EXPLANATORY NOTES

Department of
Mineral and Petroleum Resources

GEOLOGY OF THE METHWIN 1:100 000 SHEET

by R. M. Hocking and J. A. Jones

1:100 000 GEOLOGICAL SERIES

Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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Cover photograph:
Giant foresets in Wonyulgunna Sandstone (Collier Group) immediately east of Good Camp Rockhole

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Geology of the Methwin 1:100 000 sheet

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Abstract

The METHWIN 1:100 000 sheet contains the easternmost part of the Archaean Marymia Inlier, portions of the Palaeoproterozoic Earaheedy Basin, the Mesoproterozoic Bangemall Supergroup, and the ?latest Mesoproterozoic Salvation Group (previously thought to be part of the Neoproterozoic Officer Basin). The Marymia Inlier consists of weathered Archaean granite exposed in the northwestern part of METHWIN. The Yelma, Frere, and lower Chiall Formations of the Earaheedy Group are exposed in southern and central METHWIN. The lowest formation in the group, the Yelma Formation, consists of sandstone, siltstone, and rare conglomerate and dolomite. The overlying Frere Formation consists of ferruginous siltstone and shale, and granular iron-formation. Above this, the Chiall Formation is a coarsening-up sequence from laminated siltstone (Karri Karri Member) to interbedded sandstone and siltstone (Wandiwarra Member). The northern limit of their outcrop is in the Stanley Fold Belt, a narrow west-northwesterly trending linear zone of tight folds, shears, and faults that reflect the major structural imprint on the Earaheedy Basin. The fold belt probably marks the suture between the northern margin of the Archaean Yilgarn Craton and Palaeoproterozoic basement, which is similar in age to the Gascoyne Complex to the west (approximately 2.0 Ga). The age of the Earaheedy Group is poorly constrained, between about 2 Ga, the age of older rocks on which it sits, and about 1.75 Ga, when it was probably deformed. The most probable age of deposition is between 1.8 and 1.9 Ga, based on inference from nearby, better dated tectonic units. The Frere Formation has potential for iron ore deposits, particularly in areas of secondary enrichment. Carbonate rocks of the Yelma Formation (Sweetwaters Well Member) may host Mississippi Valley-type base metal deposits, but the carbonate facies appears to have very limited development on METHWIN. Gold mineralization is recorded in deformed Yelma Formation east of METHWIN.

The Wonyulgunna Sandstone of the Collier Group is the only unit from the Bangemall Supergroup on METHWIN, and is exposed in a belt trending east-southeast across central METHWIN. It is a sandstone succession that rests with angular unconformity on the Earaheedy Group and is derived in part from the Marymia Inlier. The sandstone has a possible age range of 1.6 – 1.15 Ga, although the younger end of this range is more probable. Structures in the Wonyulgunna Sandstone mostly result from reactivation of older structures in the Stanley Fold Belt, as the unconformity is locally tectonized and the faults that affect the unit are continuous from far more deformed zones in the adjacent Earaheedy Group.

The Glass Spring Formation extends over northeast METHWIN, and is tentatively placed in the Salvation Group, which is a new unit that includes the deposits of a basin succession slightly younger than the Collier Group. The Glass Spring Formation was derived from the east rather than from the adjacent Yilgarn Craton to the south, and grades upwards from fluvial to tidal sandflat deposits. There is minor silicification adjacent to faults, but the unit is otherwise undeformed apart from a slight northeastward regional tilt. The Glass Spring Formation and Wonyulgunna Sandstone are intruded by extensive mafic sills, based on magnetic images and exposures to the north and east of METHWIN. The sills are not dated on METHWIN.

The METHWIN sheet is partly under pastoral lease and partly crown land, and has tourist significance due to the Carnarvon Range in the centre of the sheet and the Canning Stock Route in the southeast. It spans the border between the sandplain and dunefields of the Little Sandy Desert and the partial etchplain of the Earaheedy Basin.

KEYWORDS: Archaean, Proterozoic, Earaheedy Group, Collier Group, Bangemall Supergroup, Sunbeam Group, Officer Basin, granular iron-formation, Marymia Inlier, base metal mineralization.

Introduction

The METHWIN* 1:100 000 map sheet (SG 51-5, 3047) is bounded by latitudes 25°30'S and 25°00'S and longitudes 120°30'E and 121°00'E (Fig. 1), and is located in the north-central part of the NABBERU 1:250 000 sheet. There are no settlements or formed roads on METHWIN. The Cunyu and Granite Peak pastoral leases extend onto the southern part of METHWIN, and the northern part of the sheet is currently vacant crown land. Access on METHWIN is provided by station tracks in the south, the Canning Stock Route in the southeast, and tracks through crown land in the north from Marymia Homestead to the Carnarvon Range (Fig. 2). Tracks vary in condition, and are generally impassable during wet weather. The nearest town is Wiluna, 180 km to the south-southwest of the southern boundary, but access to northwest METHWIN is equally fast from Meekatharra via Marymia Homestead. Muir (1996) provided anecdotal details of much of the history of settlement of the region, and descriptions of many of the topographic features on METHWIN.

The Canning Stock Route crosses the southeast corner of METHWIN, and the Carnarvon Range is a common side-trip for people travelling the stock route. The range is thus a significant resource in terms of tourism, although still little visited compared to many other parts of Western Australia. The two most visited areas on METHWIN are around Virgin Springs and Good Camp Rockhole.

METHWIN has an arid climate with average temperatures† between 39 and 24°C in summer, with a recorded maximum of 47°C, and between 20 and 6°C in winter, with a recorded minimum of –4°C. Rainfall is sporadic as a result of summer cyclones and winter depressions but averages 232 mm a year. Evaporation rates are up to 2500 mm a year.

Three major geological units are present on METHWIN. Archaean granites of the Marymia Inlier are exposed in the northwest corner, Palaeoproterozoic sedimentary rocks of the Earaheedy Group extend across the southern third of the sheet, and Mesoproterozoic sedimentary rocks (Collier and Salvation Groups) cover the remainder of the sheet (Fig. 2). Continuing work on the sedimentary successions in areas east of METHWIN has led to some lithostratigraphic revision since the map was published. The revised terminology is used in these notes, and differences from the map are summarized in Table 1.

Vegetation, landform systems, and regolith

The vegetation, physiography, and geology are closely linked. Two broad vegetation zones are present on METHWIN. The northern part of the sheet is a hummock grassland of spinifex (*Trioda* sp.) and small shrubs (notably *Thryptomene* sp.), interspersed with scattered low trees either isolated or in small stands. Beard (1981) showed this area as tree steppe, with sparse scrub steppe on the rocky ranges that extend through northern METHWIN. This area corresponds closely to the area underlain by the sand-rich rocks of the Collier and Salvation (Sunbeam on map; see Table 1) Groups, and is the southern edge of the Keartland Phytogeographic District of Beard (1981). Southern METHWIN is largely covered by low mulga woodland (Beard, 1981) with stands of gums along major watercourses, and sparse scrub steppe on rocky ridges. Samphire flats are present on and around larger periodically wet playa areas. The area is on the northern margin of Beard's (1981) Ashburton Phytogeographic District.

Two major soil-landscape (physiographic) provinces are present on METHWIN (Fig. 3). The Ayers–Canning Province of the Sandy Desert Region (Northcote and Wright, 1983) extends down through the northern part of METHWIN, and the Murchison Province of the Western Region (Bettenay, 1983) extends up across the southern half of METHWIN (Fig. 3). A finer subdivision into zones or land systems has not previously been made.

The age of the landform elements and regolith in these provinces is variably constrained. On METHWIN, regolith is shown as Quaternary (*Q*) or undifferentiated Cainozoic (*Cz*) depending on whether the regolith is considered to have a significant component related to present-day processes, or it is entirely relict. In some cases, the regolith and its associated landscape could be older than Cainozoic. The range in possible age for some regolith and landscape components in interior areas is from Pleistocene to Mesozoic, and there are some land surfaces (fossil and exhumed) in Western Australia that are known to be of Mesozoic or Palaeozoic age. The Ashburton Surface in northern Australia is probably pre-Jurassic (Hays, 1967) and possibly even Cambrian–Precambrian (Stewart et al., 1986); the oldest Hamersley Surface (Pilbara region) was considered to be Mesozoic by Twidale et al. (1985), and parts of the Yilgarn Craton landscape may be Triassic (Twidale, 2000). Pillans (1998) argued for subaerial exposure as far back as the Permian over parts of the Yilgarn Craton, and Pillans and Bateman (2000) dated regolith components near Kalgoorlie as Late Cretaceous – Early Cainozoic, Jurassic, and Early Carboniferous, using palaeomagnetic means.

The Ayers–Canning Province on METHWIN comprises the dunefield, sandplain, and range areas of the south-western Little Sandy Desert (Figs 3, 4). Three broad subdivisions are apparent in the province. The first is the elevated ranges of resistant sandstone of the Collier and Salvation Groups. Sandstones of the Salvation Group rise a few tens of metres above the surrounding landscape, whereas those of the Collier Group rise as much as 300 m above the landscape at Mount Methwin, which is the culmination of the Carnarvon Range. Ridges of Collier Group are commonly higher and more rugged than ridges of Salvation Group.

The second subdivision of the Ayers–Canning Province is the dunefield and sandplain (*Qs*), characteristic of the Little Sandy Desert and much of the Ayers–Canning

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

† Climate data from the Commonwealth Bureau of Meteorology — averaged from data from the following areas: Wiluna, Three Rivers, Meekatharra (Peak Hill), and Earaheedy.

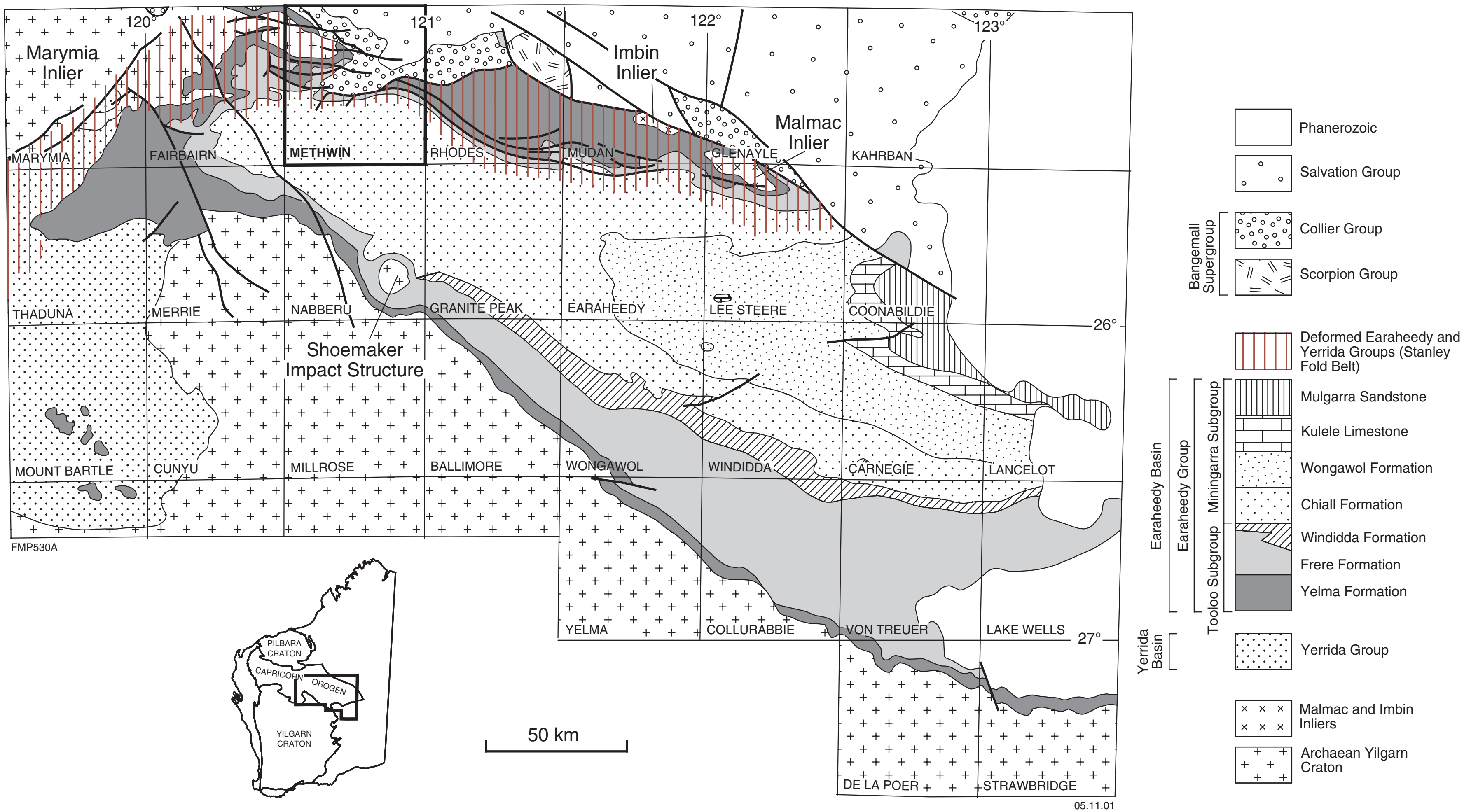

Figure 1. Simplified geology of the Earaheedy Basin and adjoining areas, and location of METHWIN

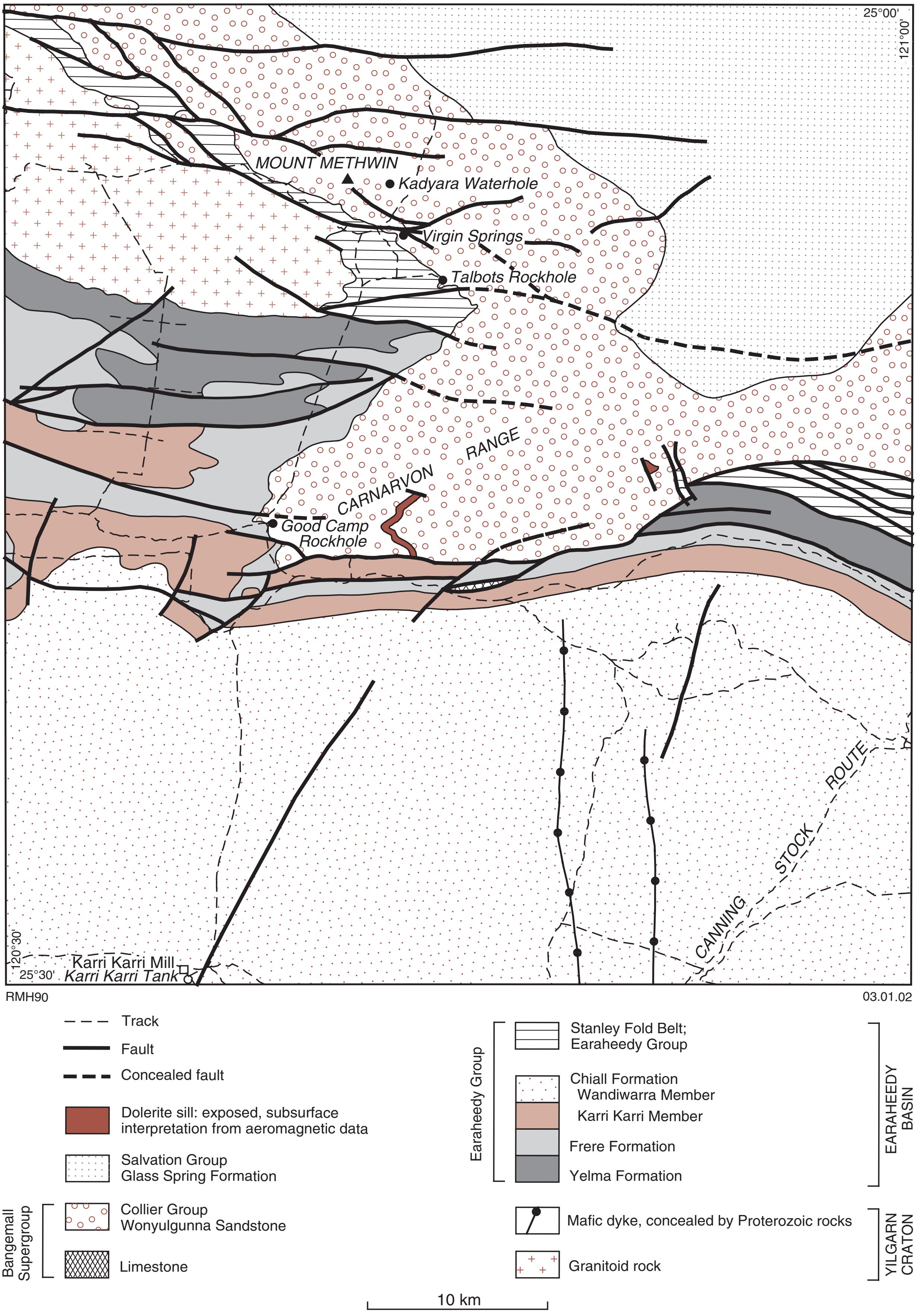

Figure 2. Tracks, localities, and interpreted bedrock geology on METHWIN

Table 1. Lithostratigraphic changes on METHWIN

On map (Hocking and Jones, 1999)	*Current lithostratigraphy*	*Reference/explanation*
Glass Spring Formation (*ⱣSg*); Sunbeam Group	Glass Spring Formation, originally in Savory Group, reassigned to Sunbeam Group, then Salvation Group	Bagas et al. (2000) to Sunbeam Group; assigned to Salvation Group here
Collier Subgroup; Bangemall Group	Collier Group; Bangemall Supergroup	Martin et al. (1999)
Karri Karri Member; Windidda Formation (*ⱣEdk*)	Karri Karri Member; Chiall Formation (*ⱣEck*)	Adamides et al. (2000) Hocking et al. (2000)
Troy Creek Schist	Subsumed into Earaheedy Group formations	Pirajno and Hocking (2000) Hocking et al. (2000)

Region. The dunes are predominantly longitudinal, 10–20 m high, 3–5 km long in open areas, and spaced up to 1 km apart. They are in places quite complex, especially near ridges and a palaeodrainage area near Lake Kerrylyn. Net dunes are present in eastern METHWIN, mainly in and adjacent to palaeodrainages (see below). Longitudinal dunes accumulated between palaeodrainage areas, and the network dunes may reflect eolian reworking of the limited sand available in the drainages. The close geographical association of the dunefield and sandplain to sandstone bedrock (Fig. 4) suggests local derivation of the sand, as Pell et al. (1999) suggested, rather than prolonged transport of sand. The dunes are presently inactive. Even where fires have burnt the vegetation cover, there appears to be minimal sand movement before grasses and low shrubs regrow and bind the sand. The last period of significant activity of dunefields was during the last glacial maximum, between 25 000 and 15 000 years ago (Bowler, 1976; Wyrwoll, 1979). Maximum aridity was between 17 500 and 16 000 years ago, when lakes dried completely, lunette development around playas was completed, and the major unconsolidated dunefields of Western Australia developed (Bowler, 1976). Conditions generally remained dry between 15 000 and 10 000 years ago, but precipitation increased slightly as temperatures slowly rose (Bowler, 1976) during a transition into the present climate.

Palaeodrainages through the dunefield area are identified by groundwater calcrete (*Qak*), complex dune patterns along their margins, and flat areas of apparently consolidated regolith with no dune cover, here mapped as older alluvium (*Cza*), although they strictly include peripheral valley deposits as well as the central channel deposits. One such drainage flows north through Lake Kerrylyn, and is large enough to merit differentiation as a separate subdivision of the Ayers–Canning Province. Network dunes are also preferentially developed along palaeodrainages. Deposits in the major palaeodrainages of Western Australia are primarily Eocene (Hocking et al., 2001; Hocking and Cockbain, 1990). Adjacent to the Pilbara, Late Eocene limestone in the Carnarvon Basin contains numerous ferruginous pisoliths, but younger units do not. This suggests that Western Australia as a whole was beginning to dry out in the Late Eocene, and that major drainages in the interior mostly had stopped flowing regularly by the latest Eocene.

The portion of the Murchison Province on METHWIN (Fig. 3) is underlain entirely by Earaheedy Group rocks or by granitoid rocks of the Marymia Inlier. It is a partial etchplain, with apparent headward erosion off several south-draining creeks. The creeks drain into Lake Nabberu, which in turn drains into the Lake Carnegie system and ultimately the north-draining Disappointment Palaeoriver (van de Graaff et al., 1977). The creeks (*Qa*) are well-defined drainage systems, and grade laterally into sheet-flood areas (*Qw*) with some patches of groundwater calcrete (*Qak*). Ridges of well-indurated iron formation cut across the drainages, and in the area west of Good Camp Rockhole are prominent and extensive enough to merit recognition as a separate subdivision of the Murchison Province. Colluvium (proximal slope deposits, *Czc*) adjacent to these and other rock ridges is generally consolidated and partially dissected, suggesting that erosion of uplands is currently only minor, and that the colluvium may be coeval with the older alluvium.

Landform elements marginal to Lake Nabberu extend onto the southwestern corner of METHWIN (Fig. 3). Relatively small saline playas (*Ql*), fringing dunes (*Qld*), and mixed dune-and-playa terrain with underlying bedded lacustrine deposits (*Qlg*) are peripheral to the larger playas at the core of the Lake Nabberu system on NABBERU. An etched rock platform is present beneath some playas, with scattered exposure of the Earaheedy Group. Scattered hills and ridges developed by headward erosion of the higher land surface north of the lacustrine area, forming a dominantly south-facing breakaway system.

Geological setting

The geology of the METHWIN area was first described by Talbot (1920, 1928). Parts of the Archaean Marymia Inlier, the Palaeoproterozoic Earaheedy Basin, the Mesoproterozoic Collier Basin, and what was previously thought to be the Neoproterozoic Officer Basin are present on METHWIN (Figs 1 and 2). Granite in the northwest margin of METHWIN is considered to be an easterly extension of the Marymia Inlier. The Palaeoproterozoic Earaheedy Basin lies at the eastern end of the Capricorn

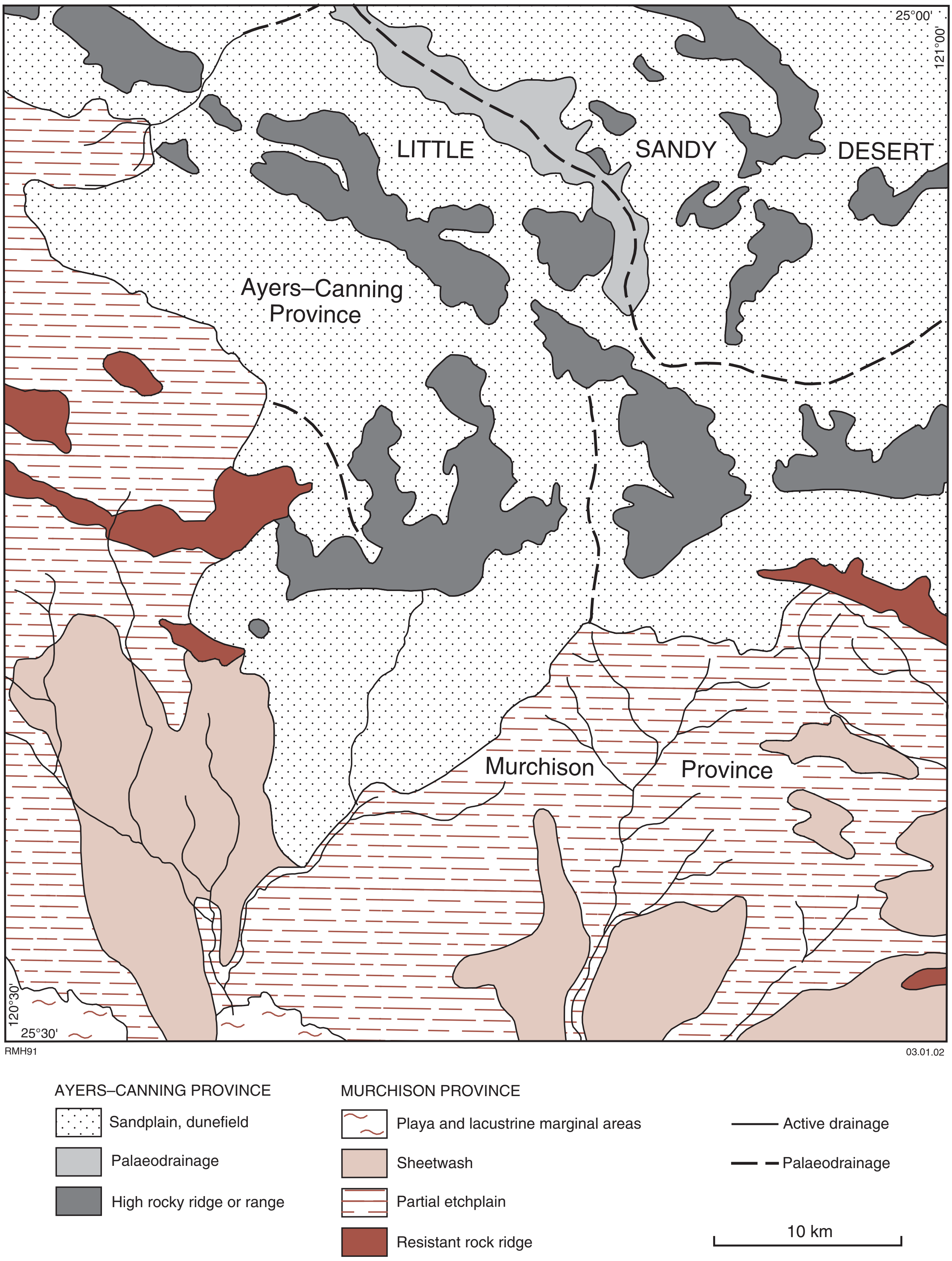

Figure 3. Landform elements on Methwin

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Figure 4. Southwestern Little Sandy Desert, looking east. Sandplain in foreground with strike ridges of Collier Group in distance, forming Mount Methwin range. Note *Thryptomene* sp. in close foreground

Orogen (Table 2), which records the collision of the Yilgarn and Pilbara Cratons (Tyler and Thorne, 1990). The Earaheedy Group extends over the southern half of METHWIN. The age of the group is poorly constrained, and is discussed below under **Earaheedy Group**. The present margins of the Earaheedy Basin are interpreted to be both erosional and structural. To the north the Earaheedy Basin succession is overlain or in faulted contact with the Collier Group (?1211–1080 Ma, Tables 2 and 3; see below), which is the younger succession of the Bangemall Supergroup. This is in turn overlain to the east and northeast by a sandstone succession that was previously thought to be the basal unit of the dominantly Neoproterozoic Officer Basin (Tables 2 and 3), and is shown as such on the METHWIN map (Hocking and Jones, 1999). A palaeomagnetic pole from related rocks to the east on MUDAN (Pirajno and Hocking, 2001) suggests that this succession is older than 1080 Ma (Wingate, M., 2000, written comm.), and thus predates the Officer Basin. It is tentatively assigned to the Salvation Group, a unit defined to include this succession.

Strongly deformed rocks in the centre and north of METHWIN are part of the Stanley Fold Belt (Bunting, 1986), which is a northwesterly trending zone of deformation within the Earaheedy Basin along its presently exposed northern margin. Rocks of the Earaheedy Group are cleaved, tightly folded, and faulted. On RHODES and MUDAN these rocks were previously interpreted to be an older tectonic entity, the Troy Creek Beds (Bunting, 1986), but are now considered to be deformed Earaheedy Group (Hocking et al., 2000; Pirajno and Hocking, 2000, 2001; Jones et al., 2001). Deformation becomes less intense south of the Stanley Fold Belt and outliers of Earaheedy Group north of the fold belt are not deformed, suggesting deformation was concentrated in this zone. Deposition of the Collier Group postdates the fold belt, but the trends of faults which cut the group clearly follow those in the underlying fold belt.

Sanders and Harley (1971) described the hydrogeology of the region surrounding METHWIN. Morris et al. (1997) discussed the regolith geochemistry of NABBERU, and presented a thematic regolith map.

Revised interpretation to published map (1999)

The METHWIN 1:100 000 map was mapped in 1997, compiled in 1998, and published in mid-1999. Ongoing mapping of the Earaheedy Basin and adjoining areas since 1997 has resulted in new insights and revised lithostratigraphy. Changes not reflected on the METHWIN map (Table 1) but incorporated in these notes are explained below:

- The Troy Creek Schist (Troy Creek Beds of Bunting, 1986) is abandoned. It is now regarded as a deformed zone of the Earaheedy Group, and strongly deformed rocks previously grouped as Troy Creek Schist are incorporated in individual formations of the Earaheedy Group (Hocking et al., 2000).

Table 2. Summary of the geological history of METHWIN and adjoining areas. Refer to text for citations and details on ages and events

Age (Ma)	*To west*	*Western 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)	
	~ ~ ~ **2100–1970 Ma** ~ ~ ~		
2100 – ?1950	• Deposition of Yerrida Group, on Yilgarn Craton		
<1970, >1802			• **Yapungku Orogeny, 1st phase (D_1)**, Paterson Orogen
~2000–1800	• Deposition of Bryah and Padbury Groups		
2000–1960	• **Glenburgh Orogeny** • Convergence of Yilgarn Craton and Glenburgh Terrane of Gascoyne Complex		
1990			• Extrusion of felsic volcanic rocks in Imbin Inlier (basement to Earaheedy Group north of Stanley Fold Belt)
	~ ~ ~ **1970–1790 Ma** ~ ~ ~		
?1900–1800		• Deposition of Earaheedy Group	
1830–1780	• **Capricorn Orogeny** • Convergence of Yilgarn and Pilbara Cratons • Deformation of Yerrida Group along Goodin Fault		
	~ ~ ~ **1790–1760 Ma** ~ ~ ~		
1790–1760		• Deformation of Earaheedy Group, formation of Stanley Fold Belt, presumably in later stages of Yapungku Orogeny	• **Yapungku Orogeny, 2nd phase (D_2)**, Paterson Orogen • Convergence of North Australian and West Australian (Yilgarn and Pilbara) Cratons
	~ ~ ~ **1760–1220 Ma** ~ ~ ~		
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	
	~ ~ ~ **1220–820 Ma** ~ ~ ~		

Table 2. (continued)

Age (Ma)	*To west*	*Western Earaheedy Basin*	*To east and north*
<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 southwest-directed compression
1070	• Emplacement of mafic sills into Collier and Edmund Groups	• Intrusion of Salvation Group by mafic sills (Glen Ayle Dolerite). Extrusion of parts of Bentley Supergroup in Musgrave Complex (1060 Ma). ?Intrusion of Earaheedy Group by mafic sills in eastern Earaheedy Basin	
<1050			• Deposition of Lamil Group, Paterson Orogen
<1070, >755	• **Edmundian Orogeny** • Deformation of Bangemall Supergroup		
	~ ~ ~ **820–?480 Ma** ~ ~ ~		
820 – c. 800			• Deposition of Sunbeam Group (base Supersequence 1, Centralian Superbasin) in northwestern Officer Basin
~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
	~ ~ ~ **Phanerozoic** ~ ~ ~		
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, formation and mobilization of major dunefields across Western Australia, during arid glacial maximum		

Table 3. Stratigraphic summary of METHWIN

Age	*Basin/Group*		*Formation/Member*	*Lithology*	*Approximate thickness (m)*	*Depositional environment*
Mesoproterozoic	Salvation Group		Glass Spring Formation	Cross-bedded sandstone, rare siltstone, and pebble conglomerate	?1 000	Fluvial, local coastal sandflat high in section
	COLLIER BASIN Collier Group		Wonyulgunna Sandstone	Cross-bedded, rippled, and horizontally bedded quartz sandstone	?1 000	Fluvial to tidal sandflat
Palaeoproterozoic	EARAHEEDY BASIN Earaheedy Group	Miningarra Subgroup	Chiall Formation; Wandiwarra Member	Thin-bedded sandstone and interbedded shale	?500	Shallow marine
			Chiall Formation; Karri Karri Member	Laminated siltstone and shale with minor sandstone lenses	500–1 000	Below wave base, uncommon interbedded storm-derived sandstones
		Tooloo Subgroup	Frere Formation	Granular and banded iron-formation, shale, chert, minor carbonate	1 500	Shallow marine (inner shelf) to coastal
			Yelma Formation	Quartz arenite, shale, minor carbonate, chert, and conglomerate	<1 000	Shallow marine, locally fluvial near base, transgressive
Archaean	Marymia Inlier			Granite		

- The Karri Karri Member is now thought to be at the base of the Chiall Formation, rather than being a deep-water facies of the Windidda Formation (Hocking et al., 2000). This follows from recognition that the Windidda Formation is a lateral equivalent of the upper part of the Frere Formation rather than conformable on it.
- The Glass Spring Formation is tentatively correlated with the Coonabildie Formation and Brassey Range Formation, and all three are interpreted as part of a basin succession between the Officer and Collier Basin successions, rather than the basal part of the northwest Officer Basin (formerly Savory Basin) succession. They are grouped as the Salvation Group. This revision goes further than that of Bagas et al. (1999), who placed the Glass Spring Formation in the Sunbeam Group rather than the Savory Group.

Archaean geology

Marymia Inlier

METHWIN contains the most eastern exposure of the Marymia Inlier (Marymia Dome of Gee, 1990), which is an inlier of granite–greenstone rocks surrounded by Palaeoproterozoic rocks (Bagas, 1999). The tectonic history, rock types, and age of mineralization indicate that the inlier is part of the Yilgarn Craton (Bagas, 1999).

Granite *(Ag)*

Granitic rocks of the Marymia Inlier are exposed in the northwest part of METHWIN. They are typically deeply weathered and are exposed as low-lying irregular outcrops consisting of silcrete, kaolinitic saprock, and rare fresh rock. Although classified as undivided, fresh rocks are typically equigranular, medium- to coarse-grained monzogranite consisting of K-feldspar, plagioclase, quartz, biotite, and secondary muscovite.

Contacts between the granite and younger rocks of the Earaheedy and Collier Groups are very poorly exposed. Coarse-grained arkosic sandstone, probably proximally derived, clearly overlies granite in the exposures about 18 km west of Talbots Rockhole (AMG 254000E 7216500N). To the west on FAIRBAIRN and MARYMIA, both shale and conglomerate unconformably overlie granite.

Proterozoic geology

Earaheedy Group

The Earaheedy Basin contains the clastic and chemical sedimentary succession of the Earaheedy Group. The basin unconformably overlies the Yilgarn Craton and, in the west, the Yerrida Basin (Fig. 1, Table 2). Outliers of sedimentary rocks are exposed to the south and southwest of the present margin, overlying the Yilgarn Craton and older Palaeoproterozoic basins (Pirajno and Occhipinti, 1998). These outliers are lithologically similar to the basal Earaheedy Group, but similarities may also be drawn with other sedimentary basins of the region, therefore correlation is equivocal. The stratigraphy of the Earaheedy Group (Fig. 5) was introduced by Hall et al. (1977) and was adopted with minor modifications by Bunting (1986). Current mapping has further modified the stratigraphy (Fig. 5; Hocking et al., 2000).

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 the Mulgarra Sandstone. Only the Yelma, Frere, and Chiall Formations are exposed on METHWIN.

Age constraints

The Earaheedy Group overlies the Yerrida Group (2200 Ma; Woodhead and Hergt, 1997). Detrital zircons in the Chiall Formation (central Earaheedy Group) with a SHRIMP U–Pb age of 1850 Ma (Halilovic, J., 2000, written comm.) provide a maximum age for the Miningarra Subgroup. Detrital zircons from the Yelma Formation at the base of the Tooloo Subgroup on NABBERU gave a SHRIMP U–Pb age of 2027 Ma (Nelson, 1997; Pirajno and Glikson, 1998), and Pb–Pb whole-rock dating of carbonate in the Yelma Formation returned ages of 2010 Ma and 1950 Ma (Russell et al., 1994). From these dates, the lower Tooloo Subgroup is younger than about 1950 Ma, and the Miningarra Subgroup is younger than 1850 Ma.

Potassium–argon and Rb–Sr ages of 1670–1710 Ma and 1556–1674 Ma respectively (Preiss et al., 1975) from glauconite grains in sandstone of the Yelma Formation on DE LA POER and 1685 Ma (Horwitz, 1975) from glauconite in the Chiall Formation provide minimum ages for the Earaheedy Group. They may have been reset during later deformation, perhaps a reactivation of the Stanley Fold Belt, by the impactor that formed the Shoemaker Impact Structure, or by a thermal event related to igneous activity at the start of Bangemall Supergroup deposition (1638 ± 14 Ma, SHRIMP U–Pb age from interbedded rhyolite; Nelson, 1995). A Pb–Pb mineralization age of 1770–1740 Ma from galena in the Magellan deposit in Yelma Formation outliers overlying the Yerrida Basin and 1650 Ma from the Sweetwaters Well Member on MERRIE (Richards and Gee, 1985; Pirajno, F., written comm.) postdate deposition and may also be related to deformation.

The Stanley Fold Belt provides a possible minimum age constraint for the Earaheedy Basin. Pirajno et al. (2000a) and Jones et al. (2000) attributed deformation in the fold belt to the second phase of the Yapungku Orogeny (1790–1760 Ma; Bagas and Smithies, 1998; Bagas et al., 2000), which records the initial collision of the North Australian and West Australian Cratons (Myers et al., 1996).

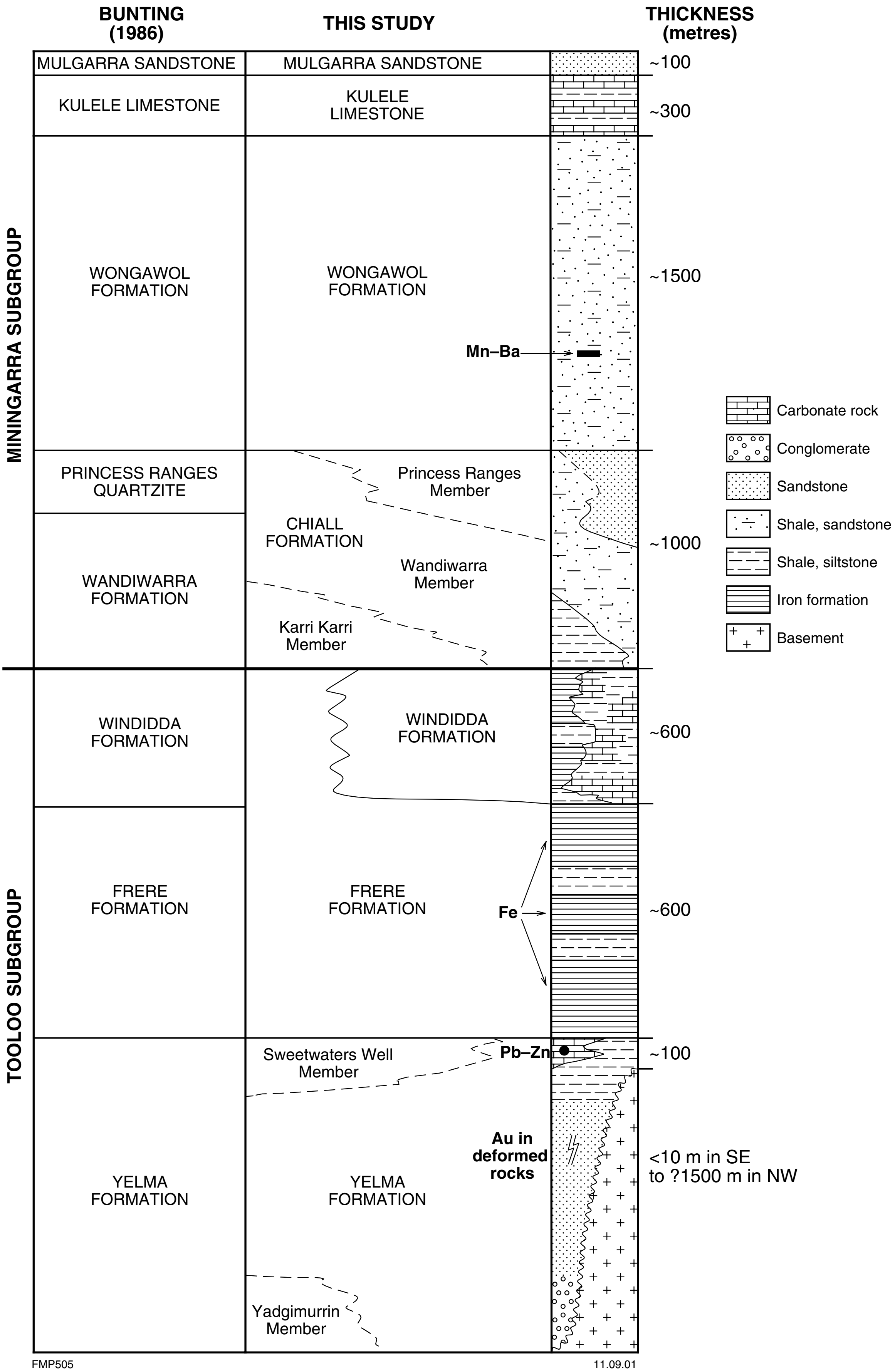

Figure 5. Stratigraphic column of the Earaheedy Group

Grey (1995) suggested a depositional age of 1900–1800 Ma based on the stromatolite taxa of the Earaheedy Group. These are broadly similar to taxa in the Duck Creek Dolomite of the upper Wyloo Group (c. 1840 Ma). This age is consistent with carbon isotope studies on carbonate (Karhu and Holland, 1996).

Neither the Glenburgh (2000–1960 Ma) nor the Capricorn (1830–1780 Ma) Orogeny (Sheppard et al., 2001) has had a major effect on the Earaheedy Group. The lack of deformation features that are clearly attributable to the Capricorn Orogeny could be interpreted to indicate that the basin is younger than the orogeny, but a similar lack of deformation is apparent in the pre-Capricorn Yerrida Basin on Mount Bartle (Dawes and Pirajno, 1998) and Cunyu (Adamides et al., 1999), which is elsewhere affected by this orogeny (Pirajno et al., 1998). From all the above inferential evidence, the preferred depositional age of the Earaheedy Group is between 1950 and 1800 Ma, based on isotope data and stromatolite appearance.

Previous work

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 Earaheedy Sub-basin and the Glengarry Sub-basin to account for differences between the eastern and western Nabberu Basin respectively. Hall and Goode (1978) provided the first comprehensive description of the Earaheedy Sub-basin. The Kingston, Stanley and Nabberu 1:250 000 sheets (Bunting, 1980; Commander et al., 1982; Bunting et al., 1982) were mapped by the Geological Survey of Western Australia as part of 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 as part of a review of the 'Nabberu Basin', and clearly foresaw the dismemberment 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 belongs to a unique basin. Pirajno et al. (1996, 1998) and Occhipinti et al. (1997) set out the present subdivision, preparatory to final reports on the Yerrida (Pirajno and Adamides, 2000), and Bryah and Padbury Basins (Pirajno et al., 2000b).

The nature and origin of iron formations in the Earaheedy Basin have been documented and discussed by Hall and Goode (1978), Goode et al. (1983) and Bunting (1986). Microfossils in the iron formation were described and compared with those in the Gunflint Formation in the Superior Province of Canada by Walter et al. (1976) and Tobin (1990). Krapez and Martin (1999) grouped the Yerrida and Earaheedy Basins as one basin. Their interpretation dealt only with the lowermost Earaheedy Group, and was based on descriptions by Bunting (1986) and how those descriptions fitted into their large-scale sequence-driven model of basin-fill patterns.

'Troy Creek Schist'

The Methwin map (Hocking and Jones, 1999) shows several areas as 'Troy Creek Schist', subdivided into rocks developed from the Yelma (*Ᵽty*), Frere (*Ᵽtf*), or Chiall (*Ᵽtc*) Formations. These are now regarded simply as deformed Yelma, Frere or Chiall Formation (*ᵽEyt*, *ᵽEft*, *ᵽEct* on later maps such as Rhodes, Earaheedy, and Mudan) for the reasons outlined below.

The Troy Creek Schist (Troy Creek Beds of Bunting et al., 1982, and Commander et al., 1982; amended but not defined by Hocking and Jones, 1999) was mapped on the Nabberu and Stanley 1:250 000 sheets, and was originally thought to be an older suite of metamorphosed rocks, overlain unconformably by the Earaheedy Basin succession. Hocking and Jones (1999) and Pirajno et al. (1999) recognized that the unit was actually deformed and low-grade metamorphosed sedimentary rocks of the Earaheedy Group in the Stanley Fold Belt, and retained the name Troy Creek Schist to differentiate it from less deformed parts of the group. However, Pirajno and Hocking (2000, 2001) abandoned the name on Rhodes and Mudan, because they could consistently recognize the formations of the Earaheedy Group in the area mapped as Troy Creek Beds by Commander et al. (1982) and Bunting et al. (1982). Additionally, there are metamorphic boundaries from less deformed rocks that are clearly part of the Earaheedy Basin succession, into deformed rocks characteristic of the Troy Creek Schist, and also the reverse, in several localities on Rhodes and Mudan.

Yelma Formation (*ᵽEy*, *ᵽEys*, *ᵽEya*, *Ᵽty*)

The Yelma Formation is the basal unit of the Earaheedy Group (Figs 5 and 6) and is exposed in the northern part of Methwin in the Stanley Fold Belt. It is a mixed sandstone–shale succession with lesser amounts of siltstone and conglomerate, and rare carbonate. The carbonate is dolomitic, and in part altered to chert. The formation is strongly deformed and commonly cut by thick quartz veins, as for example 12.5 km northwest of Good Camp Rockhole (AMG 257500E 7214800N). The unconformable lower contact with Archaean granite is not exposed on Methwin, but on Fairbairn (Adamides et al., 2000) to the west, Archaean granite is overlain by shale and conglomerate of the Yelma Formation. The upper contact with the Frere Formation is marked as the first occurrence of chert or granular iron-formation (Bunting, 1986). The contact is well exposed 12 km northwest of Good Camp Rockhole (AMG 255500E 7212700N) and is transitional over 10 m, with the upper part of the Yelma Formation consisting of interbedded shale and sandstone in which thin chert beds become interbedded (Frere Formation). Above this, sandstone beds decrease in adundance upwards, whereas granular iron-formation beds increase.

The thickness of the Yelma Formation varies. In the southeast part of the Earaheedy Basin, the formation is only a few metres thick, whereas it is clearly much thicker in and adjacent to the Stanley Fold Belt. The thickness on Methwin is difficult to estimate because of the degree of deformation and lack of marker horizons, but could easily

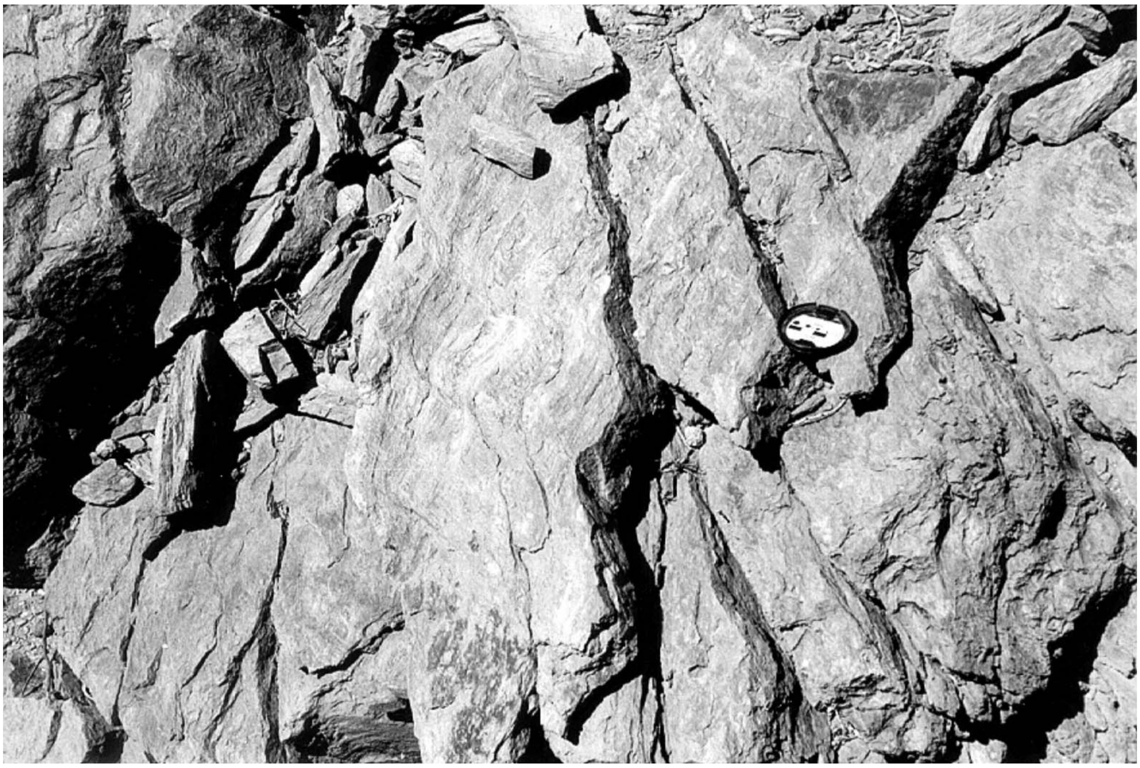

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Figure 6. Crenulated shale and fine-grained sandstone of the Yelma Formation (AMG 271600E 7217800N)

exceed 500 m, and structural repetition is probable. Bunting (1986) proposed a thickness of 1500 m on western STANLEY 1:250 000, and on RHODES the formation must be of this order of thickness, even allowing for considerable structural repetition (Pirajno and Hocking, 2000).

Undivided Yelma Formation (*ꝐEy*) consists of interbedded shale and sandstone, with some siltstone. Three outcrops of stromatolitic carbonate, all too small to show at map scale and now in part altered to chert, are present 1.5 km southwest (AMG 269450E 7218970N) and 12 km northwest (AMG 258900E 7227160N) of Virgin Springs. On NABBERU and FAIRBAIRN, carbonate at the top of the Yelma Formation is designated to the Sweetwaters Well Member, but the stratigraphic position of the exposures on METHWIN is uncertain so they are labelled as undivided Yelma Formation. Areas dominated by sandstone, and by shale and siltstone, are differentiated as *ꝐEya* and *ꝐEys* respectively. More deformed parts of the Yelma Formation have been shown as *Ꝑty* (see **'Troy Creek Schist'**, above).

Shale and siltstone (*ꝐEys*) are common rock types mapped as Yelma Formation on METHWIN and are typically light brown to greenish grey in colour and finely laminated. They commonly display two well-defined cleavages. Exposure is typically scattered and isolated, and covered by quartz sheetwash.

Sandstone (*ꝐEya*) ranges from fine to very coarse grained and locally pebbly, although fine- to medium-grained sandstone is dominant, and is composed dominantly of quartz with minor feldspar and glauconite, cemented by silica. Pebbly sandstone to pebble conglomerate, indicative of braided-fluvial deposition, is exposed 3 km southwest of Virgin Springs (AMG 267600E 7218700N). Trough cross-bedding and planar bedding can be observed in the sandstone in less deformed exposures. Sandstone is commonly thinly interbedded with shale in the upper part of the Yelma Formation, with sandstone beds typically 5–20 cm thick. Elsewhere, sandstone beds are up to 50 cm thick, in bedsets between 50 cm to 2 m thick.

The sedimentary facies in the Yelma Formation on METHWIN indicate deposition in three related settings. Pebbly and coarse-grained sandstone was deposited in an alluvial-plain environment, possibly coastally situated because they are closely associated with stromatolitic dolomite and shale units southeast of Virgin Springs. The interbedded shale and sandstone were probably deposited in a nearshore-marine to barrier and lagoonal environment, with channel deltas and washovers. The carbonate may have been deposited as both fringing reefs around fans and in coastal lagoons. The abundant shale throughout the formation on METHWIN suggests common quiet-water deposition, presumably marine rather than lacustrine because of the presence of glauconite. Chafetz and Reid (2000) suggested that glauconite developed in shallow, energetic nearshore conditions in the early Palaeozoic and Proterozoic due to differences in atmospheric composition compared to the later Palaeozoic, Mesozoic, and Cainozoic.

Frere Formation (*ᴘEf, ᴘEfg, ᴘEfs, ᴘtf*)

The Frere Formation consists of granular iron formation, jasper and chert beds, shale, and siltstone. The abundant iron formation gives a strong magnetic signature even through significant overburden. In drillcore and on FAIRBAIRN and NABBERU, the formation consists of at least four major granular iron-formation intervals separated by at least three shale and siltstone intervals. On METHWIN the Frere Formation is exposed in the Stanley Fold Belt and is locally enriched in iron and strongly foliated. The lower contact of the Frere Formation with the Yelma Formation is transitional, and was defined as the first occurrence of chert or granular iron-formation by Bunting (1986), who amended an earlier definition by Hall et al. (1977) that the contact was at the top of the uppermost quartz sandstone horizon of the Yelma Formation. The upper contact with the Karri Karri Member of the Chiall Formation is recognized at the top of the highest chert, jasper or iron formation. The contact is exposed 6.5 km southwest of Good Camp Rockhole (AMG 259000E 7198300N) where it is either locally faulted or transitional, and the upper part of the Frere Formation consists of interbedded shale and thin chert beds. The thickness of the Frere Formation was estimated by Bunting (1986) to be up to 1200 m, but we consider that this figure includes structural repetition, so the deposited thickness is probably closer to 600 m.

Undivided Frere Formation (*ᴘEf*) typically consists of shale, siltstone, granular iron-formation, and chert and jasper beds. The formation is subdivided into intervals dominated by granular iron-formation (*ᴘEfg*), and shale, siltstone, and mudstone (*ᴘEfs*). The Frere Formation is typically mapped as undivided (*ᴘEf*) where granular iron-formation is subordinate to shale and siltstone, or where the scale of the interbedded iron formation and shale is below map resolution. More strongly deformed parts of the Frere Formation are shown as *ᴘtf* (see **'Troy Creek Schist'**, above).

Granular iron-formation horizons (*ᴘEfg*) consist of individual granular iron-formation beds interbedded with shale and siltstone. Individual beds of granular iron-formation are typically 5–30 cm thick, and consist of peloids of hematite, jasper or chert in a cement of chalcedony, chert or jasper. Angular chert and jasper intraclasts are common and reach up to 20 cm in length. Primary sedimentary structures were not recognized in granular iron-formation beds on METHWIN, but cross-bedding can be seen to the southwest in less-deformed Frere Formation near the southern basin margin. Fine platy hematite is the dominant oxide and is aligned in a foliation in more strongly deformed areas (Fig. 7). Magnetite is less common but where present it comprises euhedral porphyroblasts overprinting hematite. Magnetite exhibits patchy alteration to martite and maghematite. Individual interbedded siltstone and shale beds are generally less than

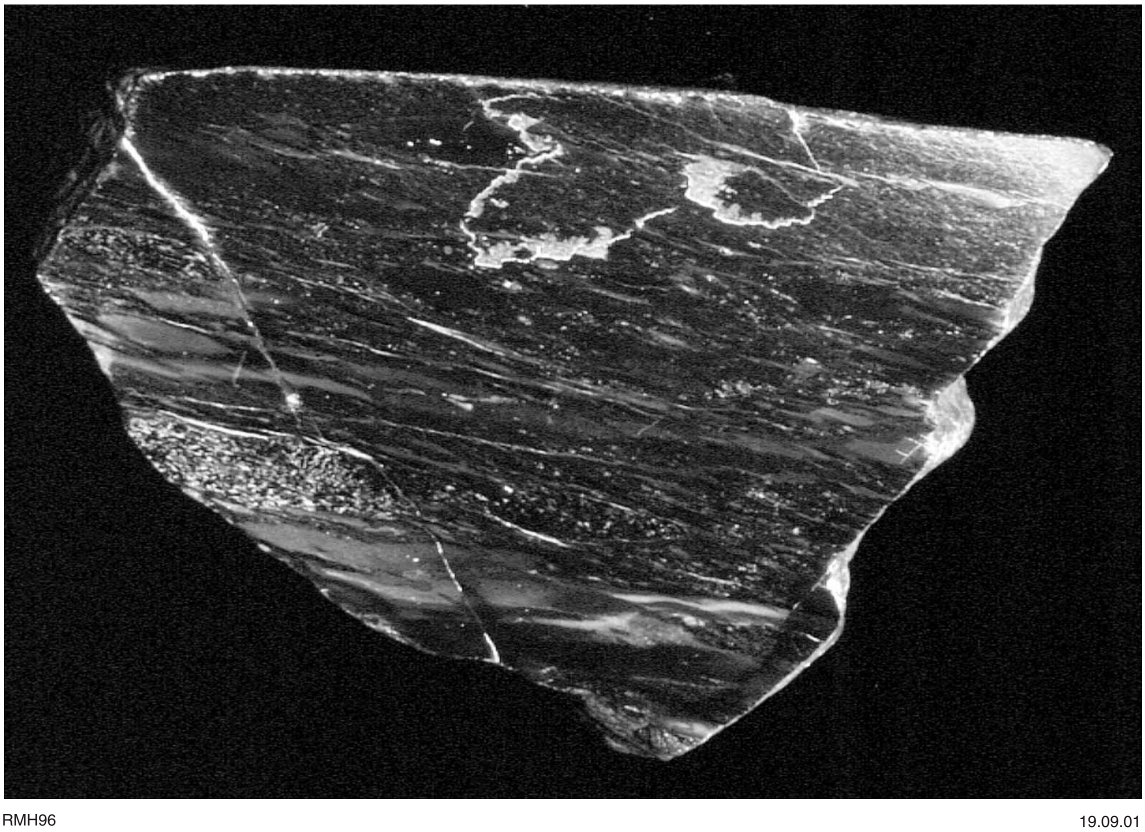

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Figure 7. Foliation defined by platy hematite in granular iron-formation, in the Stanley Fold Belt (AMG 251800E 7205900N)

5 cm in thickness, and are enriched in iron. Granular iron-formations in the Frere Formation are texturally and mineralogically similar to those in the Lake Superior region, North America, and the Gunflint Iron Formation from that region contains similar microfossils (Walter et al., 1976; Hall and Goode, 1978; Goode et al., 1983; Bunting, 1986; Tobin, 1990).

Laminar iron-formations are included within *ⱣEfg*, and are exposed 1.5 km (AMG 263000E 7206000N) and 3 km (AMG 262600E 7206500N) northwest of Good Camp Rockhole. They vary from banded granular iron-formation beds with variably ferruginous chert (Fig. 8a) to laminated chert and ferruginous chert, including jasper (Fig. 8b). They resemble banded iron-formation but contain a pervasive fabric that is interpreted to be a tectonic overprint of the original thin bedding. Lamellae vary from reasonably continuous to discontinuous lenses and are generally 10–50 mm in thickness. On RHODES (Pirajno and Hocking, 2000) and GRANITE PEAK (Jones, 2000) to the east, laminar iron-formations are distinguished as *ⱣEfgt*.

Shale and siltstone *(ⱣEfs)* intervals that separate granular iron-formation beds are similar to those of the Yelma Formation and the Karri Karri Member of the Chiall Formation. They commonly have a pervasive cleavage, accentuated by weathering, and are generally poorly exposed on METHWIN except in the far east of the sheet. Iron enrichment is common, especially close to major structures.

Strongly deformed granular iron-formation (*Ᵽtf*) in the north of METHWIN, for example 2 km southeast of Talbots Rockhole (AMG 273500E 7216500N), was mapped as an extension of the Troy Creek Schist. It consists of tectonically laminated iron formation and foliated granular iron-formation.

Two apparently dissimilar depositional environments are juxtaposed in the Frere Formation. Sedimentary structures in granular iron-formation indicate deposition largely by traction currents, in shallow water conditions. This is consistent with models proposed for the formation of granular iron-formation elsewhere, where chemically precipitated sedimentary beds are disrupted and agitated by current action either before lithification or during partial lithification (Beukes and Klein, 1990). In contrast, the lack of current-produced sedimentary structures in shale, siltstone, and mudstone horizons indicates quiet-water deposition by suspension or turbidity current processes, below fair-weather wavebase. A lagoonal setting is unlikely because the fine-grained intervals are regionally persistent, although a setting above wavebase is feasible if the basin was barred. In such a setting, shoals of granular iron-formation may have moved across a silty substrate.

The granular iron-formation, shale, peloidal chert, and peloidal jasper all have different iron and silica content both in and between units. This points to a complex, varying interrelationship between clastic influx, dissolved silica, and dissolved iron. The supply of dissolved silica appears to have been discontinuous at all scales, which is interpreted as a result of fluctuating fluid concentrations. The supply of iron is also interpreted as a result of fluctuating fluid concentrations but with a high proportion of iron remaining in suspension throughout deposition of the Frere Formation. Both iron-rich and silica-rich fluids probably had a distal source (see **Depositional setting** below). The shale interbedded with granular iron-formation and in major shale horizons may indicate periods where silica or iron precipitation was low, so that they were overwhelmed by fine-grained clastic influx, as well as a difference in oxidation versus reduction chemistry in the seawater.

Windidda Formation

The Windidda Formation is a sequence of carbonate and fine-grained clastic rocks between the Frere and Chiall Formations, which is present in the southeastern part of the Earaheedy Basin. The Karri Karri Member (*ⱣEdk*) was mapped on METHWIN as part of the Windidda Formation, when it was thought to be the lower energy, deeper water, lateral equivalent of the Windidda Formation to the southeast. More recent work, since mapping of METHWIN, has recognized that the Windidda Formation is a lateral correlative of the upper Frere Formation, not a later unit, and that the Karri Karri Member should be placed at the base of the Chiall Formation (Hocking et al., 2000; Jones et al., 2000).

Chiall Formation (*ⱣEc, ⱣEcw, ⱣEdk*)

The Chiall Formation (defined by Hocking et al., 2000) incorporates the Princess Ranges Quartzite and the Wandiwarra Formation of Hall et al. (1977) as members, and the Karri Karri Member (formerly placed in the Windidda Formation). Both the Princess Ranges Quartzite and Wandiwarra Formation were reduced to member status after the recognition that they are part of a single depositional package in which the stratigraphic level of the boundary between the two members may vary substantially. Shale, siltstone, and mudstone at the base of the Chiall Formation have been assigned to the Karri Karri Member (defined by Hocking et al., 2000; previously thought to be a fine-grained facies of the Windidda Formation). On METHWIN only the Wandiwarra Member (*ⱣEcw*) and Karri Karri Member (*ⱣEdk*) are exposed. On METHWIN, the contact between the underlying Frere Formation and the Karri Karri Member is transitional and taken at the top of the last chert bed or iron formation. On WONGAWOL, to the southeast, the Chiall Formation rests on the Windidda Formation and the contact is marked by a breccia consisting of angular carbonate clasts. The breccia was interpreted by Bunting (1986) as a disconformity, but was reinterpreted by Jones et al. (2000) as a submarine hardground. The top of the Chiall Formation is not present on METHWIN. Further east the Chiall Formation is overlain by the Wongawol Formation, and the contact is taken at the highest medium-grained sandstone. The thickness of the units that constitute the Chiall Formation was considered by Bunting (1986) to be up to 1500 m. We suggest that there has been more structural repetition than was estimated by Bunting, and that the maximum thickness of the formation may only be 1000 m.

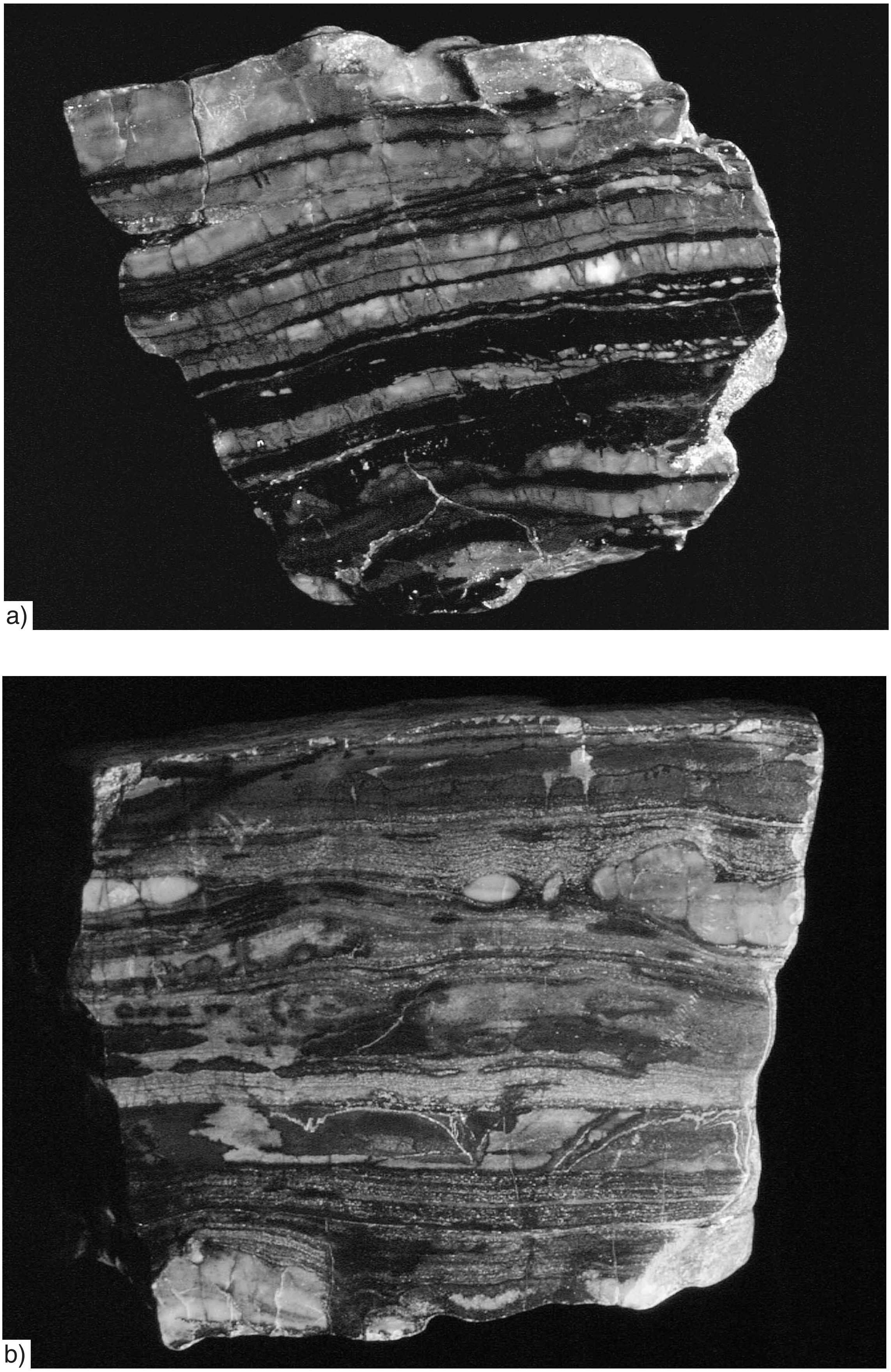

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Figure 8. Tectonically banded (laminar) iron-formation in the Stanley Fold Belt: a) banded with thin granular iron-formation beds (AMG 261200E 7198000N); b) banded chert, ferruginous chert, and jasper (AMG 262970E 7205100N)

Karri Karri Member (ⱣEdk)

The lower Karri Karri Member (*ⱣEdk,* shown as *ⱣEck* on later maps) consists dominantly of shale and siltstone, with thin interbedded sandstone beds in the upper part of the member. The member is interpreted as having a maximum thickness of 600 m on METHWIN. The lower contact with the Frere Formation is exposed 6.5 km southwest of Good Camp Rockhole (AMG 259000E 7198300N) and is locally faulted. It is defined as the top of the last major chert or iron formation. The upper contact with the Wandiwarra Member is transitional, with thin interbedded sandstone beds becoming more common in the upper part of the Karri Karri Member. The contact is taken at the first occurrence of a thick sandstone. Exposures of the member are generally folded, cleaved, and cut by small quartz veins. They are limited to the southern side of the Stanley Fold Belt in breakaways or as poor, low-lying outcrops.

Lithologically, shale and siltstone resemble lithologies similar to the underlying Frere and Yelma Formations, but generally contain a high proportion of coarse-grained siltstone. Without other stratigraphic control, the shales may be indistinguishable. They are typically thinly parallel laminated with individual lamellae 1–10 mm thick. Individual sandstone beds in the upper part of the member are typically 5–20 cm thick, and fine to medium grained. Close to the contact with the Frere Formation, 6.5 km southwest of Good Camp Rockhole (AMG 259000E 7198300N), the member has had secondary enrichment of iron oxides. Magnetite is present as euhedral porphyroblasts, which overprint platey hematite and are partially altered to martite.

The delicate, continuous lamination in the Karri Karri Member is indicative of quiet-water deposition probably below fair-weather wavebase, subsequent to a transgression at the top of the Frere Formation. Sandstone beds are interpreted as mass-flow deposits rather than turbidite deposits because of the intraclastic mudstone clasts and traction structures (cf. Shanmugan, 1997). The iron-rich nature of the rocks indicates that iron remained in suspension even after deposition of the last granular iron-formation and the silica and iron supply to the basin had ceased.

Wandiwarra Member (ⱣEcw, ⱣEcwa)

The Wandiwarra Member (*ⱣEcw*) consists dominantly of siltstone and shale, with scattered intercalations of sandstone (*ⱣEcwa*). Siltstone and shale intervals are generally well exposed on breakaways. Sandstone intervals form resistant cappings on hills.

Undivided Wandiwarra Member (*ⱣEcw*) consists mostly of siltstone and shale with minor interbedded sandstone beds. Shale intervals are generally parallel laminated with minor cross lamination. Laminations are typically 0.5 – 5 cm thick. Interbedded sandstone beds range from 5 cm to, less commonly, about 1 m thick.

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Figure 9. Base of a mass-flow sandstone bed in the Wandiwarra Member. Mass flow moved towards left, and has ploughed into and eroded underlying siltstone in the same manner as an agricultural furrow plough. From 9.5 km west of Karri Karri Tank, east side of hill (AMG 249500E 7177900N)

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Figure 10. Mass flow with flocculated top in the Wandiwarra Member. Flocculated look appears to be caused by plastic siltstone intraclasts rolling less-consolidated sandstone into balls, above main sandy portion of mass flow. Note disruption of underlying interbedded siltstone and sandstone. Location as Figure 9, but west side of hill (AMG 249400E 7177900N)

Sandstone dominated intervals (*PEcwa*) consist of sandstone beds with subordinate interbedded siltstone, generally as thin beds. Sandstone beds are generally quartz wackes that consist dominantly of rounded to subrounded quartz, with minor chert, feldspar, mica, glauconite, and tourmaline, and become more mature in the upper part of the member. South of the Stanley Fold Belt, 11 km south-southwest of Good Camp Rockhole (AMG 260600E 70908200N), sandstone has had pronounced secondary enrichment of iron oxides. Bed thickness varies from about 5 cm to 1.5 m but is typically 10–20 cm. Bedsets are generally 20 cm to 1 m thick. Sedimentary structures include cross-bedding, asymmetric ripples, and hummocky cross-stratification in the lower part of the member. Angular intraclasts of shale and flat clay-chip molds are common, and mostly have parallel bedding (Figs 9 and 10). The intraclasts are angular and typically 1–2 cm in size but reach up to 20 cm in size. Mass-flow sandstone beds are present in the basal part of the member (Fig. 9). They have ploughed into underlying unconsolidated to partially lithified siltstone beds (Fig. 10) 9.5 km west of Karri Karri Tank (AMG 249500E 7177900N). The basal part of a flow is commonly composed of poorly sorted siltstone and mudstone clasts in a matrix of sand, silt, and clay (Fig. 10). Current lineations, cross-bedding, and ripples indicate a dominant palaeocurrent flow towards the north.

Sedimentary structures in both the shale and sandstone intervals indicate that the Wandiwarra Member was deposited dominantly below fairweather wavebase, but shallowed up in the upper part of the member. Sandstone beds are probably tempestites (storm related) and seismites (related to earthquakes; Seilacher, 1969; Rodriguez-Pascua et al., 2000).

Depositional setting

The stratigraphic succession of the Earaheedy Group places strong controls on the nature of the basin. The Earaheedy Group consists of both chemical and clastic sedimentary rocks which are indicative of a shallow-marine to coastal environment that deepened to the north to northeast (Jones et al., 2000; Pirajno et al., 2000a). The exposed rocks represent only the coastal to upper shelfal portion of the continental shelf in the basin.

The grain size (dominantly fine sand to silt) suggests quiet, low-energy conditions, although this could be because coarser material was simply not available due to a low-gradient, weathered, basin hinterland. This and indicators of saline lagoonal environments (Sweetwaters Well Member; Jones et al., 2000) are consistent with deposition on an arid coast. On METHWIN the Earaheedy

Group grades from a fluvial environment at the very base of the Yelma Formation to coastal deposits in the upper Yelma Formation, through coastal and nearshore ?sub-wavebase deposits in the Frere Formation, to shelfal and then nearshore deposits in the Chiall Formation. At least two cycles, or depositional sequences, are evident. The first spans the Yelma and Frere Formations, and the second starts with the transgression at the base of the Chiall Formation, elsewhere marked by a submarine hardground. The top of the hardground may be the maximum flooding surface.

Throughout this succession there is only minor variation in bathymetry, probably only tens of metres rather than hundreds, and minor variation in grain size and sediment type (other than the iron formation of the Frere Formation), which suggests a tectonic setting without major orogenic episodes but not necessarily without earthquakes. Sea-level fluctuations are interpreted primarily as a response to subsidence, sediment loading, and compaction. The rapid transgression at the boundary between the Frere and Chiall Formations could be either eustatic or tectonic. The repeated mass-flow deposits in the Chiall Formation and ubiquitous ball-and-pillow deformation higher in the succession in the Wongawol Formation (Bunting, 1986) are suggestive of seismites, caused by repeated earthquakes which disrupted sediment and triggered mass flows but were not associated with basin uplift or subsidence.

The variation in rock types, from siliciclastic deposits through carbonates to iron formations (both primary and reworked) indicates that deposition in the Earaheedy Basin was also controlled by water chemistry. The source of iron for the iron formations in the Frere Formation is a key element in the understanding of the basin as is the lack of evidence for contemporaneous volcanism and major deformation. Beukes and Klein (1992) and Isley (1995) considered that granular iron-formation formed as the shallow-water, higher energy equivalent of deeper water banded iron-formations. The northward-deepening, passive-margin model for the Earaheedy Basin of Pirajno et al. (2000a) and Jones et al. (2000) is consistent with these models, although the palaeoslope may have faced more northeast than north. In the case of the Earaheedy Basin, the iron is interpreted to have been sourced from a mid-ocean ridge which was located substantially north or northeast of the presently exposed margin of the basin (Pirajno et al., 2000a; Jones et al., 2000). A fluctuating supply of iron and silica was carried in solution from the ridge to the southern marginal parts of the basin during phases of ocean spreading.

Structure and deformation

The Earaheedy Basin has probably been subjected to several deformation events. The relative timing of these events is not well constrained other than by regional estimates of the age of orogenic events in western and central Western Australia. The exposed Earaheedy Basin is deformed into a regional east to east-southeasterly trending, south-verging, asymmetric, open syncline, which plunges gently towards the southeast. The northern limb is deformed, steeply dipping to locally overturned, and forms the Stanley Fold Belt, a structural domain about 20 km wide and trending 110° across central METHWIN. Along the Stanley Fold Belt, rocks show strike-slip and reverse faulting, foliation fabrics, and tight folding. The fold belt is well-expressed on aeromagnetic images of the basin (Fig. 11). The deformation also affects the Archaean Marymia Inlier. Undeformed Earaheedy Group is present north of the fold belt, notably on RHODES north of the Scorpion Inlier and on COONABILDIE at Coonabildie Bluff.

The second phase of the Yapungku Orogeny, which deformed the Paterson Orogen (Bagas et al., 2000), may have been responsible for development of the fold belt, the major deformational imprint on the Earaheedy Group. Underlying basement structures appear to have been responsible for much of the localization of deformation, based on aeromagnetic patterns apparent below the Earaheedy Group in more southerly, shallower parts of the basin. Later events that undoubtedly affected the group, if only by reactivation of existing structures, are the Miles or Edmundian Orogeny, at about 1000 Ma (Bagas et al., 2000; Martin and Thorne, 2001), and the Paterson Orogeny, at about 550 Ma (Bagas et al., 2000).

Folding is irregular and varies in scale, with fold limbs commonly truncated by faults. Both fold axes and faults trend easterly, and faults show both dip-slip (dipping north), and sinistral strike-slip components. In the Stanley Fold Belt the Yelma Formation is commonly cut by east-striking quartz veins. Shales in the Yelma and Frere Formations are commonly phyllitic. An S_1 foliation is defined by platy hematite and crenulation of bedding and tectonically banded iron-formations in strongly deformed zones, generally proximal to major structures in granular iron-formation. Sense of shear indicators show reverse movement on the S_1 foliation, consistent with reverse movement on faulting in the area.

South of the Stanley Fold Belt, the Earaheedy Group is characterized by open, commonly gentle folding, locally with associated axial-plane cleavage, expressed on aeromagnetic images as a series of broad, low-amplitude, east-trending ridges and swales. This folding is associated with widespread quartz veining in the axial zones. Irregular mesoscale folding has average wavelengths of 1–10 m (Fig. 12) and reverse faulting along limbs is common. Slightly larger scale folds have a wavelength of 10–20 m. Folding is apparent down to centimetre scale with local irregular crumpling of bedding in finer grained siltstone and mudstone (Fig. 13). Sandstone beds locally exhibit a widely spaced cleavage. The folds vary from upright to inclined, with subhorizontal to moderate plunges. Bedding–cleavage intersection lineations throughout the area also plunge to the southeast. Regionally, rocks dip to the north at angles between 5 and 15°. Deformation increases northward, towards the Stanley Fold Belt.

Sedimentary rocks of the Earaheedy Group generally are weakly metamorphosed, only attaining lower greenschist grade locally. Typical metamorphic mineral phases in fine-grained rocks are sericite, muscovite, and chlorite.

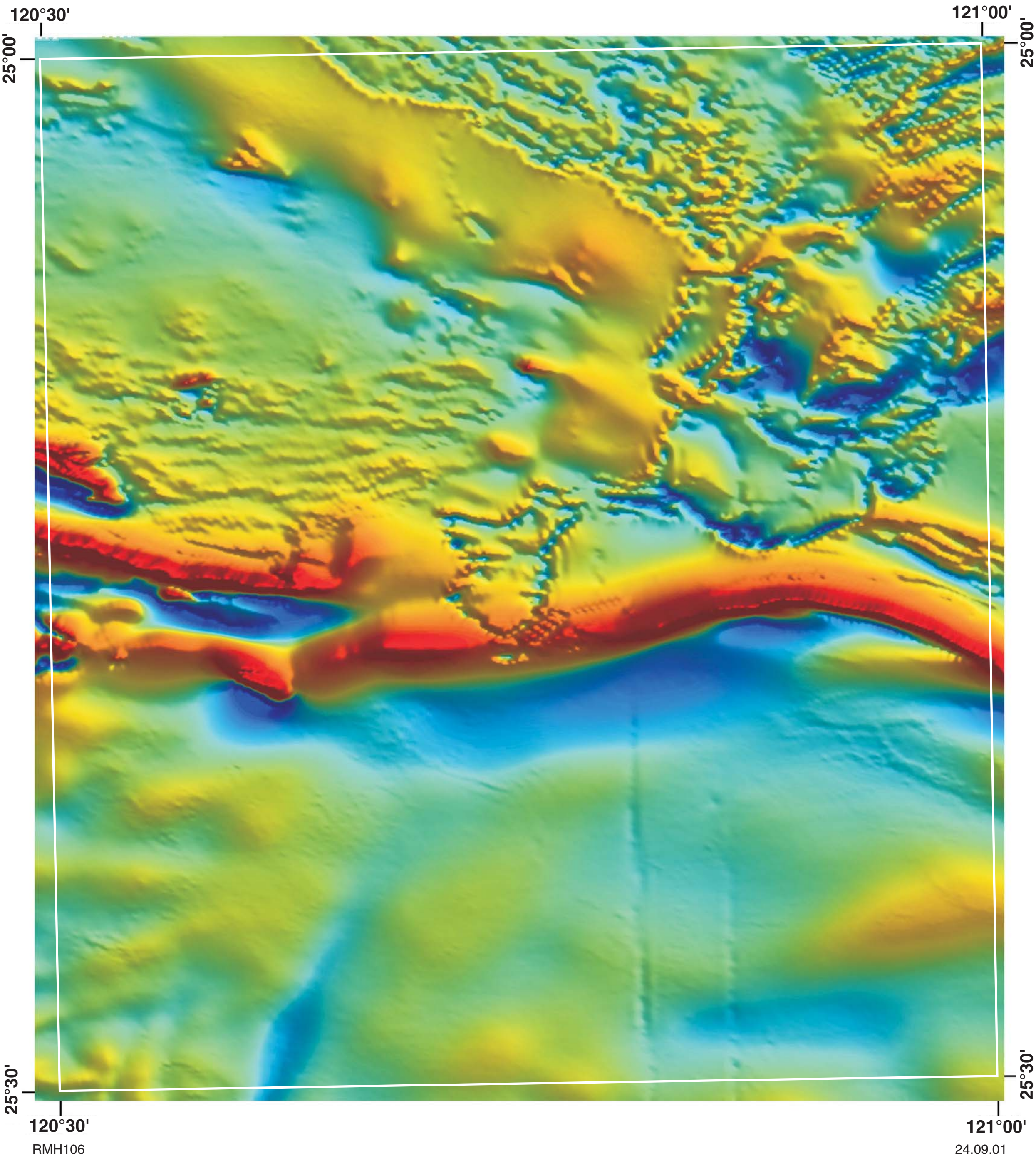

Figure 11. Aeromagnetic image of METHWIN, showing low-amplitude, deep anomalies characteristic of the Earaheedy Group in south, line of Stanley Fold Belt in centre, and high amplitude shallow anomalies due to dolerite sills in north

Bangemall Supergroup — Collier Group

The Bangemall Supergroup (previously Bangemall Group) was systematically studied in the mid-1970s. Muhling and Brakel (1985) summarized earlier work, and described the succession as a whole in the context of the 'Bangemall Group' and 'Bangemall Basin'. They defined the Collier, Kahrban, and Diebil Subgroups of the then-Bangemall Group to contain what they thought was the Mesoproterozoic succession of the eastern Bangemall Basin, following mapping along the northern margin of the Earaheedy Basin by Bunting et al. (1982), Commander et al. (1982), and Brakel and Leech (1980). At that time, the unconformity between the Collier (previously Bangemall) and northwest Officer (previously Savory) Basins had not been recognized, and Bunting et al. (1982) showed both the Glass Spring Formation and most of the Wonyulgunna Sandstone as Calyie Sandstone. Williams (1990a,b, 1992, 1995a,b) erected and described

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Figure 12. Outcrop-scale mesofolding of the Wandiwarra Member, 5 km east-northeast of CSR Well 4B (AMG 291500E 7181300N)

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Figure 13. Irregular crumpling of shale and siltstone in the Wandiwarra Member from the southwest corner of METHWIN (AMG 254000E 7176500N)

the Savory Basin, for the Neoproterozoic sedimentary rocks previously placed in the Bangemall Basin, represented on METHWIN by the Glass Spring Formation. Bagas et al. (1999) subsequently dismantled the Savory Group and Basin (see below). Martin et al. (1999) presented a preliminary re-evaluation of the lower Bangemall succession in the northwest Bangemall Basin, in which they raised the Edmund to Group status, the Bangemall to Supergroup status, and, by implication, the Collier to Group status. The 'Bangemall Basin' has been abandoned, and replaced by the Edmund and Collier Basins, because there appears to be at least a 250 m.y. gap between the two groups (Martin and Thorne, 2001).

The Collier Group is constrained between c. 1210 and 1070 Ma to the northwest (Martin and Thorne, 2001) by dolerite sills that intrude it (Wingate, M., 2000, written comm.; Nelson, 2001) and detrital zircons from near its base (Cawood, P., 2000, written comm.). The correlative Manganese Group predates the Miles Orogeny (c. 1130–820 Ma, Bagas et al., 2000) in the Paterson Orogen. In juxtaposed exposures, the Collier Group is less deformed than the Scorpion Group, a probable correlative of the lower Edmund Group (Hocking and Pirajno, in prep.), suggesting that it is significantly younger, in accordance with the c. 1620 and c. 1465 Ma age constraints on the Edmund Group (Martin and Thorne, 2001).

Wonyulgunna Sandstone (*ƤMCw*)

The Wonyulgunna Sandstone (*ƤMCw*) is the basal unit of the Collier Group (Collier Subgroup of Muhling and Brakel, 1985). The sandstone forms the Carnarvon Range, which is a significant tourist destination on METHWIN. Bunting et al. (1982) and Muhling and Brakel (1985) recognized both the Wonyulgunna and Calyie Sandstones on METHWIN, with a lateral transition eastwards from the former into the latter at a break in outcrop west of Mount Methwin. Both units rest directly on the Earaheedy Group and could not be differentiated during the current mapping. In addition, an intervening shale (Backdoor Formation) that is the basis of the separation of the Calyie and Wonyulgunna Sandstones is not present on METHWIN. Therefore, all rocks of the Collier Group on METHWIN are shown as Wonyulgunna Sandstone.

An angular unconformity between the basal Wonyulgunna Sandstone and the Earaheedy Group can be seen in several localities. Adjacent to the unconformity the Wonyulgunna Sandstone is commonly sheared and faulted, and dips are steeper, as for example immediately south of Mount Methwin. The rocks are locally strongly silicified, especially near faults, with fine euhedral quartz crystals on fracture planes. The silicification is intense in places, taking the form of silica flooding and anastomosing networks of quartz veinlets which grade into nonsilicified rock. This probably developed by hydraulic brecciation associated with tectonism. The upper contact, with rocks of the Salvation Group (previously Sunbeam Group), is everywhere obscured by Cainozoic sand. Distinction of the Wonyulgunna Sandstone from the Salvation Group is difficult in places. Similar lithofacies are present in both units, and assignment of an outcrop can depend on palaeocurrent directions and changes in dip.

The Wonyulgunna Sandstone is dominated by medium- to coarse-grained, moderately silicified, variably sorted quartz sandstone. In western and central METHWIN, the sandstone commonly shows medium- to large-scale cross-bedding, with northward to eastward palaeocurrent directions (Fig. 14). Horizontally bedded sandstone is present as bottomsets to the cross-beds and as thin discrete intervals. The cross-bedded facies is interpreted as a subaerial to subaqueous distributary system, coastally situated and sourced in part from the Marymia Inlier and in part from the Yilgarn Craton and adjacent Palaeoproterozoic sedimentary rocks. The cross-bedded facies grades upwards and eastwards into thinly horizontally bedded and rippled sandstone with scattered adhesion surfaces (Fig. 15), washouts, double-crested ripples (Fig. 16), and cross-bedded horizons. Good exposures of this facies are present south of Mount Methwin and west of Mount Salvado. They are tidal sandflat deposits, adjacent to and interfingering with the distributary systems. Coastal barrier, lagoonal, and delta front deposits have not been recognized. Conglomerate horizons are present locally at the base of the succession (e.g. near and southeast of Good Camp Rockhole, AMG 262900E 7230500N and AMG 267000E 7201800N respectively) and as discontinuous lenses higher up, in sandstone (e.g. at rockholes on the south side of the Carnarvon Range, AMG 267500E 7202000N). Clasts in these conglomerates are commonly rock types derived from the underlying Earaheedy Group.

A distinctive interval of giant-scale cross-bedding (Fig. 17 and front cover), up to about 100 m thick, extends east from Good Camp Rockhole at the base of the Wonyulgunna Sandstone. Cross-beds are broad, cross-cutting arcuate troughs up to 8 m deep and about 10 m wide, with eastward to northeastward unimodal palaeocurrent directions. Possible small tepee structures (Fig. 18), recording displacive evaporite growth, are present in horizontally bedded to rippled bottomsets near Good Camp Rockhole, and there are rare surfaces of symmetrical ripples through the facies. Foreset laminae of coarse- to very coarse grained sand are common, and rule out an eolian origin for the facies. Muhling and Brakel (1985) interpreted the giant cross-bedded facies as tidally driven sandwaves on a marine shelf. The presence of possible evaporite pseudomorphs, the unimodal palaeocurrent pattern, and the presence of symmetrical ripples suggest major braided-fluvial to coastal distributaries with intermittent emergence rather than a marine shelf setting. The size of the cross-bedding indicates avalanche deposition down the faces of giant bars, either attached to the sides of channels (McCabe, 1977) or similar to those in the Brahmaputra River today (Coleman, 1969).

The palaeocurrent pattern in the Wonyulgunna Sandstone (Fig. 14) is biased by the number of readings from the giant cross-bedded facies, but clearly shows derivation from the Marymia Inlier to the west on central and western METHWIN, and from the Earaheedy Basin and possibly Yilgarn Craton on eastern METHWIN. Coupled with the size of the cross-bedding, the pattern suggests uplift and erosion of the inlier contemporaneous with deposition, possibly as a mid-basin high.

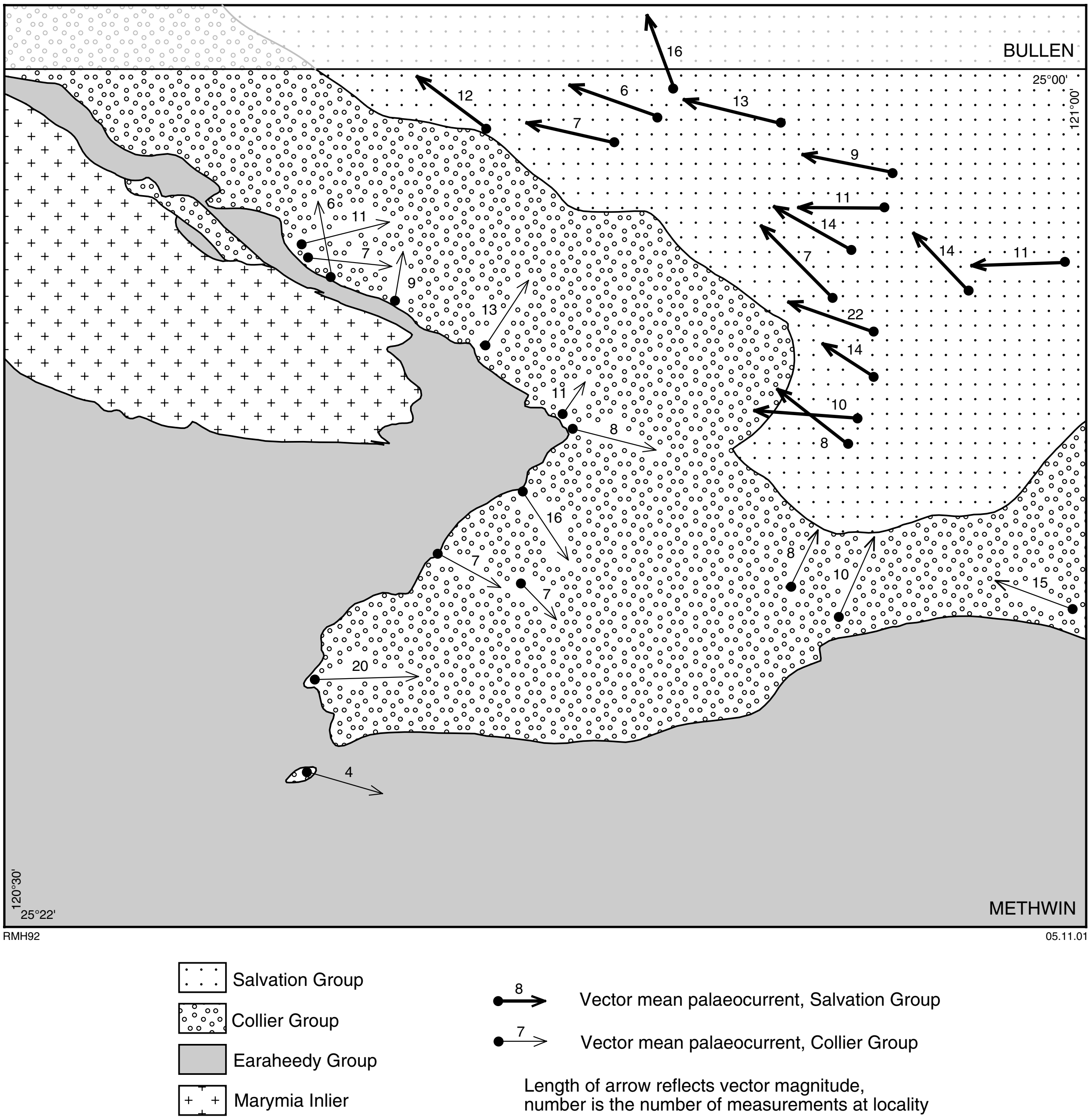

Figure 14. Palaeocurrent directions for the Collier and Salvation Groups on Methwin. Arrows are vector mean direction from each locality, length of arrow corresponds to vector mean magnitude, number refers to number of measurements at each location. Data are from cross-bedding

Structure and deformation

Dips in the Wonyulgunna Sandstone decrease from around 10–15° north to northeast, to less than 5° in more northerly exposures, with steeper dips near faults. The sandstone generally shows only minor deformation, as brittle fracturing along fault zones, associated with strong silicification. Faults are dominantly easterly trending, with linking southeast-trending faults. This fault pattern is controlled by major structures in the underlying Stanley Fold Belt, and may represent the suture between the Yilgarn Craton to the south and the unexposed Gascoyne Complex to the north. Faults in the Stanley Fold Belt have been reactivated after deposition of the Wonyulgunna Sandstone, because the sandstone is locally steeply dipping, strongly silicified and sheared in this zone, as for example near Mount Methwin (AMG 265700E 7225000N) and Virgin Springs (AMG 268500E 7220500N).

The timing of faulting and folding is poorly constrained, but presumably postdates bedding-parallel dolerite sills in the southern Carnarvon Range and further east on Mudan where they are dated as 1080 Ma (Wingate, in prep.). Deformation could have been during the Miles or Edmundian Orogenies (Table 2).

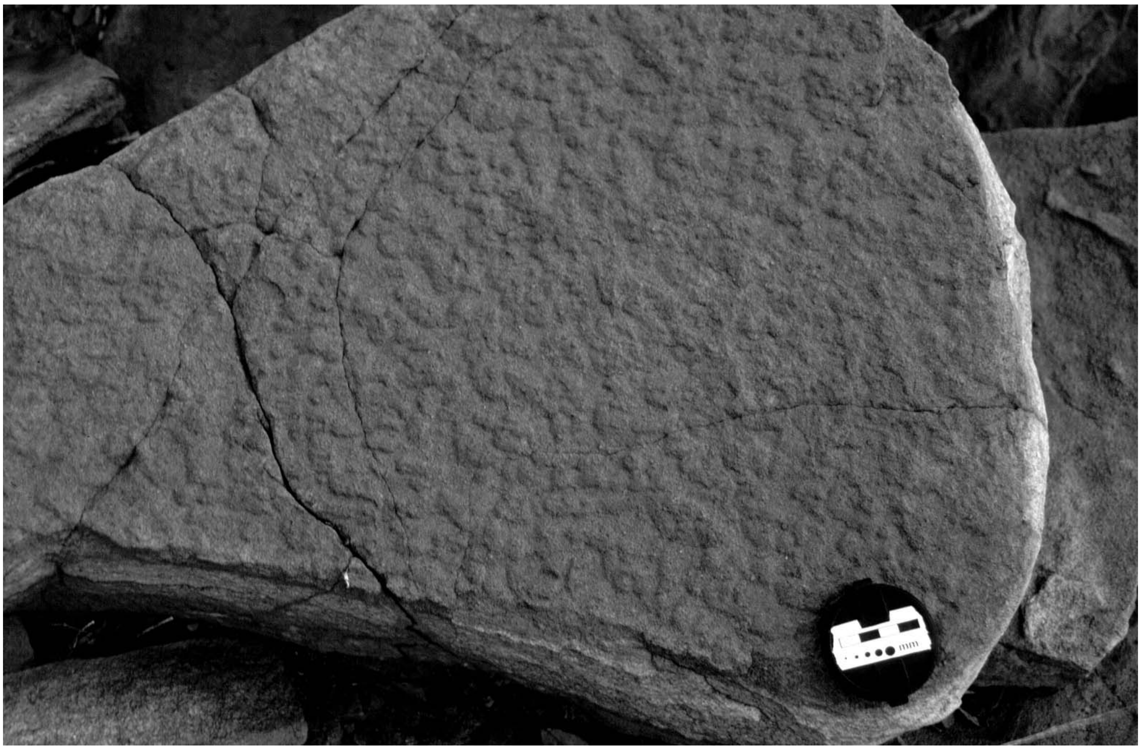

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Figure 15. Warty adhesion surface in the Wonyulgunna Sandstone. Warts form and grow upwind by wind-blown sand grains adhering to the damp surface of sand. In this case, the wind blew from lower left to upper right. Lens cap bar scale in centimetres (AMG 285000E 7209000N)

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Figure 16. Double-crested ripples in the Wonyulgunna Sandstone, indicative of rapidly decreasing, shallow water depths, probably intertidal. Lens cap bar scale in centimetres (AMG 285000E 7209000N)

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Figure 17. Giant cross-bedding in the Wonyulgunna Sandstone, looking to north from ridge north of Good Camp Rockhole campsite (AMG 263000E 7203500N). Foresets are up to 8 m thick, and flow was from left to right. Tectonic dip about 15°, to east (right)

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Figure 18. Probable small displacive evaporite structures (tepees) in the Wonyulgunna Sandstone, Good Camp Rockhole camp site (AMG 263000E 7203500N). On left side of picture, strata are disrupted (probably by evaporite growth in soft sediment) at level of top of lens cap, and laminae above are buckled up to form tepee shape. Disruption is at slightly higher level on right of picture. Lens cap bar scale in centimetres

Salvation Group

Rocks in northeast METHWIN were originally included in the 'Bangemall Basin' by Bunting et al. (1982) and Muhling and Brakel (1985). In the 1980s, they were recognized as a distinct younger succession, probably of Neoproterozoic age, and were subsequently assigned to the Glass Spring Formation of the Savory Group, Savory Basin, by Williams (1990b, 1992). Bagas et al. (1999) noted that the Savory Group contained an unconformity of about 150–200 m.y. duration, and abandoned the group and the basin. They proposed the Sunbeam Group for the lower 'Savory Group', and included the area in the Officer Basin. The Officer Basin is in turn part of the Centralian Superbasin (Walter and Gorter, 1994; Walter et al., 1995), although Apak and Moors (2000) regarded the Officer Basin as a discrete structural entity.

The westward palaeocurrent pattern for the lower Sunbeam Group (Fig. 14) was noted as a problem by Hocking and Grey (2000). Subsequently, Wingate (2000, written comm.) suggested that dolerite sills in northwest MUDAN have an age of 1080 Ma, because their palaeomagnetic poles are identical to those from similar dolerites in the Edmund Basin dated as 1080 Ma using SHRIMP U–Pb dating of baddelyite and zircon (Wingate, in prep.). The sills on MUDAN intrude the Coonabildie and Brassey Range Formations (Hocking et al., 2000), which have the same palaeocurrent pattern and broad lithofacies as the Glass Spring Formation. The Glass Spring Formation is therefore included, with the other formations sharing the westward palaeocurrent pattern and apparently similar dolerite intrusions, in a new group — the Salvation Group.

The extent, age, and possible correlatives of the Salvation Group are uncertain. It predates the Centralian Superbasin, but postdates the Collier Group. Similar ages are recorded for interbedded basalt and siltstone at the base of Empress 1A (1058 ± 13 Ma; Amdel Ltd, 1999; Stevens and Apak, 1999), and the cover succession on the Musgrave Complex (Bentley Supergroup, Glikson et al., 1996).

The age of the basal Centralian Superbasin is well constrained (Walter et al., 2000). The base of the succession has an age of about 840 Ma, and the top a minimum age of about 800 Ma. The superbasin therefore is substantially younger than the age inferred for intrusions into the Salvation Group by Wingate (in prep.; see above).

Glass Spring Formation (*ƤSg*)

The Glass Spring Formation (*ƤSg*) is the basal unit of the Salvation Group on METHWIN. Relationships with other units are obscured by sand. Compared to the Wonyulgunna Sandstone, the Glass Spring Formation generally dips at slightly lower angles, is less texturally mature, and less silicified overall, with fewer zones of fine cross-cutting quartz stockwork. The last two points relate in part to the position of outcrops of Glass Spring Formation, which are further away from the Stanley Fold Belt than those of the Wonyulgunna Sandstone. The Glass Spring Formation appears little different to the Brassey Range Formation to the east on MUDAN and TRAINOR (1:250 000), and the two units may be equivalent.

The lower Glass Spring Formation is dominated by poorly sorted, locally pebbly, moderately indurated sandstone. One siltstone interval (*ƤSgs*) was found, but could not be traced laterally. Granule conglomerate beds and quartz-pebble laminae are common, and distinguish the Glass Spring Formation from the Wonyulgunna Sandstone. Trough cross-bedding is ubiquitous. Troughs are generally medium to large scale, occasionally very large, and cross-bedding is emphasized by siltstone foreset-laminae. Horizontally bedded sandstone, as bottomsets and discrete intervals, and rippled sandstone are present locally. Higher in the succession (further north), well-sorted quartz arenite is present. This exhibits broad, medium-scale trough cross-bedding, with mega-ripples locally preserved (as for example 18.5 km east-northeast of Talbots Rockhole; AMG 288800E 7226400N), and scattered adhesion surfaces and clay intraclasts. Palaeocurrent measurements throughout the Glass Spring Formation indicate unimodal westward flow (Fig. 14). This confirms the pattern interpreted by Williams (1992) from much sparser data, and indicates a source in the area currently covered by the Officer Basin rather than from the Yilgarn Craton (Hocking and Grey, 2000). The formation is interpreted as a braided fluvial deposit, some of which may have had a tidal influence due to a coastal setting, grading upward locally to tidal sandflat deposits.

Structure

The Glass Spring Formation is gently tilted to the northeast, and shows some gentle doming and swales that may be due to underlying dolerite intrusions. The intrusions are clear on aeromagnetic images (Fig. 11) although none are exposed on METHWIN. In general, dips of bedding decrease northward from about 10° in the southernmost exposures to less than 5° in northeast METHWIN. This may reflect regional buckling after deposition, perhaps associated with the extreme southern effects of the Paterson Orogeny at about 550 Ma (Bagas et al., 2000), but is more likely a distal expression of continued reactivation of the Stanley Fold Belt. Faults cut the succession locally, and there is silicification adjacent to fault planes.

Mafic igneous rocks

Magnetic intensity images of METHWIN (Fig. 11) indicate that there are extensive intrusive sills in the Salvation and Collier Groups, but only one exposure has been located. A mafic sill intrudes Wonyulgunna Sandstone in the southern Carnarvon Range, east-southeast of Good Camp Rockhole (AMG 270000E 7202900N), and another may be exposed 10 km east of the Carnarvon Range (AMG 284000E 7207000N). Analytical data for the sill are in Table 4. Its composition is very similar to mafic sills exposed to the east and north on STANLEY, BULLEN, and TRAINOR (1:250 000). On STANLEY, these were named the Glenayle Dolerite by Hocking et al. (2000).

Table 4. Analytical data for dolerite in the Carnarvon Range

GSWA number	*148375*
AMG	*270000E 7202900N*
	Percentage
SiO_2	52.572
Al_2O_3	14.022
TiO_2	1.575
Fe_2O_3	12.614
FeO	8.19
MnO	0.179
MgO	5.963
CaO	9.140
Na_2O	2.622
K_2O	1.149
P_2O_5	0.178
S	0.018
H_2O-	0.230
H_2O+	1.052
CO_2	0.040
Total	**100.44**
	Parts per million
Ag	-0.1
As	-0.4
Ba	397.6
Bi	0.4
Br	3.0
Cd	0.2
Ce	42.6
Cr	32.7
Cs	-0.6
Cu	113.1
Ga	19.4
Ge	1.7
Hf	7.4
I	-0.3
In	-0.1
La	19.9
Mo	0.7
Nb	8.0
Nd	22.6
Ni	92.2
Pb	8.3
Rb	36.7
Sb	-0.1
Sc	30.8
Se	0.2
Sn	1.4
Sr	266.9
Te	-0.2
Th	4.4
Tl	0.8
U	0.9
V	253.0
Y	27.4
Zn	87.3
Zr	149.3
Dy	5.46
Er	2.99
Eu	1.652
Gd	5.77
Hf	4.17
Lu	0.400
Pr	5.30
Sm	5.42
Ta	0.531
Yb	2.67

NOTES: Major- and trace element oxides analysed by XRF
Rare earth elements analysed by ICP-MS
– = below limit of detection

Where exposed on STANLEY, dolerite sills (microgabbro) are typically composed of clinopyroxene (50–55 vol. %) and labradorite (30–35 vol. %), with accessory ilmenite, titanomagnetite, and apatite. Their texture ranges from gabbroic to fine grained and equigranular, both in and between sills. Patterns on gravity and aeromagnetic images indicate that feeder stocks may also be present. All contacts indicate that intrusion postdated lithification of the sedimentary succession. The chemistry of all dolerites in the area is similar suggesting a comagmatic origin, and they have a similar appearance on aeromagnetic images. The sills may be part of a large igneous province that underlies the Neoproterozoic rocks of the Officer Basin and may extend through the Musgrave Complex (Glikson et al., 1996). Intrusive mafic sills have been recorded from outcrop over the northern STANLEY, TRAINOR, BULLEN, southeast ROBERTSON, and GUNANYA 1:250 000 sheets. As discussed above, under **Bangemall Supergroup — Collier Group**, the most probable age for the dolerites is about 1080 Ma, based on SHRIMP U–Pb ages for similar dolerites in the Edmund Basin that share identical palaeomagnetic pole positions (Wingate, M., 2000, written comm.). To the southeast, mafic igneous rocks ?interbedded with siltstone at the base of Empress 1A (Carlsen and Grey, 1998; Stevens and Apak, 1999) have been dated at 1058 ± 13 Ma by K–Ar ratios (Amdel, 1999).

Mineralization

Iron

The Earaheedy Basin was considered to be highly prospective for iron ore of the Hamersley type (Broken Hill Proprietary Limited, 1978) because of the presence of the Frere Formation. Several Temporary Reserves were granted in the basin between 1973 and 1978, and zones of iron enrichment in iron formation were located.

Unaltered granular iron-formation in the Frere Formation contains varying amounts of iron. On METHWIN enrichment of secondary iron oxides is common proximal to faults as a result of hydrothermal fluids and weathering processes. Such enriched zones, as for example 7 km southwest of Good Camp Rockhole (AMG 257800E 7199400N), may have economic potential. To the west on FAIRBAIRN, platy hematite is present in a predominantly shaly sequence near the top of the Frere Formation in the Miss Fairbairn Hills area. Iron enrichment was interpreted as the result of localized chemical weathering (Robinson and Gellatly, 1978) and drilling indicated that the high-grade zones encountered during surface sampling were both small and sulfurous.

Gold

There is no gold exploration recorded on METHWIN, but there is gold mineralization to the east on RHODES (Hocking and Pirajno, in prep.) in mylonitic zones, quartz veins, and silicified fault and shear zones in the

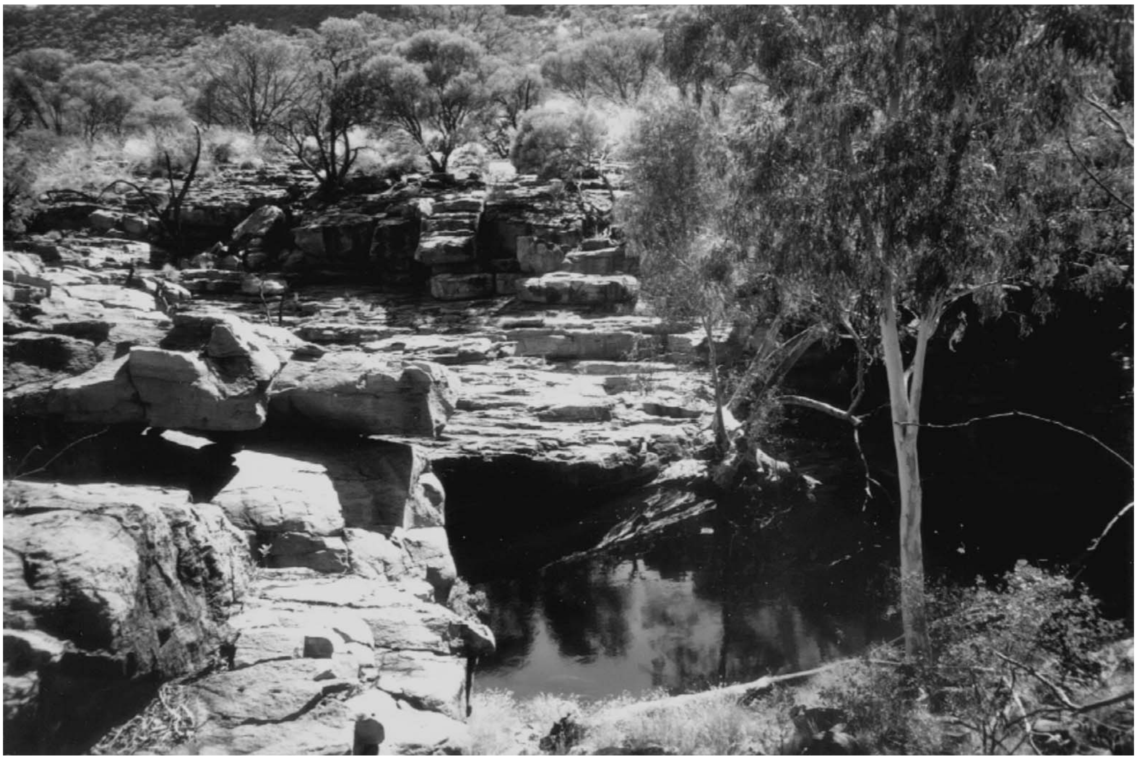

Figure 19. Talbots Rockhole, east end of Mount Methwin range (northeastern Carnarvon Range). Country rock is lowermost Wonyulgunna Sandstone. The rockhole sits below an incised ledge that forms a major terrace in the range

Stanley Fold Belt. These mylonitic zones continue westward along strike onto METHWIN in subcrop, but gold mineralization has not been recorded in this area. Mineralization is also present in quartz veins that crosscut the Earaheedy Group.

Diamonds

The exposed Earaheedy Basin has been considered prospective for diamond exploration since the discovery of diamonds and chrome spinel during initial drilling and trenching by Stockdale Prospecting. Exploration between 1989 and 1997 did not reveal any significant prospects on METHWIN. Details of the exploration history are contained in statutory company reports submitted to the Western Australia Department of Mineral and Petroleum Resources.

Base metals

The Sweetwaters Well Member of the Yelma Formation contains lead mineralization in the interstices of stromatolite columns in the Sweetwaters Well area on MERRIE (Adamides, 2000). The limited exposures of carbonate in the Yelma Formation on METHWIN have not been analysed (largely because of their very small size), but no mineralization is apparent in hand specimen or thin section.

Regolith geochemistry

Regional geochemical analysis of regolith on METHWIN was done as part of the NABBERU 1:250 000 regolith geochemical sampling program (Morris et al., 1997). Results from this program show anomalous amounts of MnO, Zn, Zr, Sn, Ni, Li, La, Cu, Co, and Ce in the Blue Hill area, in the central-southeastern part of the sheet. Anomalous concentrations of Pb, Nb and Cd were recorded on the western part of METHWIN, and anomalous Au in a single site on the southern margin of METHWIN south of Blue Hills. Gravity and magnetic images, and the known surface geology, offer no clear explanation for these anomalies. A relationship to basement structures is possible. The anomalies are south of the Stanley Fold Belt in a region of subdued magnetic character and relatively uniform geology.

Water resources

The only bores or European wells on METHWIN are at the ruins of Blue Hill Homestead and in the extreme south of the sheet. These tap groundwater in recent sediments (Karri Karri Mill) and silty sandstone intervals in the Chiall Formation. Supply from such sources is likely to be irregular and of variable quality.

Native wells have been located at Kadyara Waterhole near Virgin Springs, south of Good Camp Rockhole, and just east of METHWIN at Pierre Springs (RHODES). These used near-surface water focused by rocky gullies or gorges. There are several rockholes in the lower Wonyulgunna Sandstone (Fig. 19), including Virgin Springs, Talbots Rockhole (named because of an inscription by Talbot in 1908), and Good Camp Rockhole. All rely on refilling by rain on surrounding areas, and some are deep enough and sufficiently well protected by overhanging rocks to retain water through winter (the dry season) and into spring, and in wet years, into summer.

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Appendix

Gazetteer of localities

Locality	*Zone*	*AMG (E)*	*AMG (N)*
Blue Hill Homestead	51	281700	7296400
Canning Stock Route	51	290700	7183000
Carnarvon Range	51	266000	7203000
Cunyu Homestead (new; MERRIE)	51	233600	7154000
Earaheedy Homestead (EARAHEEDY)	51	358000	7168600
Empress 1A petroleum exploration well (WESTWOOD 1:250 000)	51	713912	7005777
Good Camp Rockhole	51	263200	7203800
Granite Peak Homestead (GRANITE PEAK)	51	334700	7163700
Kadyara Waterhole	51	269400	7223100
Karri Karri Tank	51	258950	7177950
Karri Karri Mill	51	258700	7178500
Lake Nabberu (NABBERU)	51	280000	7143000
Lake Kerrylyn	51	272000	7228300
Marymia Homestead (new) (PEAK HILL 1:250 000)	51	197800	7227250
Meekatharra (BELELE 1:250 000)	50	649400	7057000
Miss Fairbairn Hills (FAIRBAIRN)	51	233000	7206600
Mount Methwin	51	267050	7223300
Mount Salvado (RHODES)	51	300400	7206500
Pierre Springs (RHODES)	51	308500	7207000
Talbots Rockhole	51	272400	7217700
Virgin Springs	51	270200	7220200
Wiluna (WILUNA 1:250 000)	51	223500	7055500

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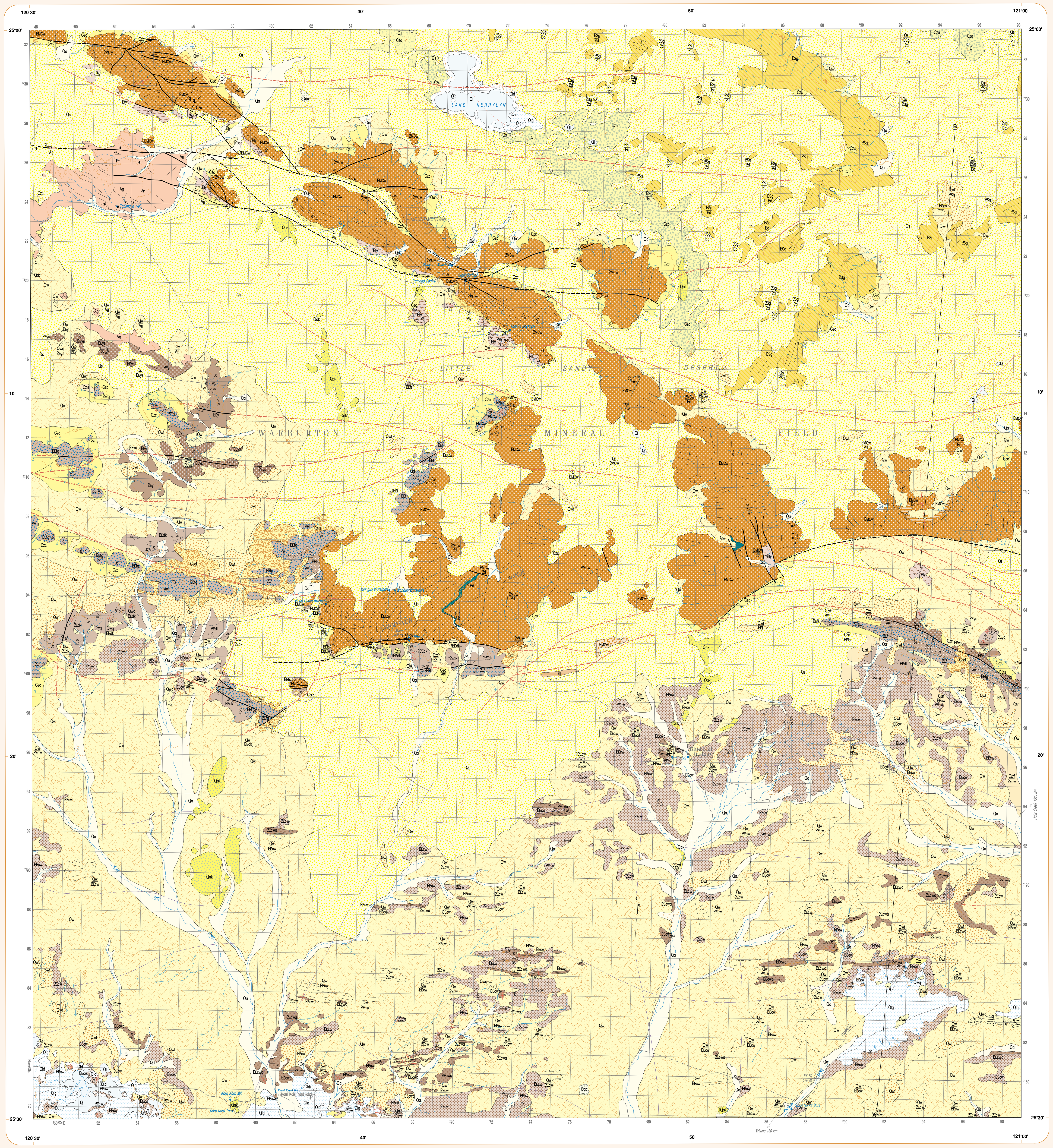
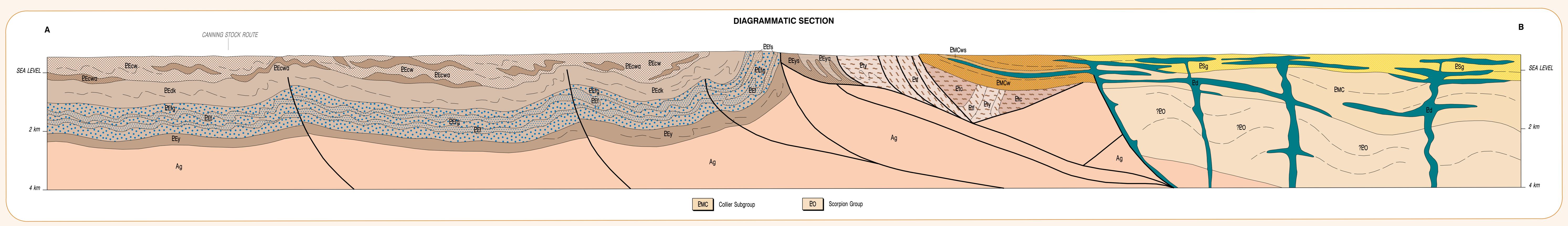
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 3047



DIAGRAMMATIC SECTION



ℙMC Collier Subgroup
ℙl Scorpion Group

PHANEROZOIC — CAINOZOIC — QUATERNARY

Ql Lacustrine deposits — saline silt, mud, and minor sand in playa lakes; primarily associated with palaeodrainage systems
Qld Sand in dunes on and around playa lakes; in places gypsiferous
Qlg Gypsiferous and saline bedded deposits adjacent to lakes
Qa Alluvium — sand, silt, and gravel in channels and channel systems; poorly consolidated
Qac Clay and silt in non-saline claypans
Qak Calcrete associated with palaeodrainage and active drainage systems
Qw Sheetwash deposits — sand, silt, and gravel in areas that lack clearly defined drainage channels
Qwf Ferruginous gravel
Qwq Quartz rubble adjacent to quartz veins and blows
Qs Sandplain and dunes — sand and minor silt; largely eolian; minor residual component

Cza Alluvium — consolidated and semi-consolidated sand, silt, and gravel associated with palaeodrainage systems
Czc Colluvium — gravel, sand, and silt, commonly consolidated and dissected
Czcf Ferruginous pisoliths and nodules; subordinate ferruginized rock and ironstone rubble

Czrf Ferruginous duricrust; nodular, pisolitic, and massive ferricrete, and associated debris
Czrz Siliceous duricrust; nodular, pisolitic, and massive silcrete, and intensely silicified rock

q Quartz veins

ℙd Dolerite sill

PROTEROZOIC

NEOPROTEROZOIC — Sunbeam Group — OFFICER BASIN

ℙSg GLASS SPRING FORMATION: poorly sorted, cross-bedded sandstone and pebble conglomerate; fluvial to ?coastal deposits
ℙSgs Siltstone and shale interval

MESOPROTEROZOIC — Bangemall Group — Collier Subgroup — BANGEMALL BASIN

ℙMCw WONYULGUNNA SANDSTONE: quartz sandstone and subordinate siltstone, commonly cross-bedded; local basal conglomerate; giant cross-bedding near base; fluvial and coastal deposits
ℙMCws Siltstone and shale interval
ℙMCwo Basal pebble to cobble conglomerate

ℙl Detrital peloidal limestone; stratigraphic affinity uncertain, possibly **Scorpion Group**

PALAEOPROTEROZOIC — Earaheedy Group — EARAHEEDY BASIN

CHIALL FORMATION
ℙEcw **Wandiwarra Member:** siltstone, shale, and fine-grained sandstone; marine shelf deposits
ℙEcwa Fine- and very fine-grained sandstone, commonly hummocky cross-stratified; subordinate interbedded siltstone and shale; storm and mass-flow deposits
ℙtc **TROY CREEK SCHIST:** metasandstone, metasiltstone, and quartz–sericite schist; probably **CHIALL FORMATION** that has been dynamically metamorphosed

WINDIDDA FORMATION
ℙEdk **Karri Karri Member:** laminated shale, siltstone, and minor sandstone; marine shelf deposits

ℙEf **FRERE FORMATION:** granular and laminar iron-formation, granular siliceous iron-formation, siltstone, shale, and chert; marine deposits
ℙEfg Granular and laminar iron-formation and granular siliceous iron-formation, in places peloidal; minor siltstone, shale, and chert
ℙEfs Siltstone and shale; minor iron-formation and chert
ℙtf **TROY CREEK SCHIST:** metasandstone, quartz–sericite schist, metamorphosed granular iron-formation, and laminated chert–magnetite–haematite rock; probably **FRERE FORMATION** that has been dynamically metamorphosed

ℙty **TROY CREEK SCHIST:** metasiltstone, metasandstone, quartz–sericite schist, and carbonate–quartz–sericite schist; probably **YELMA FORMATION** that has been dynamically metamorphosed

ℙEy **YELMA FORMATION:** sandstone, siltstone, and phyllitic shale; shallow marine to fluvial deposits
ℙEys Siltstone, shale, and minor sandstone; locally phyllitic
ℙEya Sandstone, coarse grained and locally pebbly

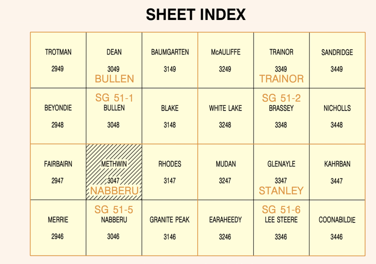
ARCHAEAN — YILGARN CRATON

Ag Granitoid rock, undivided; generally weathered

SYMBOLS

Geological boundary
exposed
concealed
Fault or shear
exposed
concealed
Fold, showing axial trace and generalized plunge direction
anticline; exposed, concealed
syncline; exposed, concealed
Bedding, showing strike and dip
inclined
horizontal
Metamorphic foliation, showing strike and dip
Cleavage, showing strike and dip
Fracture or joint, showing strike and dip
Airphoto or Landsat lineament
Aeromagnetic lineament
Track
Fence, generally with track
Homestead
Yard
Horizontal control, major, minor
Breakaway
Sand dune
Contour line, 20 metre interval
Soak
Spring
Bore, well
Windpump
Tank
Abandoned

SHEET INDEX



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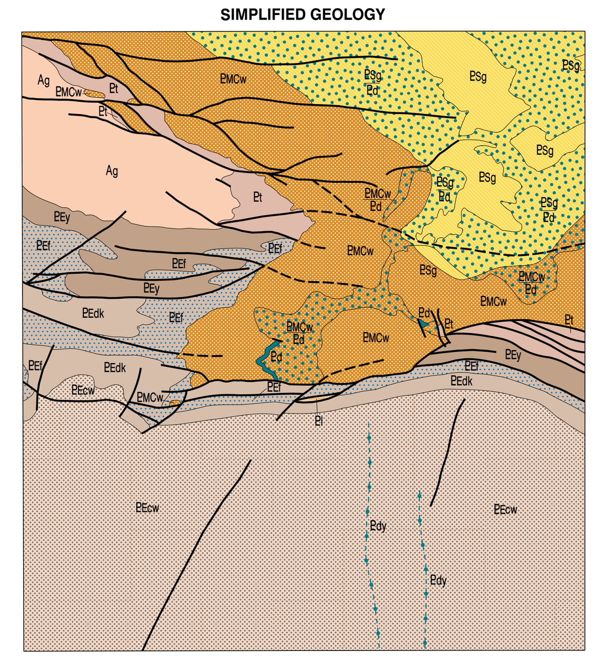
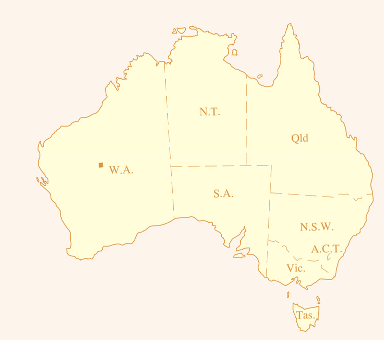
SIMPLIFIED GEOLOGY



SCALE 1:500 000
0 5 10 15 20
Kilometres

ℙd Dolerite sill; exposed, subsurface interpretation from aeromagnetic data
ℙSg Sunbeam Group — Glass Spring Formation — OFFICER BASIN
Bangemall Group: ℙMCw Collier Subgroup — Wonyulgunna Sandstone — BANGEMALL BASIN
ℙl Limestone
Earaheedy Group — EARAHEEDY BASIN:
ℙt Troy Creek Schist; metamorphosed Earaheedy Group
ℙEcw Chiall Formation — Wandiwarra Member
ℙEdk Windidda Formation — Karri Karri Member
ℙEf Frere Formation
ℙEy Yelma Formation
ℙdy Mafic dyke, concealed by Proterozoic rocks — YILGARN CRATON
Ag Granitoid rock
Fault, concealed by post-Palaeoproterozoic rocks



Geology by R. M. Hocking and J. A. Jones 1997–98, and F. Pirajno 1997

Edited by F. Eddison and G. Loan

Cartography by D. Ladbrook and K. Greenberg

Topography from the Department of Land Administration Sheet SG 51-5, 3047, with modifications from geological field survey

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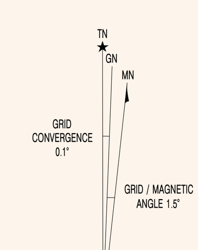

True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 1999 and moves easterly by about 0.1° in 2.5 years.

DEPARTMENT OF MINERALS AND ENERGY

GOVERNMENT OF WESTERN AUSTRALIA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SCALE 1:100 000

TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: AUSTRALIAN GEODETIC DATUM 1984
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

METHWIN

SHEET 3047 FIRST EDITION 1999