EXPLANATORY NOTES

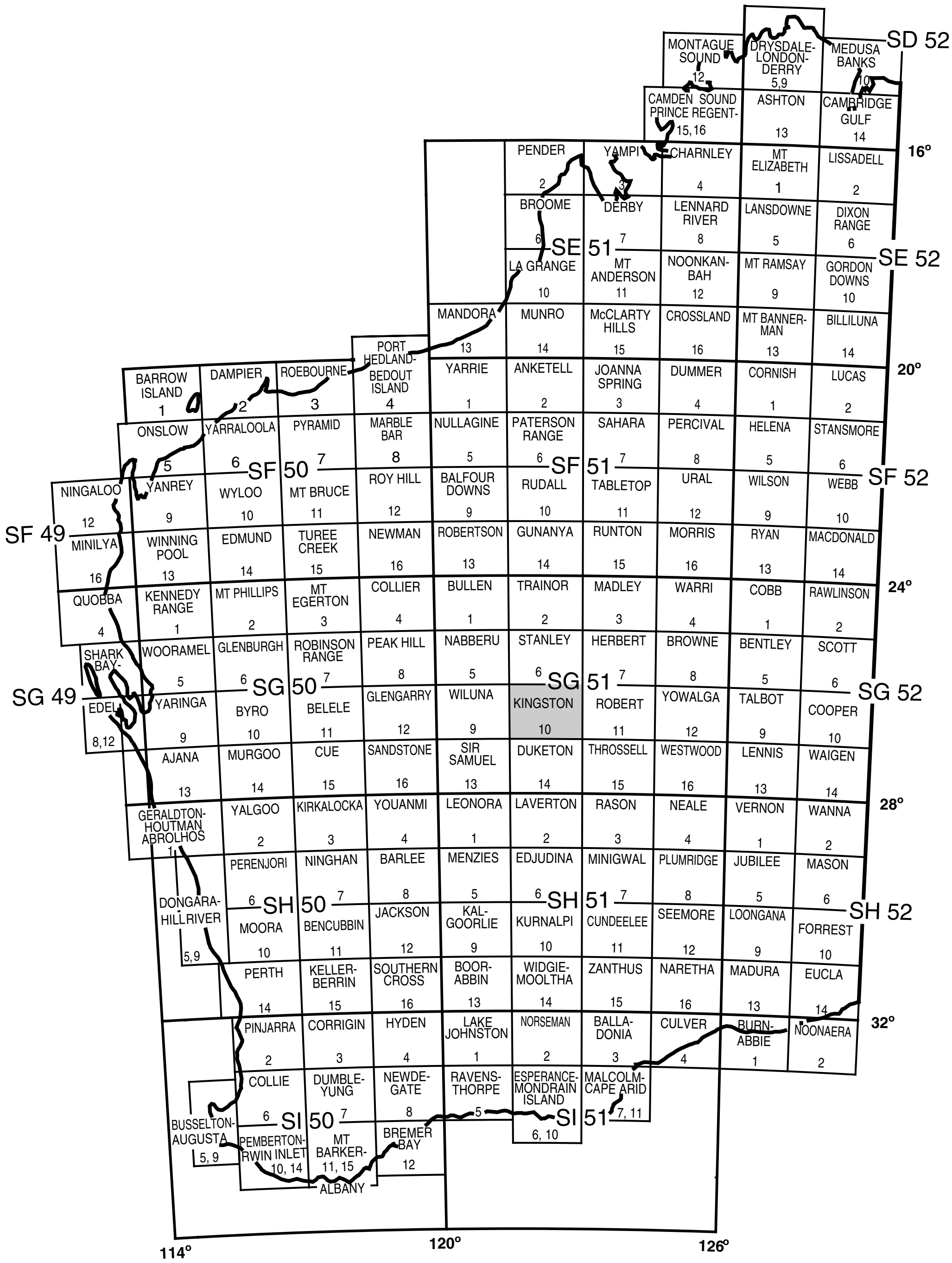
Department of
Industry and Resources

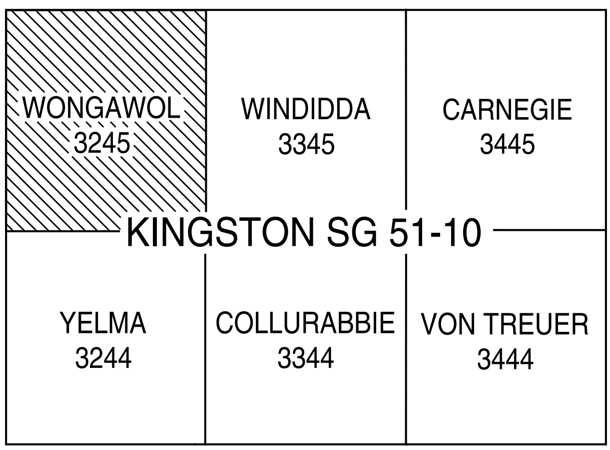
GEOLOGY OF THE WONGAWOL 1:100 000 SHEET

by J. A. Jones

1:100 000 GEOLOGICAL SERIES

Geological Survey of Western Australia





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GEOLOGY
OF THE WONGAWOL
1:100 000 SHEET

by
J. A. Jones

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Cover photograph:
Recumbent fold in the Princess Ranges Member of the Chiall Formation, 3.2 km southwest of Wadjinyanda Pool (MGA 371300E 7116400N)

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Geology of the Wongawol 1:100 000 sheet

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J. A. Jones

Abstract

The WONGAWOL 1:100 000 geological sheet consists of Archaean rocks of the Yilgarn Craton, the Palaeoproterozoic Earaheedy Basin, and discontinuous scattered exposures of the Permian Paterson Formation. Archaean rocks in the southwestern corner of WONGAWOL are part of the Eastern Goldfields Granite–Greenstone Terrane of the Yilgarn Craton. They consist of granitic rocks, banded iron-formation, and the northern part of the Mount Eureka greenstone belt, which comprises north-northwesterly trending metamorphosed ultramafic and mafic rocks.

WONGAWOL is dominated by clastic and chemical sedimentary rocks of the Earaheedy Group, which is divided into the lower Tooloo Subgroup, including the Yelma, Frere, and Windidda Formations, and the upper Miningarra Subgroup, containing the Chiall and Wongawol Formations, Kulele Limestone, and Mulgarra Sandstone. WONGAWOL contains the Tooloo Subgroup, and the Chiall and Wongawol Formations of the Miningarra Subgroup. The Yelma, Chiall, and Wongawol Formations comprise shale, siltstone, and sandstone, and the Frere Formation includes shale, siltstone, and granular iron-formation. The Windidda Formation consists of stromatolitic carbonate and shale. The maximum age for the lower part of the Earaheedy Group is 1840 Ma, whereas the maximum age for the upper part of the Earaheedy Group is 1808 Ma. This suggests that the Earaheedy Group was deposited during the Capricorn Orogeny (1830–1780 Ma). The sedimentary succession within the Earaheedy Group, combined with current age constraints, suggest the Earaheedy Basin was a complex hybrid basin influenced, at least during deposition of the upper part of the Earaheedy Group, by uplift to the west in the southern part of the Gascoyne Complex.

Glacially derived sedimentary rocks of the Permian Paterson Formation and polymictic lags with clasts up to 2 m in diameter discontinuously overlie the Earaheedy Group, and are part of a more extensive Permian landscape that once covered much of Western Australia.

KEYWORDS: Archaean, Palaeoproterozoic, Permian, Yilgarn Craton, Mount Eureka, greenstone, Earaheedy Basin, Capricorn Orogeny, Paterson Formation.

Introduction

Location, access, and previous work

The WONGAWOL* 1:100 000 geological map sheet (SG 51-10, 3245) covers the northwestern part of the KINGSTON 1:250 000 map sheet, from latitude 26°00'S to 26°30'S, and longitude 121°30'E to 122°00'E (Fig. 1). The region is about 130 km northeast of Wiluna†, 230 km east-northeast of Meekatharra, and 260 km north-northeast of Leinster. Access from the south is via the unsealed Gunbarrel Highway, from the west it is through Lorna Glen Station, and from the east, it is via the Windidda – Prenti Downs Road (Fig. 2). Numerous station tracks provide access to most of the sheet. These roads and tracks are generally inaccessible during wet weather, and main roads may be closed by the shire for brief periods following heavy rain. The sheet is covered by Wongawol, Lorna Glen, and Windidda Pastoral Leases, with Wongawol and Lorna Glen Homesteads located within the map sheet. Wongawol and Windidda Homesteads are permanently occupied. Lorna Glen Station is currently owned by the Department of Conservation and Land Management (CALM).

Mapping of WONGAWOL was carried out in 1999, using 1:25 000-scale colour aerial photographs, supplemented by Landsat and aeromagnetic imagery, as part of a remapping program of the Earaheedy Basin by the Geological Survey of Western Australia (GSWA).

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

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

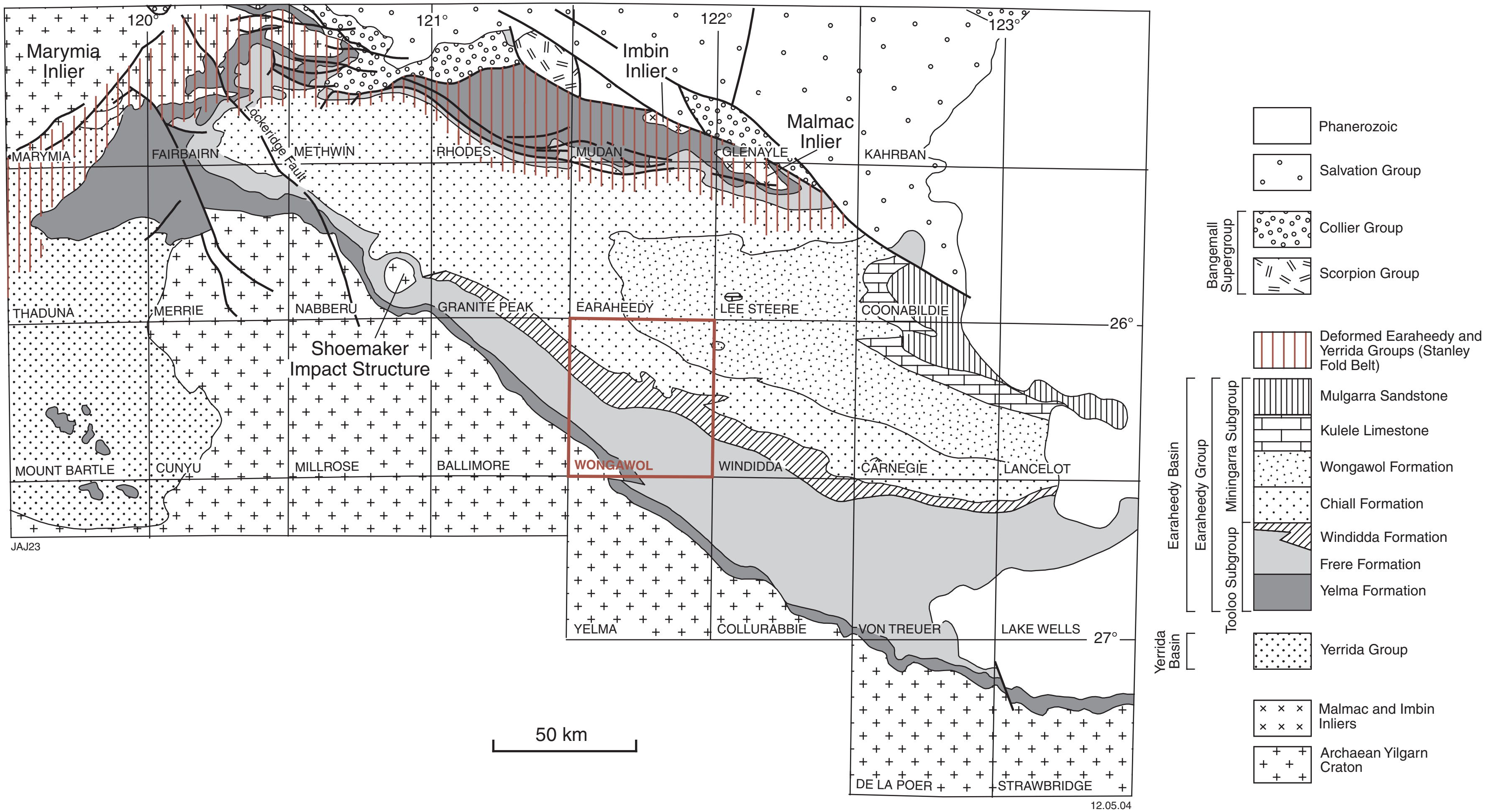

Figure 1. Regional geological setting of WONGAWOL within the Earaheedy Basin

The geology of WONGAWOL was first described by Talbot (1920, 1928). Hall and Goode (1975), and Horwitz (1975) used the name 'Nabberu Basin' for the continuous belt of Palaeoproterozoic sedimentary rocks overlying the northern margin of the Yilgarn Craton. Hall et al. (1977) and Bunting et al. (1977) introduced the terms 'Earaheedy Sub-basin' and 'Glengarry Sub-basin' to account for differences between the eastern and western parts, respectively, of the Nabberu Basin. Hall and Goode (1978) provided the first comprehensive description of the Earaheedy Sub-basin. The KINGSTON, STANLEY, and NABBERU 1:250 000 map sheets (Bunting, 1980; Bunting et al., 1982; Commander et al., 1982) were mapped by the Geological Survey of Western Australia during a study of the eastern part of the Nabberu Basin (now the Earaheedy Basin) that culminated in detailed reports by Bunting (1986) and Grey (1984, 1986, 1995). Gee (1990) presented a summary of the geology of the Earaheedy Basin during a review of the Nabberu Basin. Gee and Grey (1993) summarized work on the Nabberu Basin and recognized that the terminology was inappropriate, finding that the Earaheedy Group belonged to a separate basin. Pirajno et al. (1996, 1998) and Occhipinti et al. (1997) set out the present basin subdivision, preparatory to final reports on the Yerrida (Pirajno and Adamides, 2000), Bryah, and Padbury Basins (Pirajno et al., 2000b). However, Krapez and Martin (1999) combined the Yerrida and Earaheedy Basins, based on sequence stratigraphic analysis.

The hydrogeology of the region is discussed by Sanders (1969), and Sanders and Harley (1971), and the regolith geochemistry of the KINGSTON 1:250 000 map sheet is decribed by Pye et al. (2000).

Climate, physiography, and vegetation

The WONGAWOL region has an arid climate with summer temperatures exceeding 40°C and averaging about 37°C*. Frost is common in winter, with minimum temperatures down to –5°C and average temperatures about 20°C. Rainfall is sporadic as a result of summer cyclones and winter depressions, but averages 239 mm a year. Evaporation rates are up to 2500 mm a year.

The physiography of WONGAWOL (Fig. 2) is characterized by playa lakes and associated drainage systems, low-gradient sheetwash and sandplains, breakaways, and hills of variable relief. Elevations range from 460 m above the Australian Height Datum (AHD) in the lake systems, to 600 m above the AHD in the Princess Ranges. Playa lake systems occupy the northeastern and southwestern corners of WONGAWOL, and are distal extensions of Lake Carnegie. Erosional upland areas, which include the Princess Ranges and Wellington Range, contain resistant strike ridges and cuestas of sandstone in the Yelma, Chiall, and Wongawol Formations, and iron formation in the Frere Formation. Shale, siltstone, and very fine grained sandstone form recessive areas between hills. Breakaways and low rounded hills several metres high are common in thick shale- and siltstone-dominated units. The Archaean greenstone belt in the southwestern corner of the sheet is expressed as low hills capped by ferruginous duricrust. Permian rocks form mesas, breakaways, and low remnant duricrusted residual exposures, which are probably remnants of a more extensive plateau. Broad sheetwash flats and low-gradient slopes, characteristic of the intermediate zone between erosional uplands and saline lake systems, extend between breakaways.

WONGAWOL is within the eastern part of the Gascoyne Region of the Eremaean Botanical Province (Beard, 1990). Samphire dominates in and around the wettest parts of playa lakes, and higher ground and dunes are covered by *Frankenia* sp. and *Atriplex* sp. communities, and *Acacia* sp. scrub. The Princess Ranges and much of the erosional uplands are covered by mulga (*Acacia aneura*), and river gums (*Eucalyptus camaldulensis*) line major creeks. Sandplains and distal wash areas are characterized by spinifex cover (*Triodia* sp.). Large sand dunes are commonly vegetated by eucalypts and grevilleas.

Geological setting

WONGAWOL includes rocks of the Archaean Yilgarn Craton, Palaeoproterozoic Earaheedy Basin, and discontinuous exposures of Permian Paterson Formation. The stratigraphy and major structures on WONGAWOL are shown in Figure 3, and the geological history of the area is summarized in Table 1. The southwestern corner of the map sheet contains granitic rocks and the north-trending Mount Eureka greenstone belt, which is in the northern part of the Eastern Goldfields Granite–Greenstone Terrane in the Yilgarn Craton (Griffin, 1990; Tyler and Hocking, 2001). Magnetic and gravity images indicate that the Yilgarn Craton continues beneath the Earaheedy Group at least as far north as the Stanley Fold Belt.

The Earaheedy Basin lies at the eastern end of the Capricorn Orogen and covers most of the map sheet (Fig. 1; Table 2). The Capricorn Orogen is between the Pilbara and Yilgarn Cratons, and includes several Proterozoic sedimentary basins, the deformed margins of the Archaean Yilgarn and Pilbara Cratons, and the plutonic and high-grade metamorphic rocks of the Gascoyne Complex (Tyler and Thorne, 1990; Occhipinti et al., 1998, 1999a,b; Cawood and Tyler, 2004). Tyler and Thorne (1990) considered that the Yilgarn and Pilbara Cratons collided during the Capricorn Orogeny. Sheppard et al. (2001) suggested that the Capricorn Orogeny was intracratonic.

The Earaheedy Basin, which contains the Earaheedy Group, overlies rocks of the Yilgarn Craton and, on its western edge, the Windplain and Mooloogool Groups of the Yerrida Basin. The Earaheedy Group is overlain by the Collier Group of the Bangemall Supergroup to the north, and by rocks of the Centralian Superbasin (Officer and Gunbarrel Basins) to the east and northeast. The present exposure does not reflect the original extent of the Earaheedy Basin because outliers of probable Earaheedy Group extend for more than 100 km south and southwest over the Yilgarn Craton and older Palaeoproterozoic basins (Adamides, 1998; Dawes and Pirajno, 1998; Pirajno and Occhipinti, 1998).

* Climate data from the Bureau of Meteorology — averaged from data for the following areas: Wiluna, Yeeleerie, and Earaheedy.

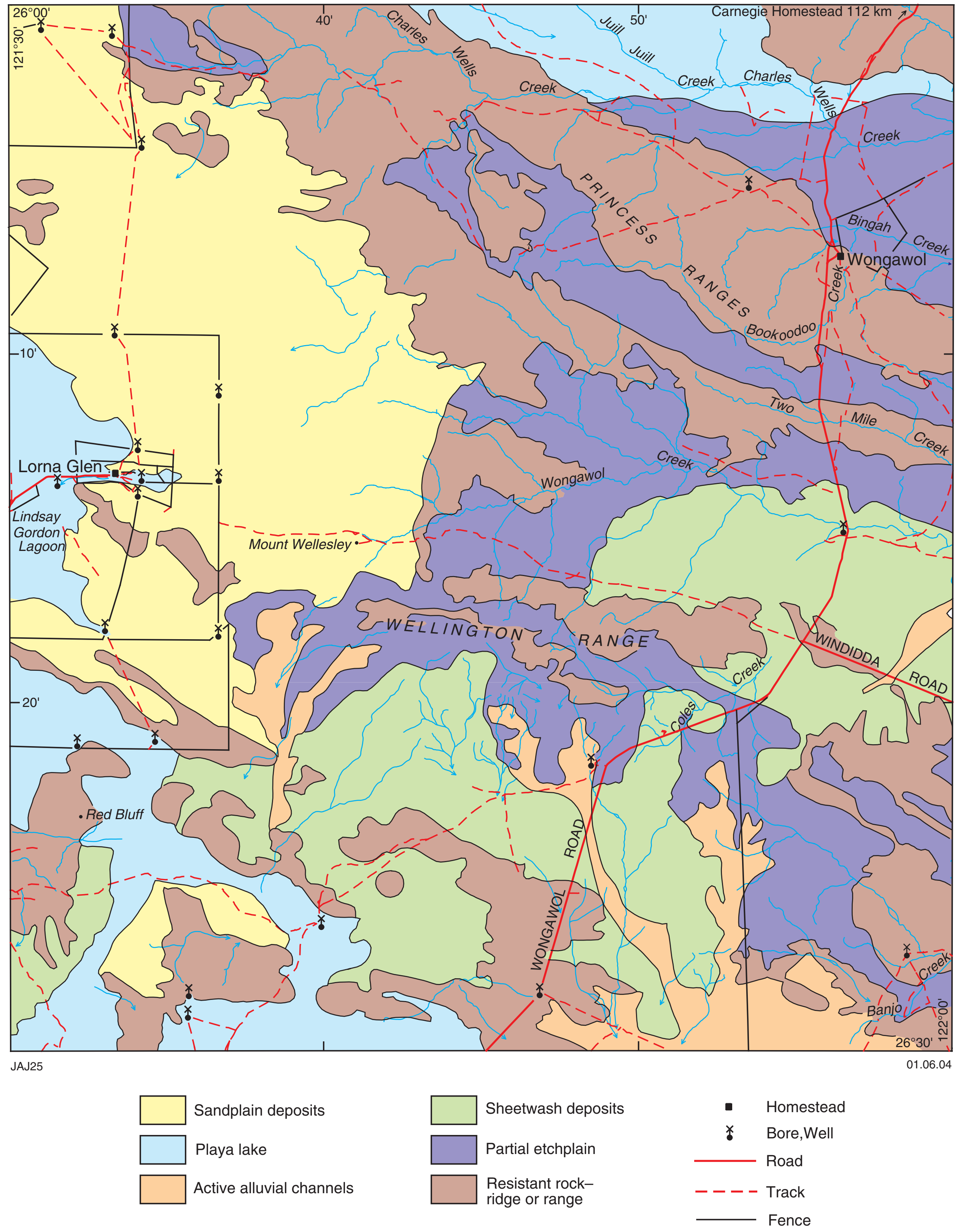

Figure 2. Physiography and access on WONGAWOL

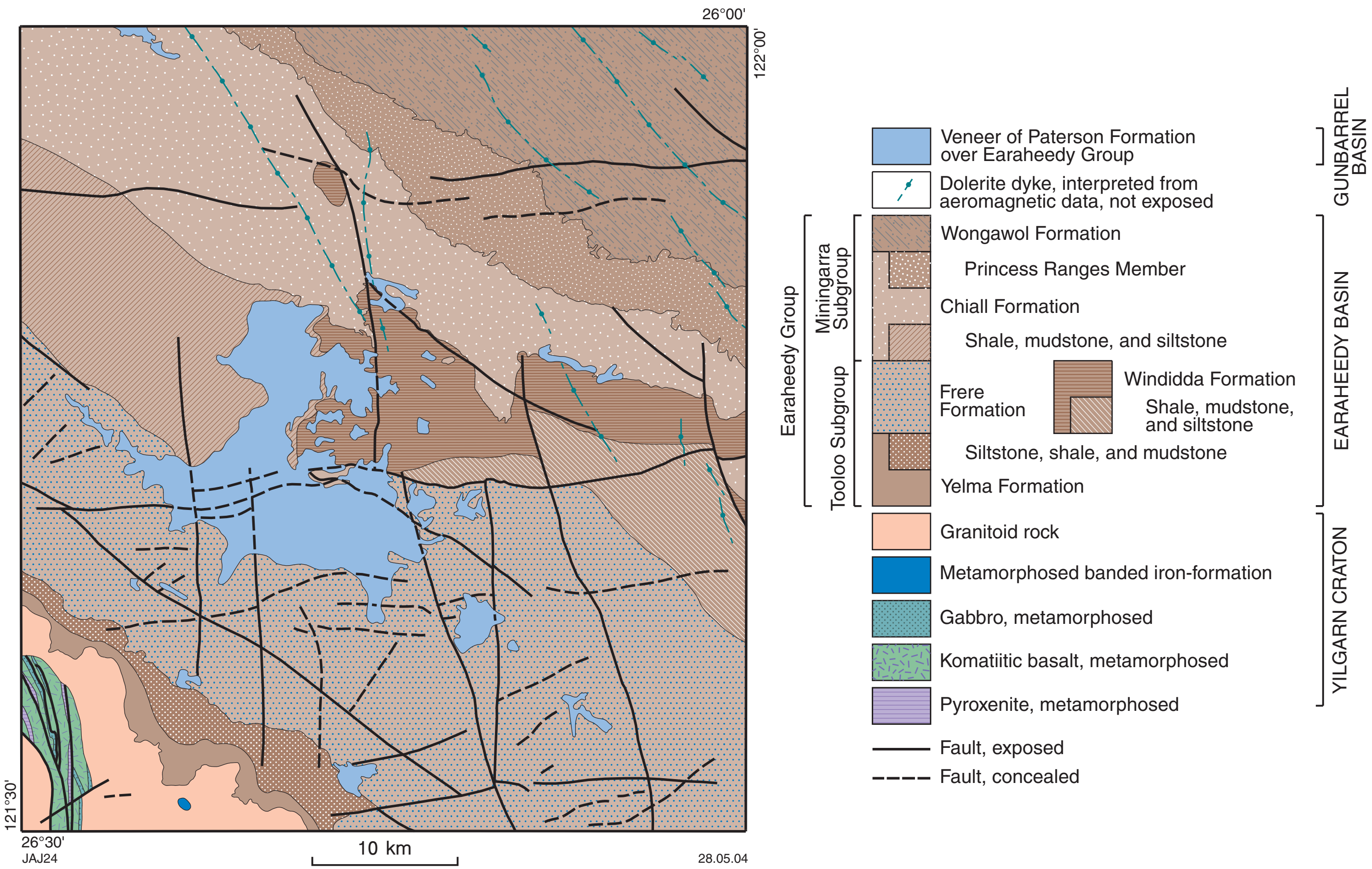

Figure 3. Simplified geological map of WONGAWOL

Table 1. Summary of the geological history of WONGAWOL and adjoining areas. Refer to text for citations and details on ages and events

Age (Ma)	*To west and south*	*Earaheedy Basin*	*To east and north*
Archaean, >2640	Age of northern Yilgarn Craton and Marymia Inlier (basement to Earaheedy Group south of Stanley Fold Belt)		
c. 2200	Deposition of the Windplain Group (Yerrida Basin), on Yilgarn Craton		
<1970, >1802			**Yapungku Orogeny, 1st phase (D_1)**, Paterson Orogen
c. 2000–1800	Deposition of Bryah and Padbury Groups		
2000–1960	**Glenburgh Orogeny** Convergence of Yilgarn Craton and Glenburgh Terrane of Gascoyne Complex		
c. 1990			Extrusion of felsic volcanic rocks in Imbin Inlier (basement to Earaheedy Group north of Stanley Fold Belt)
1840	Deposition of the Mooloogool Group (Yerrida Basin)		
1830–1780	**Capricorn Orogeny**	Deposition of Earaheedy Group	
1790–1760			**Yapungku Orogeny, 2nd phase (D_2)**, Paterson Orogen Convergence of North Australian and West Australian (Yilgarn and Pilbara) cratons
1680-1650	**Mangaroon Orogeny**		
1620	Start of deposition of Edmund Group		?Start of deposition of Scorpion Group, some syndepositional normal faulting
1465	Intrusion of dolerite sills into Edmund Group		
		Folding and erosion of older rocks	
<1211	Start of deposition of Collier Group		
?1200–1100		Deposition of Salvation Group (lower 'Savory Group') in central Western Australia	
1250–900			Deposition of Throssell Group, Paterson Orogen
c. 1130–800			**Miles Orogeny**, Paterson Orogen. Folding and regional deformation due to southwesterly directed compression
1070	Emplacement of mafic sills into Collier and Edmund Groups	Intrusion of Salvation Group by mafic sills (Glen Ayle Dolerite) Intrusion of Earaheedy Group by mafic sills in eastern Earaheedy Basin	Extrusion of parts of Bentley Supergroup in Musgrave Complex (1060 Ma)

Table 1. (continued)

Age (Ma)	*To west and south*	*Earaheedy Basin*	*To east and north*
<1050			Deposition of Lamil Group, Paterson Orogen
<1070, >755	**Edmundian Orogeny** Deformation of Bangemall Supergroup		
820–c. 800			Deposition of Sunbeam Group (base Supersequence 1, Centralian Superbasin) in northwestern Officer Basin
c. 550		**Paterson Orogeny** Brittle deformation in Paterson Orogen, from north-northeast; correlates to Petermann Ranges Orogeny in Musgrave Complex – southern Officer Basin	
?480			Intrusion of cross-cutting dolerite dykes, through Sunbeam Group and dolerite sills
Late Carboniferous – Permian	Continental-scale glaciation of Gondwana, including West Australian craton, with extensive glacially related deposition in Phanerozoic basins, and glacial remnants, surfaces, and landforms over areas of Precambrian bedrock, including eastern Earaheedy Basin		
Late Mesozoic		Development of palaeodrainage system across Western Australian interior, after some periods of ferruginous and siliceous duricrust development	
Late Eocene – Miocene		Waning of interior palaeodrainage system, last significant flow probably late Miocene	
24 000–15 000 yrs BP	Last major dune activity, with formation and mobilization of major dunefields across Western Australia, during arid glacial maximum		

Table 2. Stratigraphic sequence on WONGAWOL

Age	*Basin/Group*		*Formation/Member*	*Lithology*	*Approximate thickness (m)*	*Depositional environment*
Mesoproterozoic	**GUNBARREL BASIN**		**Paterson Formation**	Diamictite, claystone, cross-bedded sandstone	>6	Glacial, locally fluvial
Palaeoproterozoic	**EARAHEEDY BASIN** **Earaheedy Group**	**Miningarra Subgroup**	**Wongawol Formation**	Very fine grained sandstone, siltstone, mudstone, shale, conglomerate	?500	Tidal sand flat
			Chiall Formation: Princess Ranges Member	Texturally mature sandstone, siltstone, shale		Nearshore to coastal
			Chiall Formation	Sandstone, siltstone, shale, conglomerate	600	Regression from below wave base to nearshore coastal
		Tooloo Subgroup	**Windidda Formation**	Stromatolitic carbonate rock, shale, siltstone, jasper, peloidal jasper	600	Carbonate bank and lagoon
			Frere Formation	Granular iron-formation, granular chert, siltstone, shale, chert, jasper	600	Shallow marine (inner shelf) to coastal
			Yelma Formation	Quartz arenite, siltstone, shale	150	Shallow marine, locally fluvial near base, transgressive
Archaean	**YILGARN CRATON** **Mount Eureka greenstone belt**			Granitoid rock, monzogranite Pyroxenite, komatiitic basalt, gabbro		

The Stanley Fold Belt is a west-northwesterly trending zone of deformation along the northern margin of the exposed Earaheedy Basin (Bunting et al., 1982; Commander et al., 1982; Jones et al., 2000a,b; Pirajno et al., 2000a). It is 15 to 30 km wide with the southern edge defined by tectonized Frere Formation. Rocks of the Earaheedy Group are tightly folded and cleaved within the fold belt, and wide mylonite zones are present (Pirajno and Hocking, 2000). These deformed rocks were previously thought to be an older succession, the Troy Creek beds (Bunting et al., 1982; Commander et al., 1982; Bunting 1986; Troy Creek Schist of Hocking and Jones, 1999), but they are now recognized as dynamically metamorphosed Earaheedy Group (Hocking and Jones, 2002).

Scattered outcrops of flat lying to gently dipping fluvio-glacial rocks of the Paterson Formation unconformably (angular unconformity and disconformity) overlie the Earaheedy Group and northern margin of the Yilgarn Craton, and are considered to be part of an Early Permian, glacially influenced land surface.

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Figure 5. Varioles in massive fine-grained basalt, 2.7 km southwest of Red Bluff (MGA 352250E 7078260N). Varioles are rare in the area and only developed in massive fine-grained basalt. They are typically about 1 cm in diameter; coin is 19 mm in diameter

Archaean geology

The southwestern corner of Wongawol contains granitic rocks, minor banded iron-formation, and the northern part of the Mount Eureka greenstone belt (Bunting, 1980; Griffin, 1990), which are part of the Eastern Goldfields Granite–Greenstone Terrane of the Yilgarn Craton. The greenstone belt on Wongawol consists of metamorphosed mafic and ultramafic rocks.

Banded iron-formation (*Aci*)

The only exposure of banded iron-formation (*Aci*) is 1.5 km east of Granite Bore (MGA 361400E 7002000N), where it forms an isolated outcrop surrounded by granitic rocks. Its relationship to the Mount Eureka greenstone belt is unclear. The iron formation comprises parallel-bedded magnetite-rich and ferruginous chert beds, typically less than 1 cm thick, which are tightly folded (Fig. 4).

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Figure 4. Small isolated exposure of Archaean banded iron-formation, 1.5 km east of Granite Bore (MGA 361400E 700200N)

Metamorphosed mafic to ultramafic rocks (*Aux, Aog, Abk*)

The northwesterly trending Mount Eureka greenstone belt in the southwestern corner of Wongawol contains mafic and ultramafic rocks. These rock types are typically well exposed on Wongawol, although some areas are deeply weathered. Although the rocks are metamorphosed, primary textures are usually preserved.

Komatiitic basalt (*Abk*) constitutes the bulk of the Mount Eureka greenstone belt on Wongawol, and is identified by the localized presence of pyroxene spinifex and variolitic textures. About half of the sequence lacks spinifex texture, instead comprising massive fine-grained equigranular basalt. This probably represents the central portions of layered komatiitic basalt flows where spinifex texture was not developed. Varioles, which are typically present only in massive fine-grained basalt (Fig. 5), have an average diameter of 15 mm. In spinifex-textured units, primary pyroxene needles have been replaced by metamorphic amphibole (Fig. 6), and are set in a groundmass of felted chlorite or metamorphic amphibole with some opaque minerals, and interstitial areas filled by feldspar and quartz.

Gabbro (*Aog*) is generally medium grained and comprises interlocking laths of plagioclase and metamorphic amphibole, which has replaced pyroxene. Pyroxenite (*Aux*) is coarse grained and equigranular, and consists of metamorphic amphibole and chlorite (after pyroxene), minor interstitial plagioclase, and opaque minerals. Gabbro and pyroxenite units are mostly parallel to layering in komatiitic basalt, and the contact between gabbro and komatiitic basalt is transitional, possibly reflecting cumulate parts of flows that cooled slower.

Granite (*Ag, Agm*)

Granitic rocks in the southwestern corner of Wongawol are generally undivided (*Ag*) because of the degree of

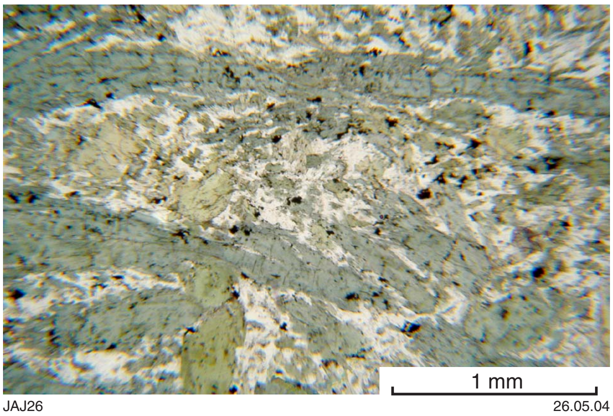

Figure 6. Metamorphic amphibole, which has replaced primary pyroxene laths, in komatiitic basalt (MGA 350120E 7077560N). Laths are up to 1 cm long and set in a groundmass of chlorite and metamorphic amphibole, with interstitial feldspar and quartz; GSWA 153688, plane polarized light, field of view is 3 mm

weathering, with feldspars completely altered to clay minerals, and biotite to chlorite and Fe–Ti oxides. Granitic rocks are typically medium to coarse grained and appear to be leucocratic, although this could be a function of the degree of weathering. Crosscutting quartz and pegmatite veins are common, the latter showing diffuse margins with granitic rocks. This could reflect a coeval, and possibly, genetic relationship. Granite locally contains a north–south-trending foliation, with the intensity of foliation varying from weak to moderate.

Monzogranite (*Agm*) is exposed 3 km northeast of Granite Bore (MGA 362300E 7071200N). It is typically leucocratic and has a typical mineral assemblage of plagioclase, K-feldspar, quartz, and minor biotite. Feldspars are commonly partially altered to sericite, and quartz generally has a granoblastic texture. Texturally, the monzogranite is equigranular and medium grained.

Proterozoic geology

Earaheedy Group

The Earaheedy Basin contains the clastic and chemical sedimentary succession of the Earaheedy Group. The basin unconformably overlies the Archaean Yilgarn Craton, and the Palaeoproterozoic Windplain and Mooloogool Groups of the Yerrida Basin. In the west, the unconformable contact with the Windplain and Mooloogool Groups is disconformable and angular (Fig. 1; Table 2). Outliers of sedimentary rocks that are similar to the Earaheedy Group are exposed to the south and southwest of the present margin, overlying the Yilgarn Craton and Yerrida Basin (Pirajno and Occhipinti, 1998). However, these outliers are also lithologically similar to rocks from other sedimentary basins in the region, so correlation is equivocal.

The Earaheedy Group has an estimated maximum thickness of 5 km, and consists of the lower Tooloo Subgroup and the upper Miningarra Subgroup. In ascending order, the Tooloo Subgroup includes the Yelma, Frere, and Windidda Formations, and the Miningarra Subgroup includes the Chiall and Wongawol Formations, Kulele Limestone, and Mulgarra Sandstone. WONGAWOL contains all the Tooloo Subgroup, and the Chiall and Wongawol Formations from the Miningarra Subgroup. In addition, WONGAWOL contains the type sections for the Yelma and Chiall Formations, and Princess Ranges Member.

The stratigraphy of the Earaheedy Group (Fig. 7) was introduced by Hall et al. (1977) and adopted with minor modifications by Bunting (1986). Current mapping has further modified the stratigraphy (Fig. 7). In the revised stratigraphy (Jones et al., 2000b), the Chiall Formation replaces the Wandiwarra Formation and the Princess Ranges Quartzite, which now have member status (Hocking et al., 2000). Only the Princess Ranges Member is present on WONGAWOL, and rocks previously mapped as Wandiwarra Formation are mapped as undifferentiated Chiall Formation. The lower shale- and siltstone-dominated part of the former Wandiwarra Formation is assigned to the Karri Karri Member, which on NABBERU is shown as part of the Windidda Formation (Pirajno, 1998). The Karri Karri Member is placed within the Chiall Formation on EARAHEEDY and GRANITE PEAK (Jones, 1999; Adamides et al., 2000). With the current boundary constraints placed on the Frere, Windidda, and Chiall Formations, and the lithological characteristics defining these formations, it is easier to assign the Karri Karri Member to the Chiall Formation. However, the lower part of the Karri Karri Member is lithologically more similar to the Tooloo Subgroup and is probably a transitional unit.

Age constraints

A maximum stratigraphic age of 1840 Ma is provided by a SHRIMP U–Pb monazite date in the Mooloogool Group of the Yerrida Basin (Rasmussen and Fletcher, 2002), which underlies the Earaheedy Group. A minimum stratigraphic age is provided by the overlying Bangemall Supergroup (maximum age of 1645 Ma; Martin and Thorne, 2001). The Stanley Fold Belt provides another possible minimum age constraint for the Earaheedy Basin. Pirajno et al. (2000a) and Jones et al. (2000a,b) attributed deformation of the Earaheedy Group in the Stanley Fold Belt to the second phase of the Yapungku Orogeny (1790 to 1760 Ma; Bagas and Smithies, 1998; Bagas et al., 2000), which records the initial collision of the North Australian and West Australian cratons of Myers et al. (1996). However, this age constraint is considered uncertain because there is little evidence to constrain the timing of deformation in the Stanley Fold Belt or the rest of the basin.

Potassium–Ar and Rb–Sr dating of glauconite grains in sandstone from the Yelma Formation on DE LA POER give ages of 1670–1710 Ma and 1556–1674 Ma, respectively (Preiss et al., 1975), and a K–Ar age of 1685 Ma (Horwitz, 1975) was obtained from the base of the Chiall Formation on WONGAWOL. An analysis of glauconite sampled from the same location on WONGAWOL indicates

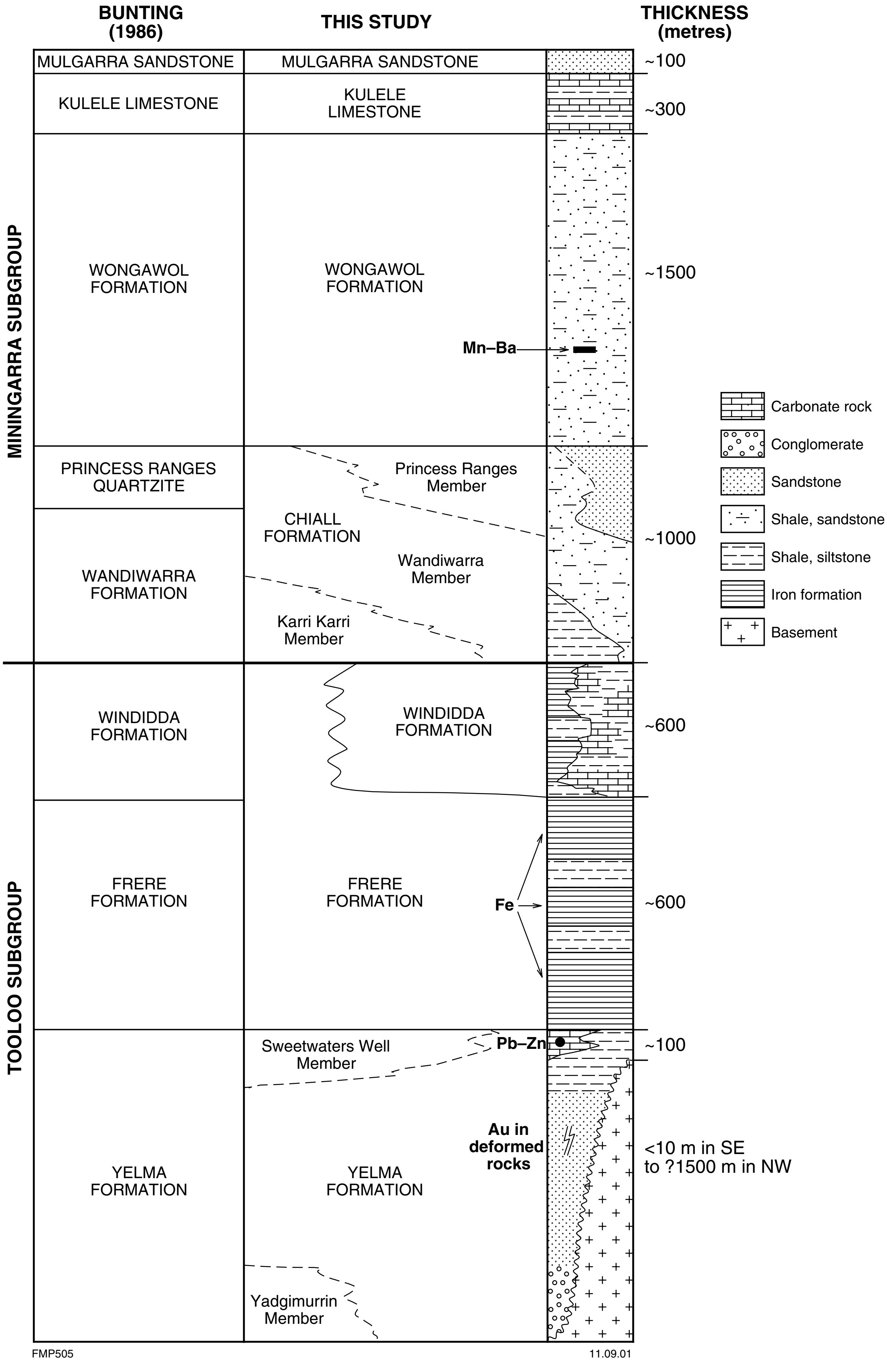

Figure 7. Stratigraphic column for Earaheedy Group, showing simplified rock types, thickness, and potential sites for mineralization

Table 3. Major and trace element data for glauconite in glauconitic sandstone, Chiall Formation

GSWA number	*148375*	
MGA	*270000E 7202900N*	*Analytical method*
	Percentage	
SiO_2	77.3	D/OES
Al_2O_3	7.39	D/OES
TiO_2	0.21	D/OES
Fe_2O_3	6.15	D/OES
MgO	1.04	D/OES
CaO	2.65	D/OES
Na_2O	0.74	D/OES
K_2O	2.01	D/OES
	Parts per million	
Cr	39	AT/OES
Ni	14	AT/OES
Cu	28	AT/OES
Zn	33	AT/OES
Ga	11	AT/MS
As	2	AT/MS
Se	<2	AT/MS
Rb	110.44	AT/MS
Sr	44.58	AT/MS
Y	15.85	AT/MS
Nb	4.05	AT/MS
Mo	0.7	AT/MS
Ag	0.1	AT/MS
Cd	<0.1	AT/MS
In	0.04	AT/MS
Sn	1.5	AT/MS
Sb	0.5	AT/MS
Te	<0.1	AT/MS
Cs	6.97	AT/MS
Ba	408.8	AT/MS
La	13.13	AT/MS
Ce	29.26	AT/MS
Nd	14.65	AT/MS
Hf	2.75	AT/MS
Tl	0.37	AT/OES
Pb	14.0	AT/MS
Bi	0.44	AT/MS
Th	5.98	AT/MS
U	1.85	AT/MS
Pr	3.66	AT/MS
Hf	2.75	AT/MS
Ta	0.54	AT/MS

NOTES: AT: Multi-acid digest (hydrofluoric, nitric, perchloric, hydrochloric) in Teflon test tubes
D: Oxidative alkaline fusion using sodium peroxide as flux in zirconium crucibles, and hydrochloric acid to dissolve melt
MS: Inductively coupled plasma mass spectrometry
OES: Inductively coupled plasma optical emission spectrometry

that the K content is extremely low (Table 3) and could reflect loss of K. These dates are therefore interpreted to be unreliable and provide minimum ages for the Earaheedy Group. The loss of K and young ages for the Earaheedy Group could relate to post-depositional resetting during either a deformational event, or a thermal event related to igneous activity, or a combination of these. Richards and Gee (1985), and Teen (1996) reported Pb–Pb mineralization ages of c. 1.65 Ga for the Magellan deposit in outliers of Yelma Formation overlying the Yerrida Basin, and c. 1.77–1.74 Ga for the Sweetwaters Well Member on MERRIE.

Maximum isotopic ages for the Earaheedy Group are provided by SHRIMP U–Pb geochronology of detrital zircons. Ages for the Yelma, Chiall, and Wongawol Formations, and Mulgarra Sandstone range between 1800 and 3400 Ma (Halilovic et al., 2002, 2004). The youngest detrital zircon age in the Tooloo Subgroup of 1990 Ma is from the Yelma Formation, and the youngest detrital zircon age in the Miningarra Subgroup of 1808 Ma is from the Mulgarra Sandstone. Detrital zircons from the Yelma Formation at the base of the Tooloo Subgroup on NABBERU gave SHRIMP U–Pb zircon ages between 2027 and 2800 Ma (Nelson, 1997).

Grey (1995) suggested a depositional age of 1900–1800 Ma, based on the stromatolite taxa of the Earaheedy Group and their similarity to taxa in the Duck Creek Dolomite of the upper Wyloo Group. Lead–Pb whole-rock dating of carbonate in the Yelma Formation returned ages of 2010 Ma and 1950 Ma (Russell et al., 1994).

The current age constraints suggest that the upper part of the Earaheedy Basin is c. 1800 Ma in age, which reflects deposition during the Capricorn Orogeny (1830–1780 Ma; Occhipinti et al., 2001). The age of the lower part of the Earaheedy Group is less well constrained. It is unclear from current age constraints whether there was a significant time break between deposition of the Mooloogool and Earaheedy Groups. There is little evidence in the Earaheedy Group to suggest major active tectonism within the exposed depocentre for the Earaheedy Basin, although there is evidence to support regional tectonism, such as the presence of seismites. Detrital zircon populations (Halilovic et al., 2002, 2004) and palaeocurrent directions indicate the Yilgarn Craton was an important source for the Earaheedy Basin, but there was also a significant source to the west and southwest, which is possibly related to uplift in the southern Gascoyne Province during the Capricorn Orogeny.

Yelma Formation (*ɆEy*, *ɆEya*, *ɆEysl*)

The Yelma Formation (*ɆEy*) is the basal unit of the Earaheedy Group. On WONGAWOL, it consists of sandstone, siltstone, shale, and mudstone. WONGAWOL contains the type section for the Yelma Formation (Hall et al., 1977), which is about 6.5 km east of Granite Bore in the southwestern corner of the sheet (between MGA 367200E 7069600N and 367200E 7071400N). The maximum thickness of the type section is 150 m, but the Yelma Formation is calculated to be locally up to 1500 m thick on the STANLEY 1:125 000 map sheet, and less than a few metres thick in the southeastern Earaheedy Basin (Bunting, 1986). The basal unconformity with Archaean granite is well exposed in the type section, 2 km north of Granite Bore and at Red Bluff. The upper conformable contact with the Frere Formation is placed at the first occurrence of chert or granular iron-formation (Bunting, 1986), and is exposed 3 km northwest of Beru Pool (MGA 369000E 7078200N). Palaeocurrent directions are variable but concentrate in a northerly to northeasterly direction.

The type section for the Yelma Formation consists, from the base upwards, of about 4 m of medium- to

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Figure 8. Mudcrack moulds in sandstone in the lower part of the Yelma Formation, 2.9 km east of Red Bluff (MGA 352385E 7080320N) indicating a locally emergent depositional environment; lens cap is 6 cm in diameter

coarse-grained sandstone (*ᵽEya*), which commonly contains varying proportions of pebble-sized clasts of subangular to subrounded vein quartz (above the unconformable contact with Archaean granitic rocks), interbedded with thin (<5 cm) siltstone and mudstone beds. This is overlain by about 50 m of interbedded medium- to fine-grained sandstone, shale, siltstone, and mudstone. The upper part of the type section, which is about 100 m thick, consists of thinly bedded siltstone, mudstone, and shale (*ᵽEysl*).

The basal medium- to coarse-grained sandstone contains asymmetrical and symmetrical ripple marks, trough cross-bedding, shrinkage textures (Fig. 8), and small stellate pseudomorphs after ?gypsum (Fig. 9). Sandstone beds are up to 1 m thick but are generally about 50 cm in thickness. Sandstone-dominated units in the overlying interbedded sandstone, shale, siltstone, and mudstone interval are typically less than 1 m thick, and individual beds are commonly less than 20 cm thick. Shale, siltstone, and mudstone in the upper part of the Yelma Formation become progressively more iron-rich towards the contact with the Frere Formation. This upper package is similar to shale, siltstone, and mudstone horizons in the Frere Formation, and was originally considered to be part of the Frere Formation (Hall et al., 1977). Bunting (1986) revised the definition for the lower contact of the Frere Formation with the Yelma Formation, and placed the upper shale, siltstone, and mudstone package in the Yelma Formation.

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Figure 9. Stellate pseudomorphs, possibly after gypsum, in sandstone in the lower part of the Yelma Formation, 2.9 km east of Red Bluff (MGA 352385E 7080320N). The pseudomorphs suggest locally evaporitic conditions

The stratigraphy in the type section is consistent for all exposures of Yelma Formation on WONGAWOL. Elsewhere in the Earaheedy Basin, this type section is not representative of the Yelma Formation because of lateral facies and thickness variations. To the southwest of WONGAWOL, on COLLURABBIE, the Yelma Formation comprises, from the base upwards, fine- to medium-grained sandstone, locally containing angular vein-quartz clasts and interbedded with minor siltstone at the base, overlain by algal-laminated carbonate units, with siltstone at the top of the formation (Jones, in prep). To the northwest of WONGAWOL, on NABBERU and MERRIE, the Yelma Formation is poorly exposed but appears to contain a lower association of sandstone and siltstone overlain by stromatolitic carbonate units (Sweetwaters Well Member), which are overlain by dolomitic, feldspathic sandstone (Adamides, 2000; Pirajno et al., 2004b). In the western part of the Stanley Fold Belt on METHWIN (Hocking and Jones, 2002) and FAIRBAIRN (Adamides et al., 2000), the Yelma Formation is considerably thicker. Although it is difficult to construct a stratigraphy for the Yelma Formation in this area due to the degree of deformation and lateral facies changes, it appears to comprise siltstone and conglomerate at the base, overlain by minor carbonate units and interbedded siltstone, sandstone, and conglomerate.

Palaeocurrent data for the Yelma Formation on WONGAWOL are limited, and restricted to the lower part of the formation. Available palaeocurrent directions are scattered but suggest sediment transport was towards the north.

The Yelma Formation is interpreted to record a marine transgression over the Yilgarn Craton. Sedimentary structures suggest a shallow water to partly emergent, fluvial to coastal marine depositional environment, which was locally evaporitic at the base of the Yelma Formation on WONGAWOL. The upper part of the Yelma Formation on WONGAWOL suggests quiet water conditions, and could reflect deposition in a lagoonal environment developed behind a carbonate bank, possibly represented by the Sweetwaters Well Member. The detrital zircon populations are dominantly 2.6–2.7 Ga in age, with a smaller 2.2 Ga population and minor 2.0 Ga zircons, and suggest the Yilgarn Craton and southern Gascoyne Complex were important sediment sources during basin development.

Frere Formation (*ᵽEf*, *ᵽEfg*, *ᵽEfgz*, *ᵽEfsl*, *ᵽEfslc*, *ᵽEfslj*)

The Frere Formation (Hall et al., 1977) consists of granular iron-formation, granular chert, chert, jasper, shale, and siltstone with minor sandstone. The lower and upper contacts of the formation are placed at the first and last thick beds of iron formation or chert (Hall et al., 1977; Bunting, 1986), and are transitional. The thickness of the Frere Formation is considered to be about 600 m in the type section on NABBERU (Pirajno et al., 2004a). The thickness on WONGAWOL is difficult to estimate because of structural complications, but is interpreted to attain a maximum of 800 m. The proportion of granular iron-formation to shale and siltstone is estimated to be about one-third of that for the type section.

Granular iron-formation (*PEfg*) consists of granular iron-oxide beds or granular chert beds (*PEfgz*) interbedded with chert and jasper, and shale and siltstone, which are locally iron-rich. On WONGAWOL, granular iron-oxide beds and granular chert beds are generally less than 10 cm thick, although locally they can be up to 20 cm thick. Granular iron-oxide beds are composed of hematite, jasper, and chert peloids, oolites, and oncolites in a chert or jasper cement. Granular chert beds are composed of variably ferruginous chert and chalcedonic peloids, oolites, and oncolites in a ferruginous chert or chalcedonic cement. Iron oxides and chert grains range from granule to medium sand (1–3 mm) in size, but are typically coarse sand-sized. The variable sphericity of granules is mainly a function of early diagenetic compaction, and the lack of structure in some granules could relate to diagenesis. Partially recrystallized grains are commonly concentrically laminated, with recrystallization enhancing the original structure of the grains. Septarian cracks are common in peloids, oolites, and oncolites, and were probably developed during diagenesis. Angular to subrounded, mostly tabular intraclasts of chert or jasper are common in granular iron-oxide and granular chert beds, and are typically up to 7 cm long. Locally, intraclasts represent in situ reworking of underlying partially lithified chert, jasper, siltstone, and mudstone beds. Cross-bedding is rare in granular iron-oxide and chert beds (Fig. 10) on WONGAWOL, but where present indicates a northwesterly palaeocurrent direction.

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Figure 10. Planar cross-bedding in a granular chert bed of the Frere Formation, 12 km northeast of Banjo Well (MGA 390735E 7068910N). Cross-bedding is rare in granular chert and granular iron-oxide beds but, where present, palaeocurrent directions are to the northwest; hammer is 32.5 cm long

Hematite is precipitated at the anoxic–oxic interface where Fe^{2+}, transported by upwelling currents, is oxidized to Fe^{3+}. Although hematite is the dominant iron-oxide, magnetite is also present as euhedral crystals that crosscut peloid boundaries, suggesting post-depositional recrystallization in less oxidizing conditions.

Siltstone and shale are interbedded with iron formation at all scales. In the lower part of the Frere Formation, thick siltstone and shale units (*PEfsl*), and siltstone and shale interbedded with chert (*PEfslc*) or jasper (*PEfslj*) horizons are typically parallel-planar laminated with minor cross-lamination. Cross-lamination, and symmetric, asymmetric, and interference ripple marks are more common in these units in the upper part of the Frere Formation. Palaeocurrent directions are dominantly towards the northwest. Minor thin (<5 cm) granular iron-oxide or granular chert beds are present within these horizons, and become more abundant close to the transitional contact with granular iron and chert horizons. Many of the chert beds represent secondary silicification of fine-grained siltstone beds, with a lateral silicification front from unsilicified mudstone into chert preserved in several areas. Siltstone and shale units are similar to those in the underlying Yelma Formation, and overlying Windidda and Chiall Formations. Sedimentary structures on WONGAWOL suggest that the base of the Frere Formation was deposited in a quiet water environment, possibly a barred lagoon. The upper part of the Frere Formation reflects a shallow water environment influenced by wave and current action.

Granular siliceous units (*PEfgz*) and siltstone, shale, and chert units (*PEfslc*) are interpreted to be produced by secondary silicification due to hydrothermal fluid flow along major structures, fluctuations in iron and silica supply during deposition, or weathering (see **Paterson Formation**), or a combination of these processes. Chert grains and cement in granular chert beds located on or proximal to interpreted faults are typically strongly recrystallized with localized crackle breccias infilled with quartz (Fig. 11). In granular chert 5.4 km northeast of Paddy Bore (MGA 366200E 7091900N), these cracks are surrounded by silicified haloes (Fig. 12).

Detailed studies of granular-iron formation in the Earaheedy Group (Hall and Goode, 1978; Goode et al., 1983; Bunting, 1986) indicate textural similarities with iron formations of the Lake Superior region of North America (Gross, 1972; Morey, 1983; Kimberley, 1989). Features common to both are peloidal, oolitic, and oncolitic textures; orthochemical and allochemical cements; iron-rich chlorite; and accessory minerals such as minnesotaite and stilpnomelane. These features are interpreted to result from chemical deposition followed by limited reworking of the sediment while still plastic (Beukes and Klein, 1990, 1992). Microfossils from the Frere Formation were described by Walter et al. (1976) and re-evaluated by Tobin (1990). Tobin (1990) recognized eight distinct microbial assemblages, which he indicated were similar to those in the Gunflint Iron Formation of North America and the Duck Creek Dolomite of Western Australia. Although the model of Beukes and Klein (1990, 1992) accounts for the volume of iron in the Frere Formation, it fails to explain the association of iron and silica in grains of biogenic origin. It is possible that many

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Figure 11. Crackle breccia infilled with quartz in granular chert of the Frere Formation, 5 km southeast of Paddy Bore (MGA 366260E 7090670N). The breccia contains clasts with a jigsaw fit, and open space filling, and is located near the intersection of major easterly and northerly trending structures. It is interpreted to be related to hydrothermal flow along these structures

of the granules were incorrectly classified as peloids. Petrographic observations suggest that, locally, these grains be identified as oncolites, in which case the model proposed by Beukes and Klein (1990, 1992) is inappropriate for the formation of granular iron-formation in the Frere Formation. Biogenic activity could be more important in the development of granular iron-formation than previously recognized.

Windidda Formation (*ⱣEd, ⱣEdj, ⱣEdh*)

The Windidda Formation consists of stromatolitic carbonate units, shale, siltstone, jasper, and granular jasper, and was interpreted by Bunting (1986) to overlie the Frere Formation. It is interpreted here as being stratigraphically equivalent to the upper part of the Frere Formation in the northern part of the exposed Earaheedy Group, based largely on stratigraphic and sedimentological relationships exposed on WONGAWOL and GRANITE PEAK. The lower contact with the Frere Formation is defined as the first occurrence of a carbonate unit or the last occurrence of iron formation, chert, or jasper. On WONGAWOL, the contact with the Frere Formation is either faulted or transitional. The upper contact with the Chiall Formation is defined as the last occurrence of a carbonate unit (Hall et al., 1977; Bunting, 1986).

The Windidda Formation on WONGAWOL has a maximum thickness of 150 m and consists of two units: a shale, mudstone, and siltstone unit (*ⱣEdh*); and a carbonate unit interbedded with shale, mudstone, and minor granular jasper (*ⱣEd*). Shale- and mudstone-dominated units (Fig. 13) contain laminated to massive carbonate beds of variable thickness that are generally less than 1 cm thick. Stromatolites are common in the carbonate-dominated units, with stromatolite taxa consisting of *Carnegia wongawolensis* Grey 1984, *Nabberubia toolooensis* Grey 1984, *Windidda granulosa* (Preiss 1976) Grey 1984, and cf. ?*Kulparia* f. indet. Preiss 1976. *Carnegia wongawolensi* is the dominant form recognized on WONGAWOL and built colonies of branching forms. Detailed descriptions of these stromatolites are contained in Grey (1984). Jasper beds, which are up to 10 cm thick, are interbedded with carbonate in carbonate-dominated units. Locally, granular jasper forms a matrix to stromatolites. In places, the proportion of granular jasper is high, forming granular iron-formation beds (*ⱣEdj*). Thirteen kilometres east of Curdle Well (MGA 374040E 7103130N), the cores of some concentrically zoned larger granules consist in places of a yellowish-green iron-silicate mineral, possibly glauconite or chamosite, which is partially replaced by hematite, suggesting the iron oxides are secondary. Intraclastic carbonate breccias are common in the Windidda

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Figure 12. Silicification haloes surrounding quartz fracturing in granular chert of the Frere Formation, 5.4 km northeast of Paddy Bore (MGA 366000E 7091740N). Very fine grained disseminated pyrite and arsenopyrite are present in the alteration haloes, and their abundance increases with increasing intensity of fracturing, brecciation, and leaching; pen is 14 cm long

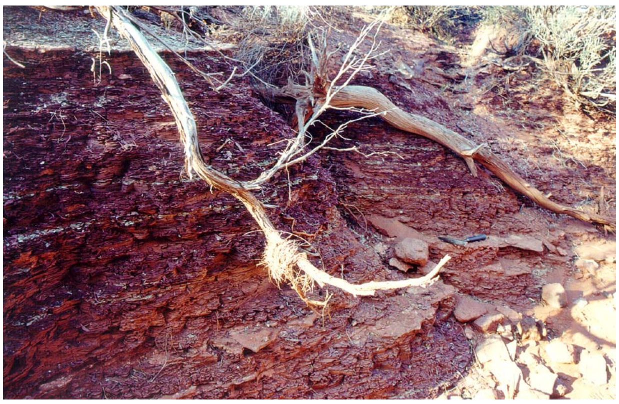

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Figure 13. Interbedded siltstone and thin carbonate beds within a shale- and mudstone-dominated unit of the Windidda Formation, from a creek cutting 10.5 km southeast of Curdle Well (MGA 371610E 7102415N). The carbonate beds are typically less than 1 cm thick, and are massive to laminated

Formation, becoming more abundant towards the upper part of the formation. Locally, carbonate conglomerate is exposed at the top of the Windidda Formation, and is commonly transitional to a siliciclastic conglomerate at the base of the Chiall Formation. Clasts are generally well rounded, up to 15 cm in length, comprising mainly carbonate-dominated rock or siltstone, and imbricate in places. The horizon contains rare small stromatolites. The conglomerate is cemented by carbonate, and has a glauconite and quartz sandstone matrix.

Inliers of stromatolitic carbonate units, surrounded by Chiall Formation, about 7.5 km southwest of Wadjinyanda Pool (MGA 371000E 7113000N), are considered to be part of the Windidda Formation because of the similarity in stromatolite forms. The carbonate units are interpreted to have been uplifted along a reactivated Archaean structure trending north–south. Stromatolites in this area are typically elongate, with their long axes measuring up to 30 cm, suggesting the influence of current action.

Where the Frere Formation is not in faulted contact with the Windidda Formation, it is overlain by poorly exposed shale, siltstone, and mudstone (*PEdh*). This is similar to shale, siltstone, and mudstone units in the Frere Formation and upper part of the Yelma Formation, and possibly the Karri Karri Member at the base of the Chiall Formation. The shale, siltstone, and mudstone package (*PEdh*) at the base of the Windidda Formation was incorporated into the Windidda Formation because of limitations in the current definition for the Frere Formation, but it is lithologically more consistent with the Frere Formation.

The Windidda Formation is interpreted to reflect a carbonate bank and lagoonal environment that developed synchronously with deposition of granular iron-formation. Minor jasper granules, washed into the carbonate bank and lagoonal environment, and intraclastic breccias probably reflect storm events.

Chiall Formation (*PEc*, *PEcp*, *PEcpp*, *PEcsa*, *PEcs*, *PEcsp*, *PEcsha*, *PEcsh*, *PEcse*)

The Chiall Formation (Hocking and Jones, 1999; Hocking et al., 2000) consists mainly of very fine grained sandstone, siltstone, shale, and mudstone punctuated by fine- to medium-grained sandstone beds and minor conglomerate. It contains the Karri Karri, Wandiwarra, and Princess Ranges Members. The Wandiwarra and Princess Ranges Members, which were previously considered formations (Hall et al., 1977; Bunting, 1986), were relegated to member status within a single formation after being recognized as part of a single depositional package**.** Only the Princess Ranges Member is identified on WONGAWOL. The Wandiwarra and Karri Karri members are not present on WONGAWOL because of either lateral facies variations or poor stratigraphic controls.

Undivided Chiall Formation (*PEc*) consists of shale, mudstone, and siltstone, interbedded with fine- to medium-grained sandstone beds that range in thickness from 5 to 50 cm but are typically less than 10 cm.

The base of the Chiall Formation is transitional and laterally variable on WONGAWOL. On the western part of the sheet, the base of the Chiall Formation apparently comprises siltstone, shale, and mudstone (*PEcsh*), which are probably equivalent to the Karri Karri Member. However, the rocks are not assigned to the Karri Karri Member because exposure is poor, with small isolated outcrops, so identification is uncertain. Shale, siltstone, and minor very fine grained sandstone (*PEcsha*) are similar to the upper part of the Karri Karri Member on METHWIN, NABBERU, and GRANITE PEAK but are not assigned to that member because of poor stratigraphic constraints. In the central part of WONGAWOL, the base of the Chiall Formation consists of very fine to fine-grained sandstone, siltstone, shale, and mudstone. Further east, conglomerate is interbedded with this facies at the base of the Chiall Formation (*PEcse*), with the proportion of conglomerate increasing eastward.

Conglomerate (*PEcse*) at the base of the Chiall Formation is texturally variable, consisting of poorly sorted boulder conglomerate and pebble conglomerate. Clasts are locally imbricate and the clast type is variable, commonly reflecting the underlying rocks and suggesting a strong local source control. Fine-grained sandstone, siltstone, and carbonate-rich rock are the dominant clast types, with the proportion varying both up sequence and along strike. Poorly sorted boulder conglomerate is generally laterally restricted and weakly bedded. Clasts vary from subrounded to angular, but are typically angular. About 5 km northwest of Kepaltin Spring (MGA 389980E 7099132N), poorly sorted boulder-conglomerate beds (Fig. 14) are up to 4 m thick. They consist of angular clasts of dominantly carbonate-rich rock and minor sandstone, in a coarse-grained sandstone matrix containing glauconite peloids and cemented by a ferruginous clay. Pebble conglomerate beds,

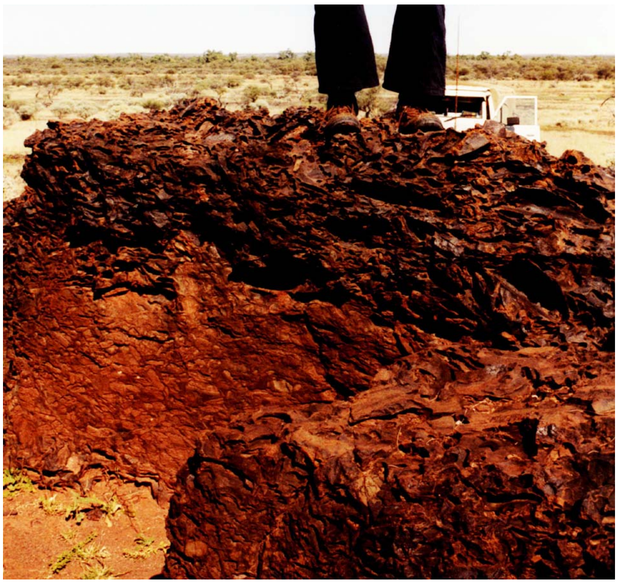

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Figure 14. Conglomerate at the base of the Chiall Formation, 5.1 km northwest of Kepaltin Spring (MGA 389980E 7099132N). Clasts are dominantly carbonate, in a glauconitic sandstone matrix

which are interbedded with siltstone, mudstone, and very fine and fine-grained glauconitic sandstone at the base of the Chiall Formation, are typically less than 50 cm thick.

Bunting (1986) suggested that conglomerate at the base of the Chiall Formation represented a disconformity between the Tooloo and Miningarra Subgroups. However, there is little evidence to support a significant break in sedimentation between the two subgroups. The contact between conglomerate of the Chiall Formation and the Windidda Formation is transitional, except for localized exposures of cobble conglomerate, and reflects a change from carbonate-cemented conglomerate to conglomerate with a sandstone matrix. It is also important to recognize that basal conglomerate in the Chiall Formation is relatively restricted both laterally and up sequence, and mostly overlies carbonate units of the Windidda Formation.

Interbedded siltstone, mudstone, shale, and fine- to very fine grained sandstone, which is locally calcareous (*ⱣEcsa*), typifies the lower part of the Chiall Formation below the Princess Ranges Member, and is similar to the lower part of the Wongawol Formation. The sandstone contains green iron-silicate minerals, especially near the base of the Chiall Formation. These iron-silicate grains were previously referred to as glauconite in the Earaheedy Group, but other iron-bearing species such as berthierine and chamosite are probably present. In addition, jasper peloids are also common at the base of the Chiall Formation in fine- and very fine grained sandstone. The green iron-silicate grains are commonly peloidal and oolitic. At the base of the Chiall Formation, in the central part of WONGAWOL, green iron-silicate grains are flattened and deformed in particular beds (Fig. 15), indicating they were plastic during compaction. The proportion of green iron-silicate minerals in these beds is generally high. Sedimentary structures at the base of the Chiall Formation include parallel laminations, load casts, and minor cross-laminations. These are overlain by units characterized by symmetrical and asymmetrical ripple marks, rills (Fig. 16), wrinkle marks, and contorted bedding, which overall are more common sedimentary structures in the lower Chiall Formation.

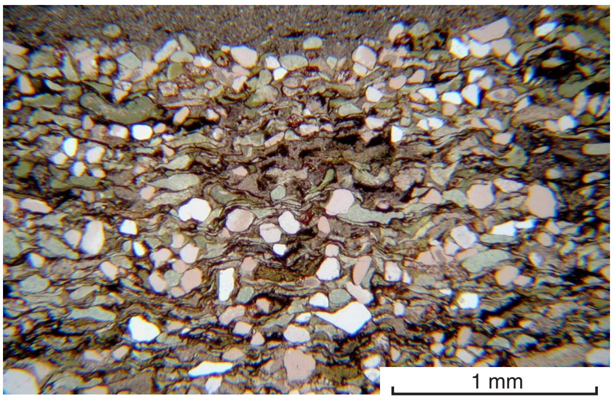

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Figure 15. Glauconitic sandstone in the Chiall Formation (MGA 373010E 7104665N). Glauconite peloids show varying degrees of compaction indicating they were plastic during compaction. The sandstone also contains angular to subrounded quartz and chert clasts; GSWA 153697, plane polarized light, field of view is 3 mm

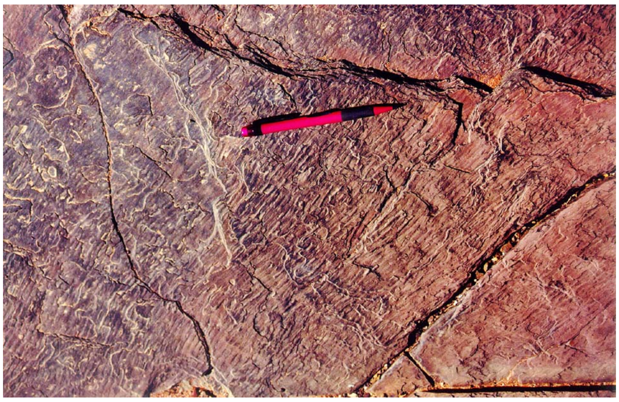

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Figure 16. Rill marks in very fine grained sandstone in the lower part of the Chiall Formation, 5.7 km northeast of Sandstone Bore (MGA 361575E 7120255N). Rill marks are developed during waning water levels, where a thin layer of water flows over a sediment surface. Their presence suggests deposition in shallow water for the lower part of the Chiall Formation

Fine- to medium-grained sandstone-dominated units in the Chiall Formation (*ⱣEcs*) form prominent topographic ridges on WONGAWOL. The sandstone is mature, interbedded with siltstone, shale, and mudstone, and commonly silicified. Sandstone beds comprise mainly subrounded to rounded quartz, with minor chert, feldspar, and glauconite, and accessory zircon and tourmaline. Chert is more common in sandstone in the lower part of the Chiall Formation. Glauconite is typically concentrated at the base of fine- to medium-grained sandstone-dominated units, suggesting it was reworked from underlying shale, siltstone, and very fine grained sandstone facies where glauconite abundances are high. In units mapped as fine- to medium-grained glauconitic sandstone (*ⱣEcsp*), the proportion of glauconite is generally much higher than in other fine- to medium-grained sandstone units in the Chiall Formation.

The Chiall Formation records a change from iron oxide and chert to iron silicate mineralogy. The presence of iron silicate minerals, such as glauconite, berthierine, and chamosite, indicates dominantly low sedimentation rates for the finer grained facies of the lower Chiall Formation. Sedimentary structures suggest that the lower Chiall Formation was deposited in a shallow marine environment, with deposition from below fairweather wave-base grading upwards into a shallow water, possibly nearshore, environment. Conglomerate at the base of the Chiall Formation represents reworking of the underlying rocks and localized channel fill.

Princess Ranges Member (ⱣEcp, ⱣEcpp)

The Princess Ranges Member (*ⱣEcp*) on WONGAWOL consists of fine- to medium-grained sandstone, siltstone, shale, and mudstone units interbedded with very fine grained sandstone- and siltstone-dominated units (*ⱣEcpp*). It is characterized by an increase in the volume of fine- to medium-grained sandstone relative to the lower part of the Chiall Formation. In addition, fine- to medium-grained sandstone-dominated units are laterally more extensive.

Fine- to medium-grained sandstone is typically texturally mature, consisting of well-rounded and well-sorted quartz grains, and accessory tourmaline and zircon. Mudchip intraclasts and glauconite peloids are commonly concentrated at the base of fine- to medium-grained sandstone-dominated units, suggesting high-energy erosional bases. Coarse-grained siltstone and very fine grained sandstone contains mainly angular to subrounded quartz, with subordinate glauconite and detrital mica. Locally, the base of the Princess Ranges Member contains coarse-grained sandstone with pebble-sized subangular to subrounded clasts of vein quartz and sandstone.

Common sedimentary structures include symmetrical, asymmetrical, interference, and megaripple marks, rills, shrinkage moulds, trough and planar cross-bedding, and cross-lamination. Symmetrical ripple marks are mostly straight crested, whereas asymmetric ripple marks vary from straight crested to linguoidal (Fig. 17). Megaripple marks (Fig. 18) are generally straight crested and symmetrical, with wavelengths up to 1 m and amplitudes around 50 cm. Palaeocurrent trends are variable but are dominantly towards the north-northwest.

Sedimentary structures suggest that the Princess Ranges Member was deposited in a shallow-water marine to locally emergent environment, which was affected by both wave and current action. Together with the compositional and textural maturity of coarser grained sandstone, which indicates a higher energy depositional environment in the Princess Ranges Member, these features suggest deposition in a tidal sand-flat environment.

Wongawol Formation (*ⱣEo*, *ⱣEoc*)

The Wongawol Formation (Hall et al., 1977; Bunting, 1986) is a monotonous succession of shale, mudstone, siltstone, very fine grained feldspathic sandstone, and minor conglomerate (*ⱣEo*). Only the lower part of the formation is exposed on WONGAWOL. The lower contact with the Chiall Formation is placed at the top of the uppermost mature sandstone. The upper contact with the Kulele Limestone is not exposed on WONGAWOL but is transitional and placed where limestone becomes the dominant rock type (Bunting, 1986).

Sandstone in the Wongawol Formation is mostly very fine grained, commonly silicified, and locally glauconitic. Locally, sandstone contains mudchip and well-rounded siltstone intraclasts, with in situ brecciation of thin siltstone beds.

Sedimentary structures include swash marks, ripple washouts, wrinkle marks, ball-and-pillow structures at sandstone–siltstone interfaces, primary current lineation, and symmetrical and interference ripple marks. The symmetrical ripple marks (Fig. 19) have crests that are

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Figure 18. Straight crested, symmetrical megaripple marks in fine- to medium-grained sandstone of the Princess Ranges Member, 3 km northeast of Wadjinyanda Pool (MGA 373310E 7116345N). Wavelengths are up to 1 m and amplitudes are up to 50 cm

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Figure 17. Linguoidal ripple marks in very fine grained sandstone of the Princess Ranges Member, 3 km northeast of Wadjinyanda Pool (MGA 373310E 7116345N)

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Figure 19. Symmetrical ripple marks in sandstone in the Wongawol Formation, 4.5 km northeast of Sholl Bore (MGA 395315E 7120265N). These marks suggest deposition in shallow water

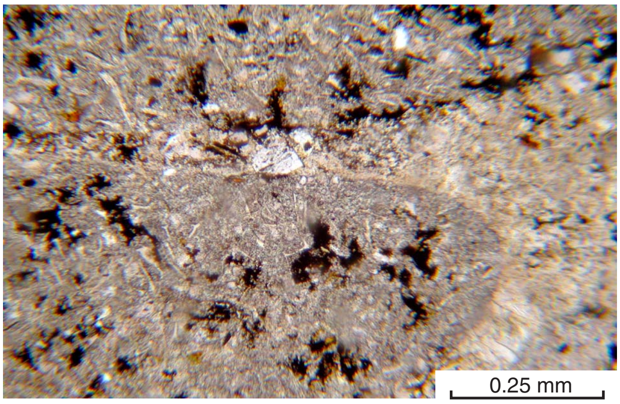

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Figure 20. Volcaniclastic clasts in conglomerate of the Wongawol Formation, 12.5 km northeast of Wadjinyanda Pool (MGA 386810E 7122850N). The clasts contain well-preserved relic glass shards that are uncompacted and show bubble-wall, triple point textures. The provenance of the clasts is unclear as there is little evidence of contemporaneous volcanism in the Earaheedy Basin; GSWA 175303, plane polarized light; field of view is 3 mm

typically peaked and straight, with wavelengths of 8–10 cm and amplitudes around 2–3 cm. Weakly developed ladder ripple marks are locally present in the troughs of some symmetrical ripple marks.

Exposure of conglomerate (*PEoc*) is localized, and clasts are typically well rounded, matrix supported, pebble sized, and composed of carbonate and volcaniclastic fragments. The carbonate clasts could be intraclastic because carbonate beds increase in abundance higher in the Wongawol Formation. The volcaniclastic clasts contain vitriclastic textures (Fig. 20). These clasts could either represent reworking of thin volcaniclastic beds, which have not been preserved, or be allochthonous. The matrix to the clasts consists of poorly sorted, angular to subangular clasts of quartz, feldspar, and biotite, which are dominantly silt to very fine grained sand in a micritic cement.

The Wongawol Formation is similar to the shale, mudstone, siltstone, and very fine grained sandstone facies in the Chiall Formation. Sedimentary structures suggest deposition was in shallow water to locally emergent conditions interpreted to be similar to the tidal sand-flat environment proposed for the Princess Ranges Member.

Structure and deformation

The exposed Earaheedy Basin is deformed into an east-southeasterly trending, south-verging, asymmetric, open syncline, which plunges gently towards the southeast. The northern limb is generally more intensely folded and faulted than the southern limb, and is termed the 'Stanley Fold Belt'. Major structures within the Stanley Fold Belt commonly trend east or northwest, and are positively magnetized. On the southern margin of the exposed Earaheedy Basin, which extends onto WONGAWOL, major structures typically trend east, northwest, and north. Northwesterly trending structures in this part of the basin are negatively magnetized, and easterly trending structures are positively magnetized.

Northerly trending structures are probably reactivated basement structures, and their orientation is similar to D_3 structures of the Yilgarn Craton, which formed during sinistral transpression (e.g. Swager, 1997; Wyche and Farrell, 2000). A major northerly trending structure on WONGAWOL could be a continuation of a major northerly to north-northeasterly trending structure on the eastern margin of the Duketon greenstone belt. The age of easterly trending structures is not well constrained (Groenewald et al., 2001), although they postdate D_3 structures in the Yilgarn Craton and are thought to be Palaeoproterozoic in age, because an age of 2420 Ma was obtained from the easterly trending Binneringie dyke in the southeastern Yilgarn Craton (Nemchin and Pidgeon, 1998). The age of easterly trending structures in the northeastern Yilgarn Craton is also not well constrained, and it is unclear whether they represent reactivated basement structures or were developed during a deformational event after deposition of the Earaheedy Group. Movement on the easterly trending structures is interpreted to have been dominated by vertical displacement. Concentrations of botryoidal and platy types of manganese are commonly associated with northerly trending structures, and quartz fracturing and silicification are present along easterly trending structures.

Northwesterly trending, negatively magnetized structures are interpreted to post-date deposition of the Earaheedy Group. The aeromagnetic signature is consistent with shallow-level, low-angle structures dipping to the northeast. The northwesterly trending structures are not related to features in the Yilgarn Craton because they do not parallel other structures in the northeastern Yilgarn Craton. Instead, these structures appear to be mostly bedding parallel with the Earaheedy Group, but they are not the magnetic response of layering in the Frere Formation. The features correspond to neither individual granular iron-formation horizons nor any iron-rich layer. Indeed, most granular iron-formation appears to have little or no magnetic signature on WONGAWOL. The Frere Formation only has a strong magnetic signature where major structures have been enriched by secondary fluids. Given the intense but continuous nature of these northwesterly trending features, it seems likely that they are the product of fluid flow parallel to bedding. On GRANITE PEAK (Pirajno et al., 2004a) and MERRIE (Adamides, 2000), they coincide with silicification of granular iron-formation in the Frere Formation, and the presence of stilpnomelane in shale and siltstone beds.

Aeromagnetic images indicate that movement along easterly and northerly trending structures offsets, and therefore post-dates, northwesterly trending structures. The overprinting relationships between the easterly and northerly trending structures give ambiguous relative timing results. In addition, magnetization along northerly trending structures is discontinuous, and could reflect localized movement during more than one event.

WONGAWOL covers part of the southeastern limb of the syncline, and the degree of deformation in the Earaheedy Group on the map sheet varies from relatively undeformed flat-lying to gently dipping beds in the south, to mesoscale folding in the north. Folds vary from open, upright, and gently plunging to localized and recumbent, with the degree and style of folding typically strongly dependent on rock type. Mesoscale folds in intervals of fine- to coarse-grained sandstone typically form doubly plunging, elongate anticlinal features. In intervals dominated by siltstone to very fine grained sandstone, mesoscale folds vary from doubly plunging folds to localized disharmonic folding. Sporadic, northeasterly trending anticlines, which vary in scale from tens of metres up to about 1 km, are common in intervals dominated by fine- to coarse-grained sandstone such as the Princess Ranges Member. Deformation associated with these features is typically more intense than for surrounding areas, suggesting they represent localized zones of space accommodation. Five hundred metres east of Skull Soak (MGA 368382E 7120014N), on the northwestern limb of a northeasterly trending fold, micaceous beds are crenulated parallel to the fold trend (Fig. 21). Recumbent folding is present on the southwestern limb of one of these structures (MGA 371300E 7116400N; cover photograph).

The structural history suggests that at least two major deformation events are recorded in the Earaheedy Group on WONGAWOL. The first resulted in low-angle, mostly bedding-parallel movement, which produced northwesterly trending structures at various scales. A later, mainly north–south compression resulted in vertical displacement along easterly trending structures. The orientation of the northwesterly trending structures and the lack of evidence for major displacement or strike-slip movement suggest that the deformational event associated with these structures was due to compression directed southwest–northeast. The timing of both events is not well constrained. Lead–Pb ages on Pb–Zn mineralization in the Sweetwaters Well Member (Richards and Gee, 1985), and Rb–Sr and K–Ar ages on glauconite (Horwitz, 1975; Preiss et al., 1975), which have probably been reset, intimate a thermal event at c. 1650 Ma. This age coincides with granitoid ages in the Gascoyne Complex (c. 1620–1670 Ma; Nelson, 2002), suggesting they are related to a more regionally significant event.

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Figure 21. Crenulated bedding constrained to micaceous horizons in the Princess Ranges Member (MGA 368382E 7120014N). The crenulation is developed on the northwestern limb of a northeasterly trending fold, parallel to the fold trend

Depositional setting

Any model for the Earaheedy Basin must consider the regional tectonic framework, which is heavily reliant on good age constraints, and the sedimentary record contained in the Earaheedy Group. A passive margin model for the Earaheedy Basin was proposed by Jones et al. (2000a,b) and Pirajno et al. (2000a, 2004b), whereas Krapez and Martin (1999) proposed a strike-slip basin model. The passive margin model was proposed to account for the volume of iron interpreted to have been supplied to the basin to form the granular iron-formation in the Tooloo Subgroup.

The chemical and clastic rocks contained in the Earaheedy Group are interpreted to have been deposited in a shallow marine to coastal environment (Jones et al., 2000a,b; Pirajno et al., 2004b), with fine-grained siliciclastic rocks dominating the succession. Saline lagoonal environments are interpreted along parts of the southern margin of the basin (Jones et al., 2000a,b), particularly during periods of low detrital sand supply. Several transgressive events are recorded by the Earaheedy Group, including the base of the Earaheedy Group, the base of the Chiall Formation, and possibly the base of the Mulgarra Sandstone. However, bathymetric changes in the Earaheedy Group are generally minimal, both vertically and laterally, suggesting subsidence mostly matched sediment supply. In addition, the minimal lateral bathymetric changes, combined with the dominantly fine grained nature of the Earaheedy Group and the interpretation of saline lagoonal environments, suggest that the Earaheedy Group records a low-gradient coastal environment. In the Tooloo Subgroup, palaeocurrent directions are mainly towards the northwest. In the Miningarra Subgroup, the dominant palaeocurrent direction is towards the north and northeast, and is consistent with the sedimentary facies, which deepen minimally in a northerly direction.

Detrital zircon populations from the Earaheedy Basin suggest sediment supply was mostly from the Yilgarn Craton and the southern Gascoyne Complex to the west (Halilovic et al., 2004), and at least the upper part of the Earaheedy Group was probably related to the Capricorn Orogeny. The transgressive events at the base of the Yelma and Chiall Formations could be eustatic or tectonic, or a combination of these processes. It is reasonable to assume that the distal effects of the Capricorn Orogeny have influenced deposition of at least the upper part of the Earaheedy Group. For example, downward crustal flexure of the region combined with subsidence from sediment loading probably provided a depocentre, thus forcing a tectonic, rather than eustatic, sea level change, with hinterland uplift providing a source. Alternatively, these large-scale cycles could be eustatic and reflect flooding of tectonically controlled drainage patterns. Hocking et al. (2001) suggested small-scale cycles are probably eustatic in origin. Further evidence supporting deposition in a tectonically active environment includes mass flow deposits, which are common in the lower part of the Chiall Formation on METHWIN (Hocking and Jones, 2002) and NABBERU – GRANITE PEAK (Pirajno et al., 2004a), and ball-and-pillow deformation (Bunting, 1986). Pirajno et al. (2004a) interpreted the mass flow deposits on NABBERU – GRANITE PEAK as seismites. These features were probably caused by seismic activity fluidizing sediment, and their combination implies that tectonic activity controlled at least some deposition. Beukes and Klein (1992), and Isley (1995) suggested granular iron-formation developed in a shallow water, higher energy environment equivalent to that of banded iron-formation in deeper water, and the volume of iron and silica could only have been sourced from a mid-ocean ridge or an oceanic plateau. Movement of the iron and silica by currents onto a passive margin is applicable to the Superior granular iron-formations of North America (Beukes and Klein, 1992; Isley, 1995). However, the Earaheedy Basin does not appear to fit a simple passive margin model, but was deposited in a tectonically active environment influenced by uplift in the southern Gascoyne Complex during the Capricorn Orogeny. The source of iron in the Frere Formation is still unclear. If the Earaheedy Basin was deposited during the Capricorn Orogeny, it is difficult to reconcile a mid-ocean ridge or an oceanic plateau model for the source of iron in the Frere Formation because palaeocurrent directions and the lateral distribution of iron in the Formation suggest a source to the northwest.

Mafic dykes (*Ᵽd*)

Northerly and northwesterly trending, linear aeromagnetic anomalies, both negatively and positively polarized, are present on WONGAWOL. These anomalies are interpreted as dykes (*Ᵽd*) because exposed dolerite dykes in the Yilgarn Craton have similar aeromagnetic responses and orientations. The age of these ?dykes is not known but is assumed to be Proterozoic. They could be feeders for the Prenti Dolerite (Pirajno and Hocking, 2002).

Quartz veins (*q*, *qs*)

On WONGAWOL, quartz veins (*q*) intrude Archaean rocks, whereas quartz stockwork veining (*qs*) is more typical in the Earaheedy Group. Quartz veins in Archaean rocks are up to 50 m long and 5 m wide, and in granite are massive and form prominent topographic ridges.

Quartz stockwork veining is developed in granular chert in the Frere Formation (Jones and Pirajno, 2003) where it is cut by major easterly trending structures. Intense quartz stockwork veining is developed at the intersection of easterly trending structures with other major structures, such as the Proterozoic northwesterly oriented structures and the reactivated northerly oriented structures. Intense stockwork veining is exposed on WONGAWOL 5.4 km northeast of Paddy Bore (MGA 366200E 7091900N), at the intersection of easterly and northerly oriented structures (Fig. 11). Granular chert is intensely silicified at this locality, and commonly displays hydraulic brecciation, with local jigsaw fit of clasts. There is open space filling, and iron staining commonly rims vugs. Locally, quartz veins have silicified haloes (Fig. 12). Sulfides are present in intensely veined granular chert as finely disseminated grains, rimming vugs within quartz veins, and locally as isolated grains within quartz veins. Table 4 presents whole-rock geochemical analyses of rocks with quartz stockwork veining. Analyses indicate strong elevation of Hg content (≤2.07 parts per million), and minor elevation of Ag, Bi, Sb, and As contents, relative to upper crustal values (Levinson, 1974; Taylor and McLennan, 1985), in a sample (GSWA 175306) from the intersection of easterly and northwesterly trending structures. There is also strong elevation of Hg content, and minor elevation of Sb content, relative to upper crustal values, in a sample (GSWA 175307) from the intersection of easterly and northerly trending structures.

Palaeozoic geology

Permian

Late Carboniferous to Early Permian glacially influenced sedimentary rocks cover much of Western Australia (Eyles et al., 2002). There are no age constraints for sedimentary rocks mapped as Permian on WONGAWOL, and correlation with the Paterson Formation is based entirely on their glacial origin.

Paterson Formation (*Pa, Pal*)

Non-fossiliferous outcrops of sandstone and claystone, and lags of polymictic boulder conglomerate that appear to be glacially influenced overlie the Earaheedy Group, mainly on the KINGSTON and STANLEY 1:250 000 map sheets (Bunting, 1986). They are assigned to the Paterson Formation (*Pa*), or are a boulder lag of Paterson Formation (*Pal*). The unit was originally defined for the Permian glacially related deposits of the southern Canning Basin (Talbot, 1920; Traves et al., 1956) and later extended to the Officer Basin by Lowry et al. (1972). On WONGAWOL, the beds are flat lying or dip less than 3° to the north. The unconformable contact with the Earaheedy Group is an angular disconformity that is always marked by claystone containing coarse sand to boulder-sized clasts, which are poorly sorted and compositionally varied (Fig. 22). Silcrete commonly caps the Paterson Formation.

The Paterson Formation on WONGAWOL is dominantly composed of claystone containing clasts ranging in size from very coarse sand to boulder. Although clasts typically comprise only about 10% of the rock, removal of the claystone matrix and deflation of the sedimentary pile has resulted in Permian lags composed of dominantly boulder-sized clasts of varying composition overlying the Earaheedy Group. Clasts span a wide variety of rock types, including vein quartz, quartzite, granitic rocks, metamorphic rocks, jasper and chert, greenstone, and granular iron-formation. Very coarse sand to pebble-sized clasts are typically angular to subangular, whereas cobble

Table 4. Trace element data for quartz stockwork veining in granular chert, Frere Formation

GSWA number *MGA* *1:100 000 map sheet*	*175305* *313627E* *7132348N* GRANITE PEAK	*175306* *313567E* *7131606N* GRANITE PEAK	*175307* *366000E* *7091740N* WONGAWOL	*175308* *366000E* *7091740N* WONGAWOL	*175309* *400429E* *7053902N* COLLURABBIE	*175310* *468500E* *7150300N* COONABILDIE	*Analytical method*
			Parts per million				
Ag	<0.1	0.7	<0.1	<0.1	<0.1	<0.1	AT/MS
As	1	23	4	2	4	8	AT/MS
Au	<0.001	<0.001	2	<0.001	<0.001	<0.001	FA25/SAAS
Ba	136.6	33.3	385.5	253.3	203.8	125.5	AT/MS
Bi	0.19	0.39	0.22	0.21	0.15	0.18	AT/MS
Co	0.8	1	1.3	0.6	0.5	1.7	AT/MS
Cr	114	98	99	74	128	148	AT/OES
Cu	3	21	7	12	4	6	AT/OES
Mo	0.5	0.9	0.6	0.4	0.5	0.4	AT/MS
Nb	0.21	0.32	0.26	0.26	0.18	0.33	AT/MS
Ni	8	7	8	5	7	9	AT/OES
Pb	15	13	3	2	3	–	AT/MS
Sb	0.32	1.64	1.44	0.36	0.24	0.39	AT/MS
Sc	<1	<1	<1	<1	<1	2	AT/OES
Se	<2	<2	<2	<2	<2	<2	AT/MS
Sn	0.3	0.3	0.3	0.2	0.3	0.3	AT/MS
Te	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	AT/MS
Th	0.28	0.57	0.6	0.21	0.27	0.26	AT/MS
U	0.11	0.23	0.13	0.06	0.06	0.07	AT/MS
V	3	6	6	5	6	4	AT/M
W	0.2	0.6	0.4	0.5	<0.1	0.2	AT/MS
Y	0.52	0.57	3.61	0.47	0.24	0.56	AT/MS
Zn	9	8	6	5	3	10	AT/OES
Hg	0.04	2.07	0.17	0.02	<0.1	0.01	CM/CVAP

NOTES:
AT: Multi-acid digest (hydrofluoric, nitric, perchloric, hydrochloric) in Teflon test tubes
CM: Controlled temperature nitric–perchloric acid oxidative attack specific for mercury
CVAP: Cold vapour generation atomic absorption spectrometry
FA25: Lead collection fire assay using a 25 g charge
MS: Inductively coupled plasma mass spectrometry
OES: Inductively coupled plasma optical emission spectrometry
SAAS: Flame atomic absorption spectrometry after extraction of analyte into organic solvent

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Figure 22. Polymictic Permian boulder lag overlying the Earaheedy Group, 2.5 km south of Little Banjo Bore (MGA 381185E 7080950N). Clasts are poorly sorted and range from subangular to well rounded. The lag is developed by the collapse of a thick diamictite as a result of the removal of the matrix. The size of the clasts suggests they were unlikely to have been transported after deposition and removal of the matrix. Many of the clasts are striated, indicating their glacial origin

to boulder-sized clasts are typically subrounded to rounded.

Sandstone only outcrops in the northwestern part of WONGAWOL, and is poorly sorted and coarse to very coarse grained, with thin pebble to boulder lenses commonly at the base of beds. Sandstone beds range in thickness from 40 cm to one metre, but are generally around 50 cm thick, and planar cross-bedded. An east to southeast palaeocurrent direction is indicated by cross-bedding.

Evidence supporting a glacial origin includes parallel striations on clasts, and a well-preserved striated pavement of Frere Formation exposed 9.3 km northwest of Alf Bore (MGA 389100E 7076600N; Fig. 23), which is overlain by an outcrop of deeply weathered claystone containing coarse sand to boulder-sized clasts. Striations on the pavement indicate an east–west transport direction.

The glacial striation directions for the Paterson Formation on WONGAWOL indicate mainly east–west movement. Transport directions on EARAHEEDY are mostly towards the north and northeast (Hocking et al., 2001). This suggests that either deposition was locally topographically controlled or there were two periods of ice movement.

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Figure 23. Pavement of Frere Formation striated by Permian glacial abrasion, 9.3 km northwest of Alf Bore (MGA 389100E 7076600N). Striations indicate east–west transport

Relict land surface (*Rls*)

Peneplained hills of Earaheedy Group, capped by a siliceous duricrust on WONGAWOL, are interpreted to be part of a Permian land surface (*Rls*) developed during the Gondwana-wide, continental-scale glaciation in the latest Carboniferous and Early Permian (Hocking and Preston, 1998). Scattered erratic boulders, many glacially striated, overlie the duricust and support a Permian age for the land surface.

Cainozoic geology

Cainozoic regolith deposits on WONGAWOL suggest complex weathering and sedimentation events, which are divided into residual and depositional regimes.

Residual and relict deposits reflect deep weathering of Archaean, Proterozoic, and Permian rocks, with variation in deposits strongly controlled by the underlying bedrock geology. On WONGAWOL, siliceous duricrust (*Rz*) is exposed at only one locality, 2.5 km northeast of Mount Wellesley (MGA 369800E 7097400N), and forms a localized northwesterly trending deposit over Palaeoproterozoic shale and Permian diamictite. The linear and restricted nature of the deposit could reflect a structure that is not exposed. Residual deposits over granitic rocks (Rgp_g) are found only in the southwestern corner of WONGAWOL, and consists of a saprolite zone of kaolinized granite in which relict textures are generally preserved. Ferricrete (*Rl*) is developed only over mafic igneous rocks of the Yilgarn Craton in the southwestern corner of the sheet, and the term 'ferricrete' is used where remnant textures are locally preserved. Ferruginous duricrust (*Rf*) caps both ferricrete profiles and iron formations of the Frere Formation on WONGAWOL, and consists of nodular, pisolitic, and massive ferricrete.

Colluvium and sheetwash deposits are defined as a function of slope gradient. Colluvium (*C*) is deposited on steep slopes, with ferruginous colluvium (*Cf*) deposits associated with granular iron-formation in the Frere Formation. Sheetwash (*W*) is deposited on non-channelized, gently sloping plains. Ferruginous sheetwash (*Wf*) is commonly adjacent to and sourced from granular iron-formation in the Frere Formation, whereas calcareous sheetwash (*Wkk*) is commonly adjacent to and sourced from carbonate in the Windidda Formation. Claypans within sheetwash plains (*Wp*) are typically isolated features, and contain mainly clay- and silt-sized material.

Alluvial deposits (*A*, A_pc, *Ak*) comprise clay-, silt-, sand-, and gravel-sized material in ephemeral fluvial channels, associated floodplains, and distributaries feeding playa lakes. Clast composition is commonly strongly controlled by proximal source areas. Calcrete (*Ak*) is usually associated with drainage patterns around playa lakes, and forms by precipitation below the watertable under conditions of low rainfall and high evaporation (Mann and Horwitz, 1979). Small claypans (A_pc) associated with palaeodrainage and playa lake systems are present in low-lying depressions, and are filled with clay and silt.

Sandplain deposits (*S*) consist predominantly of sand- and silt-sized quartz, mostly of eolian origin, which is commonly covered by a thin lag of coarse sand-sized ferruginous pisoliths of probable residual origin. Active to partially stabilized dunes are locally present within sandplains.

Playa lake systems on WONGAWOL reflect complex sedimentation, and consist of saline playa lakes (*L*), mixed dune and playa lakes (*Lm*), active dunes (L_d1), and stabilized dunes (L_d2). Saline playa lakes (*L*) comprise saline mud, silt, and sand deposits. Mixed deposits (*Lm*) are adjacent to playa lakes, and comprise interfingering dunes, alluvial deposits, and playa lake deposits. Dunes (L_d1) that fringe small playa lakes typically consist of gypsum and quartz sand. They generally lack vegetation or are partially vegetated by samphire. Older stabilized dunes (L_d2) are vegetated, and consist of quartz sand and ferruginous pisolites.

Economic geology

Gold

The Mount Eureka greenstone belt in the southwestern corner of WONGAWOL contains shallow workings, but there are no associated production records. Drilling and sediment sampling were undertaken during exploration in the belt. Gold was mined further south at Mount Eureka and Mount Fisher, with 709.8 kg of gold produced from Mount Fisher between 1987 and 1988 by Sundowner Minerals NL (Jorgensen, 1990).

Iron and manganese oxides

Least-weathered granular iron-formation within the Frere Formation contains varying amounts of iron. Bunting (1986) reported iron enrichment in some units, ranging from 27 to 47% with less than 0.06% P_2O_5. Secondary iron oxides are commonly enriched close to faults as a result of hydrothermal fluid flow and weathering. The Frere Formation was considered to be highly prospective for iron ore of the Hamersley type (Broken Hill Pty Limited, 1978). Several Temporary Reserves were granted within the Earaheedy Basin between 1973 and 1978, and zones of iron enrichment within granular iron-formation were located. On WONGAWOL, manganese concentrations are fault controlled, and associated with shale and sandstone in the Chiall Formation, and shale and iron formation in the Frere Formation.

Regolith geochemistry

The results of a regional regolith geochemistry survey over KINGSTON 1:250 000 are presented by Pye et al. (2000), and an overview of the entire Earaheedy Basin is provided by Morris et al. (2003). Regolith geochemistry is influenced by the underlying bedrock geology and weathering processes, with the effects of these controls being highly variable (Pye et al., 2000). The results of the survey are consistent with some bedrock control. Pye et al. (2000) and Morris et al. (2003) showed, for example, that samples from greenstone belts exhibit higher concentrations of elements such as K, V, Zn, Ta, Sr, Rb, Ni, Mo, Pt, Pb, Cu, and Cr, whereas higher concentrations of Be, Y, Zn, Co, Cd, Li, La, Ce, Pb, and Ni are present in the Mount Wellesley area, and higher concentrations of Th, Ta, In, Ga, Bi, and As are recorded on the western side of the Wellington Range. The Wellington Range anomalies coincide with quartz stockwork veining developed along major easterly trending structures and their intersection with northerly trending structures in peloidal chert in the Frere Formation (Jones and Pirajno, 2003). The anomalous concentrations in the Mount Wellesley area appear to coincide with the thickest exposure of the Permian Paterson Formation.

Groundwater

Groundwater salinity varies on WONGAWOL, but the water is generally suitable for livestock, and is mainly obtained from bores and wells. In addition, the map sheet contains numerous ephemeral pools, which contain water for much of the year. They are most common in creeks cutting the Windidda and Chiall Formations. Calcrete is up to 20 m thick along major drainage channels, and has long been known for its aquifer qualities (Talbot, 1920), yielding large quantities of water. A regional survey of the hydrogeology is presented by Sanders (1969), and Sanders and Harley (1971).

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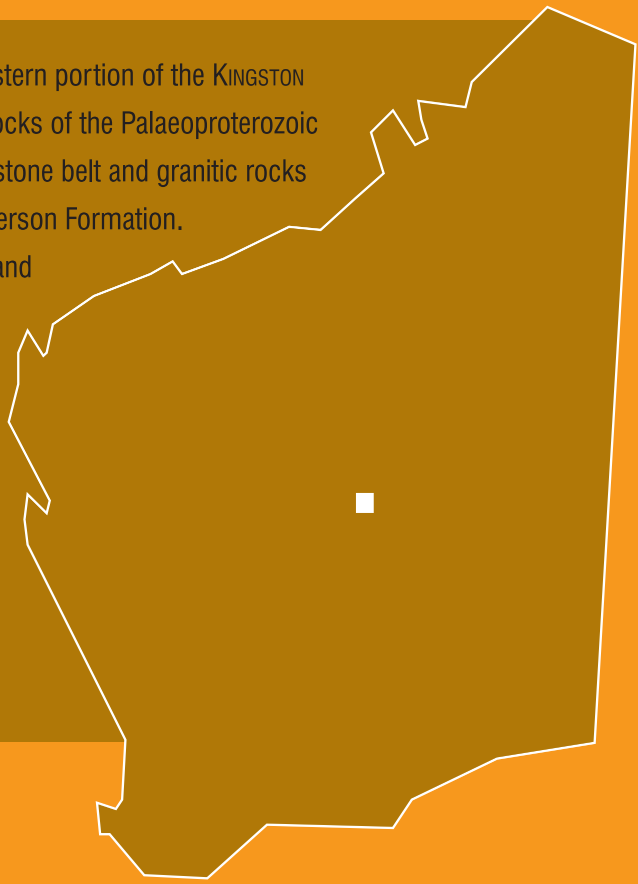
Appendix

Gazetteer of localities on WONGAWOL

Locality	*Zone*	*MGA (E)*	*MGA (N)*
Alf Bore	51	397900	7073600
Banjo Well	51	378500	7071300
Beru Pool	51	363700	7076600
Curdle Well	51	361200	7102900
Granite Bore	51	359850	7070000
Kepaltin Spring	51	394150	7096400
Lake Carnegie (WINDIDDA 1:100 000)	51	448000	7103000
Leinster	51	274700	6909000
Little Banjo Bore	51	381300	7083500
Lorna Glen Homestead	51	352700	7098100
Meekatharra (BELELE 1:250 000)	50	649400	7057000
Mount Eureka (YELMA 1:100 000)	51	354500	7068000
Mount Fisher (SANDALWOOD 1:100 000)	51	249000	7029000
Mount Wellesley	51	368500	7095200
Paddy Bore	51	361200	7190200
Princess Ranges	51	379400	7114000
Red Bluff	51	354050	7080450
Sandstone Bore	51	356900	7115900
Sholl Bore	51	397800	7123800
Skull Soak	51	367800	7120300
Wadjinyanda Pool	51	374400	7119600
Wellington Range	51	374600	7090200
Wiluna (WILUNA 1:250 000)	51	223500	7055500
Windidda Homestead (WINDIDDA 1:100 000)	51	421000	7081000
Wongawol Homestead	51	394200	7110500

The WONGAWOL 1:100 000 sheet covers the northwestern portion of the KINGSTON 1:250 000 sheet. WONGAWOL contains sedimentary rocks of the Palaeoproterozoic Earaheedy Basin, the Archaean Mount Eureka greenstone belt and granitic rocks of the Yilgarn Craton, and the glacigene Permian Paterson Formation. These Explanatory Notes describe the Precambrian and Permian rock types, structure, mineralization, and regolith. The stratigraphy, tectonic evolution, and implications for mineralization are also discussed. Significant resources include iron ore deposits in the Frere Formation, and gold mineralization in the Mount Eureka greenstone belt.



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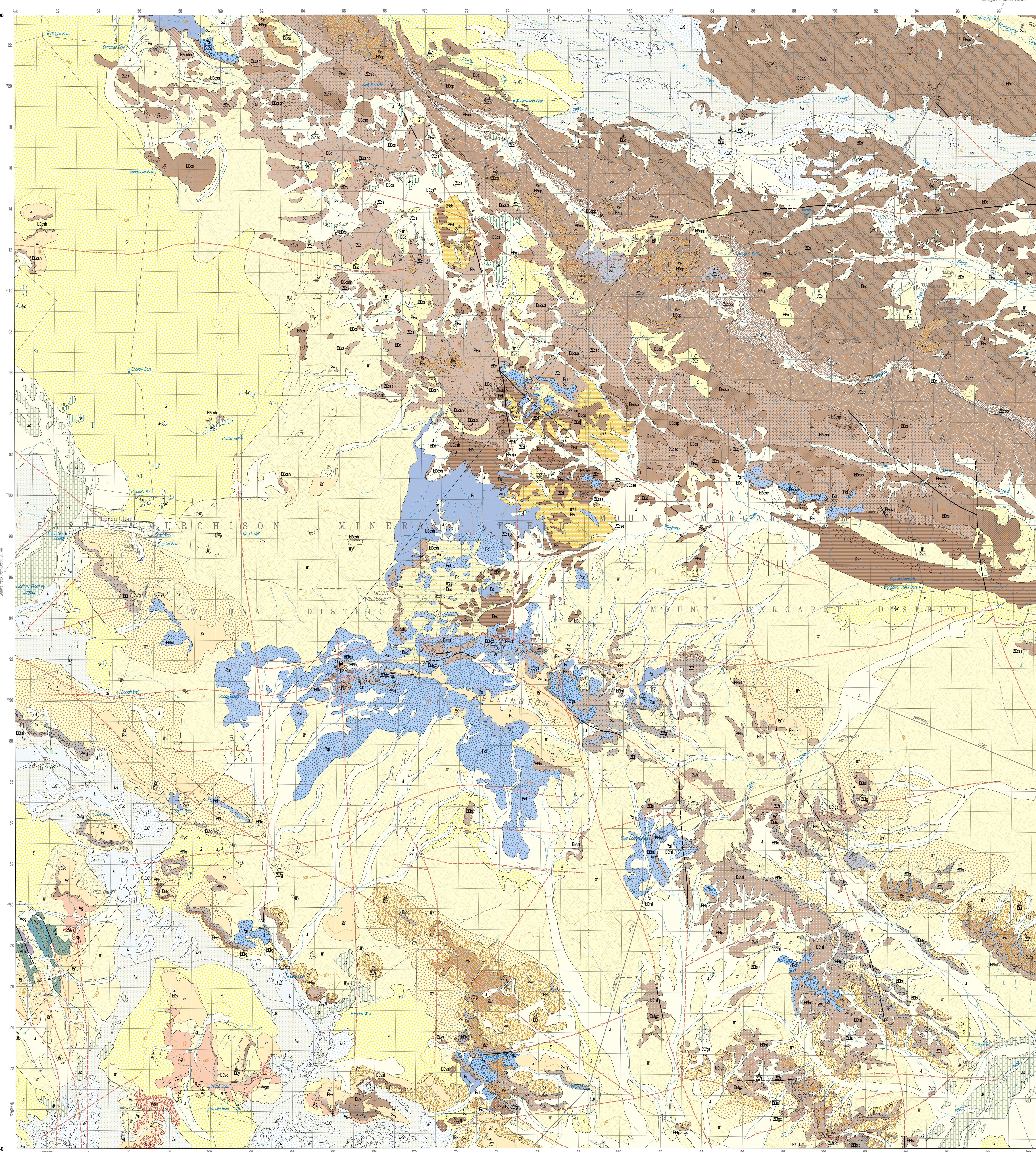
JONES

Geology of the Wongawol 1:100 000 sheet

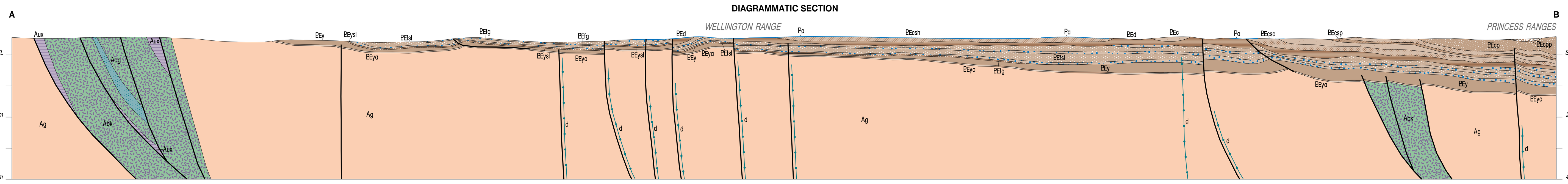
EXPLANATORY NOTES

WONGAWOL

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



DIAGRAMMATIC SECTION



Reference

CAINOZOIC

Colluvial units
- C — Colluvium; silt, sand, and gravel deposited on proximal slopes
- Cf — Ferruginous colluvium typically developed on slopes adjacent to iron formation

Sheetwash units
- W — Silt, sand, and gravel deposited on low-gradient slopes with no clear channel pattern
- Wf — Ferruginous sheetwash, derived largely from adjacent ferricrete and ironstone areas
- Wkk — Calcareous sheetwash, derived from adjacent carbonate rocks
- Wp — Clay and silt in claypans on sheetwash

Alluvial units
- A — Clay, silt, sand, and gravel deposited in channels and adjoining areas within channel systems
- Apc — Clay and silt in claypans
- Ak — Calcrete associated with palaeodrainage and active drainage systems; includes calcrete now associated with lakes

Lacustrine units
- L — Clay, silt, and sand in saline playa lakes
- Lm — Clay, silt, and sand in mixed dune-and-playa terrain associated with lacustrine systems
- Ld1 — Active dune systems adjacent to playa lakes, typically non-vegetated and gypsiferous; first generation

Sandplain unit
- S — Sand and subordinate silt of eolian and probable residual origin in sandplain; includes minor small dunes; sand reddened by iron-oxide coatings

Lacustrine unit
- Ld2 — Stabilized dunes adjacent to playa lakes, typically vegetated; second generation

Residual or relict units
- Rf — Ferruginous duricrust; nodular, pisolitic, and massive ferricrete, and associated debris
- Rgpg — Saprolite overlying granitoid rock
- Rl — Ferricrete, including underlying saprolite, developed largely on mafic igneous rocks
- Rz — Siliceous duricrust; intensely silicified rock, variably ferruginous

PHANEROZOIC

PALAEOZOIC — PERMIAN

Relict unit
- Rls — Siliceous duricrust with occasional boulders; probably relict Permian land surface

GUNBARREL BASIN
- Pa — **PATERSON FORMATION:** poorly sorted sandstone, claystone, and conglomerate; glacigene to fluvioglacial
- Pal — Boulder lag, polymictic, clay matrix commonly absent; underlying Proterozoic rock commonly exposed

- q — Quartz vein
- qs — Quartz stockwork veining and silicification of wallrock

PROTEROZOIC — PALAEOPROTEROZOIC

EARAHEEDY BASIN — Earaheedy Group

Miningarra Subgroup

- ĿEo — **WONGAWOL FORMATION:** very fine grained sandstone, siltstone, shale, mudstone, and minor intraclastic sandstone and carbonate rock breccia; locally glauconitic
- ĿEoc — Carbonate conglomerate with glauconitic sandstone matrix, and clasts of carbonate rock

CHIALL FORMATION
- ĿEcp — **Princess Ranges Member:** fine- to medium-grained sandstone, generally texturally mature, locally pebbly and glauconitic; subordinate siltstone, shale, and mudstone
- ĿEcpp — Very fine to fine grained, typically glauconitic sandstone, and siltstone; mica and glauconite content increases upwards
- ĿEc — Undivided sandstone, siltstone, shale, mudstone, and carbonate rock breccia
- ĿEcsa — Fine to very fine grained sandstone, siltstone, and shale; glauconitic ferruginous chert peloids common towards the base; locally calcareous
- ĿEcs — Fine- to medium grained, locally glauconitic sandstone, shale, and siltstone
- ĿEcsp — Fine- to medium-grained glauconitic sandstone, shale, and siltstone
- ĿEcsha — Shale, mudstone, and siltstone, and minor very fine-grained sandstone
- ĿEcsh — Shale, mudstone, and siltstone
- ĿEcse — Ferruginous, glauconitic sandstone and conglomerate, with clasts of carbonate rock or ferruginous sandstone, in a matrix of calcarenite to ferruginous glauconitic sandstone

Tooloo Subgroup

- ĿEd — **WINDIDDA FORMATION:** stromatolitic carbonate rock, minor shale, and siltstone, jasper, and peloidal jasper
- ĿEdj — Stromatolitic carbonate rock and shale with peloidal jasper
- ĿEdh — Shale, mudstone, and minor siltstone

- ĿEf — **FRERE FORMATION:** granular iron-formation, granular siliceous iron-formation, siltstone, shale, jasper, and chert
- ĿEfg — Granular iron-formation and granular siliceous iron-formation; minor siltstone, shale, jasper, and chert
- ĿEfgz — Granular siliceous iron-formation
- ĿEfsl — Siltstone and shale; minor iron-formation
- ĿEfslc — Siltstone, shale, and chert; minor iron-formation
- ĿEfslj — Siltstone, shale, and jasper; minor iron-formation

- ĿEysl — Siltstone, shale, and mudstone, with minor sandstone; commonly ferruginous
- ĿEy — **YELMA FORMATION:** sandstone, siltstone, and shale; shallow marine to fluvial deposits
- ĿEya — Sandstone, coarse-grained and locally pebbly

ARCHAEAN

YILGARN CRATON
- Ag — Granitoid rock; highly weathered; undivided
- Agm — Monzogranite
- Aci — Banded iron-formation, metamorphosed
- Aog — Gabbro, metamorphosed
- Abk — Komatiitic basalt, pyroxene spinifex textured; metamorphosed
- Aux — Pyroxenite, metamorphosed

Symbols

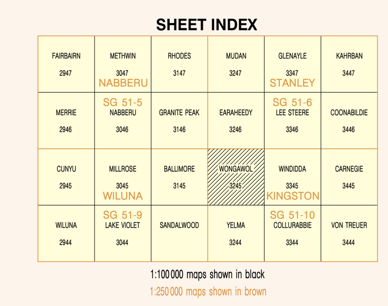
- Geological boundary
  - exposed
  - concealed
- Fault
  - exposed
  - concealed
  - concealed, interpreted from aeromagnetic data
- Fold, showing axial trace and generalized plunge direction
  - anticline; exposed
  - mesoscale folding
- Small-scale fold axial surface, showing strike and dip
  - inclined
- Small-scale fold axis, showing trend and plunge
  - unspecified
  - anticline
  - syncline
  - S-vergence
- Bedding, showing strike and dip
  - inclined
  - strike and dip estimated from aerial photography
    - 5–15°
    - 15–45°
  - trend of bedding
- Palaeocurrent, showing trend and sense of direction
  - from megaripples, sense of direction known
  - from asymmetrical ripple marks, sense of direction known
  - from cross-bedding, sense of direction known
  - from current lineation, sense of direction not known
  - from clast imbrication, sense of direction not known
  - from asymmetrical ripple marks, sense of direction not known
- Glacial striae, showing trend and sense of direction of ice movement
  - sense of direction not known
- Metamorphic foliation, showing strike and dip
  - inclined
  - vertical
- Cleavage, showing strike and dip
  - inclined
  - vertical
- Mineral lineation, showing trend and plunge
  - inclined
- Airphoto or satellite image lineament
  - unspecified
- Aeromagnetic lineament

- Formed road
- Track
- Fence, generally with track
- Homestead — Wongawol
- Building
- Yard — Yard
- Microwave repeater station
- Horizontal control; major, minor
- Breakaway
- Sand dune
- Contour line, 20 metre interval — 220

- Watercourse with ephemeral pool
- Pool — Pool
- Soak, spring — Soak, Spring
- Bore, well — Bore, Well
- Windpump

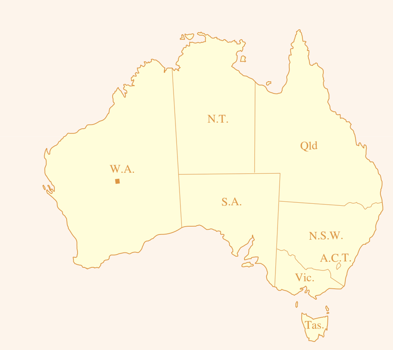
- Mineral field boundary
- Mineral occurrence
  - Manganese — Mn

SHEET INDEX

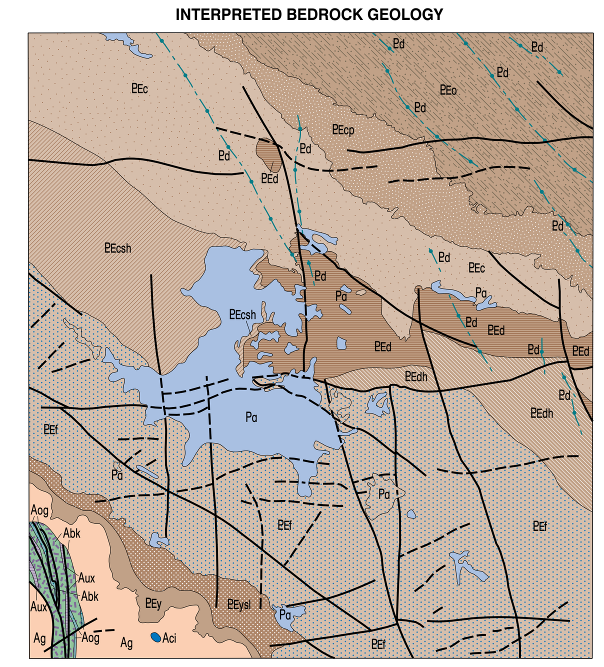


1:100 000 maps shown in black

1:250 000 maps shown in brown



INTERPRETED BEDROCK GEOLOGY



GUNBARREL BASIN
- Pa — Veneer of Paterson Formation over Earaheedy Group
- Ŀd — Dolerite dyke, interpreted from aeromagnetic data, not exposed

EARAHEEDY BASIN — Earaheedy Group (Miningarra Subgroup; Tooloo Subgroup)
- ĿEo — Wongawol Formation
- ĿEcp — Princess Ranges Member
- ĿEc — Chiall Formation
- ĿEcsh — Shale, mudstone, and siltstone
- ĿEf — Frere Formation
- ĿEysl — Siltstone, shale, and mudstone
- ĿEy — Yelma Formation
- ĿEd — Windidda Formation
- ĿEdh — Shale, mudstone, and siltstone

YILGARN CRATON
- Ag — Granitoid rock
- Aci — Metamorphosed banded iron-formation
- Aog — Gabbro, metamorphosed
- Abk — Komatiitic basalt, metamorphosed
- Aux — Pyroxenite, metamorphosed

Geology by J. A. Jones 1999

Edited by N. Tetlaw, C. Strong, and G. Loan

Cartography by A. Veale, P. Taylor, and K. Greenberg

Topography from the Department of Land Administration Sheet SG 51-10, 3245, with modifications from geological field survey

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Plotted by the Geological Survey of Western Australia

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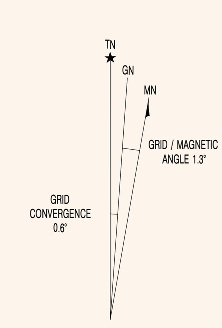

True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 2001 and moves easterly by about 0.2° in 3 years.

Department of Mineral and Petroleum Resources

Geological Survey of Western Australia

CLIVE BROWN, M.L.A.
MINISTER FOR STATE DEVELOPMENT

JIM LIMERICK
DIRECTOR GENERAL

TIM GRIFFIN
DIRECTOR

SCALE 1:100 000

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

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

Grid lines indicate 1000 metre interval of the Map Grid Australia Zone 51

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

WONGAWOL

SHEET 3245 FIRST EDITION 2002