. The opaque minerals are altered to leucoxene. Cleavage in the foliated types is defined by the alignment of chlorite crystals. In other cases, ultramafic rocks are composed of an intimate association of chlorite and abundant tremolitic amphibole, with scattered, microcrystalline titanite.

### Mafic rocks (*Ab*, *Aba*, *Abae*, *Abaf*, *Abf*, *Abe*, *Aby*)

Only undifferentiated mafic rock (*Ab*) has been mapped at the surface from the Merrie greenstone belt and includes fine- and medium-grained mafic rocks, as well as intermediate types. The other units are identified only in the subsurface from drillhole information.

Amphibolite (*Aba*) has been intersected in drillholes in the southern parts of the Merrie greenstone belt. On the basis of the interpretation of this belt as a northerly plunging syncline, the presence of this rock type is consistent with deeper levels of the greenstone belt. Samples of amphibolite contain an assemblage of hornblende crystals up to 4 mm in length, and plagioclase (?oligoclase), which commonly preserves its igneous zoning. The opaque minerals are mostly altered around margins to microcrystalline titanite.

A small outcrop of high-grade amphibolite, a few square metres in size, is located 6 km south-southeast of No 3 Govt Well (AMG 417409) and probably represents a raft within the granite. The rock has a foliated structure (Fig. 5a) and mafic appearance, with a grain size of 0.1 – 0.3 mm. The amphibolite rock consists of strongly pleochroic hornblende, subordinate clear clinopyroxene, and minor quartz and plagioclase (Fig. 5b). Foliation is defined by alignment of the hornblende crystals. Euhedral magnetite, marginally altered to hematite, is the opaque mineral enclosed in the hornblende. The amphibole is retrogressively replaced locally along cleavages by a microcrystalline mixture of epidote and quartz.

In schistose mafic types (*Abf*, *Abaf*), the schistosity is defined by the alignment of chlorite flakes. Epidotized rocks (*Abe*, *Abae*) are characterized by abundant epidote, which occurs both in veins and the groundmass. In the latter paragenesis, the epidote occurs in granular aggregates of crystals, which overprint the earlier assemblages and do not bear any relationship to the cleavage.

Strongly fractionated types (?meta-andesites) are present, with abundant plagioclase as a phenocryst phase. Such plagioclase-phyric varieties (Fig. 6a) typically consist of plagioclase laths up to 0.5 mm in length, enclosed in a fine-grained matrix of abundant albitized plagioclase, with secondary minerals including quartz, chlorite, and actinolite after ferromagnesian components.

Hornblende diorite was intersected in one drillhole, close to the core of the Merrie syncline, 3.7 km southeast of 21 Well (GSWA 152709, AMG 147476). The rock is

coarse grained (grain size >4 mm) and composed of euhedral to subhedral plagioclase and anhedral, uraltized clinopyroxene. K-feldspar is totally absent. Incipient brittle deformation is indicated by kink-banded plagioclase lamellae. The opaque minerals are represented by skeletal crystals totally replaced by well-crystallized titanite. This diorite is considered to be an integral part of the greenstone sequence compared to adjacent greenstone belts, such as Millrose (Farrell, T. R., 1999, pers. comm.).

Mafic rocks on MERRIE typically consist of an assemblage of albite, chlorite, actinolite, epidote, and quartz. The original mafic minerals are replaced by actinolite; plagioclase is commonly albitized. The fine-grained mafic rocks consist of interlocking plagioclase laths in a matrix composed of chlorite and actinolite. In vesicular types (*Aby*), vesicles are commonly filled with quartz, chlorite, and clinozoisite, with the last two minerals replacing plagioclase.

### Metasedimentary rocks (*As*)

Deeply lateritized outcrops of folded and schistose metasedimentary rocks (*As*) are present in the core of the syncline 3.5 km west-southwest of 6 Mile Well (AMG 156497), and spatially associated with felsic volcanoclastic units (*Af*). The metasedimentary rocks show a laminated texture that is preserved through the lateritization, and contain quartz, actinolite, and epidote. Strongly pleochroic alkali amphibole (?arfvedsonite) forms acicular crystals partially oriented along the cleavage. A zonation between quartz-rich and quartz-poor assemblages, abundance of epidote, and complete absence of feldspar are used as evidence in the interpretation of these rocks as metasedimentary.

### Granite (*Ag*, *Agm*)

Granite outcrops are located mainly in the eastern parts of MERRIE, with greenstones confined to the southwest. A major north-northwesterly trending structure, the Merrie Range Fault (Myers and Hocking, 1988, 1998), forms the boundary with the greenstones of the Merrie greenstone belt. The Merrie Range Fault is a D<sub>3</sub> structure (see **Structure and metamorphism**) that has been reactivated in Proterozoic times.

Most of the granite (*Ag*) is lateritized and silcretized. Outcrops of fresh monzogranite (*Agm*) are commonly limited to 'windows' in the lateritic duricrust. The granite varies from fine to coarse grained, with medium-grained granite being the most common; the granite is commonly biotite rich and porphyritic, with subordinate aphyric types. Porphyritic granite contains phenocrysts of K-feldspar up to several centimetres long, and is locally present in well-defined nests within fine-grained granite; in other cases, it veins fine-grained granite (Fig. 7a) and is in turn veined by later, fine-grained granite. These relationships suggest penecontemporaneous emplacement of the fine- and coarse-grained types. Thin (30 cm) veins of pegmatite cut the granite and are composed of quartz and feldspar crystals up to 5 cm long (Fig. 7b).

- Figure 5. High-grade amphibolite:
- (a) Foliated amphibolite, interpreted as a raft in granite. Outcrop 5.9 km south-southeast of No 3 Govt Well (AMG 417409). The lens cap is 5.5 cm;
  - (b) High-grade amphibolite composed of hornblende, clinopyroxene, and quartz with minor plagioclase. Foliation is defined by alignment of hornblende crystals. GSWA 152852, plane-polarized light



- Figure 6. Rock textures from the Merrie greenstone belt:
- (a) Plagioclase-phyric mafic rock, with abundant plagioclase in groundmass composed mainly of epidote and biotite. Merrie greenstone belt. GSWA 152875, plane-polarized light;
  - (b) Felsic volcaniclastic rock with recrystallization of kaolinite to illite around quartz phenocrysts. GSWA 152892, transmitted light, crossed polars

Figure 7. Lithological features of granite. The diameter of the lens cap is 5.5 cm:

- (a) Crosscutting relationships in granite, with fine-grained granite veined by coarser grained granite. Outcrop 7 km east-southeast of Bungarra Bore (AMG 307223);
- (b) Pegmatite in a vein that intruded granite. Outcrop 5.6 km southeast of No 3 Govt Well (AMG 437423);
- (c) Primary igneous layering in granite. Outcrop 15 km south-southeast of No 3 Govt Well (AMG 427317)

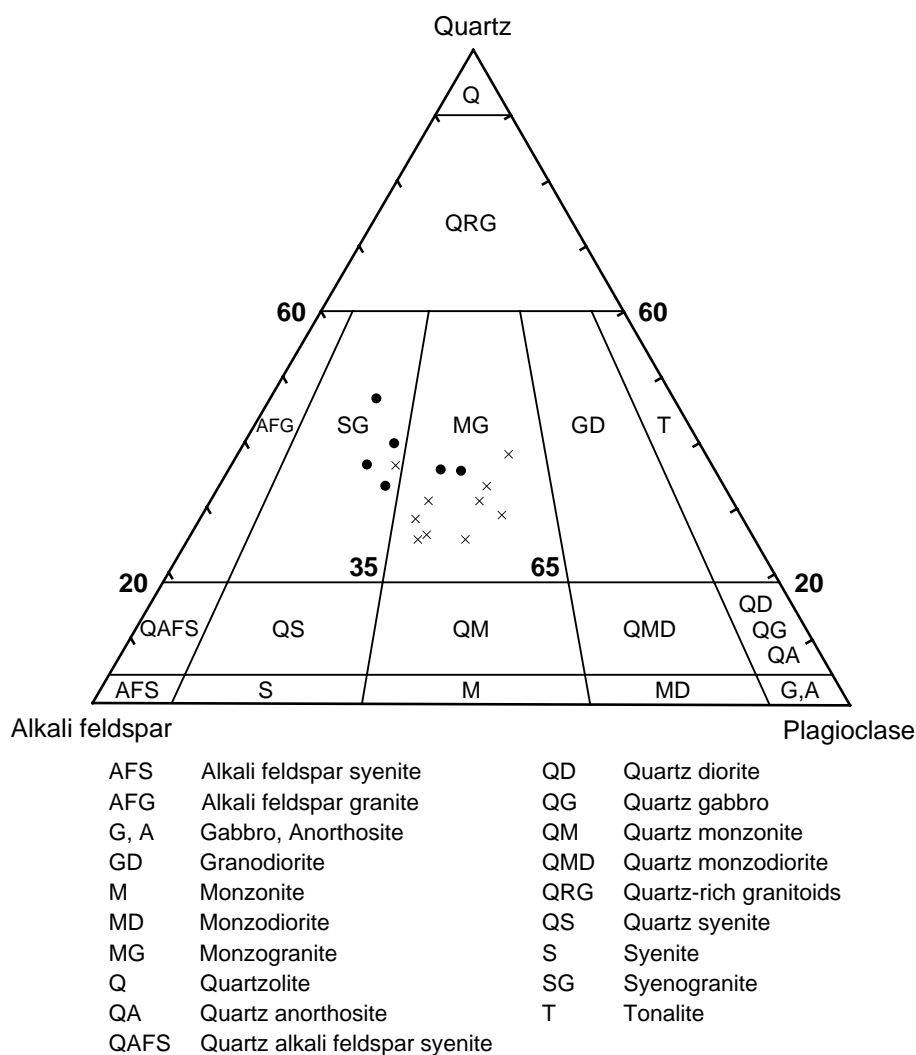
A primary igneous layering is evident on much of the granite outcrop, defined by a general alignment of feldspars (Fig. 7c). In some cases, the layering takes the form of alternating coarse- and fine-grained facies and is associated with minor shearing, probably indicating tectonism during emplacement. Commonly, the igneous layering is enhanced by parallel development of joints.

Grain counting of a number of samples from MERRIE (Fig. 8) confirms that the granite is dominated by a monzogranite composition. Grain size varies from 1 to 2 mm in the fine-grained types, to 4–5 mm in the coarse-grained varieties. The mineralogy of all granitic types is broadly similar. Fine-grained granite shows equigranular texture with quartz, K-feldspar with abundant microcline, saussuritized plagioclase, biotite, and trace amounts of white mica. The plagioclase in places contains bleb-like or amoeboid inclusions of quartz, and is euhedral against the microcline, which is in turn euhedral against the quartz. The microcline encloses rounded quartz and altered plagioclase. Biotite is chloritized with anomalous

purple birefringence and commonly associated with fine-grained, euhedral epidote; muscovite is a late-stage, fracture-filling mineral. In medium-grained varieties, some of the plagioclase has a well-defined calcic interior that is completely saussuritized, with a shell of sodic, mostly unaltered plagioclase. Accessory minerals in the granite include titanite, commonly as microgranular inclusions in biotite, opaque oxides, apatite, zircon, and carbonate. The quartz is commonly strained and encloses sparse rutile needles. The mineralogy of the granite, with the presence of biotite and titanite and the complete absence of minerals such as cordierite, garnet, sillimanite, and andalusite, is typical of I-type granitoids (Shelley, 1983).

### Felsic porphyry and felsic volcaniclastic rocks (*Afp*, *Afs*)

In the area 2.7 km northwest of Curvaceous Carly Bore (AMG 135251), a northerly trending, dyke-like body of quartz porphyry (*Afp*) cuts the granite. The body is poorly



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Figure 8. Plot of mineral proportions for granite from MERRIE (crosses) and from the Goodin Inlier (filled circles)

exposed in the form of low, rubble-strewn outcrop. There is no perceptible fabric in the rock, which has a microporphyrritic texture, with phenocryst phases of quartz, K-feldspar (including microcline), plagioclase, and minor brown biotite. Lithic fragments of granitic derivation are present in a fine granular matrix composed of a mixture of plagioclase, microcline, quartz, and abundant white mica. The rock is interpreted to be felsic volcanic or volcanoclastic that probably crystallized at shallow levels in the crust and did not reach the surface. A weakly schistose equivalent of this rock (*Afs*) from the core of the Merrie syncline 3.5 km west-southwest of 6 Mile Well (GSWA 152892, AMG 156493), contains both a laminated, fine-grained, kaolinitic facies with sparse, angular quartz clasts and a clast-rich facies in which both euhedral, as well as embayed and fragmentary quartz and minor feldspar, are enclosed in a fine-grained, kaolinitic matrix. This matrix is recrystallized around the clastic fragments into radial aggregates of illite (Fig. 6b). Similar illite forms along poorly developed cleavages as a result of recrystallization of the kaolinite by deformation.

## Structure and metamorphism

The Merrie greenstone belt is inferred to have had the same deformation history as adjacent greenstone belts (Liu et al., in prep.; Farrell and Wyche, in prep.); by comparison, therefore, with the geology of those belts, its deformation history is described below.

The first deformation event ( $D_1$ ) is considered to be one of recumbent folding and thrusting, and is reflected in the greenstones by a subhorizontal foliation.

The second period of deformation ( $D_2$ ) is in the form of open, upright folds that were initially aligned east-northeast. Planar fabrics associated with these structures are rarely seen (Griffin, 1990).

The event responsible for the present north-north-westerly linearity of the Merrie and adjacent Wiluna and Yandal greenstone belts is attributed to a third period of deformation ( $D_3$ ). This event is considered to be a complex combination of folding and strike-slip faulting. The Merrie Range Fault is a structure probably associated with  $D_3$ , and the north-northwesterly orientation of the Merrie greenstone belt is also the result of this deformation event. In the greenstones,  $D_3$  is reflected by the presence of a subvertical, northerly trending cleavage ( $S_3$ ). The granite is typically undeformed, with the exception of local brittle deformation and cleavage development commonly associated with faulting and quartz veining. The quartz veins are predominantly oriented east-southeast, parallel to similarly oriented faults that terminate against the Merrie Range Fault. These faults are probably Proterozoic in age, were affected by later rejuvenation of the Merrie Range Fault, and are described later (see **Structure and metamorphism**, p. 28). All faults are represented by zones of decreased magnetic intensity, attributed to destruction of magnetite by hydrothermal alteration along these faults (Phillips et al., 1998).

The Merrie Range Fault is a major north-northwesterly trending structure that juxtaposes Proterozoic sedimentary

rocks against Archaean rocks, and has a distinct response on Landsat TM, gravity, and aeromagnetic images. It is, together with a second structure called the Lockeridge Fault (on NABBERU), considered to be a continuation of the Celia Lineament (Hall, 1979). The surface outcrop of the Merrie Range Fault is very poor and mostly marked by zones of shearing, brecciation, and quartz veining. In the area of the Merrie greenstone belt, movements along the fault resulted in the development of a broad zone of isoclinal folding, interpreted from recent drilling, and named the Cunyu Tectonic Corridor (Marymia Exploration NL, 1998).

The greenstones contain metamorphic assemblages that suggest peak metamorphism of lower amphibolite facies. Amphibolites are mainly confined to the southern, deeper parts of the belt and characterized, in the coarser grained types, by prismatic hornblende in association with plagioclase (?oligoclase) and titanite. Most of the other mafic assemblages in other parts of the belt contain minerals characteristic of lower greenschist facies metamorphism (albite, epidote, chlorite, actinolite). In the metamorphic assemblages, chlorite and actinolite replace the ferromagnesian minerals, and chlorite, clinozoisite, and quartz locally pseudomorph plagioclase. The association of tremolite and chlorite replacing ferromagnesian minerals in ultramafic units is also consistent with lower greenschist facies. Biotite and epidote, in addition to being common associates of the metamorphic assemblage, locally overprint the metamorphic minerals, suggesting potassium and  $\text{CO}_2$  metasomatism respectively. The potassium metasomatism may be related to later granitoid intrusions, as suggested by the incursion of granitoid into the greenstones at the southwestern side of the Merrie greenstone belt (see simplified geology on map).

As mentioned above, the highest metamorphic grades (upper amphibolite facies) on MERRIE are associated with an outcrop of hornblende-clinopyroxene amphibolite, probably representing a raft within granite. Retrogression of the high-grade metamorphic assemblage to greenschist facies is indicated by replacement of the amphibole by epidote and prehnite along cleavages.

## Proterozoic geology

### Dolerite dykes (#dy)

The area has been intruded by a series of mafic dykes of presumed Proterozoic age. These have been interpreted mostly from aeromagnetic data and have a predominantly northeasterly orientation. They probably belong to the post-cratonization dyke suite of Hallberg (1987), which is developed throughout the Yilgarn Craton. On MERRIE, the dykes are indicated by linear zones of mostly normal polarity. On the northern part of MERRIE in the area around Frank Well (AMG 246600 and 235567), poorly exposed dolerite dykes intrude granite and partly follow east-southeasterly trending interpreted faults. The rocks are fine grained, unaltered, undeformed, and have a holocrystalline texture. Locally, a ribbed structure is present, resembling flow layering, and

probably resulted from differential weathering of rock of variable composition. The dykes contain equal proportions of plagioclase and clinopyroxene, and have an alteration assemblage of quartz, epidote, chlorite, and titanite. Pyrite is locally present in the form of subhedral concentrations commonly associated with chlorite, which is strongly pleochroic and shows anomalous purple and brown birefringence. The opaque minerals also include magnetite and ilmenite altered to leucoxene. The replacement of the original igneous assemblage by secondary minerals characteristic of the lower greenschist facies is compatible with metamorphism of the dykes under hydrous conditions.

## Yerrida Group

The Yerrida Group (Table 1; Occhipinti et al., 1997) includes clastic sedimentary, chemical sedimentary, and volcanic rocks that were deposited in the Yerrida Basin. The age of the group is poorly constrained between 2200 and 1900 Ma, based on a Pb–Pb isochron from stromatolitic carbonate of the basal Juderina Formation (Woodhead and Herget, 1997), and the age of the Earahedy Group, which is currently estimated at 1800–1900 Ma (Grey, 1995). The group is subdivided into a basal Windplain Subgroup, interpreted as a sag-basin succession, and the Mooloogool Subgroup, which overlies it and is interpreted as a rift succession. On MERRIE, the Windplain Subgroup is represented by the Juderina Formation, which is intruded by sills of the Killara Formation (Mooloogool Subgroup). The Maraloou Formation is interpreted from adjacent THADUNA (Pirajno and Adamides, 1998) to underlie parts of the western edge of MERRIE.

## Windplain Subgroup

The Windplain Subgroup consists of two formations, the Juderina Formation and the overlying Johnson Cairn Formation. The Juderina Formation, in areas where fully developed, consists of quartz arenite overlain by, or locally interbedded with, chert breccia after stromatolitic carbonate (Bubble Well Member, Occhipinti et al., 1997). Quartz siltstone is interbedded with sandstone, and conglomerates form an important component in places. The Juderina Formation is interpreted as a predominantly shallow water sequence, with local development of sabkha conditions (Gee and Grey, 1993).

The Johnson Cairn Formation conformably overlies the Juderina Formation and consists of argillaceous siltstone and minor turbidite units. The formation is interpreted as signalling deepening of the Yerrida Basin and the transition from a sag-basin to a rift facies in its development. The Johnson Cairn Formation is not present on MERRIE, but is exposed on adjacent THADUNA (Pirajno and Adamides, 1998).

### Juderina Formation (#vj, #vjf, #vjs)

The type locality for the Juderina Formation is around Juderina Bore on DOOLGUNNA, where it is represented by

a thin (50 m) sequence of ripple-marked quartz arenite and interbedded siltstone and chert breccia (Gee, 1987). Elsewhere, the formation is much thicker and shows more complex lithological relationships.

On MERRIE, outcrops of the Juderina Formation are mainly distributed in the central-western parts of the sheet, around Verscher Range, with limited outliers at Merrie Range and in the central parts where they unconformably overlie granite. The outcrops are commonly covered unconformably by chert breccia of the basal Earahedy Group (Yelma Formation).

The thickness of the Juderina Formation is difficult to estimate due to shallow dips, possible fault repetition, and intercalated dolerite intrusives; however, on the basis of geological sections in the Verscher Range area (Fig. 9), it is estimated to exceed 2 km. This thickness includes the dolerite intrusives.

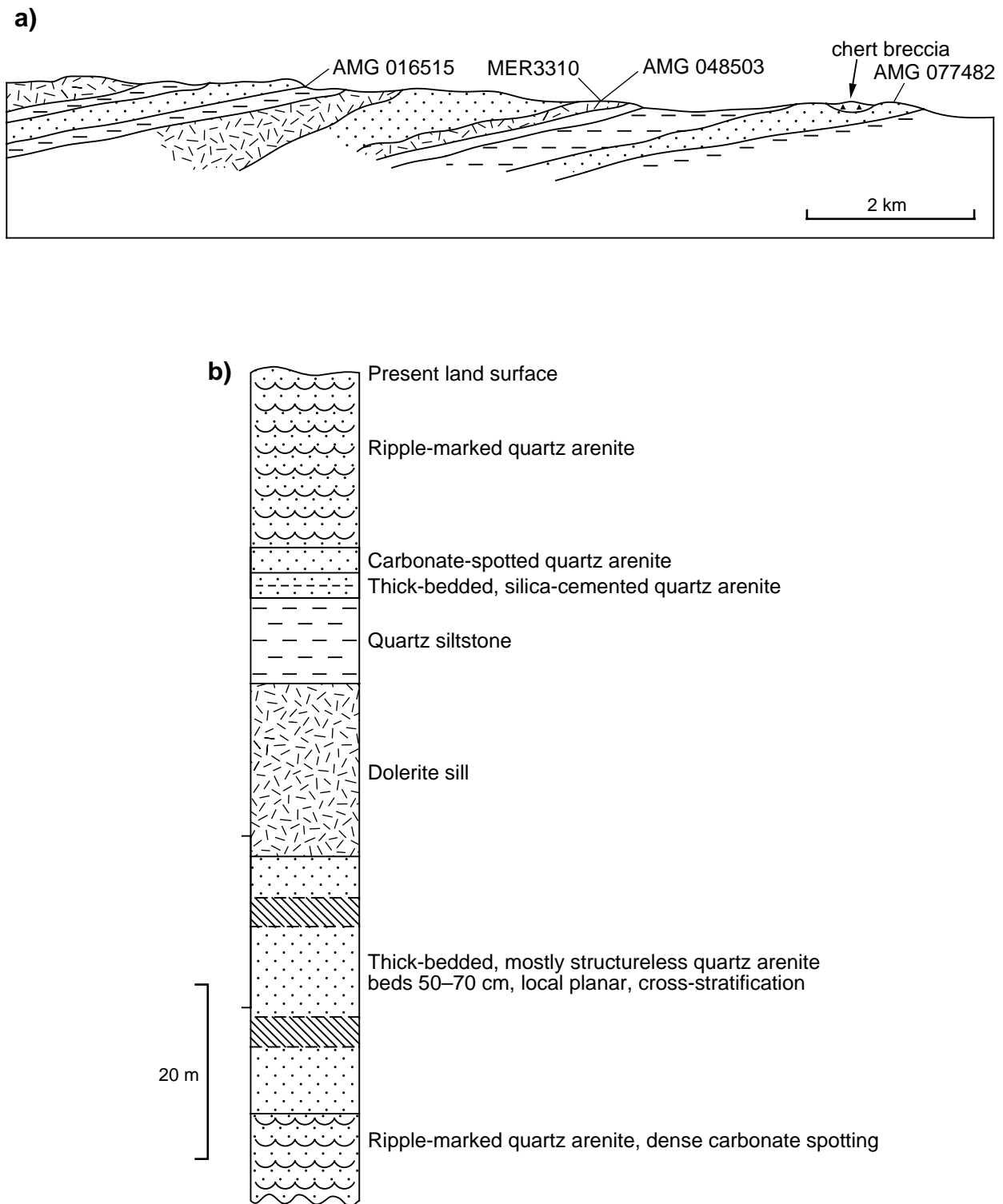
The basal unconformity is exposed at several places in the Merrie Range area. At an outcrop 1.4 km northwest of Dingy Well (AMG 249501), for example, the unconformity surface is marked by a 1 m-thick band of granulestone consisting of subrounded quartz in a fine-grained, quartzose sandy matrix. Above the granulestone, the arenite is predominantly thinly bedded with local flaggy interbeds, parallel and planar cross-laminations, and mudflakes on bedding planes.

The lithology of the Juderina Formation on MERRIE mainly comprises well-bedded quartz arenite (#vjf) interbedded with quartz siltstone (#vjs). The assignment of the whole of the outcrop of Juderina Formation to the Finlayson Member (#vjf) is due to the abundant presence of ripple marks, which are the characteristic feature of this member. The Juderina Formation (#vj) is not subdivided on the simplified geology map (see map).

The quartz arenite is typically well bedded, fine to medium grained, and well sorted, with beds 20–40 cm thick. Thin-bedded and flaggy sandstone units are also present. Quartz grains vary from well rounded to angular. A purplish, hematitic surface colouration is locally present, and the arenite is commonly affected by secondary silicification. There are local interbeds of conglomeratic sandstone, with the moulds of original rounded clasts in a silica-cemented sandstone matrix.

Although in most outcrops the arenite occurs in beds 20–50 cm thick, thicker bedded arenite is also present; for example, 2.3 km west-northwest of Wynn Well (AMG 060516), with individual beds 70–100 cm thick. This arenite is silica cemented, medium grained, and well sorted with mainly angular grains; it is associated with matrix-supported breccias in beds over 1 m thick consisting of quartzite clasts in a sandy matrix.

The arenite units are characterized by an abundance of sedimentary structures. The most common structures on bedding planes include symmetrical and asymmetrical ripple marks, and shallow troughs; rare current lineations are present on thin-bedded sandstone units. Interference between ripple marks, probably the result of side currents or wind effects, is locally present (Fig. 10a). Structures



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**Figure 9. Geological sections through the Juderina Formation:**  
**(a) Geological section through the Juderina and Killara Formations on MERRIE;**  
**(b) Detailed section through the Juderina Formation showing the main lithological features**

within the beds include parallel, planar, herringbone, and trough stratification. Delicate cross-laminations are present in some beds (Fig. 10b), probably indicating ripple migration under varying current and bed-load conditions

(Coleman and Gagliano, 1965) in a shallow-water environment. Soft-sediment deformation features, in the form of distortion of laminations (Fig. 10c), suggest local sediment movement prior to diagenesis. Beds of coarse,

clast-supported intraformational breccia on the other hand, composed of angular sandstone fragments identical to the enclosing rocks, suggest post-diagenetic brecciation, probably by syndimentary tectonism, and incorporation of the breccias in the form of scree deposits within the rock sequence.

Brown spotting, probably after carbonate, is common and locally intense, resulting in a dense, fine-honeycomb texture and a spongy appearance of the arenite. The spotting appears to be limited to specific beds with others being comparatively clean. At an outcrop 1.5 km southwest of Mount Paterson (AMG 032506), concentric structures varying from a few millimetres up to 10 cm in diameter are present in the arenite (Fig. 10d). These are composed of annular arrangements of brown (?carbonate-rich) and light-coloured layers, which overprint the enclosing arenite and suggest an early diagenetic origin, probably by a *liesegang* process.

The orientation of palaeocurrent indicators (Fig. 11a) suggests a northwesterly palaeoshoreline, with predominant transport direction towards the northeast (Fig. 11b). Opposing current directions are consistent with a shallow-water environment. A statistical examin-

ation of ripple marks around Mount Paterson (AMG 046512) indicates wavelengths of 3–9 cm and amplitudes of 0.2 – 1.5 cm, with a linear relationship between the two parameters.

The quartz arenite typically varies in grain size from 0.1 to 0.2 mm and is commonly very well sorted. Quartz grains are commonly defined by dust rings and surrounded by crystallographically continuous overgrowths that infill intergranular spaces. Locally, a bimodal distribution of grains is present, with larger grains up to 0.3 mm in diameter scattered in a matrix of well-sorted, fine-grained quartz. The grains are well packed and show mild compaction, but no obvious deformation. Pellets of kaolinitic clays are locally present within the arenite and in the same size range as the quartz grains. Zircon and tourmaline are the dominant heavy minerals.

Quartz siltstones (#Yjs) are interbedded with the quartz arenite at several levels (Figs 9a, b). They are commonly thinly bedded and finely laminated, and when weathered, give rise to a scree of slab-like blocks. The siltstones are best exposed on cliff faces, elsewhere forming recessive units. Beds are 2–10 cm thick and show delicate millimetre-scale laminae. They are dark grey on the

Figure 10. Sedimentary structures in the Finlayson Member, Juderina Formation. The lens cap is 5.5 cm in diameter:

- (a) Interference between ripples of two orthogonal orientations, 1.4 km south-southwest of Mount Paterson (AMG 039501);
- (b) Delicate cross-laminations in quartz arenite, 3 km northwest of Mount Paterson (AMG 024532);
- (c) Soft-sediment deformation structures in quartz arenite, 4 km northwest of Mount Paterson (AMG 012533);
- (d) Diagenetic (?*liesegang*) structures in quartz arenite, 1.5 km west-southwest of Mount Paterson (AMG 032506)



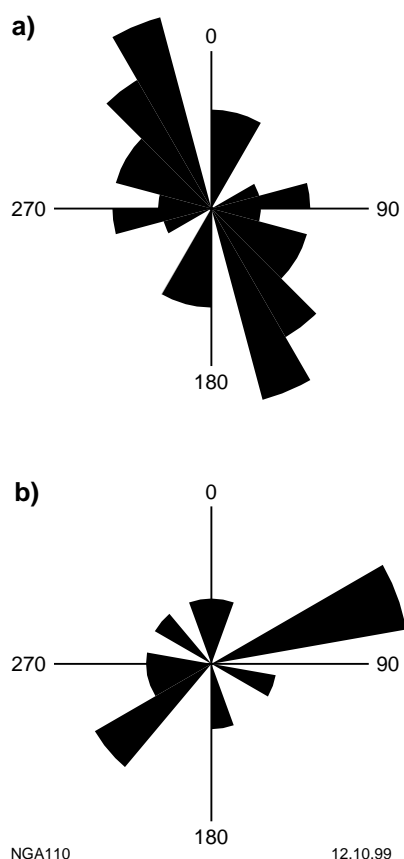


Figure 11. Palaeocurrent data from the Finlayson Member, Juderina Formation:

- Rose diagram showing crest orientation of symmetrical and asymmetrical ripple marks in the Finlayson Member. The figure suggests a northwesterly oriented palaeoshore;
- Rose diagram of directional palaeocurrent data in the Finlayson Member, highlighting the bidirectional nature of the palaeocurrents consistent with a shallow-water environment. Predominant current directions were to the northeast and southwest

weathered surface, locally with a pitted texture infilled with ferruginous material.

The quartz siltstones typically have a hematitic colouration and are strictly parallel laminated, with the laminae defined by alternations of clay-rich and quartz-rich material. There is abundant clastic quartz and detrital white mica. Laminae are 0.2 – 2 mm thick and composed of thinner laminae of around 30 µm.

In the area 1.2 km south-southwest of Quartz Well (AMG 989558), thicker bedded (20 cm) dolomitic siltstones underlie the quartz siltstones. Dolomitic siltstone is laminated on a millimetre scale, with alternating layers of clastic carbonate rock and thin, argillaceous, ferruginous laminae. The carbonate is composed of clasts up to 30 µm in diameter set in a ferruginous matrix. The laminae have an irregular wavy appearance and are probably of microbial origin. Disseminated carbonate, in the form of rhombic crystals, is present in the matrix.

## Mooloogool Subgroup

The Mooloogool Subgroup (Occhipinti et al., 1997) is composed of the Thaduna, Doolgunna, Killara, and Maraloou Formations. The Doolgunna and Thaduna Formations are predominantly turbidite sequences that were deposited in a northeasterly trending rift. The Doolgunna Formation is mainly a kaolinitic quartz wacke of granitic derivation with interbedded siltstone; the Thaduna Formation is a mafic litharenite partly sourced from a volcanic terrain. Interfingering relationships between these two formations are demonstrated on THADUNA (Pirajno and Adamides, 1998). The Killara Formation consists of tholeiitic basalt, dolerite, and gabbro and intrudes rocks of the Yerrida Group at all levels. The formation is interpreted to be related to rifting, with lava extrusion controlled by northeasterly or northerly structures. Locally, as on THADUNA, MOUNT BARTLE, and CUNYU (Pirajno and Adamides, 1998; Dawes and Pirajno, 1998; Adamides et al., 1999), the end of the vulcanicity of the Killara Formation is marked by a chemical-evaporitic unit, the Bartle Member (Occhipinti et al., 1997). The Maraloou Formation is composed of carbonate, siltstone, and black shale that, in places, is unconformable on the older rocks of the Yerrida Group. The relationship between the Killara and Maraloou Formations is transitional to discordant, with up to 100 m of intercalated mafic and sedimentary rocks defining the boundary on MOOLOOGOO and MOUNT BARTLE (Pirajno et al., 1998; Dawes and Pirajno, 1998).

On MERRIE, the Killara Formation is the only representative of the Mooloogool Subgroup, with the Maraloou Formation inferred to underlie parts of the western edge of the sheet by extrapolation from THADUNA.

### Killara Formation (#yk, #ykf, #ykb, #ykd)

The Killara Formation (Occhipinti et al., 1997) is named after Killara Homestead on GLENGARRY (1:250 000) and is an association of mafic intrusive and extrusive rocks and subordinate chemical precipitates (Bartle Member), which is well developed particularly in the south and southeast parts of the Yerrida Basin.

On MERRIE, rocks assigned to the Killara Formation (#yk) are confined to the western part of the sheet in the Verscher Range area, where they intrude rocks of the Juderina Formation. They are subdivided, on the basis of grain size, into fine-grained basaltic rocks (#ykf) and medium-grained dolerite (#ykd). Both rock types are texturally and mineralogically similar. An outcrop of basalt (#ykb), probably extrusive, is present in the area of Quartz Well, on the western edge of the map. Extensive outcrops of basalt, with unequivocal extrusive characteristics, are present on adjacent THADUNA (Pirajno and Adamides, 1998).

Outcrops of the Killara Formation commonly form positive features. The rocks are brownish-black on the weathered surface, with the coarser grained varieties weathering into large blocks of rounded outline, and the finer types into smaller round blocks, which is the result of exfoliation weathering. A rough surface texture is

characteristic, and microphenocrysts commonly stand out as positive relief by differential weathering. A faint flow layering is present in places, and the rocks are stained by widespread green alteration (nontronite), with local veining by quartz, epidote, and sulfides. A crude columnar jointing is present in some outcrops with the cooling joints giving the attitude of the intrusions. Traces of sulfides are disseminated in the rocks. The dolerite typically has low magnetic susceptibility ( $50\text{--}60 \times 10^{-5}$  SI), suggesting that no widespread crystallization of magnetite has taken place. Thick (30 cm) quartz–epidote–carbonate veins are present in places, with the epidote forming nests several centimetres long composed of acicular crystals (Fig. 12), commonly occupying the walls of the veins. This vein association suggests limited, fracture-controlled movement of hydrothermal fluids in the rocks of the Killara Formation.

The texture of the dolerite is commonly equigranular, with clinopyroxene and plagioclase (andesine–labradorite) in subequant crystals averaging 0.5 – 1 mm in size. The plagioclase is commonly weakly altered along veinlets and fractures to finely granular clinozoisite and carbonate, with the clinopyroxene remaining generally fresh. In typical examples, first-generation plagioclase about 0.1 mm in size is enclosed in larger plagioclase and clinopyroxene, which are in interlocking aggregates of grain size 0.8 – 1 mm. In other cases, the plagioclase is altered to sericite. Hypersthene, in the form of euhedral crystals partly pseudomorphed by serpentine, is present in a corona-type texture, poikilitically enclosing

euhedral altered plagioclase and partly surrounded by fresh clinopyroxene, probably augite. Thin veinlets of magnetite are associated with the alteration products of orthopyroxene. These mineral associations suggest early crystallization of calcic plagioclase, followed by orthopyroxene and then, in turn, by simultaneous crystallization of more sodic plagioclase and clinopyroxene.

The opaque minerals in the dolerite are titanomagnetite and ilmenite, commonly altered to fine-grained alteration products (leucoxene).

Traces of chalcopyrite are locally present within the altered matrix of magnetite. Weak pyritization affects the rocks in the form of veinlets and concentrations of euhedral pyrite following intergranular boundaries between plagioclase and clinopyroxene. These features, in association with quartz–epidote–carbonate veining, suggest the presence of weak mineralization. In situations of more intense alteration, the plagioclase is totally altered to chlorite, epidote, and quartz, with the clinopyroxene remaining mostly unaffected. Two types of chlorite with contrasting optical properties are present and associated with quartz and sulfides.

### **Maraloou Formation**

The Maraloou Formation (Bunting et al., 1977) is a sequence of argillaceous sedimentary rocks, black shale, marl, dolostone, and minor chert, and forms the uppermost

**Figure 12** Association of quartz and epidote in dolerite of the Killara Formation. The diameter of the lens cap is 5.5 cm

unit of the Yerrida Group (Occhipinti et al., 1997). The formation interfingers with the Killara Formation on MOUNT BARTLE (Dawes and Pirajno, 1998), but unconformable contacts with the Doolgunna Formation have been established during recent mapping on THADUNA (Pirajno and Adamides, 1998).

On MERRIE, the Maraloou Formation is not exposed; however, it is interpreted from the adjacent THADUNA sheet to underlie part of the western end of MERRIE. The lithology of the formation on THADUNA (Pirajno and Adamides, 1998) consists of thin-bedded, laminated siltstone and interbedded ferruginous shale with intercalated marly bands.

## Earaheedy Group

Details of the lithology of the Earraheedy Group (Hall et al., 1977) are contained in Bunting (1986). Modifications of the stratigraphy of the group have been described previously (see **Stratigraphic nomenclature**). The group contains clastic and chemical sedimentary rocks that were deposited in the Earraheedy Basin c. 1800–1900 Ma during the Capricorn Orogeny. The Earraheedy Basin is exposed in an east-southeasterly trending synclinorium, with minor outcrops of presumed basal Earraheedy Group rocks also present in several localities west of the main basin, unconformably overlying the rocks of the Yerrida and Bryah Groups. On MERRIE, only the Yelma and Frere Formations are exposed with isolated outcrops of the Karri Karri and Wandiwarras Members in the northeastern corner of the sheet.

### Yelma Formation (#Ey, #Eyc, #Eya, #Eys, #Eyo, #Eyw)

The Yelma Formation (Table 1) is a complex association of sandstone, shale, arkosic conglomerate, and stromatolitic dolomite. The formation is overlain conformably by the Frere Formation, and the contact is locally defined by lenses of stromatolitic dolomite, the Sweetwaters Well Member. In the absence of the dolomite, the contact is placed at the first appearance of iron formation. The Yelma Formation forms the basal unit of the Earraheedy Group and is distributed throughout the basin. The formation shows wide variations in thickness, from a few metres in the southeastern parts of the basin, to about 1500 m in the northwest (Bunting, 1986).

On MERRIE, the Yelma Formation (#Ey) is represented mainly by chert breccia after stromatolitic dolomite (#Eyc), local feldspathic sandstone (#Eya), and siltstone (#Eys). The type locality for the Sweetwaters Well Member (#Eyw) is located within the sheet area. The thickness of the formation, based on drillhole evidence and surface geology, is estimated to be around 700 m.

Outcrops of chert breccia (#Eyc) are widely scattered throughout the central and western parts of MERRIE, where they commonly overlie quartz arenite of the Juderina Formation (Finlayson Member). Although they are commonly spatially related, they were found nowhere to

be interbedded with the quartz arenite. Bunting et al. (1982) assigned these breccias to the Glengarry (Yerrida) Group, thus considering them equivalent to similar breccias in the Bubble Well Member. However, the identification of numerous species of *Asperia digitata* during the current mapping, a stromatolite that is characteristic of the Yelma Formation (Grey, 1995), suggests that the breccias unconformably overlie the Juderina Formation and belong to the basal Earraheedy Group.

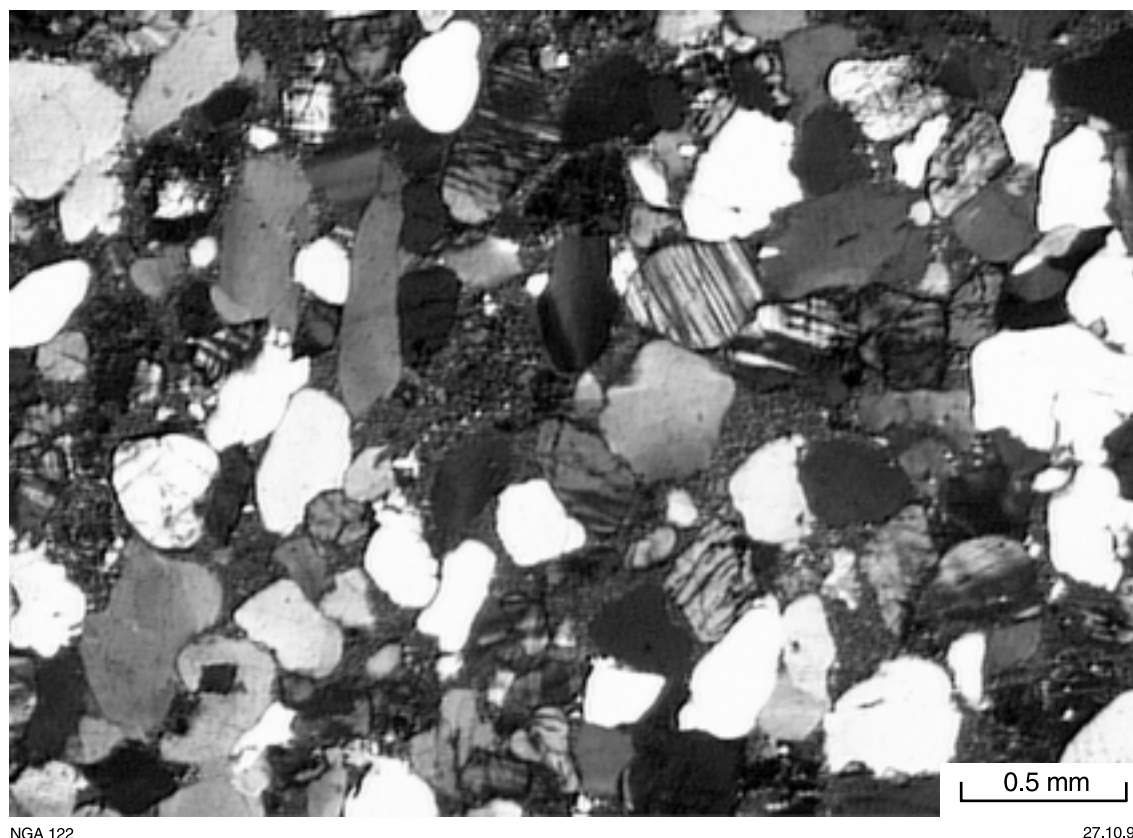
The best outcrops of these breccias are present 3 km south-southwest of Wynn Well (AMG 076486) and in a second outcrop 1500 m further north. In these areas, an association of thin-bedded, cross-laminated, impure, brown feldspathic quartz sandstone, siltstone, chert, and chert breccia is exposed. The chert is laminated in shades of grey, with local hematitic jasper bands. A thin conglomerate is present close to the contact with the quartz arenite of the Juderina Formation. Abundant columnar stromatolites are present in these outcrops, and Bunting et al. (1982) reported a rich microfauna mainly of algal filaments from chert in this area.

Arkosic sandstone (#Eya) is present in a series of outcrops close to the basal unconformity with the Archaean granite in the area 2.4 km southeast of Boody Hole Well (AMG 226615). The outcrops are in the form of brown-weathering, medium- to coarse-grained, poorly sorted, feldspathic sandstone in beds around 40 cm thick, locally associated with cross-laminated sandstone. Bedding is commonly planar but locally hummocky, and there are local interbedded pebbly bands. The sandstone varies in grain size from 0.2 to 0.7 mm and is composed of quartz and abundant K-feldspar. The outlines of grains are well defined by dust rings. There is cementation of the quartz grains by crystallographically continuous overgrowths, but no observable deformation. The feldspar grains are rounded to subrounded (Fig. 13), commonly unaltered, and include abundant microcline. There is widespread white mica; however, no plagioclase is preserved. The amount of matrix is highly variable, locally forming a considerable part of the rock. The arkosic sandstone is probably derived from a proximal granitic source with minimal reworking of material.

A small outcrop at the western edge of MERRIE, 900 m south of Quartz Well (AMG 991563), consists of thin-bedded, coarse-grained, poorly sorted, pebbly quartz sandstone. This outcrop is the easterly continuation of an outcrop of conglomerate (#Eyo) on THADUNA (Pirajno and Adamides, 1998), which is located close to the unconformity with the Yerrida Group. The sandstone is highly immature with abundant chlorite probably after biotite, and minor white mica. Lithic fragments include fine-grained quartzite and chert. Detrital quartz, locally with overgrowths from a previous silicification event, suggests partial derivation from a recycled sedimentary environment.

### Sweetwaters Well Member (#Eyw)

The type locality for the Sweetwaters Well Member (#Eyw) is about 3.5 km southeast of the abandoned



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Figure 13. Feldspathic sandstone showing subrounded quartz, K-feldspar, and subordinate lithic fragments at the base of the Yelma Formation. GSWA 152883, transmitted light, crossed polars

Sweetwaters Well on MERRIE. The member is represented by a low-dipping sequence of laminated stromatolitic dolomite. It defines the upper contact of the Yelma Formation at this locality, and is separated from the overlying Frere Formation by a thin (5 m) sequence of hematitic siltstone. Smaller outcrops of this member, in the same stratigraphic position, are present further northwest of the type locality, and an extensive area of calcrete surrounding Sweetwaters Well is probably underlain by this unit.

The carbonate is in the form of grey, well-bedded stromatolitic dolomite (Fig. 14a). A section about 10 m thick is exposed at the type locality, but in excess of 300 m of interbedded siltstone and dolomite were intersected in a diamond drillhole northwest of Mount Deverell (Johnston and Hall, 1980). The stromatolites *Asperia digitata* (Fig. 14b) and *Pilbaria deverella* are the predominant species associated with domical stromatolites (Fig. 14c). *Murgurra nabberuensis* is present in isolated outcrops. The association of *Asperia* and *Pilbaria* is interpreted, in light of similar associations in the lithologically equivalent Duck Creek Dolomite (Grey and Thorne, 1985), as indicative of upward-shallowing sequences in a lagoonal to intertidal setting. At least three such cycles have been identified in the exposed section (Grey, K., 1999, pers. comm.), representing successive transgressions and regressions.

The dolomite is composed of clear microcrystalline carbonate in irregular, probably microbial laminae, with variations in grain size from fine-grained carbonate with crystals 50 µm in diameter to coarse-grained carbonate over 1 mm in length occupying areas of dissolution. Empty spaces are filled with an assemblage of detrital quartz and clays. Stylolitic fractures are abundant in the carbonate and commonly filled by chlorite in association with sulfides.

At the type locality, the contact between the stromatolitic dolomite and the Frere Formation is marked by a 5 m-thick band of thinly bedded and laminated hematitic siltstone. Similar siltstone, locally associated with thin-bedded, glauconitic quartz sandstone, is exposed 1 km west of Mount Deverell (AMG 330676) at the same stratigraphic level below the basal iron-formation. At this last locality, the siltstone shows abundant lenticular laminations on a microscopic scale (Fig. 15a) with the texture defined by dark-coloured, ferruginous, micaceous and quartz-rich material, alternating with clay-rich laminae. The clays show moderate, bedding-parallel, preferred orientation due to diagenetic compaction and belong to the illite group, as judged from their optical properties. The laminations are 0.1 – 0.3 mm thick and are composed of thinner laminae around 20 µm thick. The fine-grained quartz arenite, which is interbedded with the siltstone, is thin bedded with obstacle scours on

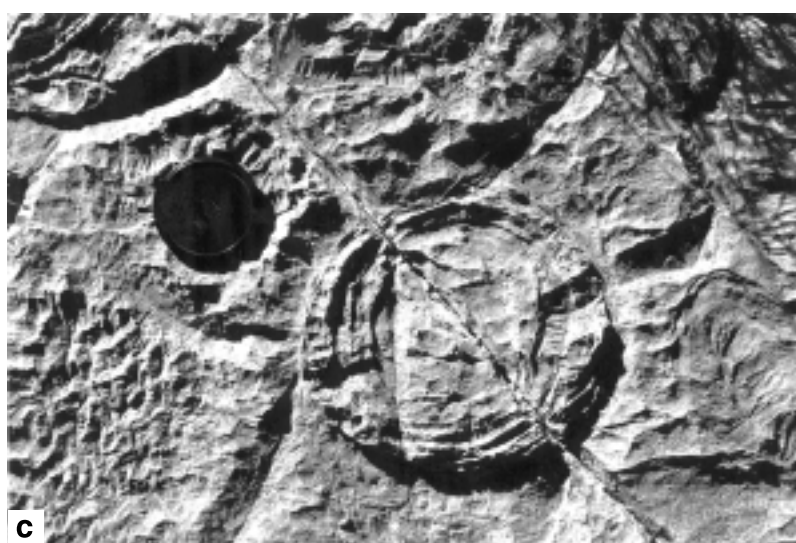
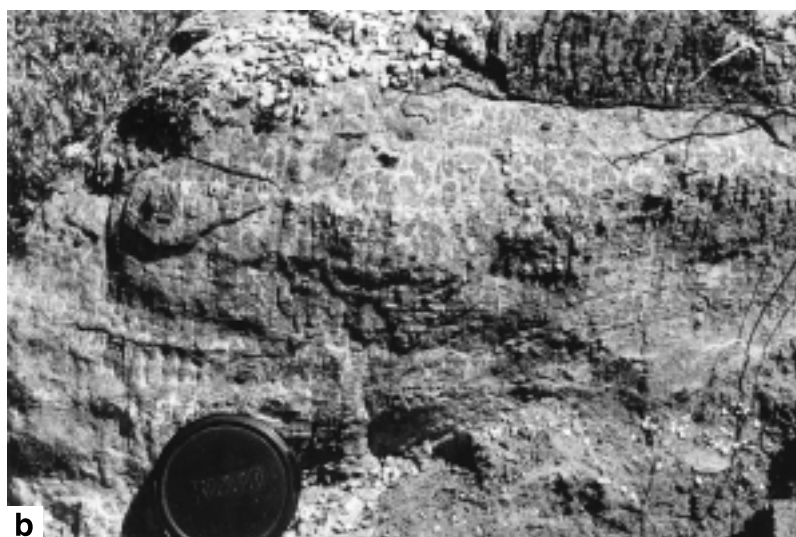


Figure 14. Sweetwaters Well Member:

- (a) Well-bedded stromatolitic dolomite, exposed at the type locality 3.5 km south-east of Sweetwaters Well (AMG 389649);
- (b) Digitate stromatolite *Asperia digitata*, type locality of Sweetwaters Well Member. The diameter of the lens cap is 5.5 cm;
- (c) Domical stromatolite, type locality, Sweetwaters Well Member. The diameter of the lens cap is 5.5 cm

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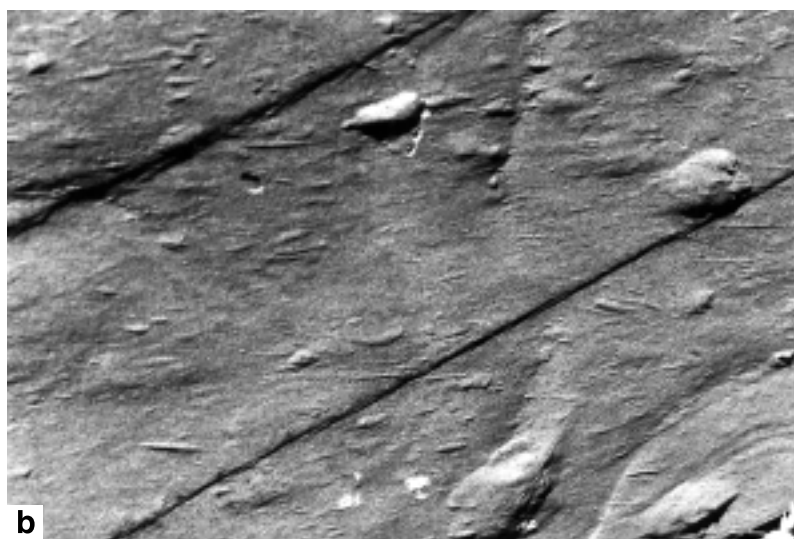
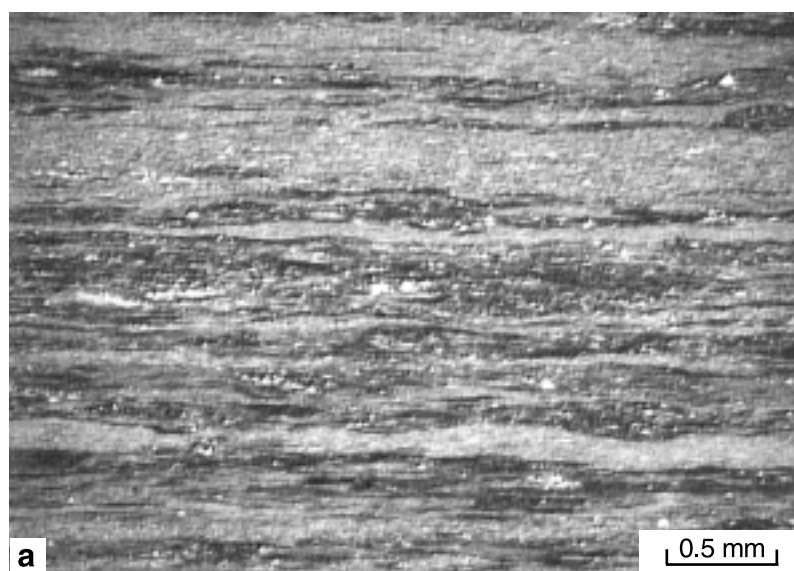
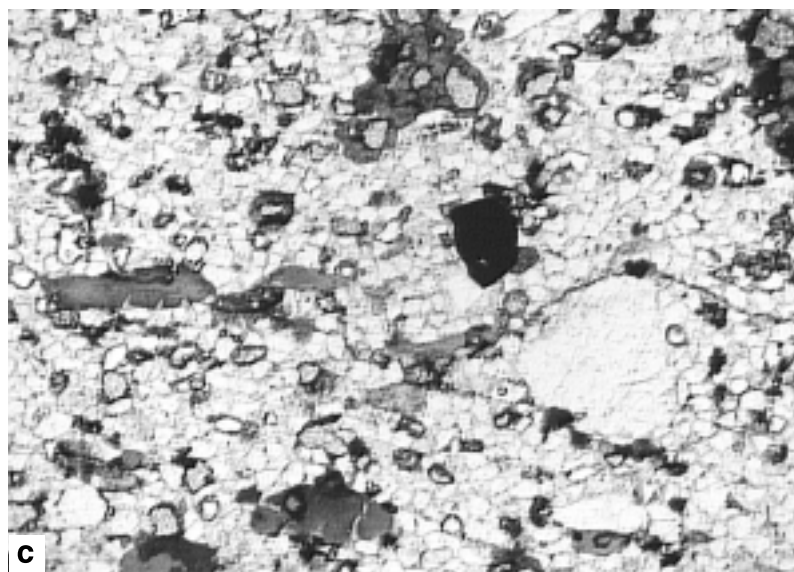


Figure 15. Siltstone and sandstone associated with the Sweetwaters Well Member:

- (a) Small-scale, lenticular laminations in siltstone. GSWA 152822, plane-polarized light;
- (b) Obstacle scours in glauconitic sandstone associated with siltstone. Outcrop 1 km west of Mount Deverell (AMG 330676). Length of field of view is 20 cm;
- (c) Texture of glauconitic sandstone of (b) showing flattened glauconite pellets associated with quartz and pyrite in a fine-grained, quartz-rich matrix. GSWA 152823, plane-polarized light, length of field of view is 3.5 mm



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bedding planes (Fig. 15b). The unit is silica cemented, moderately sorted, and composed of subangular quartz with the grains defined by dust rings, together with widespread elliptical glauconite pellets (Fig. 15c). Tourmaline is the predominant heavy mineral. There is no observable deformation and the glauconite has retained its original shape. Considerable empty space suggests the presence of weathered-out labile grains. Some of these grains may have been feldspars and there are also widespread, large (0.4 mm across) concentrations of micas mostly weathered to kaolinite. Diagenetic pyrite occurs as cubes 0.3 mm in diameter, replaced by iron hydroxides. The glauconite pellets and some intermixed quartz grains are larger in size than the matrix quartz, probably suggesting an intraclastic origin of the glauconite and derivation from adjacent parts of the basin.

The lenticular laminations in the siltstone and the presence of glauconite, typically considered to be an indicator of low sedimentation rates (Amorosi, 1995), suggest quiet conditions of sedimentation in a restricted basin where the bottom currents were commonly weak (Reineck and Wunderlich, 1968). The lithological associations are consistent with a subtidal to intertidal setting.

### Frere Formation (#Ef, #Efg, #Efgz, #Efs, #Efi)

The Frere Formation (Hall et al., 1977) is composed of granular iron-formation and interbedded shale, and named after the Frere Range on NABBERU (1:250 000). The formation conformably overlies the Yelma Formation throughout the Earahedy Basin, with the contact placed at the first occurrence of granular iron-formation. The upper contact with the Karri Karri Member of the Windidda Formation is placed at the last occurrence of iron formation.

Detailed studies of the granular iron-formations of the Earahedy Group (Hall and Goode, 1978; Goode et al., 1983; Bunting, 1986) highlighted their textural similarities to similar rocks in the Lake Superior region of North America (Gross, 1972; French, 1973; Klein, 1974; Floran and Papike, 1975). Peloidal, pelletal, and oolitic textures are common in both and have been interpreted as the result of the formation of these rocks as chemical sediments followed by disruption of sedimentary layers prior to diagenetic consolidation.

The Frere Formation occupies the northern part of MERRIE, and represents parts of the southern limb of a regional syncline structure, which affected the rocks of the Earahedy Group. The formation is subdivided, on the geological map, into several lithotypes: iron-rich, commonly jaspery iron-formation (#Efg); grey, siliceous iron-formation (#Efgz); laminated siltstone and shale (#Efs); and laminar iron-formation (#Efi).

At the type locality of the Sweetwaters Well Member, the basal unit of the Frere Formation is a grey, siliceous iron-formation. A similar association is present 3.8 km northwest of Mount Deverell (AMG 312702). At this locality, greenish-grey, massive to peloidal iron-formation,

in beds around 30 cm thick, is overlain by siltstone with thin interbeds of peloidal chert. Shallow, slightly asymmetrical ripple marks are present in peloidal chert interbedded with the siltstone. The upper part of the section is taken up by well-bedded, peloidal, grey, siliceous granular iron-formation in beds averaging 30 cm, with sparse intraclastic facies and disrupted cherty layers.

Jaspery granular iron-formation (#Efg) is present at two stratigraphic levels separated by ferruginous shale (Fig. 16a). At outcrop scale, the unit is interbedded with siliceous iron-formation and shale, with a commonly lensoidal arrangement of layers (Fig. 16b). Beds range from 10 to 40 cm in thickness, commonly have a flinty texture, and are interbedded with siltstones. The jasper layers locally display a texture of jigsaw fit of fragments with interstitial silica, suggesting that the fragments have undergone only minimal displacement from the site of formation. Such jasper grades laterally into peloidal jasper, which incorporates intraclasts of siliceous iron-formation derived from adjacent parts of the basin. Elsewhere, thin, continuous jasper layers are enclosed within thicker semi-continuous layers, which display pelletal or peloidal textures.

Jaspery iron-formation is typically composed of ferruginous peloids, mainly of jasper in the form of microcrystalline aggregates of finely divided iron oxides and silica, or in other cases of platy hematite 20–80 µm in size. Other peloids consist totally of euhedral magnetite or hematite. The peloids are in the form of elliptical bodies averaging 0.5 – 1 mm in size (Fig. 17a) and commonly display syneresis cracks. Open-weave peloids are also present, composed of a jasper shell within which is coarsely crystalline hematite growing on the walls, with the interior of the peloid occupied by a quartz mosaic. The silica interstitial to the ferruginous peloids is in the form of grains 10–15 µm in diameter, reaching up to 30 µm in the recrystallized types. The relationship of the siliceous matrix with the peloids indicate epitaxial growth of the quartz and suggest that the silica is a later cement, and not the original matrix of the peloids. Peloids composed of coarse, euhedral magnetite are also present, and in the weathered samples the mineral is martitized along crystallographic directions. In some cases, rounded jasper peloids enclosed within later peloids provide indications of a complex history of gel deposition, synsedimentary disruption, and diagenesis (Fig. 17b). A number of peloids consist of magnetite–hematite, with the magnetite in the form of large octahedra and the hematite in smaller platy crystals. This may suggest that both minerals were stable in the environment of deposition of these rocks.

The siliceous iron-formation (#Efgz) is commonly exposed in the form of beds, around 30 cm thick, composed of grey quartzite and interbedded cream-coloured chert, and gives rise to scree of irregular-shaped boulders. The unit is composed of elliptical peloids of partly recrystallized chert (Fig. 18), intermixed with ferruginous peloids. Many of the chert peloids display features of partial replacement by euhedral magnetite (altered to hematite). This suggests that most of the ferruginization in this unit may be secondary. The material



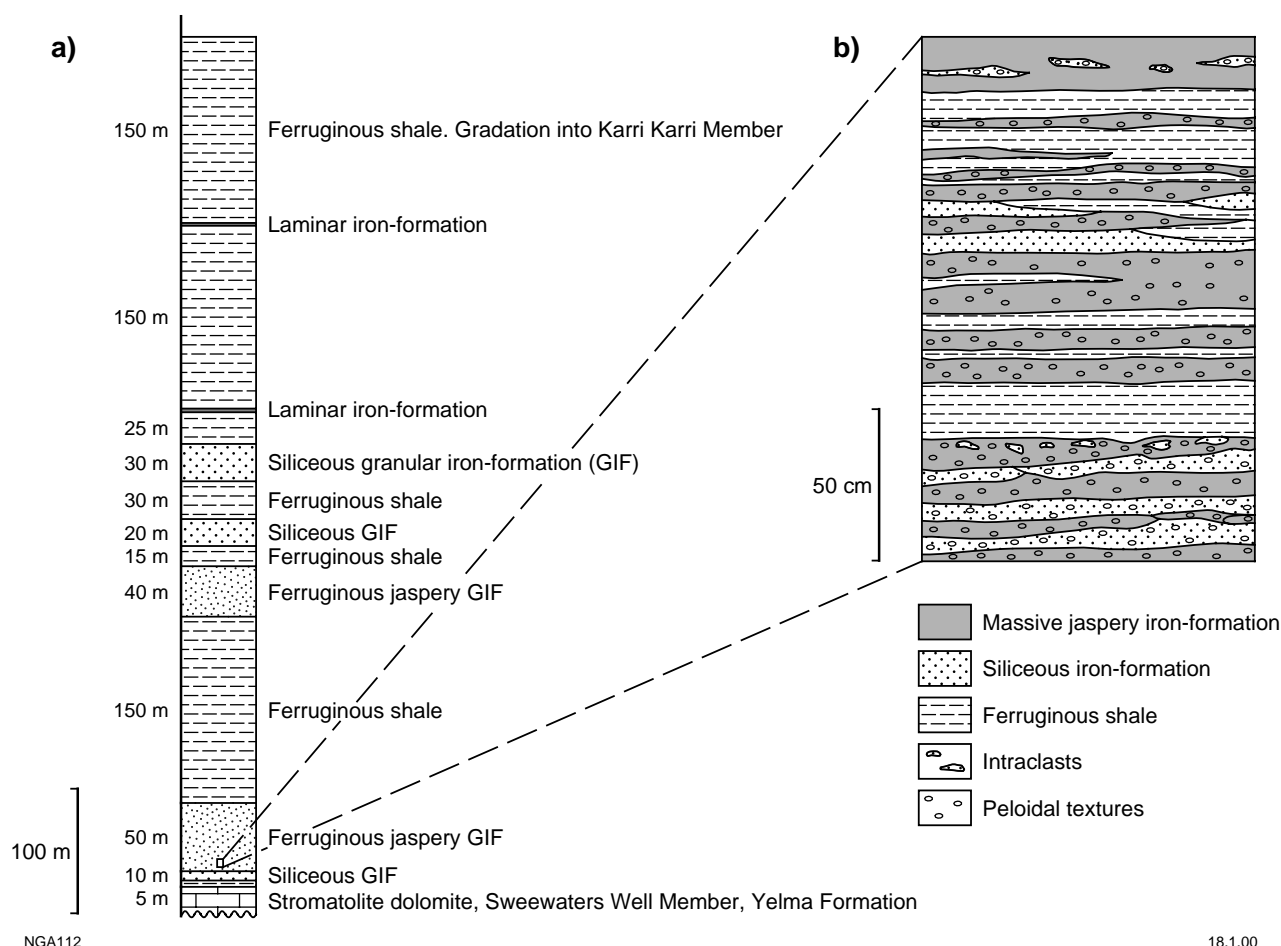


Figure 16. Geological sections through the Frere Formation:

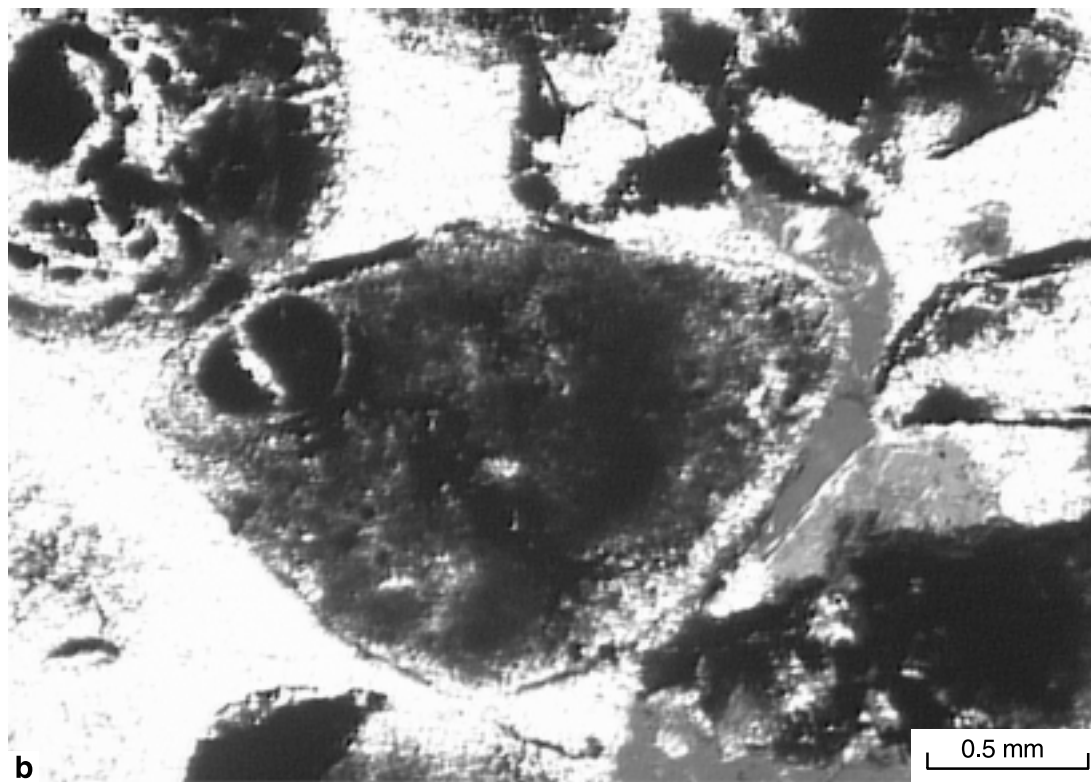
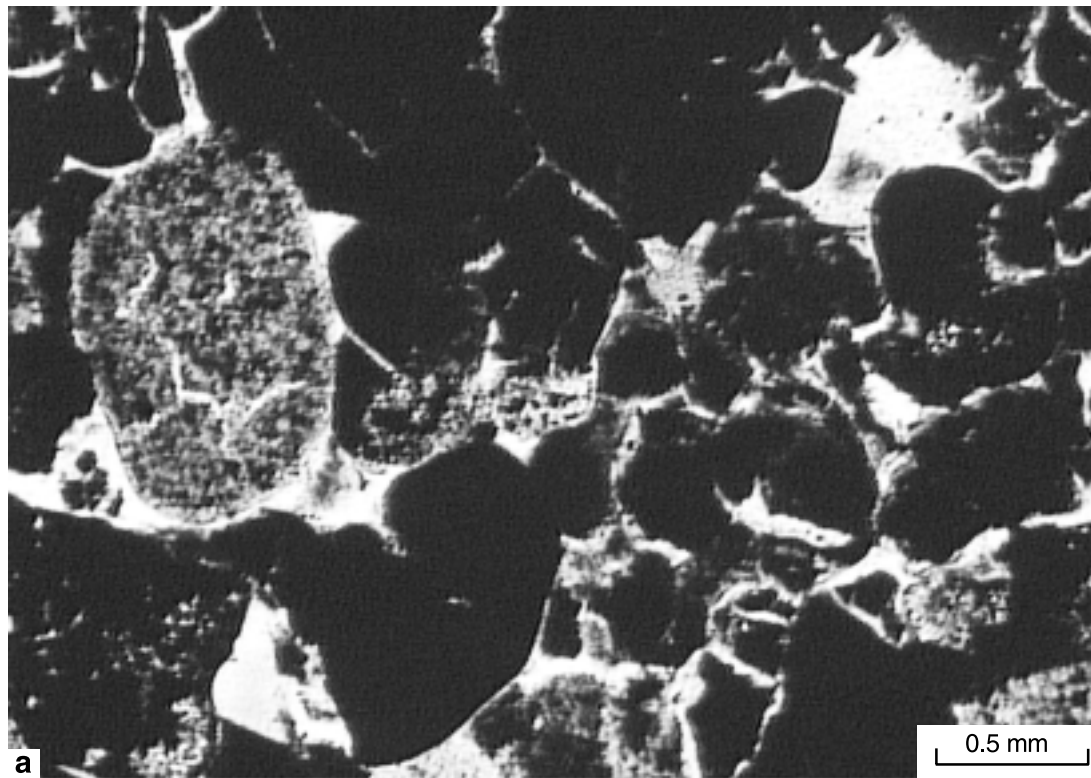
- (a) Composite section showing the distribution of ferruginous and siliceous facies of iron formation and relationships with shale and laminar iron-formation;  
 (b) Detailed section showing relationships between rock types of the Frere Formation

interstitial to the peloids is made up of quartz, with grain size 30–50  $\mu\text{m}$ , which displays an epitaxial relationship with the peloids, suggesting that it is a later cement. In other cases, the interstitial material is made up of radiating sheaves of chalcedony. In some facies of the siliceous iron-formation, the peloids are composed of brownish, interlocking polygonal aggregates of quartz where there are disseminated needles of possible stilpnomelane. The association suggests that the peloids may have had a greenalite precursor, altered to stilpnomelane during low-grade metamorphism, as documented in iron formations from North America (French, 1973).

Sedimentary structures are abundant in both types of granular iron-formations. These include syndimentary disruption of chert bands, which occur in the form of semi-continuous, locally boudinaged layers. This disruption was produced when the chert was still in a semiplastic state, as suggested from the fact that associated jasper beds are free of similar features. Coarse, angular intraclasts, predominantly of chert, suggest post-diagenetic brecciation and deposition as intraformational breccia. In some cases, disrupted siliceous layers show imbrication due to lateral movement. Bedding in the jaspery iron-

formation is mostly planar; however, many of the tops of siliceous beds show irregular load casts, suggesting a more plastic behaviour probably due to the higher water content. Poorly preserved ripple marks are present in both types of iron formation and current lineations have been observed on some bedding planes. Minor structures within the beds include gentle, wavy laminations and local, shallow cross-laminations. All these features are compatible with a shallow-water environment.

Siltstones (*#Efs*) interbedded with the iron formations are hematitic, commonly laminated, and variably ferruginous. Locally, for example, 3.1 km northeast of Mount Deverell (AMG 354703), the siltstones are buff-coloured and dolomitic. Beds average 10–30 cm in thickness, and the bedding is planar with small-scale lenticular lamination. Thick-bedded, massive, grey quartz siltstones with beds up to 40 cm thick are also present 2 km northeast of Lake Nabberu at the eastern edge of MERRIE (AMG 487679), and are typically composed of clastic quartz and white mica in a fine-grained matrix. This suggests that periods of predominantly chemical deposition were periodically interrupted by clastic sedimentation.



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Figure 17. Textures of jaspery iron-formation:

- (a) Jaspery, peloidal iron-formation composed predominantly of jasper and subordinate ferruginous chert peloids in a siliceous matrix. Note syneresis cracks in the ferruginous chert peloid at left. GSWA 149377, plane-polarized light;
- (b) Rounded ferruginous peloid enclosed within larger peloid. The texture suggests a protracted history of deposition, disruption, and redeposition of ferruginous material. GSWA 152832, plane-polarized light

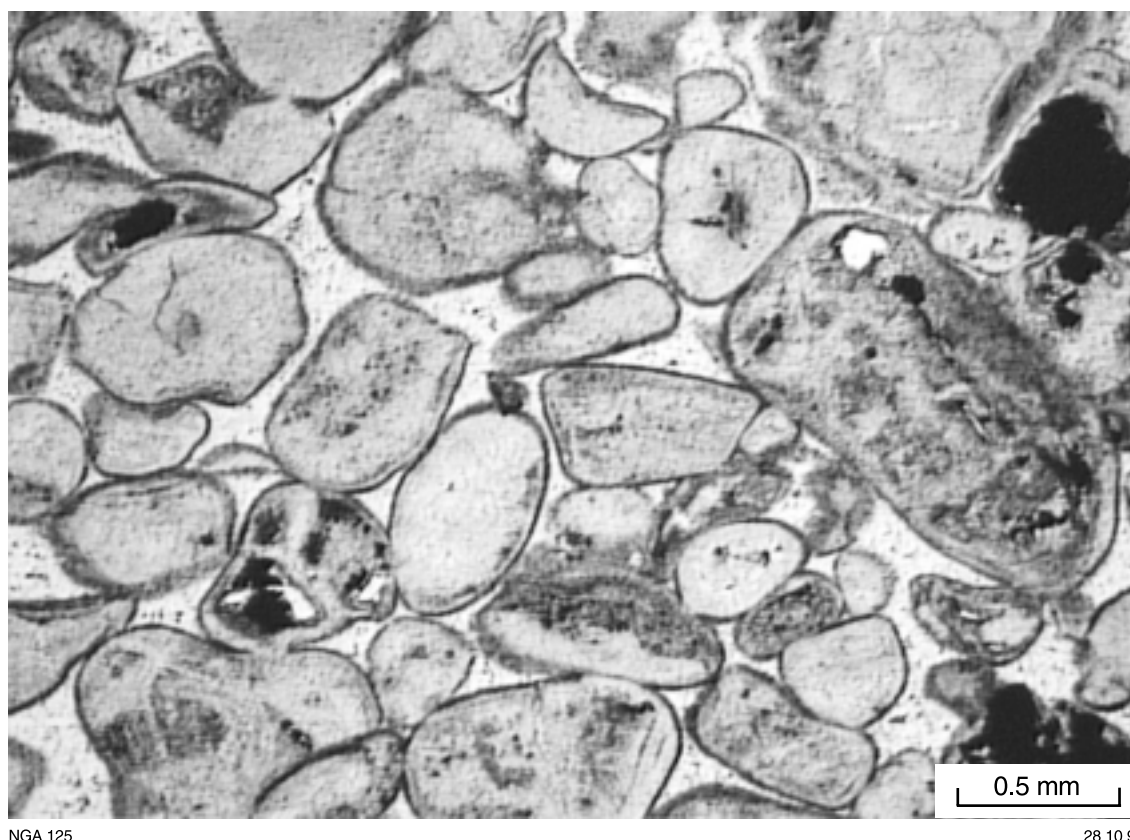


Figure 18. Granular siliceous iron-formation showing typical peloidal texture and partial ferruginization of chert peloids. GSWA 152841, plane-polarized light

Typical mesobanded iron-formation consisting of decimetre-scale alternations of microbanded silica-rich and iron-rich layers is absent on MERRIE. Laminar iron-formation (*#Efi*) consists of finely laminated ironstone with very sparse siliceous bands, forming topographically positive features within shales. The thickness of these units varies from a few tens of centimetres upwards to 2 m. At least two bands of laminar iron-formation are exposed within the uppermost shales, which define the contact of the Frere Formation with the overlying Karri Karri Member (Fig. 16a).

The ferruginous layers in the laminar iron-formation are made up of minute crystals of hematite (2–5  $\mu\text{m}$ ) in a matrix that is dominated by iron hydroxides. Martitized porphyroblastic magnetite, in crystals up to 50  $\mu\text{m}$  in size, is dispersed throughout and probably secondary after hematite. The siliceous layers consist of mostly aphanitic material, which consists of disseminated euhedral magnetite crystals and subordinate acicular hematite. Rare, altered carbonate rhombs are present in the groundmass. Intraclastic fragments are commonly enclosed within the siltstone layers.

Lateritic weathering resulted in the almost total obliteration of primary mineralogy of iron formations on MERRIE, with the exception of silica and iron oxides. However, examination of unweathered samples from drillcore (Adamides, in prep.a) from adjacent NABBERU

indicated the presence of abundant stilpnomelane, both primary and early diagenetic, widespread minnesotaite, minor greenalite, and various types of carbonate (dolomite, ankerite, siderite). Interbedded siltstones are locally composed of a microcrystalline assemblage of quartz and chlorite. All these assemblages are directly comparable to examples from North America (Gross, 1972; Floran and Papike, 1975) and suggest a similar genesis. The quartz–chlorite association has been described from Algoma-type iron-formations of the Weld Range (Gole, 1981), where it was interpreted as a primary sedimentary assemblage.

Secondary processes affecting the iron formations are represented by carbonate alteration in the form of trails of euhedral carbonate rhombs (probably ankerite and siderite) following fractures. Ferruginization takes the form of fracture-controlled replacement by euhedral magnetite, or the partial replacement of siliceous peloids. Distinction between primary and secondary magnetite is made on the basis of crosscutting relationships with the primary assemblages. Almost complete replacement of siltstone by a carbonate–stilpnomelane assemblage was noted in drillhole samples from the area 3.5 km northeast of Mount Deverell (AMG 366698). The stilpnomelane replaces the matrix and forms veins composed of acicular birefringent crystals. Abundant porphyroblastic carbonate is present and associated with disseminated magnetite; chlorite is an additional component of the vein assemblage.

## Windidda Formation (#Ed)

The Windidda Formation (after Windidda Homestead on the KINGSTON 1:250 000 sheet) consists of siltstone, quartz sandstone, and carbonate, and conformably overlies the Frere Formation. The lower contact is placed at the last occurrence of iron formation. The upper contact with the Chiall Formation is defined by the occurrence of thin-bedded quartz sandstone and siltstone. The Windidda Formation is represented by outcrops of the Karri Karri Member in the northeastern part of MERRIE.

### Karri Karri Member (#Edk)

The Karri Karri Member (new name, after Lake Karri Karri on the NABBERU 1:250 000 sheet) is typically composed of parallel-laminated siltstone and shale, with local quartz sandstone lenses.

The siltstones are typically argillaceous and parallel-laminated, and were deposited at water depths below storm wave-base. The laminae are defined by alternations of clay-rich and quartz-rich material and trails of weathered ferruginous material, probably representing sedimentary diagenetic sulfides. The presence of diagenetic pyrite, in association with anomalous manganese and base metal values in similar rocks from EARAHEEDY (Adamides, in prep.b), suggests that the shales were partly deposited in anoxic conditions. This conclusion may have an important bearing on the mineralization potential of the Earahedy Basin (see **Economic geology**).

## Chiall Formation (#Ec)

The Chiall Formation (new name, after Chiall Spring on the KINGSTON 1:250 000 sheet) is a sequence of thinly bedded quartz sandstone and siltstone (Wandiwarra Member) with local orthoquartzite lenses (Princess Ranges Member), which conformably overlies the Windidda Formation. On MERRIE, only the Wandiwarr Member is present, confined to the northeast corner of the sheet.

### Wandiwarra Member (#Ecw)

On MERRIE, the Wandiwarr Member (after the abandoned Wandiwarr Well on the KINGSTON 1:250 000 sheet) is very limited in extent and represented by a sequence of grey quartz arenite and interbedded siltstone. The arenite is mostly structureless with the exception of widespread mud clasts in the body of the rock and parallel laminations in the higher parts. Mud-clast moulds are rounded and range up to several centimetres in size. There are local, poorly preserved ripple marks and current lineations. The arenite is well sorted and composed of subrounded to subangular grains around 0.2 mm in diameter, with grain boundaries defined by fine dust rings; the arenite is silica cemented and contains kaolinitic pellets in the same size range as the quartz grains.

A sample of siltstone spatially associated with the quartz arenite was found to be laminated on a millimetre

scale and strongly chloritic, with dense disseminations of iron hydroxides. Chlorite is abundant in the matrix of the rock, either in small flakes or larger grains, and is strongly pleochroic from yellow to deep green with anomalous birefringence. It is similar in nature to chlorite associated with the iron formations and may be derived from them.

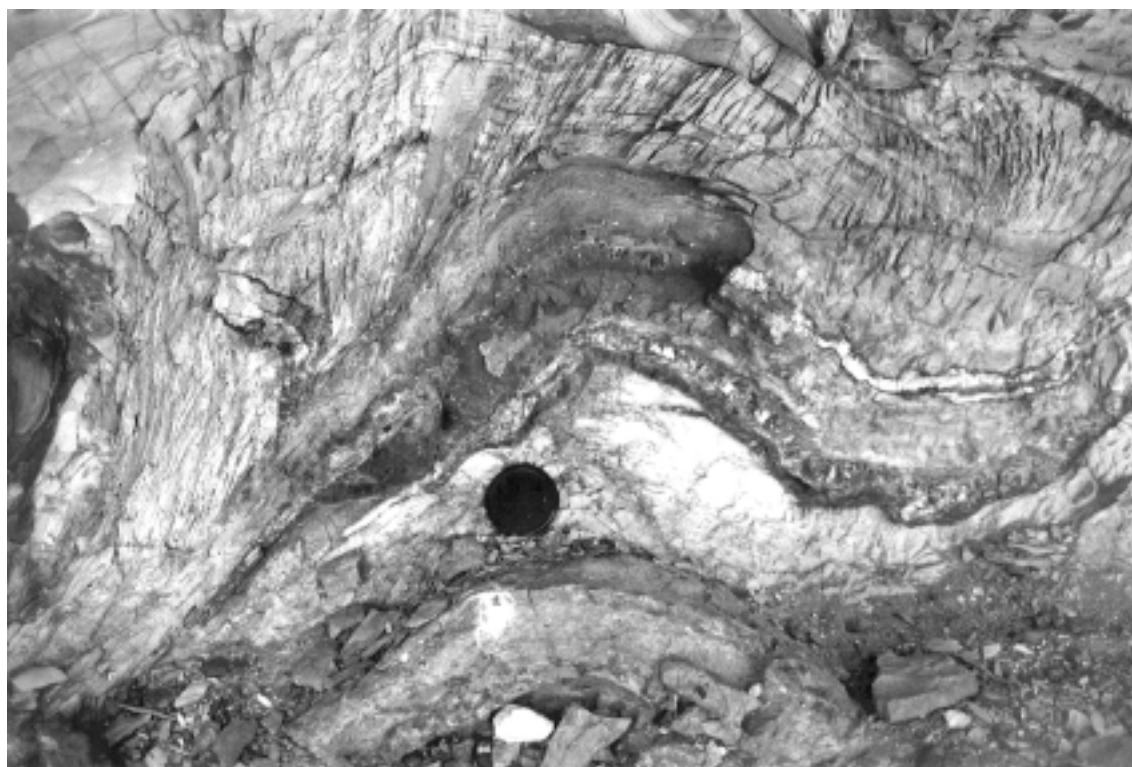
## Structure and metamorphism

The earliest Proterozoic structures are probably represented by a series of east-southeasterly trending faults that are exposed within granitoid rocks on central and eastern MERRIE. Both the faults and associated quartz veins are steeply dipping. They are reflected on aeromagnetic images by linear negative anomalies, and have laterally displaced the Yandal greenstone belt on CUNYU (Adamides et al., 1999). The structures terminate against the Merrie Range Fault, suggesting that this structure has been rejuvenated during the Capricorn Orogeny. The faults have an associated conjugate set of faults and fractures oriented northeast and are also defined by quartz veins.

MERRIE is located at the junction between the Yerrida and Earahedy Basins and the deformational regime varies accordingly. The Juderina and Killara Formations are typically undeformed, resting unconformably on Archaean basement. The outcrop forms part of the stable Paroo Platform (Gee and Grey, 1993), which passes northwestwards into a belt of strong deformation and isoclinal folding between the Goodin and Marymia Inliers. This belt has been termed the Glengarry Fold Belt by Gee (1987). Deformation along this belt, related to northwest-directed compression, has not affected the Yerrida Group on MERRIE.

Deformation of the Yerrida Group was followed by deposition of the Earahedy Group and its subsequent deformation. The Earahedy Group is folded into an east-southeasterly plunging synclinorium (Bunting, 1986), with part of the southwestern limb exposed on the northern part of MERRIE. On FAIRBAIRN (Adamides and Pirajno, in prep.), abundant evidence of small-scale thrusting and associated bedding-parallel quartz veining, particularly evident in the granular iron-formations, is probably related to compression associated with this folding.

Mesoscale folding, with well-developed axial-plane cleavage (Fig. 19) within Windidda siltstones at the northeast end of MERRIE, indicates orientations of fold axes oblique to the synclinal axis and suggests the presence of cross folds, which are oriented north-northeast. The cross folds are related to a later period of deformation, which on FAIRBAIRN (Adamides and Pirajno, in prep.) is indicated by the presence of crenulation cleavage in the siltstones of the Yelma Formation. This later deformation implies northwest-directed compression and may be related to a Bangemall event. Similar northeasterly trending folds have been identified on NABBERU, where interaction with structures associated with the Lockeridge Fault resulted in small-scale dome and basin interference folds (Hall, 1979).



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Figure 19. Mesoscale folding of laminated siltstones of the Karri Karri Member, showing axial-plane cleavage. Seven kilometres east of Eladgee Bore (AMG 440743). The diameter of the lens cap is 5.5 cm

After the deposition and deformation of the Earraheedy Group, movements along the Merrie Range Fault resulted in the disruption of the outcropping Yelma and Frere Formations and the earliest easterly structures evident in the granite. Observations of the outcrop pattern (see simplified geology on map) suggests a possible left-lateral displacement of several kilometres along this structure.

The most sensitive indicators of metamorphism are the mafic rocks of the Killara Formation. These rocks usually preserve most of their primary mineralogy. Plagioclase is commonly weakly altered along veinlets and fractures to granular clinozoisite and carbonate, or, elsewhere, to sericite commonly associated with chlorite. The titanomagnetite is altered to leucoxene and ilmenite. Hypersthene is serpentinized. The alteration is non-pervasive and may be interpreted as mostly the result of autometasomatism, probably coupled with the effects of mild, hydrothermal metamorphism indicated by quartz–epidote–carbonate veining.

The sedimentary rocks of the Yerrida Group (Juderina Formation) preserve their primary sedimentary features, which also suggests that they have not undergone significant metamorphism. Quartz grains in the arenite units are defined by dust rings and are commonly undeformed. Associated siltstones commonly preserve their original clay mineralogy, with minor formation of illite. This suggests very mild metamorphism, probably equivalent to the archimetamorphism grade of Kisch (1987).

One sample of a blotchy-textured, poorly sorted quartz arenite from the area 1.6 km west-northwest of Haden Well close to the Merrie Range Fault (AMG 248458) contained widespread, newly formed tourmaline as a replacement of the matrix interstitial to the quartz grains. This tourmaline is interpreted as evidence of mild boron metasomatism, probably from fluids originating from this fault.

The metamorphism of the Earraheedy Group is similar to that of the Yerrida Group. The formation of illite is locally associated with axial-plane cleavage. Chert crystallinity is commonly considered to be a sensitive indicator of metamorphic grade, increasing in grain size parallel with increasing grade (Klein, 1983; Goode et al., 1983). Peloidal chert from the Frere Formation is typically composed of grains around 5 µm in size, suggesting minimal recrystallization. This feature, together with the preservation of primary to early diagenetic assemblages in the iron formations (Adamides, in prep.a), suggests very low grades of metamorphism.

## Cainozoic geology

Recent deposits have been subdivided into Quaternary (prefixed *Q*) or Cainozoic (prefixed *Cz*) on the basis of their relative age of deposition and evidence of dissection. Older deposits are typically dissected and may represent remnants of the old lateritic duricrust. This duricrust is

mostly preserved in areas of outcrop of the Merrie greenstone belt, and is composed of indurated ferruginous and fragmentary laterite and associated coarse rubble (*Czrf*). In granite terrain, silcrete (*Czrz*) is commonly developed and gives rise to coarse, angular, bouldery scree. Silcrete is composed of angular quartz grains set in a siliceous aphanitic matrix. Laterite passes on flat ground into finer grained rubble, commonly pisolitic (*Czcf*), or on floodplains, where it is reworked by present-day alluvial processes, into ferruginous gravel (*Qwf*) mixed with soil. Lateritic ironstone (*Czri*), resulting from percolation of iron-rich waters in fault zones, is commonly massive to rubbly in outcrop and commonly associated with quartz veins.

Areas of outcrop are fringed by a mixture of loose or consolidated gravel and silt, mixed with abundant angular rock fragments (*Czc*). This material grades at lower levels into sheetwash deposits (*Qw*). This last unit is commonly indicated on aerial photographs by a characteristic arrangement of vegetation patterns, and is distinguished from the smoother appearance of colluvial deposits. The sheetwash deposits (*Qw*) and alluvium (*Cza*) are equivalent terms on the map, with the latter transferred from CUNYU (Adamides et al., 1999). A specific type of colluvium (*Czcq*) limited to areas around quartz veins, is composed predominantly of quartz rubble and debris almost to the exclusion of rock fragments. This passes at lower levels into sheetwash areas.

Active alluvial channels (*Qa*) are defined by zones of sand, silt, and coarse gravel and boulders. These are commonly lined with calcrete (*Qak*), a mixture of carbonate and opaline silica a few metres thick that commonly lines the main drainage channels. The formation of calcrete is linked to precipitation below the water table under conditions of low rainfall and high evaporation (Hocking and Cockbain, 1990). Claypans (*Qac*), composed mostly of silt and clay, form in low-lying areas of sheetwash plains by the settling of material from suspension following flooding.

Quartz sand (*Qs*) forms extensive plains in the southeastern and southwestern parts of MERRIE and commonly overlies granite. The sand, which is red-brown and composed of iron-stained, subangular quartz grains averaging 0.5 mm in diameter, is probably only a few metres thick. The sandplain is featureless except in the southern parts where northerly to northeasterly trending dunes are present.

The playa lake-system of Lake Gregory – Lake Nabberu is characterized by a complex system of sediments. The lakes are flooded by deposits of sand and silt with subordinate evaporites (*Ql*), with the surrounding low-lying areas composed of gypsiferous and saline deposits (*Qlg*). Fringing the lakes are sand dunes (*Qld*) composed of fine-grained, red-brown sand and silt made up of angular quartz grains mixed with lateritic ironstone grains, which are polished by wind action. The deposits build gentle mounds a few metres high that are vegetated mainly by mulga.

Lake calcrete (*Qlk*), distinctly different in genesis to alluvial calcrete, is particularly developed in the

inner parts of the lake system. Formation of this calcrete is linked to evaporitic processes and the deposit is commonly gradational lakewards into the gypsite facies (Arakel and McConchie, 1982). Lake areas are commonly characterized by a distinct vegetation, with samphire communities being prominent.

## Geochemistry

Two rock-chip samples were collected during mapping and analysed for a number of elements. Analytical methods and results are shown in Table 3. One sample of ironstone (GSWA 149379), spatially associated with chert breccia after dolomite (Sweetwaters Well Member), was found to be strongly anomalous in lead (4700 ppm), zinc (6200 ppm), and silver (0.4 ppm). The anomalism is related to mineralization within carbonates in this member (see **Economic geology**). The second sample (GSWA 152849), collected from a fault zone in granite, is associated with silicification, quartz veining, and local boxworks after pyrite. The sample is anomalous in gold (14 ppb), silver (1.6 ppm), and barium (3665.2 ppm). The anomalous values are interpreted as due to the action of hydrothermal fluids enriched in these elements, which used the fault zone as a passageway to higher levels in the crust.

## Economic geology

A listing of exploration reports on open file in the Western Australian mineral exploration database (WAMEX) of the Department of Minerals and Energy is presented in Appendix 2 (April, 1999). The reports contain full details of exploration on MERRIE.

### Gold

Potential for gold mineralization exists within favourable lithologies and structures of the Merrie greenstone belt, and the area is currently subject to active exploration. A limited study of the alteration mineralogy of the greenstone belt (Farrell and Adamides, 1999) indicated typical weak alteration, dominated by epidote, biotite, and chlorite, with general scarcity of carbonates; however, the possibility exists for stronger mineralization hosted in suitable structures.

### Iron

The iron-rich granular iron-formations and associated ferruginous shales of the Frere Formation are potential hosts of economic mineralization, particularly in areas of supergene enrichment. Such areas of enrichment are widespread in the Miss Fairbairn Hills area on FAIRBAIRN (Adamides and Pirajno, in prep.) and in the area of Frere Range on MERRIE and FAIRBAIRN. Examination of these occurrences (Item 590, Appendix 2) by grab sampling detected assays up to 66% Fe with corresponding low phosphorus (0.08%). Subsequent

Table 3. Trace-element analyses of samples from MERRIE

GSWA sample AMG coordinates Lithology	149379 329682 ironstone	152849 448440 silicified zone	Detection limit	Analytical method
<b>Parts per million</b>				
Ag	0.4	1.6	0.1	A/MS
As	245	25	0.1	A/MS
Au (ppb)	1	14	1	FA*/MS
Au-Repeat (ppb)	—	13	1	FA*/MS
Ba	230	3 665.2	0.1	A/MS
Bi	0.16	6.15	0.01	A/MS
Co	78	22.6	0.1	A/MS
Cr	<2	3	2	A/OES
Cu	102	115	1	A/OES
Mo	0.5	25.1	0.1	A/MS
Ni	220	4	1	A/OES
Pb	4 700	104	2	A/MS
Pd	<1	<1	1	FA*/MS
Pt	<1	<1	1	FA*/MS
Se	—	15	2	A/MS
Sn	0.6	0.7	0.1	A/MS
Th	3.6	18.52	0.01	A/MS
U	3.6	1.55	0.1	A/MS
V	<2	8	2	A/OES
W	0.2	0.5	0.1	A/MS
Zn	6 200	16	1	A/OES
Mn	800	0.006	1	A/OES
Fe (%)	50	9.34	0.01	A/OES

**NOTES:** A/MS: Multi-acid digest including hydrofluoric, nitric, perchloric, and hydrochloric acids. Analyzed by inductively coupled plasma mass spectrometry

FA\*/MS: Lead collection fire assay using new pots. Analyzed by inductively coupled plasma mass spectrometry

A/OES: Multi-acid digest including hydrofluoric, nitric, perchloric, and hydrochloric acids. Analyzed by inductively coupled plasma optical (atomic) emission spectrometry

drilling was aimed at locating synclinal structures within shales, amenable to secondary enrichment.

## Uranium

The playa system of Lake Gregory – Lake Nabberu, with its prolonged history of precipitation and evaporation, draining extensive areas of granite to the south, is a favourable site for carnotite deposition. Exploration, based on this model, was performed on adjacent NABBERU (Taylor, 1980).

## Base metals

The Sweetwaters Well Member of the Yelma Formation locally contains traces of galena. Grab samples of dolomite from the type locality assayed 6% Pb, 53 ppm Ag, 31.4 ppm As, 80 ppm Co, 70 ppm Cu, 1900 ppm Mn, 105 ppm Ni, and 230 ppm Zn (Hall and Haslett, 1978). Shallow drilling intersected highest Pb of 1.6% over 1 m, with other intersections being 6 m of 0.49 – 0.81% Pb. The mineralization either follows stylolitic fractures or forms in the cores of domal stromatolitic forms (Bunting et al., 1982). Diamond drilling northwest of Mount Deverell (Johnston and Hall, 1980) penetrated a thickness of interbedded dolomite and shale in excess of 300 m. This dolomite horizon has been recently explored by Renison Goldfields Consolidated

(Item 9569, Appendix 2). The drilling intersected widespread, subeconomic lead mineralization both on MERRIE and NABBERU, with the best intersections around 1% combined Zn+Pb over 2 m (Dörfling, 1997).

The identification of lithologies with black-shale affinities in rocks of the Karri Karri Member suggests the possibility that these rocks may have acted as repositories of a number of elements including manganese, barium, copper, zinc, uranium, and vanadium, as is the case in black-shale basins (Coveney and Martin, 1983). Subsequent mobilization of these elements by tectonism may lead to concentration in suitable rock types (such as carbonates), resulting in the formation of sediment-hosted, epigenetic base metal deposits. The presence of volcanic activity in close association with black shales is commonly considered to be a favourable factor, both in the mobilization of fluids and contribution of metals to the system (Delian et al., 1992). Mafic dykes are interpreted, from aeromagnetic data, to underlie the Earahedy Basin rocks at shallow depths.

## Groundwater

Most of the groundwater suitable for livestock is derived from wells in calcrete and thick alluvial accumulations in drainage channels. Smaller quantities of water may be obtained from fractured, jointed, or weathered bedrock. The salinity of the water increases towards the Nabberu



Lake system, reaching values up to 7300 ppm TDS (total dissolved solids) in the areas around the salt lakes (Sanders and Harley, 1971) and values around 1000–3000 ppm TDS in areas away from the lakes.

The best potential for groundwater on MERRIE is offered by the thick calcrete concentrations in the area

around Eladgee Bore in the northeast corner of the sheet, and the thick alluvial accumulations and calcrete deposits in the north-flowing Mibbeyean Creek on the western edge of the sheet.

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## Appendix 1

## Gazetteer of localities mentioned in text

Locality <sup>(a)</sup>	Latitude (S)	Longitude (E)	AMG coordinates	
			Easting	Northing
6 Mile Well (abd)	25°44'21"	120°11'57"	219000	7150200
21 Well	25°45'30"	120°07'08"	211000	7147900
Boody Hole Well	25°37'49"	120°12'56"	220400	7162300
Bulletin gold mine	26°37'00"	120°14'00"	224500	7053000
Bungarra Bore	25°58'41"	120°14'29"	223800	7123800
Canning Stock Route	25°54'24"	120°21'53"	236000	7132000
Chiall Spring	26°06'23"	121°51'07"	385200	7112000
Curvaceous Carly Bore	25°59'11"	120°09'08"	214900	7122700
Dingy Well (abd)	25°44'52"	120°16'07"	226000	7149400
Doyle Well	25°49'10"	120°09'58"	215900	7141250
Eladgee Bore	25°31'27"	120°22'55"	236900	7174400
Frank Well (abd)	25°39'50"	120°16'46"	226900	7158700
Frere Range	25°35'00"	120°27'41"	245000	7168000
Haden Well (abd)	25°46'59"	120°16'15"	226300	7145500
Halls Creek <sup>(b)</sup>	18°14'00"	127°40'00"	359000	7983500
Joe Bore	25°42'41"	120°21'07"	234300	7153600
Juderina Bore <sup>(c)</sup>	25°52'53"	119°12'03"	720500	7135600
Killara Homestead <sup>(c)</sup>	26°20'55"	118°57'25"	695300	7084200
Kimberley Range <sup>(c)</sup>	26°19'00"	119°48'00"	779500	7086200
Lake Carnegie	26°10'00"	122°25'00"	441700	7105700
Lake Karri Karri	25°36'21"	120°44'22"	273000	7166000
Lake Nabberu	25°36'00"	120°07'00"	210400	7165400
Lake Wells	26°40'00"	122°59'00"	498300	7050500
Meekatharra <sup>(c)</sup>	26°36'00"	118°30'00"	649400	7057000
Merrie Range	25°43'26"	120°14'57"	224000	7152000
Miss Fairbairn Hills	25°14'00"	120°21'00"	233000	7206600
Mount Deverell	25°35'13"	120°21'14"	234200	7167400
Mount Paterson	25°43'35"	120°03'25"	204700	7151300
Nabberu Tank	25°38'19"	120°25'13"	241000	7161800
Neds Creek Homestead <sup>(c)</sup>	25°28'52"	119°38'52"	766200	7179100
Newman <sup>(c)</sup>	23°16'00"	119°38'52"	762600	7424600
No 3 Govt Well	25°46'32"	120°24'30"	240100	7146600
Quartz Well	25°40'23"	120°00'09"	199100	7157100
Sweetwaters Well (abd)	25°35'33"	120°22'18"	236000	7166800
Vermin-proof fence	25°56'11"	120°02'41"	204000	7128000
Verscher Range	25°44'00"	120°05'00"	207400	7150600
Wandiarra Well (abd)	26°22'30"	122°19'30"	432660	7082600
Weld Spring	25°01'00"	121°35'00"	357000	7232400
Wiluna	26°35'39"	120°13'25"	223500	7055500
Windidda homestead	26°23'00"	122°13'00"	421900	7081600
Wynn Well	25°43'35"	120°05'37"	208400	7151400

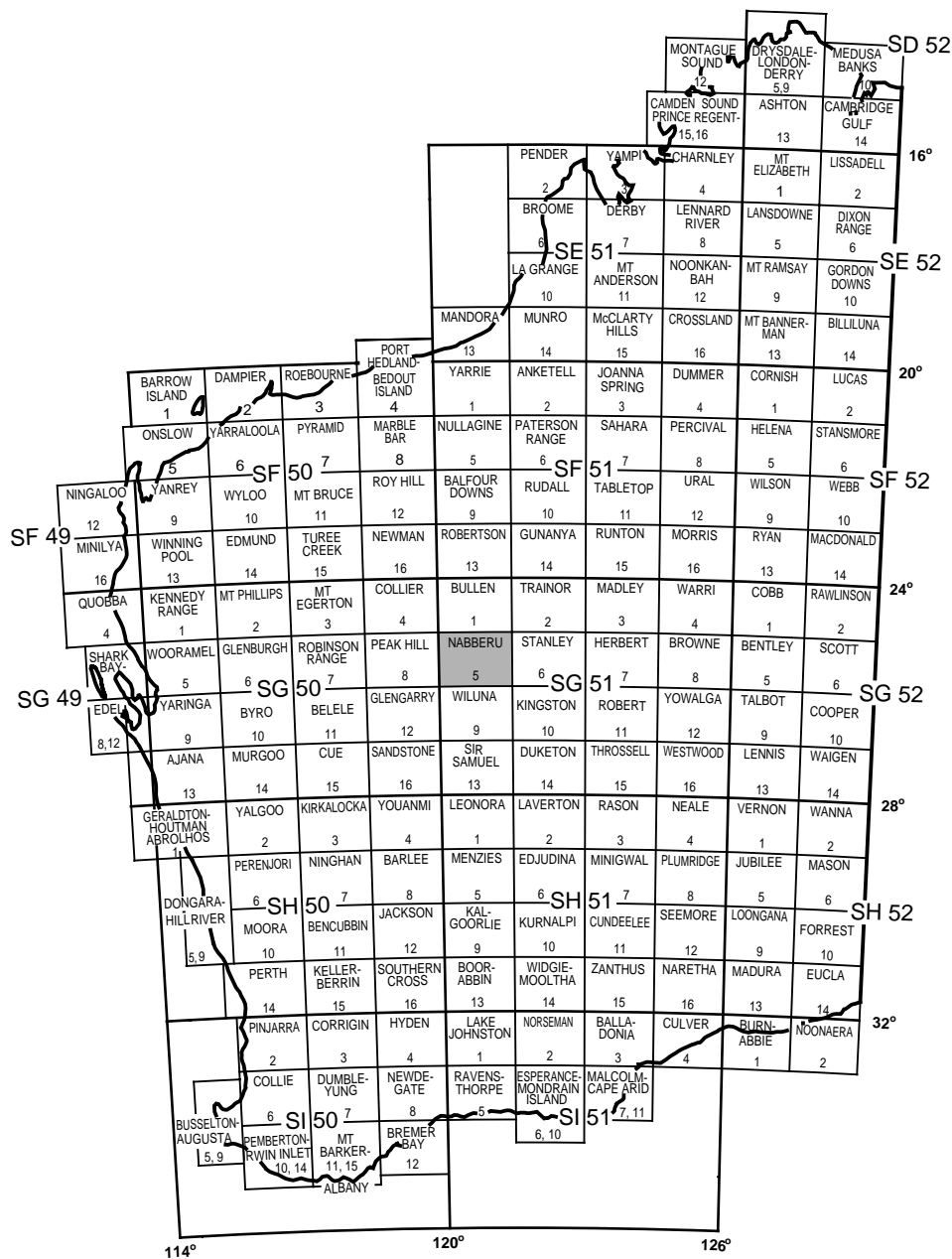
NOTES: (a) Localities are within Australian Map Grid (AMG) Zone 51 unless specified otherwise  
 (b) Locality within AMG Zone 52  
 (c) Locality within AMG Zone 50  
 abd: abandoned

## Appendix 2

## Reports currently (April, 1999) on open file in the Western Australian mineral exploration (WAMEX) database

<i>GSWA WAMEX Item number<sup>(a)</sup></i>	<i>Reports</i>	<i>Duration</i>	<i>Title</i>	<i>Company</i>
1155	7	1972–76	Baumgarten nickel–copper exploration	Dampier Mining Company Ltd
180	1	1975–76	Corners Well manganese iron exploration	Dampier Mining Company Ltd
590	1	1977–78	Nabberu Basin iron exploration	Dampier Mining Company Ltd
2181	3	1977–80	Sweetwaters Well lead–zinc exploration	Dampier Mining Company Ltd
1138	2	1979–80	Bridleface Outcamp uranium exploration	Uranerz Australia Pty Ltd
2020	9	1981–82	Lake Gregory copper–lead–zinc exploration	Esso Exploration Australia Inc.
2684	1	1982–84	Quartermaine Well copper–uranium exploration	Amoco Minerals Australia Company
3223	1	1986–87	Cunyu Woolshed–Davis Well gold exploration	BHP Minerals Pty Ltd
4595	1	1987–90	Gray Well gold exploration	Eon Metals
5547	2	1987–90	Baumgarten gold exploration	Eon Metals
9247	8	1989–97	Nabberu diamond–gold exploration	Resolute Resources Ltd
4373	2	1989–90	Horseshoe gold exploration	ACM Gold Ltd
6077	1	1990–91	Terabubba gold exploration	Western Mining Corporation
7836	1	1991–94	Seven Mile base metals–gold exploration	Plutonic Operations Ltd
9016	5	1991–96	Simpson Well gold–diamond–base metals exploration	Galtrad Pty Ltd
9705	5	1991–97	Cunyu gold–base metals exploration	Cyprus Gold Australia Corporation
7939	3	1992–94	Lake Nabberu diamond exploration	Stockdale Prospecting
8511	1	1991–95	Merrie Range gold–diamond exploration	Marymia Exploration NL
9165	1	1991–96	Cunyu gold–diamond exploration	Cyprus Gold Australia Corporation
7858	3	1991–94	Bundel Well gold exploration	Eagle Mining Exploration
9613	1	1993–96	Teague base metals exploration	Renison Goldfields Consolidated
9569	5	1993–98	Canning Gap base metals–diamond exploration	Renison Goldfields Consolidated
8071	1	1993–93	Nabberu diamond exploration	Cladium Mining Pty Ltd
8979	1	1993–96	Canning Gap diamond exploration	Renison Goldfields Consolidated
9769	1	1993–97	Canning Gap lead–zinc exploration	Renison Goldfields Consolidated
8146	1	1994–95	Deary Bore gold–base metals exploration	Plutonic Corporation Ltd
9389	2	1994–97	Freshwater base metals exploration	Renison Goldfields Consolidated
9489	2	1996–97	Hawkins Knob lead–zinc exploration	RGC Exploration Pty Ltd

**NOTE:** (a) Information is available from the Department of Minerals and Energy Library, Mineral House, 100 Plain Street, East Perth, WA, 6004



FAIRBAIRN 2947	METHWIN 3047	RHODES 3147
NABBERU SG 51-5		
MERRIE 2946	NABBERU 3046	GRANITE PEAK 3146

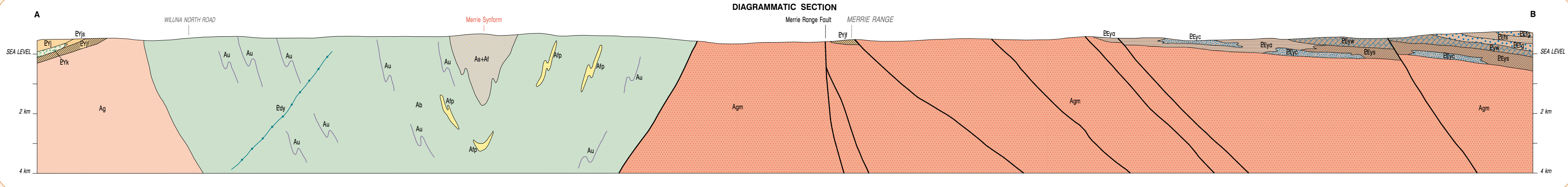
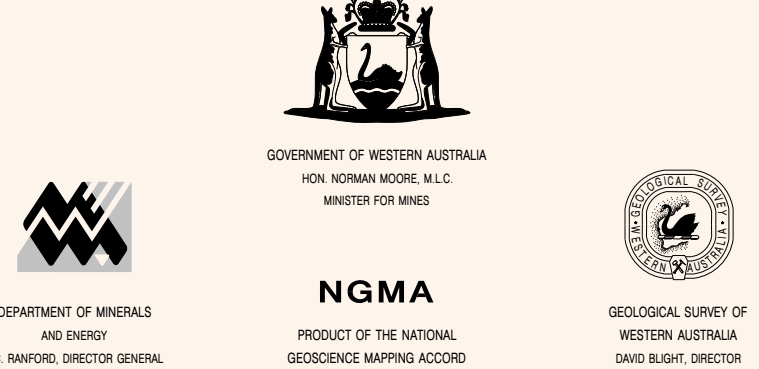
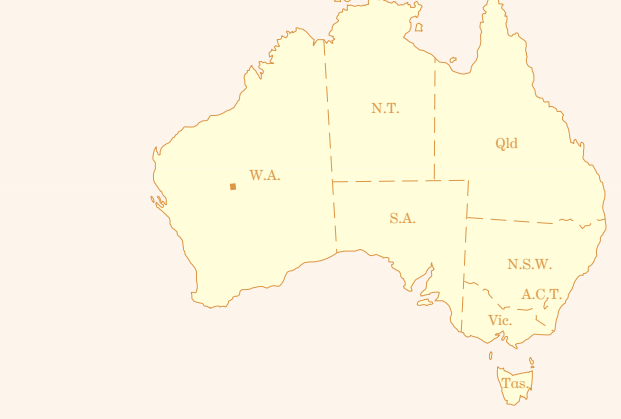
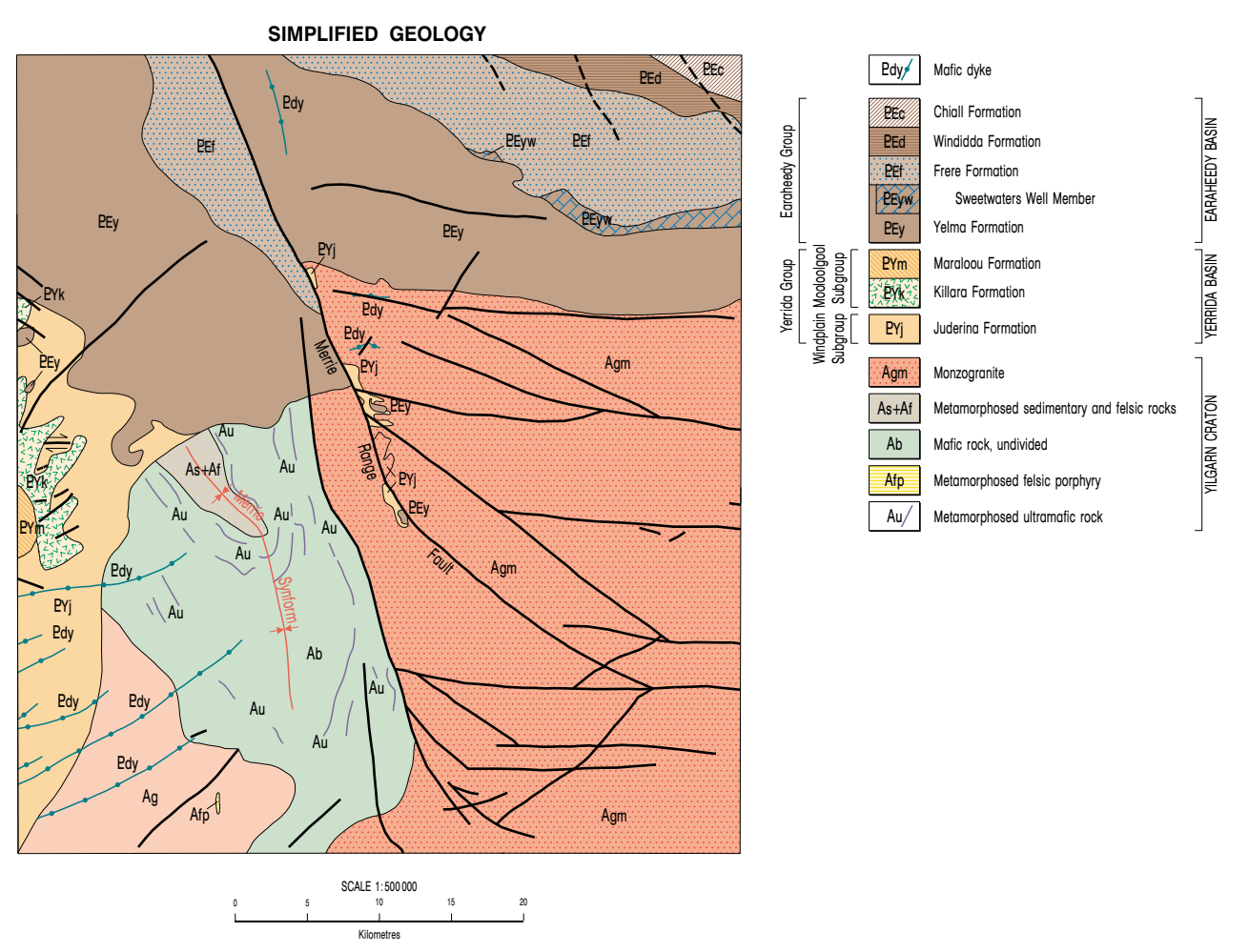
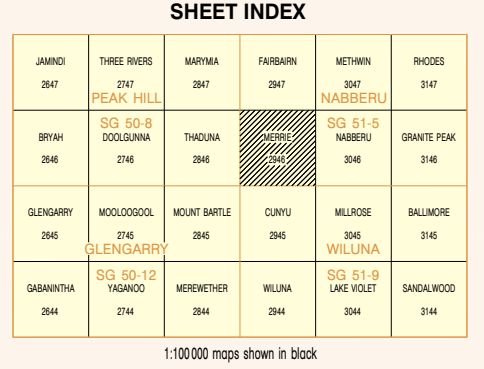
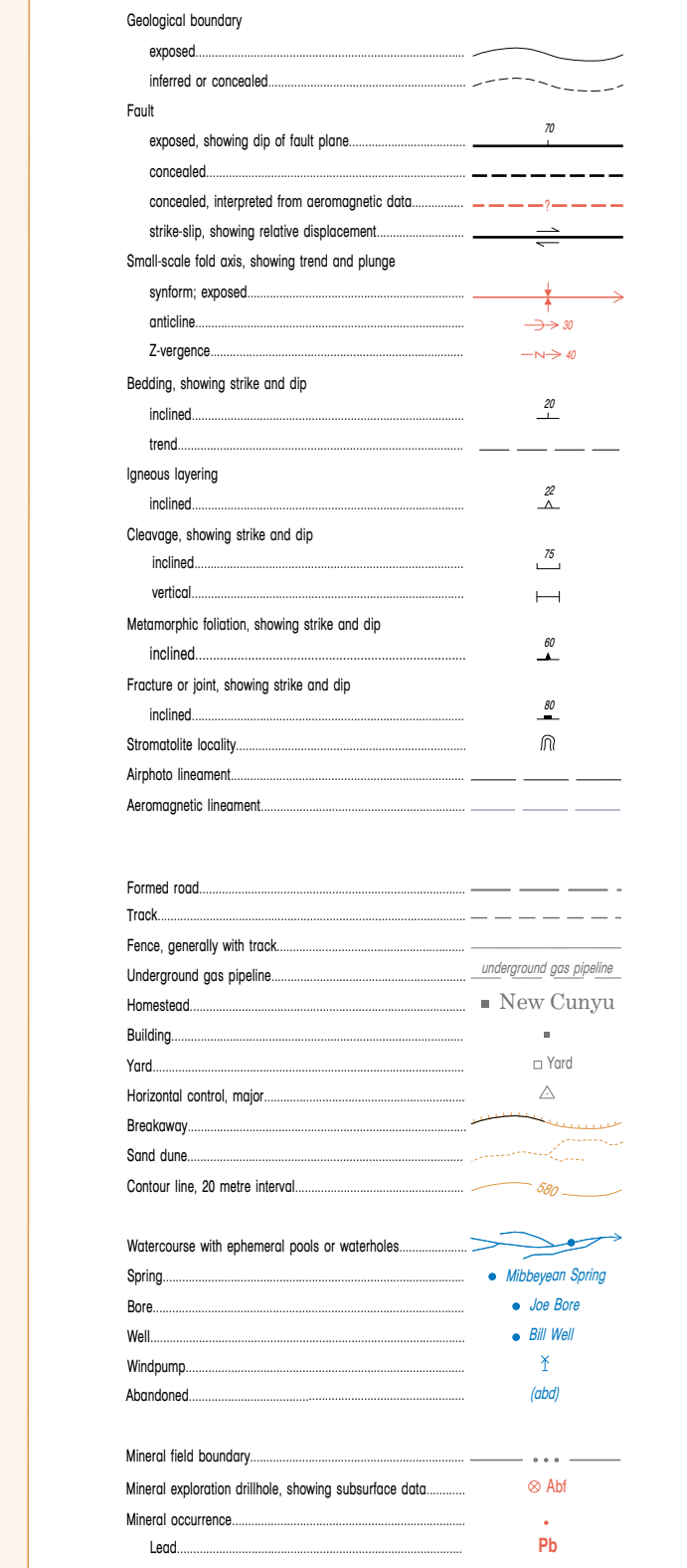
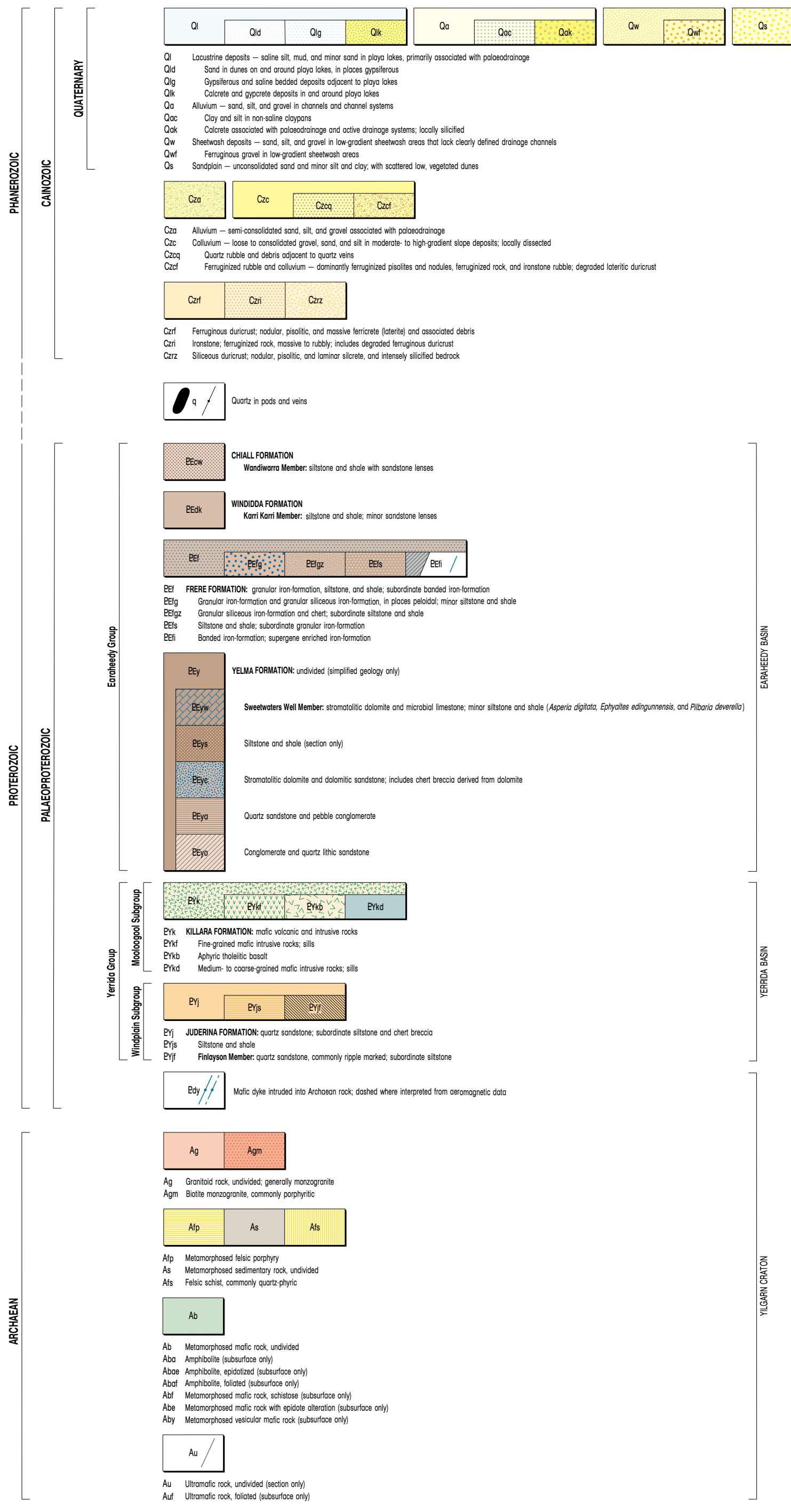
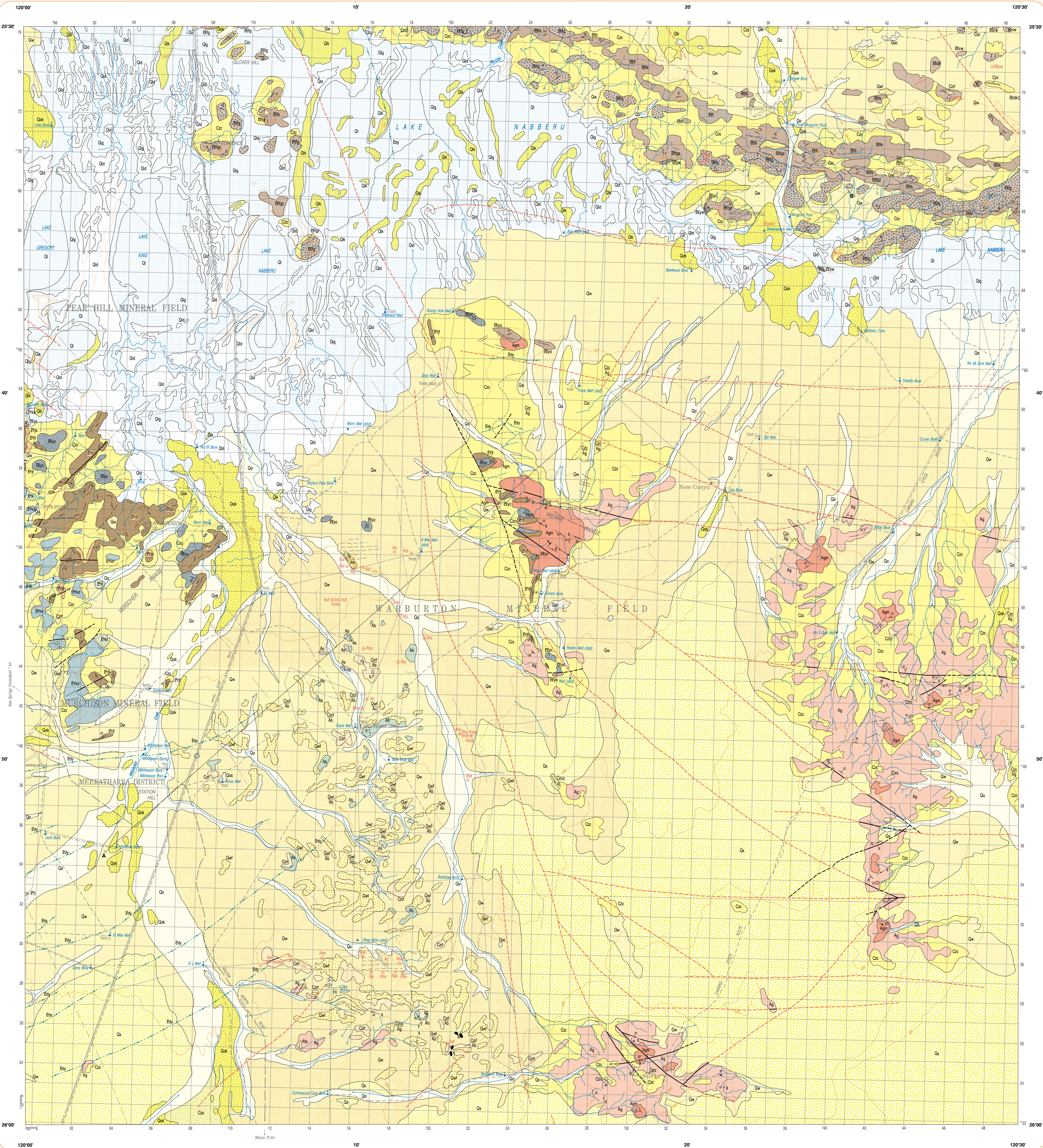
The MERRIE 1:100 000 sheet covers the southwestern part of the NABBERU 1:250 000 sheet. These Explanatory Notes accompany the geological map and describe the geology, structure, and mineralization of this area. The map area includes sedimentary rocks of the Palaeoproterozoic Yerrida and Earraheedy Groups, and Archaean granite–greenstones of the Eastern Goldfields Province. The Archaean rocks contain the Merrie greenstone belt, which is prospective for gold mineralization. The Proterozoic succession mainly consists of shallow-water sandstone and siltstone, locally intruded by mafic rocks, and subordinate carbonates and Superior-type iron-formations. The sedimentary rocks are prospective for Mississippi Valley-type base metal deposits, iron ore, and black-shale-related base-metal mineralization.



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Geology by N. G. Adair  
Edited by G. F. Adair  
Cartography by G. F. Adair  
Topography from the Department of Land Administration Sheet 50 51 52, 2046,  
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ADAIR, N. G., 1999, Merrie, WA Sheet 2946,  
Western Australia Geological Survey, 1:100 000 Geological Series

