Department of
Mineral and Petroleum Resources

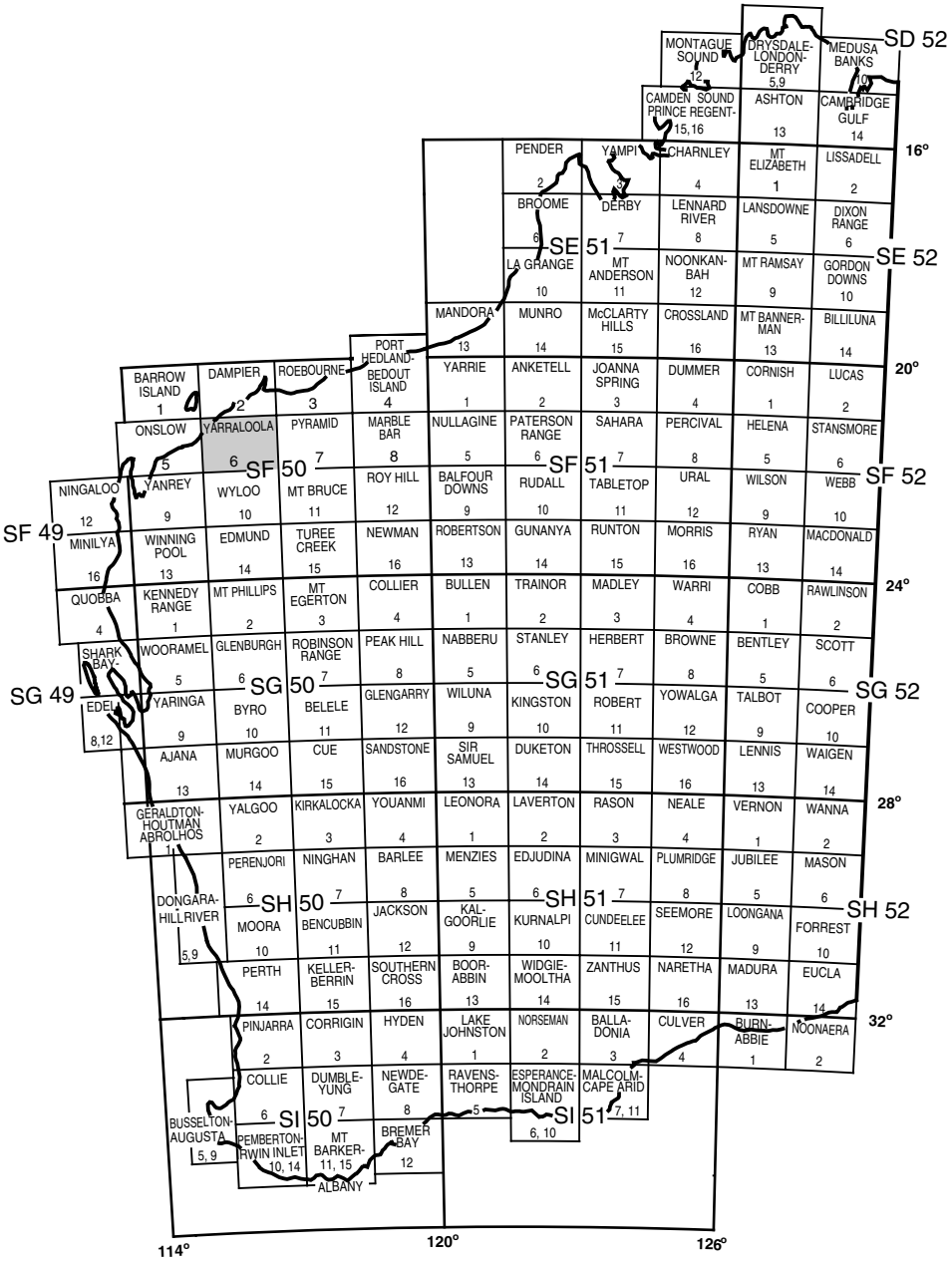
EXPLANATORY NOTES

GEOLOGY OF THE PINDERI HILLS 1:100 000 SHEET

by A. H. Hickman and C. J. Kojan

1:100 000 GEOLOGICAL SERIES

Geological Survey of Western Australia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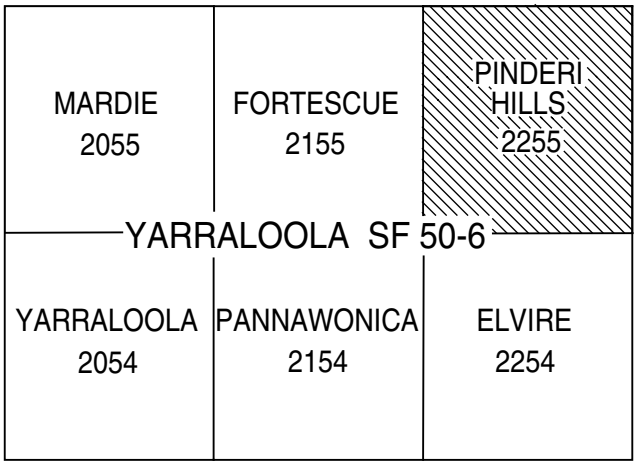
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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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by
A. H. Hickman and C. J. Kojan

Perth 2003

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REFERENCE
The recommended reference for this publication is:
HICKMAN, A. H., and KOJAN, C. J., 2003, Geology of the Pinderi Hills 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 36p.

National Library of Australia Card Number and ISBN 0 7307 8902 0

ISSN 1321–229X

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94). Locations mentioned in the text are referenced using Map Grid Australia (MGA) coordinates, Zone 50. All locations are quoted to at least the nearest 100 m.

Copy editor: L. Day
Cartography: S. Dowsett
Desktop publishing: K. S. Noonan
Printed by Haymarket Printing, Perth, Western Australia

Published 2003 by Geological Survey of Western Australia

Copies available from:
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EAST PERTH, WESTERN AUSTRALIA 6004
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Cover photograph:
View westwards of the basal unconformity of the Fortescue Group, west of Munni Munni Creek (MGA 478700E 7663800N). Sandstone of the Hardey Formation overlies granitoid rocks of the Cherratta Granitoid Complex

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Geology of the Pinderi Hills 1:100 000 sheet

by

A. H. Hickman and C. J. Kojan

Abstract

The PINDERI HILLS 1:100 000 sheet is located in the northwestern part of the Pilbara Craton, and covers parts of the mid-Archaean West Pilbara Granite–Greenstone Terrane (WPGGT) and the late Archaean to early Palaeoproterozoic Hamersley Basin. The WPGGT is strongly deformed, whereas on PINDERI HILLS the Hamersley Basin succession (Mount Bruce Supergroup) is relatively undeformed, and almost flat lying. This results in an angular unconformity between the WPGGT and the late Archaean Fortescue Group, the basal group of the Mount Bruce Supergroup.

On PINDERI HILLS, the WPGGT consists of the Cherratta Granitoid Complex and greenstones of the Pilbara Supergroup. The Cherratta Granitoid Complex of northwestern PINDERI HILLS contains remnants of the newly named Weelarra greenstone belt that was fragmented and metamorphosed by granitoid intrusion between 3130 and 2940 Ma. In contrast, the Sholl greenstone belt in the northeastern part of the sheet area is extremely well preserved, and in this belt the Pilbara Supergroup is represented by the Whundo Group. Volcanic and sedimentary rocks of the Whundo Group were deposited between 3130 and 3115 Ma, probably in a major northeasterly trending rift between older rocks of the WPGGT and the East Pilbara Granite–Greenstone Terrane (EPGGT). The Whundo Group is an approximately 10 km-thick succession dominantly composed of tholeiitic basalt, but which also includes felsic volcanic rocks. The contact between the Whundo Group and the Cherratta Granitoid Complex is partly tectonic (Maitland Shear Zone) and partly intrusive. Later components of the Pilbara Supergroup are major layered mafic–ultramafic intrusions that intruded the Cherratta Granitoid Complex and the Whundo Group at about 2925 Ma.

Structural correlations with other areas of the west Pilbara indicate that the first recognizable deformation event on PINDERI HILLS was D_3 of the WPGGT. D_3 involved c. 3015 Ma north–south thrusting of the Whundo Group onto older components of the Cherratta Granitoid Complex; D_4 was an event of northeasterly trending transpressional folding at 2945–2930 Ma; and D_5 involved c. 2930 Ma strike-slip faulting along the Maitland Shear Zone.

The c. 2770–2630 Ma Fortescue Group of the Mount Bruce Supergroup unconformably overlies all units of the WPGGT. Early deposition of basaltic and sedimentary rocks of the Fortescue Group was controlled by a northeasterly striking rift system. Following clastic sedimentation and andesitic to dacitic volcanism (Hardey Formation) at c. 2760 Ma, a thick succession of dominantly basaltic and andesitic volcanic rocks was deposited, and this now forms most of the Fortescue Group on PINDERI HILLS. The Fortescue Group contains two unconformities on PINDERI HILLS: an erosional disconformity at the base of the Hardey Formation, and an unconformity between the Kylena and Tumbiana Formations. The c. 2719 Ma Tumbiana Formation is a succession of basaltic and andesitic pyroclastic and reworked pyroclastic rocks containing thin units of siltstone, quartzite, stromatolitic carbonate rocks, and minor felsic pyroclastic and felsic volcaniclastic rocks near the top of the formation. The Tumbiana Formation is conformably overlain by the c. 2717 Ma Maddina Formation that comprises volcanic rocks ranging in composition from high-Mg basalt to rhyolite. The Fortescue Group was deformed during two deformation events that, based on structural correlations with other areas of the west Pilbara, are assigned to D_{10} and D_{11}. D_{10} involved syndepositional northeasterly trending rifting and open folding, and D_{11} is correlated with D_2 of the Capricorn Orogeny, at 1830–1780 Ma.

Mineralization on PINDERI HILLS was first discovered in 1911 when Cu–Zn deposits were found at Whundo and nearby Yannery Hill. The area currently contains Australia's largest layered intrusion-hosted platinum group element (PGE) deposit, Munni Munni, discovered during the 1980s. Small deposits of gold, silver, copper, chrysotile asbestos, and building stone have also been mined.

Recognition that the volcanic rocks of the Fortescue Group are not entirely basaltic, but include basaltic andesite, dacite, and minor rhyolite, has increased the area's potential to contain base metal mineralization.

KEYWORDS: Archaean, Pilbara Craton, West Pilbara Granite–Greenstone Terrane, Hamersley Basin, Whundo Group, Fortescue Group, deformation events, mineralization.

Introduction

The PINDERI HILLS* 1:100 000 geological sheet (SF 50-6, 2255), bounded by latitudes 21°00'S and 21°30'S and longitudes 116°30'E and 117°00'E, is situated in the north-western part of the Pilbara region (Fig. 1). It occupies the northeastern corner of the YARRALOOLA 1:250 000 sheet.

Since the recent relocation of the Cherratta Homestead onto DAMPIER, there is no longer any permanent habitation on PINDERI HILLS. Mining and mineral exploration camps periodically exist in northeastern PINDERI HILLS, mainly in the areas of Whundo†, Elizabeth Hill, and Munni Munni Creek. Access is poor across most of PINDERI HILLS, particularly in the southern and central parts of the sheet area where the only good line of access is along the Robe River Railway (private road). In northern PINDERI HILLS, access to 4WD vehicles is provided by a system of partly disused pastoral and mineral exploration tracks.

Climate and vegetation

PINDERI HILLS has a tropical, semi-desert climate with an average rainfall of between 250 and 300 mm. However, total precipitation is extremely variable from year to year, being largely dependent on the passage of tropical cyclones through the area. Such cyclones generally develop off the northwest Kimberley coast during January to April, and subsequently move southwestwards parallel to the Pilbara coastline. Some continue westwards into the Indian Ocean and have no effect on the Pilbara, but others swing southwards and southeastwards, crossing the coast and bringing torrential rainfall and strong winds to country along their paths. Rainfall in excess of 100 mm during 24-hour periods is common, causing rivers to flow and eventually flood parts of the coastal plain. Outside the cyclone season, longer periods of low to moderate rainfall, commonly during May and June, are associated with southeasterly moving low-pressure systems or with the trailing southern edges of strong equatorial systems.

Summer daily maximum temperatures are generally about 35–40°C. Daily maximum temperatures during winter months are typically about 25°C, with night temperatures about 10–15°C.

PINDERI HILLS occupies part of the Fortescue Botanical District (Beard, 1975), in which flora is related to topography, soil types, and proximity to the coast. The valleys of the Maitland and Yanyare rivers contain poorly drained sands, silt, and expansive silty clay (gilgai). Beard (1975) described this country as short grass savanna mixed with spinifex. Fine-grained soils support grasses such as *Eragrostis setifolia* and *Triodia wiseana* (buck spinifex), whereas colluvial slopes near hills also contain *Acacia pyrifolia* (kanji), and creeks and rivers are lined with eucalypts.

In southern and central PINDERI HILLS, formations of the Fortescue Group form a rocky dissected plateau, and there are large areas without soil cover. The basaltic rocks of this area have given rise to hard alkaline soils and shallow loams. This country consists of sparse tree steppe with *Eucalyptus brevifolia* (snappy gum) and *Triodia wiseana*, and scattered shrubs such as *Acacia xiphophylla* (snakewood). In this area, trees and shrubs are typically confined to the banks of creeks. Low hills and ridges, corresponding to outcrops of granitoids and metamorphosed volcanic and sedimentary rocks ('greenstones') in northern and eastern PINDERI HILLS, are dominated by spinifex and scattered shrubs.

Physiography

Figure 2 summarizes the major physiographic divisions of PINDERI HILLS, and closely follows divisions previously used by Hickman (1983). The present physiography of PINDERI HILLS is mainly the product of erosional and depositional processes during the Cainozoic, but deep erosion of the Precambrian rocks also occurred as far back as the Archaean.

The alluvial plain division (Fig. 2) forms gently sloping tracts of sand, silt, and clay deposited from rivers, creeks, and minor channels. The rivers and larger creeks occupy wide alluvial channels containing unconsolidated sand and pebble beds. Scree and outwash fans are shown (Fig. 2) in northwestern PINDERI HILLS, where there are wide colluvial aprons fringing outcrops of the Fortescue Group.

Erosional land surfaces are separated into two divisions (Fig. 2). The low hills division comprises areas of undulating low hills, including many areas of Archaean granitoid hills, and scattered inselbergs. The range division consists of strike-controlled ridges that are separated by narrow, locally steep-sided valleys. In most areas the ranges are formed over steeply dipping greenstones. The preferential weathering of the less resistant rock types has locally produced a trellised drainage pattern in these areas. Remnants of an older (Late Cretaceous to Eocene) land surface, named the 'Hamersley Surface' by Campana et al. (1964), are preserved in the more elevated areas of PINDERI HILLS, and are underlain by rocks relatively resistant to erosion, such as volcanic rocks of the Fortescue Group. The dissected plateau division rises abruptly from the plain and low hills divisions, and prominent cliffs or escarpments up to 100 m high typically define its boundary. Where it is underlain by near-horizontal strata the dissected plateau contains steep V-shaped valleys, gorges, nick-points, dendritic drainage patterns, and abrupt margins. Where the underlying rocks are more steeply dipping, however, variations in resistance to weathering result in dip slopes and some strike control of drainage. Remnants of the Hamersley Surface are preserved in southern PINDERI HILLS (Fig. 2) and the surface of this old plateau is visible throughout much of this area (Fig. 3).

Previous investigations

Geological interest in the west Pilbara dates from 1872, when copper and lead were discovered near the then recently established township of Roebourne. In 1877 auriferous quartz veins were discovered near Roebourne

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

† MGA coordinates of localities mentioned in the text are listed in Appendix 1.

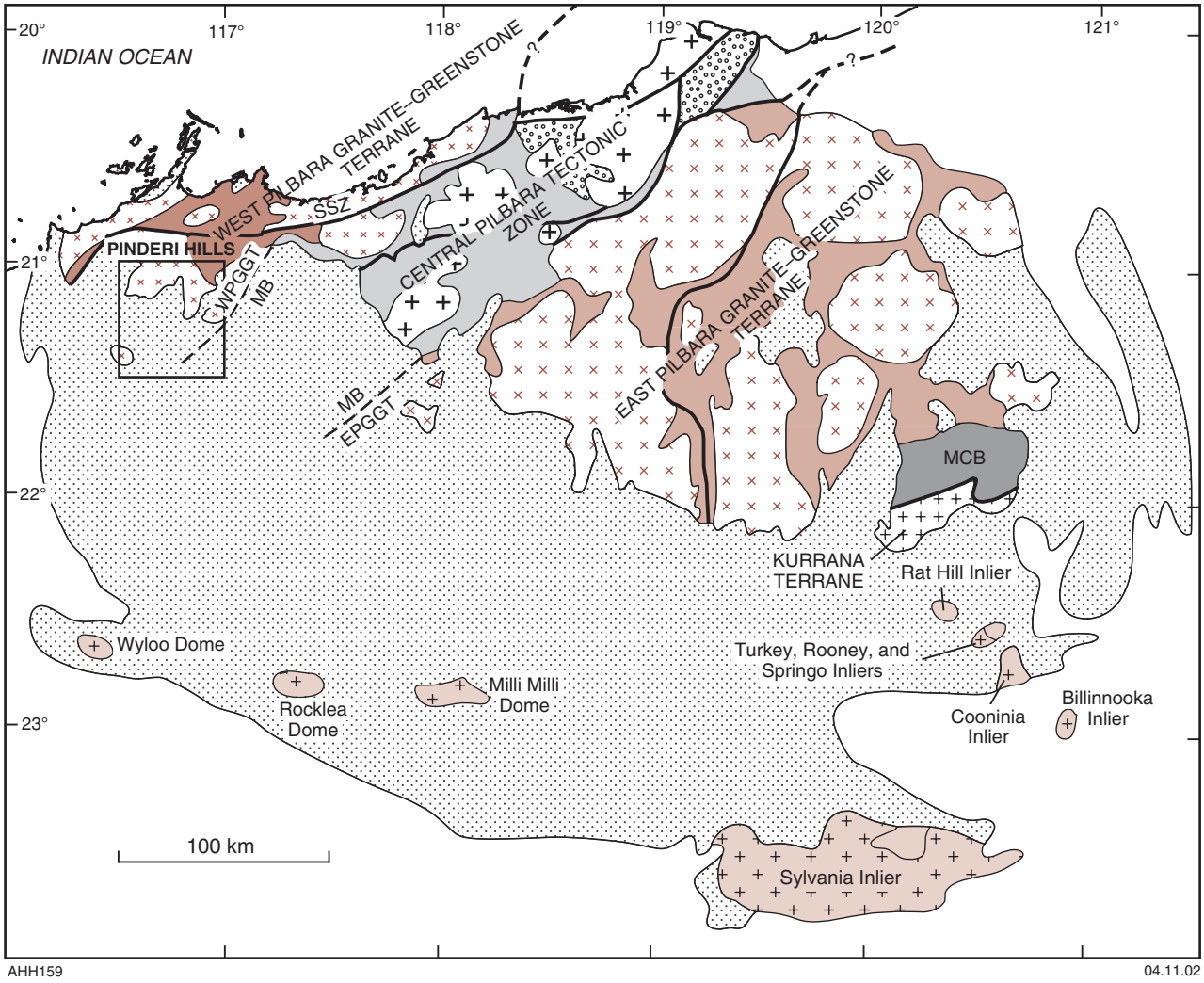
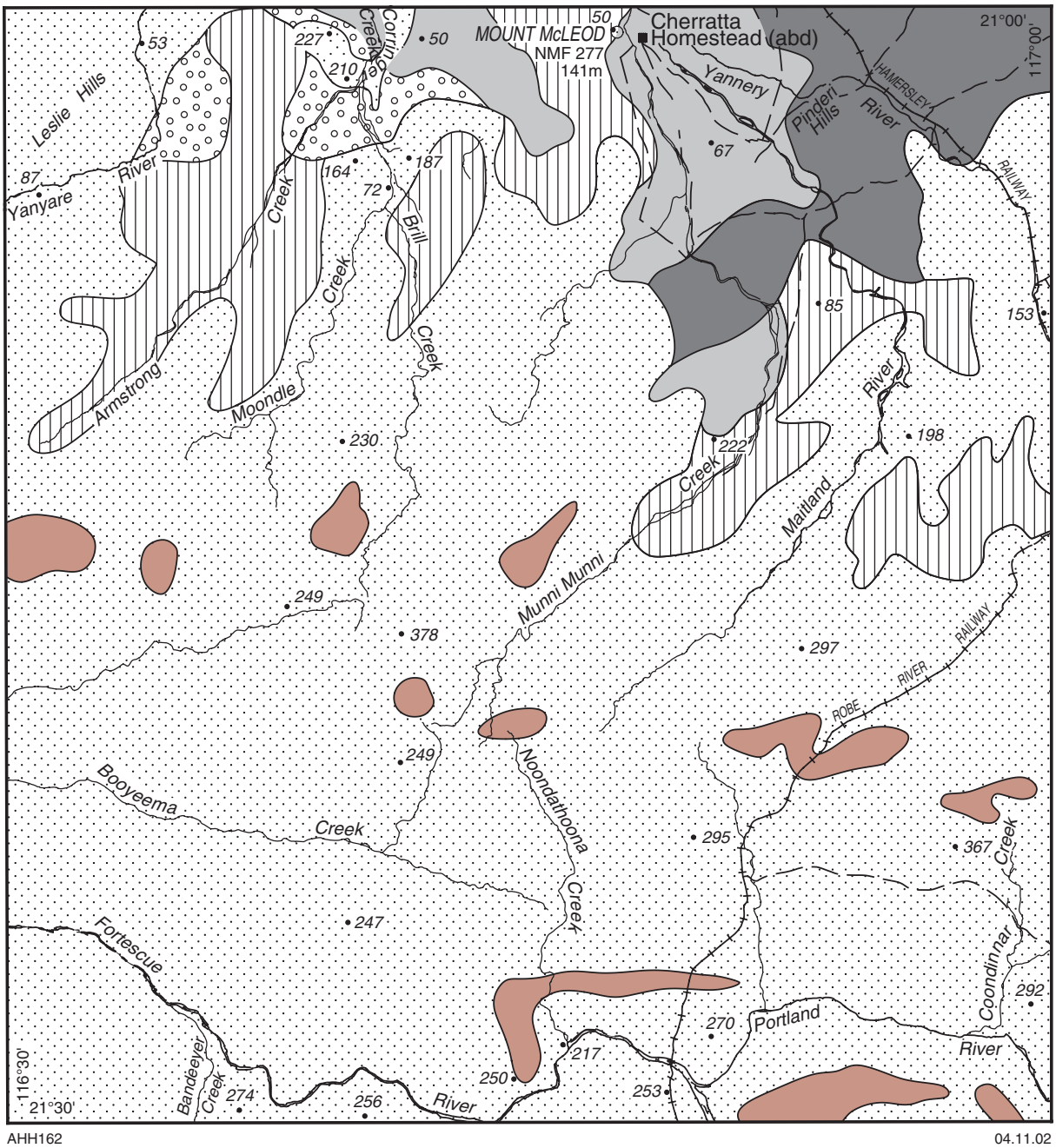


Figure 1. Regional geological setting of Pinderi Hills within the Pilbara Craton

(Maitland, 1909). However, prior to 1960 all geological investigations of the Dampier–Roebourne area were either of a reconnaissance nature or limited to local studies of mineral deposits. Consequently, knowledge of the regional geology of the west Pilbara was extremely limited until the Geological Survey of Western Australia (GSWA) commenced a 1:250 000-scale geological mapping program in 1962. Earlier references to the Pinderi Hills area are listed in Kriewaldt (1964), and Hickman (1983) reviewed investigations to 1979. Ruddock (1999) reviewed the mining and mineral exploration history of the west Pilbara, and Hickman (2001) summarized other geoscientific investigations in the west Pilbara between 1962 and 1995. Most early work was concentrated on the greenstones of northeastern Pinderi Hills, but more recently there have been regional studies of the Fortescue Group (Blake, 1993; Thorne and Trendall, 2001).



RECENT LAND SURFACE

Depositional

- Alluvial plain
- Scree and outwash fans

Erosional

- Low hills
- Range, strike-controlled ridges

TERTIARY LAND SURFACE

- Dissected plateau
- Plateau

- Geological boundary
- Drainage
- Track
- Railway
- 132 Spot height (m)

Figure 2. Physiography and access on Pinderi Hills

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Figure 3. View (looking west from MGA 472000E 7622300N) showing the Fortescue River incised in thick basalt flows of the upper Maddina Formation in the Chichester Ranges. The plateau of the Hamersley Surface is visible in the distance

Pilbara Supergroup

Hickman (1997) revised the lithostratigraphy of the Roebourne–Whundo area based on the mapping of DAMPIER, PINDERI HILLS, and ROEBOURNE. This revision replaced previous stratigraphic schemes (Ryan, 1965; Fitton et al., 1975; Hickman, 1983; Krapez, 1993) with an interpretation that divided the greenstones into three groups and three unassigned formations. A major crustal fracture, the Sholl Shear Zone (Fig. 1), separates two distinct stratigraphic packages. North of this east–west trending shear zone, the c. 3270–3250 Ma Roebourne Group was overlain by the c. 3020 Ma Cleaverville Formation, whereas south of the shear zone the c. 3130–3115 Ma Whundo Group was overlain by, in ascending order, the Cleaverville Formation, the c. 3010 Ma Whim Creek Group, the Louden Volcanics, and the c. 2970 Ma Kialrah Rhyolite. Of all these units, only the Whundo Group outcrops on PINDERI HILLS. Subsequent Nd isotopic data (Sun and Hickman, 1998) indicated that the Whundo Group formed from juvenile crust, whereas magmatism of the Roebourne Group involved c. 3480 Ma crust or enriched lithospheric mantle. Smith et al. (1998) suggested that the Whundo Group formed in a subduction zone environment, and Krapez and Eisenlohr (1998) interpreted the Whundo Group as a back-arc basin succession. However, as noted by Hickman (2001), no remnants of any related c. 3130–3115 Ma volcanic arc, nor extensive granitoids of this age, have been identified in the northwest Pilbara.

Hickman (1999) recognized three major tectono-stratigraphic terranes in the 'north Pilbara granite–greenstone terrane' (Griffin, 1990). In Hickman's (1999) interpretation, the west and east Pilbara terranes are separated by the Mallina Basin. Hickman et al. (2000) introduced the name 'West Pilbara Granite–Greenstone Terrane' for the western terrane, and this was divided into tectono-stratigraphic domains (Fig. 4) by Hickman (2001).

The West Pilbara Granite–Greenstone Terrane (WPGGT) includes a number of large mafic–ultramafic intrusions that occupy a northeasterly trending zone from Mount Hall on ROEBOURNE to Munni Munni Creek on PINDERI HILLS. An early detailed account of the Munni Munni Intrusion was provided by Donaldson (1974), who described it as a layered sequence of clinopyroxenite, peridotite, and gabbro with a total thickness of 5500 m. Geochronology on the Munni Munni Intrusion (Arndt et al., 1991) indicated emplacement at about 2925 Ma. However, the age of the Andover Intrusion (ROEBOURNE) is at least 2990 Ma (Hickman, 2002). Hoatson et al. (1992) and Hoatson and Sun (2002) have described the geology, geochemistry, and mineralization of the layered mafic–ultramafic intrusions.

Fortescue Group

About 70% of the area of PINDERI HILLS is underlain by the Fortescue Group. Hickman (1983) reviewed available information on the Fortescue Group in the northern part of the Pilbara Craton, and presented an interpretation of its regional stratigraphy. Four volcanic formations were recognized, three of which, the Mount Roe, Kylena, and Maddina Basalts, were described as being composed of basalt and andesite. The fourth volcanic unit, the Nymerina Basalt (beneath the Maddina Basalt), was described as dominantly basalt, but including local units of tuff and rare rhyolite. Separation of the Nymerina and

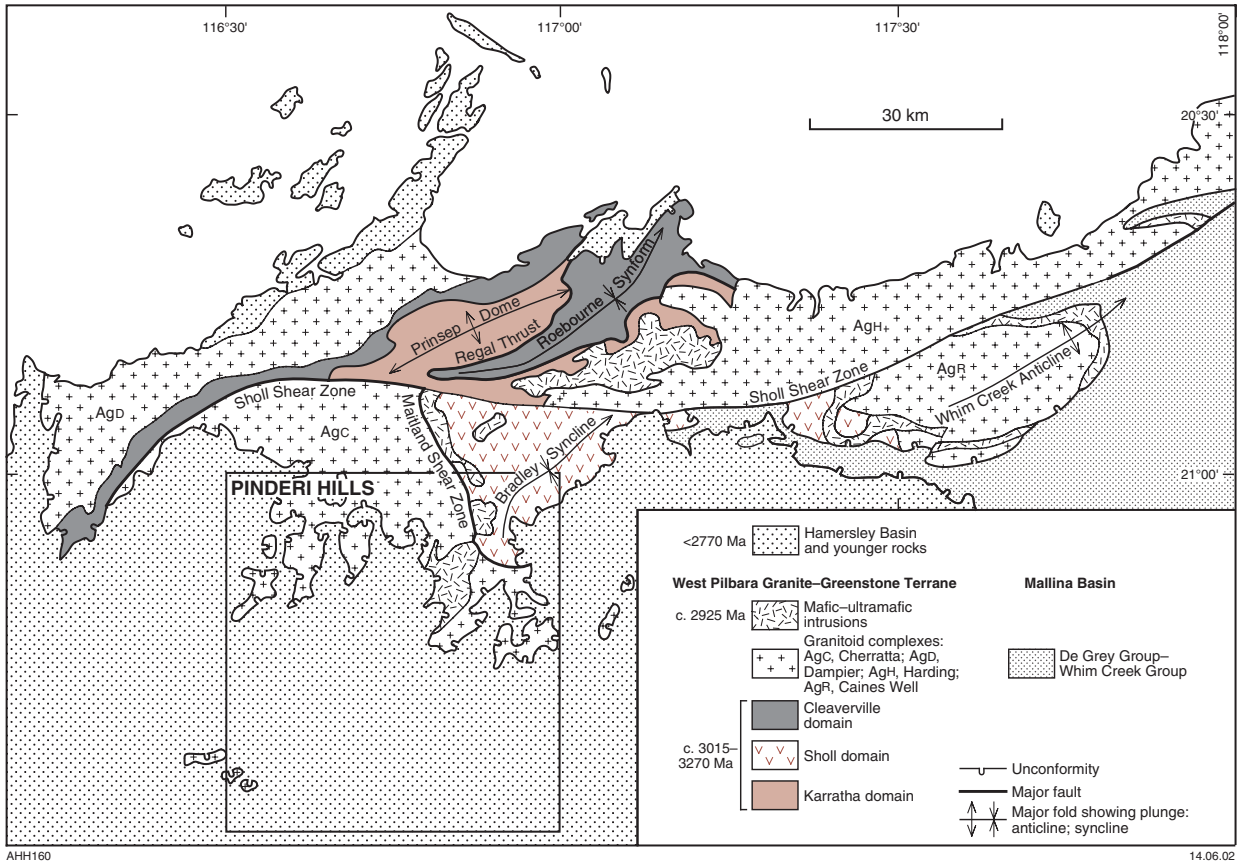


Figure 4. Tectono-stratigraphic domains of the West Pilbara Granite–Greenstone Terrane

Maddina Basalts was subsequently found to be difficult in areas where the intervening Kuruna Member (a clastic sedimentary unit) is absent. Consequently, Thorne and Tyler (1997a) redefined the Maddina Basalt to include all rocks previously assigned to the Nymerina Basalt.

Blake (1993) and Nelson et al. (1999) described the volcanic rocks of the Fortescue Group as flood basalts. However, Kojan and Hickman (1998) presented geochemical, gamma-ray, and petrographic data to show that the middle and upper parts of the Fortescue Group succession on PINDERI HILLS consist of volcanic rocks ranging in composition from high-Mg basalt to rhyolite. They observed that basaltic andesite, andesite, and dacite are dominant in the central and upper sections of both formations. Accordingly, Kojan and Hickman (1998) renamed the Kylena and Maddina Basalts as the Kylena and Maddina Formations. They noted that regional airborne-gamma ray data across the west and east Pilbara indicate that andesite and dacite may be widespread in the Kylena and Maddina Formations.

Felsic volcanic rocks have also been mapped at other stratigraphic levels of the Fortescue Group. In the west Pilbara, Kriewaldt and Ryan (1967) mapped felsic volcanic rocks of the 'Lyre Creek Agglomerate Member' of the 'Cliff Springs Formation' between the Mount Roe Basalt and the Kylena Formation in the west Pilbara. The Cliff Springs Formation was later correlated with the Hardey Formation (Hickman, 1983). Near the top of the Fortescue Group, Kriewaldt and Ryan (1967) also discovered a felsic volcanic unit in the Jeerinah Formation, and named this the 'Nallanaring Volcanic Member'. In the east Pilbara, Hickman (1978) identified felsic volcanic rocks below the Kylena Formation, and named these the 'Koongaling Volcanics'. Geochronology (Arndt et al., 1991; Nelson, 1996) has indicated that the age of the Koongaling Volcanics is c. 2760 Ma, and the formation should be assigned to the Hardey Formation. Hickman and Chin (1977) identified felsic volcanic rocks in the Jeerinah Formation of the east Pilbara, and included these within a unit they named the 'Barramine Volcanic Member'. Subsequently, Williams and Trendall (1998) separated the felsic volcanic component of this unit as the Isabella Member. Thorne and Trendall (2001) recorded minor felsic tuff within the Mount Roe Basalt of the southern Pilbara Craton.

Thorne and Trendall (2001, p. 220) described the Mount Roe Basalt, and the Kylena and Maddina Formations of the northern Pilbara as principally composed of subaerial to shallow-marine mafic lavas closely similar to those of Phanerozoic flood basalt provinces. However, they stated that most of the lavas are basaltic andesite rather than basalt, and acknowledged the evidence of Kojan and Hickman (1998) that andesite, dacite, and rhyolite form parts of the Kylena and Maddina Formations on PINDERI HILLS.

Thorne and Trendall (2001) agreed with Blake (1993) in explaining the felsic volcanic rocks of the Hardey Formation in the northeast and northwest Pilbara as being related to major north-northeasterly trending faults. They argued against the Fortescue Group being a plume-related continental flood basalt province, partly on the basis of its lithological diversity and partly on the duration of deposition (approximately 140 million years). However, Arndt et al. (2001) attributed Fortescue Group volcanism to melting of the lithosphere above three successive mantle plumes.

Thorne and Trendall (2001) concluded that the Hamersley Basin formed by lithospheric stretching, and evolved from rift-related volcanism and sedimentation to deposition on a subsiding, passive continental margin. The tectonic model preferred by Thorne and Trendall (2001) involved protracted north–south or north-northeast – south-southwest crustal extension related to a major rift along the present-day southern Pilbara margin. In this model, north-northeasterly trending rifts in the northern Pilbara were interpreted to have formed at a high angle to the principal east-southeasterly trending rift of the southern Pilbara, probably analogous to a failed rift arm.

National Geoscience Mapping Accord

The National Geoscience Mapping Accord (NGMA) Pilbara project, between GSWA and the Australian Geological Survey Organisation (AGSO, now Geoscience Australia), commenced in 1995. In this year, GSWA mapped Dampier and Sherlock, supported by data from NGMA aeromagnetic and radiometric surveys of the west Pilbara. Other west Pilbara 1:100 000-scale sheets were mapped between 1996 and 1999.

Geological mapping of Pinderi Hills was undertaken during 1997 using 1987 colour aerial photographs at 1:25 000 scale, and by field interpretation of multispectral Landsat TM images provided by AGSO. Preliminary images generated from high-resolution magnetic and gamma-ray spectrometric data obtained in 1995 (part of the North Pilbara NGMA program) were also used during map compilation. These data were subsequently published by GSWA (Geological Survey of Western Australia, 1995a,b).

Geological mapping of the apparently monotonous sequences of the Kylena and Maddina Formations that cover large parts of southern Pinderi Hills was supplemented by a reconnaissance whole-rock geochemical sampling and by petrographic studies. These investigations were designed to test the interpretation of the gamma-ray spectrometric data that significant parts of the Kylena and Maddina Formations are composed of felsic rocks.

Regional geological setting

Pinderi Hills is located in the northwestern part of the Pilbara Craton, and includes parts of the WPGGT and the northwestern part of the Hamersley Basin (Fig. 1). Most of the WPGGT on Pinderi Hills lies within the Central Pilbara Tectonic Zone (CPTZ), a northeasterly trending belt of faulting and folding, volcanic and sedimentary deposition, and granitoid intrusion. The CPTZ originated through 3280–3240 Ma plume-related rifting of the northwestern East Pilbara Granite–Greenstone Terrane (EPGGT; Van Kranendonk et al., 2002; Hickman, in prep.b). The CPTZ is characterized by igneous rocks with crystallization ages younger than c. 3240 Ma, and by Sm–Nd data that indicate no underlying crustal material older than c. 3280 Ma (Sun and Hickman, 1998). By contrast, Sm–Nd data from rocks to the northwest and southeast of the CPTZ support reworking of c. 3500–3300 Ma crustal material (Sun and Hickman, 1998; Van Kranendonk et al., 2002).

The tectono-stratigraphic domains of the West Pilbara Granite–Greenstone Terrane are shown in Figure 4, the stratigraphy and major structures on Pinderi Hills are shown in Figure 5, and the geological history of the area is summarized in Table 1.

Granitoids

The oldest rock identified on Pinderi Hills is a hornblende–biotite tonalite from 2.5 km north of the Fortescue River, close to the western boundary of the sheet area. This rock, dated at 3236 ± 3 Ma (Nelson, 1998, p. 93–95), outcrops in a small inlier surrounded by rocks of the Fortescue Group, and has been assigned to the Cherratta Granitoid Complex based on regional gravity data. If correct, this interpretation implies that this granitoid complex contains components that are significantly older than greenstones of the Whundo Group. The Cherratta Granitoid Complex is dominantly composed of c. 2990–2940 Ma granitoids (Hickman, 2001), although granitoids between c. 3130 and 3060 Ma have been dated east of the Munni Munni Intrusion (Nelson, 1998, 1999).

Lithostratigraphy

As Pinderi Hills was one of the first North Pilbara NGMA 1:100 000-scale sheet areas to be mapped, the Pinderi Hills map shows lithological components of the lower part of the Pilbara Supergroup in the WPGGT without stratigraphic subdivision. However, rocks of the Fortescue Group are mapped stratigraphically. A stratigraphic interpretation of the entire succession is provided in the accompanying map's interpreted bedrock geology diagram, in Figure 5, and in Table 2.

The lithostratigraphy of Pinderi Hills is summarized in Table 2. In the Sholl domain (Fig. 4), the greenstone succession is assigned to the c. 3130–3115 Ma Whundo Group (see the interpreted bedrock geology diagram on the map). The original stratigraphic base of the Whundo Group is not exposed, but isotopic data indicate that the succession is not underlain by crust older than about 3240 Ma. At 2925 Ma, the Whundo Group and the Cherratta Granitoid Complex were intruded by several large layered mafic–ultramafic intrusions. These intrusions, which include the Munni Munni and Maitland Intrusions, occupy a broadly northeasterly trending zone in northeastern Pinderi Hills and southeastern Dampier.

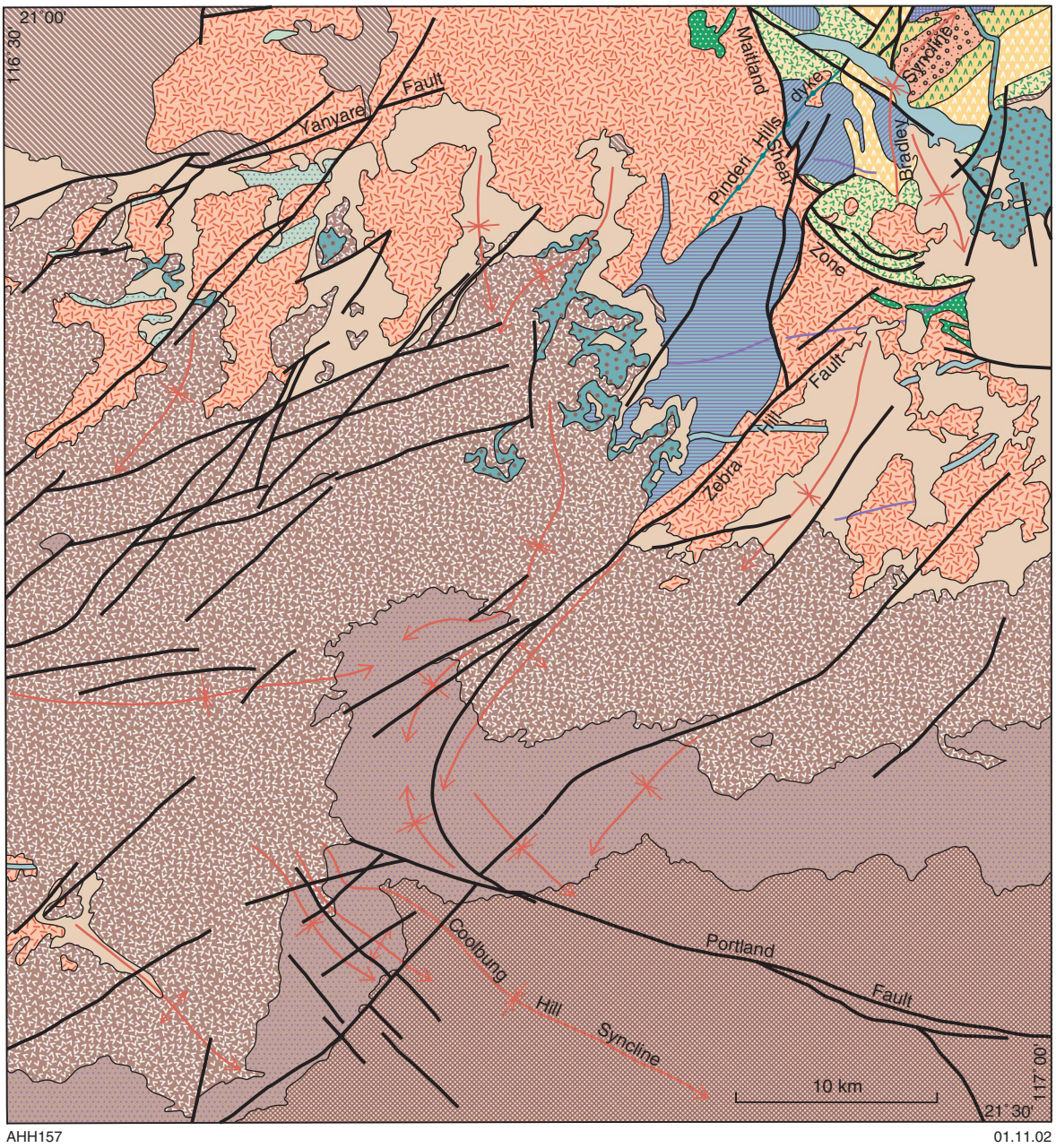


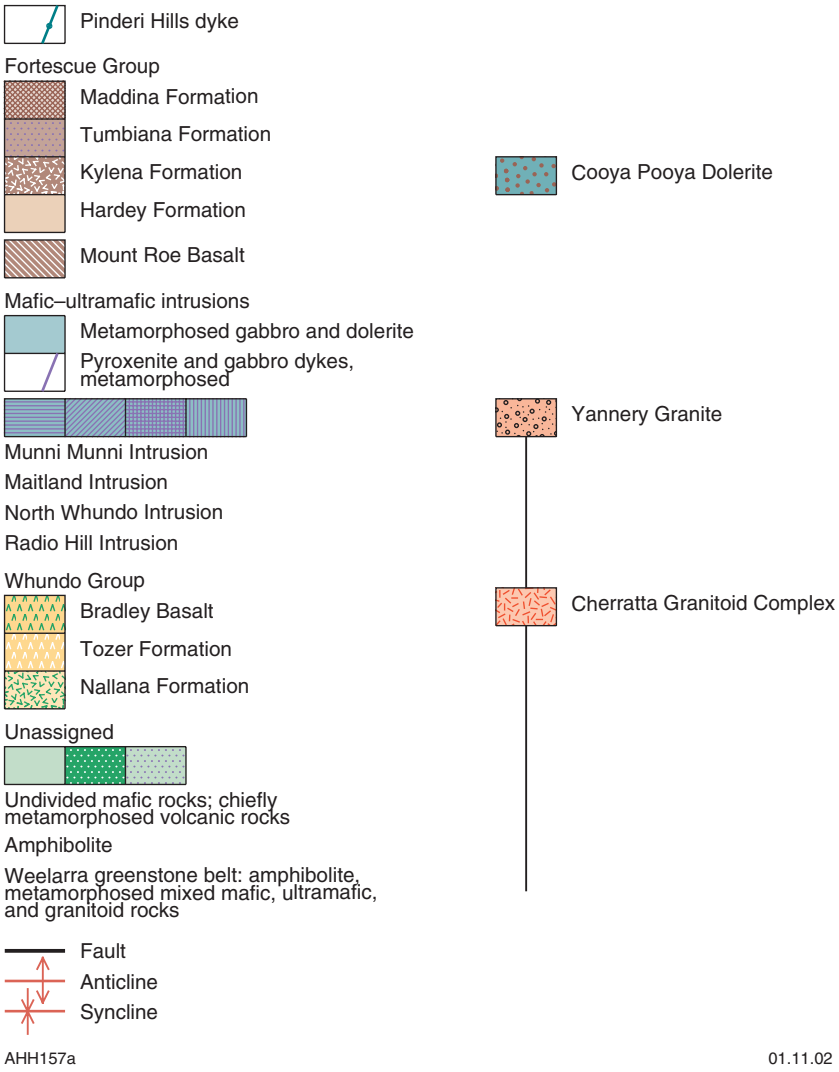
Figure 5. Stratigraphy and structural geology of PINDERI HILLS

This zone is parallel to the northwestern margin of the Central Pilbara Tectonic Zone (Fig. 1), indicating deep structural control over emplacement of the intrusions. In western PINDERI HILLS, the Cherratta Granitoid Complex contains a west-southwesterly striking belt of large greenstone enclaves. These greenstones are interpreted to be remnants of a greenstone belt that was extensively intruded and fragmented by the Cherratta Granitoid Complex, probably at c. 3000 Ma (geochronology is not currently available). This newly recognized greenstone belt is here named as the Weelarra greenstone belt.

The Fortescue Group of the Mount Bruce Supergroup is a continental succession of volcanic and sedimentary rocks that unconformably overlies the Whundo Group, the Cherratta Granitoid Complex, and the layered mafic–ultramafic intrusions. Deposition of the Fortescue Group commenced at about 2770 Ma (Arndt et al. 1991; Nelson et al., 1999). The regional extent and angular nature of this unconformity provides testimony to major erosion of the WPGGT and Mallina Basin between 2940 and 2770 Ma. On PINDERI HILLS, volcanic formations of the Fortescue Group include basalt, high-Mg basalt, andesite, dacite, and minor rhyolite (Kojan and Hickman, 1998).

Geochronology

Precise U–Pb geochronology from PINDERI HILLS is summarized in Table 3, and other geochronology is



outlined in Table 4. The U–Pb data, which indicate crystallization ages of granitoids or volcanic rocks, are used in the map legend, and are referred to throughout these Explanatory Notes. The neodymium-isotope depleted-mantle model ages (Nd T_{DM}) in Table 4 provide evidence on the ages of the sources (e.g. by melting of older crust or lithospheric mantle) of the rocks analyzed. On this basis, most Archaean rocks from PINDERI HILLS are interpreted to have been derived either by melting of c. 3300–3140 Ma crust or mantle, or to have been contaminated by crust of this age during intrusion. As noted above, the oldest identified component of the Cherratta Granitoid Complex is a c. 3236 Ma tonalite from an inlier near Tarlwa Pool on the Fortescue River. This rock also has the oldest Nd T_{DM} model age (3339 Ma, Table 4) recorded on PINDERI HILLS, or from elsewhere in the CPTZ (Fig. 1), suggesting that the Tarlwa Pool area lies west or northwest of this belt of rifting, and may be underlain by crust pre-dating separation of the WPGGT from the EPGGT.

Structure

On PINDERI HILLS, the WPGGT is situated on the northwestern margin of the Central Pilbara Tectonic Zone (Fig. 1), and consequently the structural geology of the granite–greenstone terrane is dominated by northeasterly

Table 1. Summary of the geological history of PINDERI HILLS, with reference to adjacent areas

Age (Ma)	*Geological event*
3280–3240	Plume-related rifting of the EPGGT to initiate development of the northeasterly trending CPTZ. Granitoid intrusion and deposition of volcanic and sedimentary rocks (Roebourne Group) northwest of the rift (on DAMPIER, PRESTON, and ROEBOURNE) to form the oldest outcropping components of the WPGGT
3236–3160	Inferred progressive widening of the rift, accompanied by early granitoid intrusion of the Cherratta Granitoid Complex
3130–3090	Deposition of the Whundo Group (c. 3130–3115 Ma) in the CPTZ; intrusion of c. 3130–3090 Ma granitoids in the Cherratta Granitoid Complex
3070–3050	Intrusion of tonalite in the Cherratta Granitoid Complex
3015	D_3 of WPGGT: north–south thrusting of the Whundo Group onto existing components of the Cherratta Granitoid Complex
3010–2990	Extensive intrusion of granitoids throughout the WPGGT, including the Cherratta Granitoid Complex, and volcanism of the Whim Creek Group (not preserved on PINDERI HILLS); possibly related to a northeasterly trending volcanic arc
2945–2930	D_4 of WPGGT: transpressional, northeasterly trending tight to open folding of the Whundo Group, and late felsic magmatism in the Cherratta Granitoid Complex
c. 2930	D_5 of WPGGT: westerly to northwesterly striking strike-slip faulting along the Maitland Shear Zone
c. 2925	Emplacement of layered mafic–ultramafic intrusions, followed by intrusion of syenogranite, monzogranite, and granodiorite (*Agi, Agm, Agya*)
2920–2770	Erosion
2770–2720	D_{10}: north-northeasterly trending rifting of the WPGGT, and deposition of the Mount Roe Basalt and Hardey Formation (2770–2760 Ma); intrusion of dolerite and pyroxenite dykes. Deposition of the Kylena Formation (post-2750 Ma), accompanied by intrusion of the Cooya Pooya Dolerite. Open folding about northeasterly trending axes
2720–2700	Erosion, followed by deposition of the Tumbiana and Maddina Formations. Continuation of D_{10} open folding about northeasterly trending axes
1830–1780	D_{11}: Capricorn Orogeny D_2: open folding of the upper Fortescue Group about northwesterly trending axes. Movement on the Portland Fault. Intrusion of west-northwesterly trending dolerite dykes
755	Intrusion of east-northeasterly trending dolerite dykes (Mundine Well suite)
545–65	Palaeozoic and Mesozoic erosion
55–present	Uplift and dissection of plateau surface, deposition of Cainozoic units

trending structures formed by successive periods of northwest–southeast to north–south extension and compression. Deformation after c. 3160 Ma (Table 1) included thrusting, strike-slip faulting, and folding in the WPGGT. Outside PINDERI HILLS the granitoid complexes of the WPGGT are elongated in a northeast–southwest direction, suggesting linear belts of felsic magmatism. The Cherratta Granitoid Complex has the same orientation, although more than 60% of it is concealed by the Hamersley Basin. Tectonic environments responsible for formation of the WPGGT have been discussed by Van Kranendonk et al. (2002) and Hickman (in prep. b).

The Hamersley Basin succession on PINDERI HILLS is deformed by structures related to c. 2770–2700 Ma northeasterly trending rifting and open folding, and by c. 1830–1780 Ma northwesterly trending open folds on the northern margin of the Capricorn Orogen. The Portland Fault, in southern PINDERI HILLS, is interpreted to have formed at c. 1830–1780 Ma, and to overlie an earlier fault formed during c. 2770–2760 Ma rifting. This early Portland Fault is here interpreted to coincide with an abrupt southerly deepening of the Hamersley Basin (see the diagrammatic sections on the PINDERI HILLS map).

Archaean rocks

The Archaean rocks of PINDERI HILLS form parts of the West Pilbara Granite–Greenstone Terrane and the Hamersley Basin (Fig. 1).

West Pilbara Granite–Greenstone Terrane

The WPGGT comprises an Archaean supracrustal succession of metamorphosed volcanic, sedimentary, and intrusive rocks (generally referred to as ‘greenstones’) that has been intruded by major granitoid complexes (Figs 1 and 4). The entire greenstone succession is referred to as the Pilbara Supergroup (Hickman, 1983).

During the mapping of PINDERI HILLS, a reliable stratigraphic interpretation had not been developed for the lower part of the Pilbara Supergroup in the west Pilbara. The stratigraphic subdivision of the greenstones was therefore delayed pending additional information from the wider west Pilbara mapping program.

Table 2. Archaean lithostratigraphy of Pinderi Hills

Group	*Formation*	*Thickness (m)*	*Lithology and relationships*
Fortescue	Maddina Formation	700–1100	Massive and amygdaloidal basalt, basaltic andesite, andesite, dacite, and rhyolite; local high-Mg basalt and high-Mg andesite. Age 2717 ± 2 Ma
	Tumbiana Formation	190–250	Sandstone, siltstone, basaltic and andesitic tuff, and stromatolitic limestone and dolomite; local basalt. Age 2719 ± 6 Ma
~ ~ ~

Hickman (1997) presented a lithostratigraphic interpretation of the west Pilbara greenstones that represented a major revision of the previously published interpretation (Hickman, 1983). This later stratigraphy forms the basis of the stratigraphic summary in Table 2. Krapez (1993) subdivided the greenstone succession of the west Pilbara using principles of sequence stratigraphy, but the recent mapping and sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon geochronology have supported the present litho-stratigraphic interpretation.

The lithological components of Pilbara Supergroup rocks, most of which are not stratigraphically assigned on the map, are described under the broad lithological groupings that are used in the map legend. Thus, no age relationships are implied, and many lithological codes (e.g. *Ab*) apply to several units that are clearly at different stratigraphic positions. Granitoids of the WPGGT are described under a separate heading, and include rocks spanning a similar age range to the components of the Pilbara Supergroup.

Metamorphosed volcanic and sedimentary rocks of the Pilbara Supergroup (not stratigraphically subdivided on the map)

Ultramafic rocks (Au, Aur, Auz)

Except for ultramafic rocks within layered mafic–ultramafic intrusions and later minor intrusions, most of ultramafic rocks on PINDERI HILLS have, since the map was published, been assigned to the Whundo Group. However, metamorphosed and otherwise altered ultramafic rocks also outcrop as xenoliths within the Cherratta Granitoid Complex. The ultramafic rocks are extensively altered (e.g. by serpentinization, carbonation, and silicification), but preservation of spinifex texture, and other volcanic features, indicate that most of the rocks are volcanic in origin.

Undivided ultramafic rock (*Au*) and tremolite–chlorite schist (*Aur*) form the lower part of the greenstone succession 3.5 km south and southwest of Whundo. These ultramafic units are extensively deformed and metamorphosed, but interlayering with mafic and felsic volcanic units indicates a volcanic origin. At East Well (incorrectly labelled Last Well on the map) a unit of undivided ultramafic rock (*Au*) is a variably carbonated and silicified ultramafic schist that is underlain and overlain by units of grey and white banded chert *Acw*), suggesting a volcanic origin. Smaller units of undivided ultramafic rock (*Au*) are located 5 km east of Zebra Hill and 3 km west of Weelarra Hill. These units consist of schist that has been contact metamorphosed and then subsequently altered by variable serpentinization, carbonation, and silicification.

Silicified ultramafic rock (*Auz*), 0.5 km south of Yathala Hill, is interpreted to have formed by near-surface alteration of ultramafic xenoliths within banded grey monzogranite–granodiorite gneiss (*AgCn*).

Mafic volcanic rocks (Ab, Aba, Abp, Abgp)

As occurs elsewhere in the WPGGT, mafic volcanic rocks are the most common components of the greenstone successions on PINDERI HILLS. Most of the mafic rocks are tholeiitic (Glikson et al., 1986).

Undivided basaltic rock (*Ab*) is widespread on PINDERI HILLS, and consists mainly of massive or pillowed basalt that has been metamorphosed to greenschist facies. Varying degrees of strain are indicated by local flattening or shearing of pillow structures. Vesicles in the pillows are filled with quartz, carbonate minerals, or chlorite. Interstitial material between the pillows is composed of cryptocrystalline chloritic rock, palagonite, chert, or altered tuff. Flow tops within the basaltic units are generally difficult to recognize except where there are interflow sediments or altered flow-top breccias. Alteration in the upper sections of flows has mainly involved silicification and epidotization.

The *Ab* unit locally includes komatiitic basalt. Most basalt of the *Ab* unit is a fine-grained assemblage of amphibole (actinolite, tremolite, or hornblende), quartz (largely secondary), albite, epidote, chlorite, and minor sericite, sphene, clinozoisite, carbonate minerals, and opaques. Relict clinopyroxene phenocrysts are locally preserved, but replacement by amphibole is normally complete. Plagioclase is extensively albitized.

Foliated amphibolite-facies metabasalt (*Aba*) forms the lowermost 1000 m of the greenstone succession south of Whundo, and is also common as large enclaves within the Cherratta Granitoid Complex. Deformed pillow structures testify to an extrusive origin for large parts of this unit, but thin sills of metadolerite and metagabbro are also included. Massive units consist of a medium-grained, randomly oriented assemblage of secondary amphibole and altered plagioclase. Hornblende or actinolite may ophitically enclose relics of primary pyroxene. Minor components include chlorite, quartz, calcite, sphene, phlogopite, rutile, and opaques. In more deformed areas, amphibolite schist consists mainly of felted to granoblastic actinolite or hornblende, with subordinate plagioclase, chlorite, and epidote, and minor quartz, opaques, and carbonate minerals.

Plagioclase-phyric basalt (*Abp*) outcrops 3 km north-northeast of Mackies Well, where it forms the southern extension of a larger outcrop on DAMPIER. This unusual and highly distinctive basalt contains numerous small euhedral plagioclase phenocrysts. In thin section, saussuritized phenocrysts of plagioclase up to 5 mm across make up about 30% of the rock. The matrix is a fine-grained assemblage of actinolite, epidote, and quartz.

Foliated and sheared amphibolite-facies metabasalt, with sheared veins and sheets of microgranite and pegmatite (*Abgp*), is restricted to northwestern PINDERI HILLS, where it outcrops between the Yanyare River and Moondle Creek. The unit formed in a zone of shearing and granitic intrusion and, combined with amphibolite-facies metabasalt (*Aba*), probably represents the remnants of an easterly trending greenstone belt.

Felsic volcanic rocks (Af, Afd, Afr, Afs, Aft)

Undivided metamorphosed felsic volcanic rocks (*Af*) outcrop northwest and southeast of the North Whundo Intrusion (*AaN*), and are stratigraphically assigned to the Tozer Formation. The rocks vary in composition from dacite to rhyolite and appear to be mainly metamorphosed lava, but some units may be fine-grained intrusive rock. Visible pyroclastic textures are absent, but phenocrysts are locally present. Parts of the undivided metamorphosed felsic volcanic rock (*Af*) units have been deformed to produce quartz–sericite schist with minor chlorite, and the rock is locally silicified.

Metamorphosed dacite to andesite with local pyroclastic units (*Afd*) forms thin units within metabasalt 2 km west of Whundo. Metamorphosed rhyolite (*Afr*) outcrops northwest of the North Whundo Intrusion, where it forms part of the Tozer Formation. The rhyolite is fine grained to glassy, and in thin section its texture is porphyritic, glomerocrystic, and spherulitic. Phenocrysts are composed of sodic plagioclase, epidote, quartz, or chlorite (replacing ferromagnesian minerals). The aphanitic groundmass consists of ovoid intergrowths of radiating feldspar and quartz, feldspar microlites, anhedral interstitial quartz and chlorite, and subhedral granular epidote, sericite, titanite, and accessory minerals. Sericitic patches within the fine-grained felsic matrix define a remanent tuffaceaous texture with shards and pumice lapilli.

Rhyolite to andesite schist (*Afs*) outcrops in the lower part of the greenstone succession 3 km south of Whundo. The rock locally displays fragmental textures, but deformation and amphibolite-facies metamorphism make it difficult to determine if this is a relict pyroclastic texture or the result of tectonic brecciation related to local thrusting.

Metamorphosed rhyolite and dacite tuff (*Aft*) forms large outcrops north of Whundo, and northwest and southeast of the North Whundo Intrusion. In all three areas these felsic units are assigned to the Tozer Formation. In thin section, felsic tuff consists of devitrified felsic glass, with abundant chlorite, minor quartz and feldspar, and accessory leucoxene, titanite, zircon, carbonate, and sericite. Excellent exposures of least deformed and least altered rhyolite and dacite tuff (*Aft*) are accessible 1 km northwest of Whundo. Here, creek exposures (MGA 491700E 7669800N) reveal a succession of rhyolite and dacite–rhyolite tuff units dipping northwards at 30°. These are overlain by a unit of metasedimentary rocks and metamorphosed dolerite sill. Metamorphic grade is upper greenschist to lower amphibolite facies. Units of coarse- and fine-grained tuff alternate at intervals of 5–10 m. The tuff is bedded, quartz-phyric, and pale to dark grey. Microscopic examination reveals a porphyritic rock composed of rounded, lightly sutured phenocrysts of quartz about 0.8 mm in diameter, and several 0.5 to 1 mm-sized, heavily sutured, anhedral plagioclase phenocrysts in a quartz–plagioclase groundmass. The groundmass contains abundant interstitial foliated, penetrative chlorite–leucoxene, minor prismatic opaques, and trace apatite. Parts of the rock are embedded with 0.1 to 5 mm-sized masses of mostly randomly oriented prismatic to acicular hornblende. These are lightly poikiloblastic with inclusions of quartz and locally show weak partial replacement by carbonate. The chlorite–leucoxene probably represents altered biotite and is commonly embedded with epidote granules. The quartz and plagioclase in the groundmass form a very ragged mosaic of heavily sutured and strained grains. All plagioclase is moderately altered to fine sericite, muscovite, chlorite, carbonate and minor epidote (Watmuff, 1997, unpublished).

A thin section of a rhyolite sample showed a sutured granular mosaic of quartz and subordinate potash feldspar embedded with abundant 0.1 to 0.5 mm-sized ragged porphyroblasts or phenocrysts of plagioclase. The mosaic also contains fine, interstitial, penetrative, foliated muscovite and chlorite–leucoxene (retrograde after biotite), with minor epidote and trace carbonate. These phases are also concentrated with sericite into elongated masses and stringers running parallel to the muscovite–chlorite foliation.

Metamorphosed sedimentary rocks (Ac, Acw, Asv, Alas, Alf)

Metamorphosed sedimentary rocks constitute an extremely small percentage of the greenstone succession on Pinderi Hills. Undivided chert (*Ac*) outcrops at one locality only, 6 km southeast of Whundo. The chert here is massive, contains minor chlorite and opaque minerals, and may be a silicified fine-grained clastic sedimentary or felsic volcanic rock. Grey and white banded chert (*Acw*) outcrops only in the East Well area, where it forms thin units above and below a unit of undivided ultramafic rock (*Au*).

Quartzofeldspathic schist (*Asv*), derived from volcanogenic sedimentary rocks, is restricted to the immediate area of Yannery Hill mine. Exposures in and around the old mine workings consist of variably pyritic chlorite schist within metamorphosed (greenschist–amphibolite transition facies) volcanogenic sedimentary rocks. Other lithologies include quartz–sericite schist and chlorite–quartz–sericite schist with local porphyroblasts of andalusite. All these units are assigned to the Tozer Formation.

Scapolite-bearing calc-silicate schist (*Alas*) and quartz–feldspar rock (*Alf*) are restricted to the immediate vicinity of the Maitland Shear Zone between 2 and 3 km north of Elizabeth Hill. The scapolite-bearing calc-silicate schist (*Alas*) is composed of anhedral crystals of scapolite to 1 cm in length, abundant apatite, and variable amounts of quartz, carbonate, clinochlore, biotite, fibrous to prismatic tremolite (extensively altered to chlorite), and opaque minerals. The scapolite (pseudomorphed by illite) shows irregular, rounded, and interlocking grain boundaries. The rock is currently interpreted to be a metamorphosed sedimentary rock, but because of its location close to a possible hydrothermal conduit (see **Economic geology — silver**) and its content of disseminated opaque minerals, it merits further examination.

The quartz–feldspar rock (*Alf*) has a gneissic fabric related to the adjacent Maitland Shear Zone. In thin section, the rock consists of a granoblastic mosaic of quartz, altered feldspar, biotite, muscovite, chlorite, and

rare zircon. Some of the quartz grains are up to 4 mm across. The rock is either a strongly deformed quartzo-feldspathic sedimentary rock or a felsic igneous rock.

Mafic–ultramafic intrusions of the Pilbara Supergroup

The mafic–ultramafic intrusions of the west Pilbara are discrete bodies that have been formally named and, based on field observations and geochronology, can be positioned stratigraphically within the Pilbara Supergroup succession. Field observations on PINDERI HILLS have established that these intrusions post-date the metamorphosed volcanic and sedimentary units of the greenstones, and also that they intrude the Cherratta Granitoid Complex. Available geochronology indicates that they intruded the WPGGT at c. 2925 Ma. Other metamorphosed mafic and ultramafic intrusive rocks, not assigned to any of the named intrusions, are described under a separate heading, and are mostly younger than the mafic–ultramafic intrusions.

Most of the mafic–ultramafic intrusions are lopoliths or funnel-shaped bodies (Hoatson et al., 1992). The intrusions occupy a broadly northeasterly trending zone in northeastern PINDERI HILLS, southeastern DAMPIER, and southwestern ROEBOURNE. The southeastern limit of this zone coincides with northeasterly trending synclines in the Whundo and Fortescue Groups, and with the Zebra Hill Fault on PINDERI HILLS. It is also parallel to, and approximately along strike from, major faulting of the WPGGT – Mallina Basin contact on ROEBOURNE (Hickman, 2000), suggesting that the mafic–ultramafic intrusions were emplaced along deep crustal structures close to the northwestern margin of the Central Pilbara Tectonic Zone (Fig. 1).

Surface geology indicates that the west Pilbara mafic–ultramafic intrusions differ considerably with respect to proportions of mafic and ultramafic components, with larger intrusions typically containing the most ultramafic rocks. This is the situation on PINDERI HILLS where the largest intrusion, the Munni Munni Intrusion, contains about 30% ultramafic rocks, and the smallest body, the North Whundo Intrusion, contains no exposed ultramafic rocks. The thicknesses of the intrusions range from several hundred metres (North Whundo Intrusion) to over 5 km (Munni Munni Intrusion). Mineral exploration (summarized by Ruddock, 1999) has resulted in discoveries of significant mineralization in the Radio Hill Intrusion (Ni–Cu–Co) and in the Munni Munni Intrusion (platinum group elements and Ni–Cu). The Radio Hill Intrusion has been mined, and the Munni Munni Intrusion is still being explored.

In the following account, general descriptions of the four mafic–ultramafic intrusions on PINDERI HILLS are followed by descriptions of their component lithologies.

Radio Hill Intrusion (AaR, AaRo)

The Radio Hill Intrusion (*AaR*) outcrops mainly on southeastern DAMPIER, but the southern margin of the intrusion is exposed on northeastern PINDERI HILLS, immediately south of Radio Hill, and about 3 km south of Radio Hill nickel mine. The geology of the intrusion has been described by Hoatson et al. (1992), Frick et al. (2001), and Hoatson and Sun (2002), and mineralization in the intrusion was summarized by De Angelis et al. (1987) and Ruddock (1999). Frick et al. (2001) dated massive sulfides of the intrusion at 2892 ± 34 Ma. Exposure on PINDERI HILLS is restricted to the upper gabbroic zone (*AaRo*) of the intrusion, but on DAMPIER this is underlain by an ultramafic zone of interlayered dunite, lherzolite, websterite, and clinopyroxenite, and a basal zone of gabbro, gabbronorite, and plagioclase websterite containing zones of Ni–Cu sulfide (Frick et al., 2001). About 3 km north of Mackies Well, a small body of monzogranite and granodiorite (*Agm*) is surrounded by gabbro of the Radio Hill Intrusion. Where exposed, the contact between this granitoid and the gabbro is gradational, indicating that the granitoid may be a late-stage differentiated phase of the intrusion.

Metamorphosed gabbro and minor dolerite and microgabbro (*AaRo*) make up the greater part of the Radio Hill Intrusion. The rocks are massive, jointed at 0.5 to 2 m intervals, and weather to form dark-grey to black bouldery hills and ridges. Rare, weakly developed mineral layering is present, and is generally defined by plagioclase-rich layers 1–10 cm thick. In thin section, the gabbro has a hypidiomorphic assemblage of saussuritized plagioclase, pyroxene (variably replaced by actinolite and chlorite), and brown hornblende. Accessory minerals include sphene and carbonate, and some samples contain minor quartz.

North Whundo Intrusion (AaN, AaNo, AaNd)

The North Whundo Intrusion (*AaN*) is exposed in northeastern PINDERI HILLS, where it consists of gabbro and leucogabbro (*AaNo*) and dolerite (*AaNd*) that are lithologically indistinguishable from gabbro, leucogabbro, and dolerite in the larger mafic–ultramafic intrusions. The North Whundo Intrusion is inclined southwards, and appears to be overlain by the Yannery Granite (*Agya*). No intrusive relationships have been observed between this granitoid and gabbro of the intrusion. The Yannery Granite is lithologically similar to a granitoid in the southern part of the Radio Hill Intrusion (see above), and it is possible that the Yannery Granite has a similar genetic relationship to the North Whundo Intrusion.

Munni Munni Intrusion (AaU, AaUdq, AaUl, AaUo, AaUp, AaUx, AaUxo)

The Munni Munni Intrusion (*AaU*) is by far the largest mafic–ultramafic intrusion on PINDERI HILLS, and outcrops over an area of 135 km^2 in the vicinity of Munni Munni Creek. The outcrop area is elongated in a northeast–southwest direction, and airborne magnetic data indicate that the Fortescue Group conceals most of the south-western upper section of the intrusion. The Munni Munni Intrusion intrudes the Cherratta Granitoid Complex, which locally contains granitoids (GSWA samples 142661, 142438, and 142657 shown on the map) ranging in age from 3068 to 2966 Ma (SHRIMP U–Pb zircon geochronology, Nelson, 1998, 1999). The northeastern part of the intrusion is intruded by dykes of monzogranite to quartz diorite (*Agi*), one of which (GSWA 142436

Table 4. Other geochronological data on rocks from PINDERI HILLS and adjacent areas

Age (Ma)	*Method*	*Material*	*Rock unit/age*	*Sample*	*Reference*
3339	Nd T_{DM}	rock	Cherratta Granitoid Complex, 3236 Ma	142535	GSWA data (unpublished)
3313 ± 17	Nd T_{DM}	rock	Cherratta Granitoid Complex, 3114 Ma	JS33	Smith et al. (1998)
3246	Nd T_{DM}	rock	Cherratta Granitoid Complex, 2995 Ma	136826	S-S. Sun (writt. comm., 1998)
3221 ± 17	Nd T_{DM}	rock	Cherratta Granitoid Complex, 3013 Ma	JS35	Smith et al. (1998)
3218	Nd T_{DM}	rock	Cherratta Granitoid Complex, 3068 Ma	142661	GSWA data (unpublished)
3212	Nd T_{DM}	rock	Cherratta Granitoid Complex (na)	142536	GSWA data (unpublished)
3202	Nd T_{DM}	rock	Cherratta Granitoid Complex (na)	84770083	Sun and Hoatson (1992)
3192	Nd T_{DM}	rock	Cherratta Granitoid Complex (na)	142534	GSWA data (unpublished)
3171	Nd T_{DM}	rock	Cherratta Granitoid Complex (na)	84770115	Sun and Hoatson (1992)
3149	Nd T_{DM}	rock	Cherratta Granitoid Complex (na)	136833	S-S. Sun (writt. comm., 1998)
3139	Nd T_{DM}	rock	Cherratta Granitoid Complex (na)	136834	S-S. Sun (writt. comm., 1998)
2935 ± 23	Sm–Nd isochron	mineral	Munni Munni Intrusion, c. 2925 Ma	84770061	Hoatson et al. (1992)
2927 ± 19	Sm–Nd isochron	mineral	Munni Munni Intrusion, c. 2925 Ma	84770052	Hoatson et al. (1992)
2915 ± 23	Sm–Nd isochron	mineral	Munni Munni Intrusion, c. 2925 Ma	84770094	Hoatson et al. (1992)
2927 ± 13	Sm–Nd isochron	weighted mean	Munni Munni Intrusion, c. 2925 Ma	multiple	Hoatson et al. (1992)
2892 ± 34	Re–Os isochron	Ni–Cu sulfide	Radio Hill Intrusion, c. 2925 Ma	multiple	Frick et al. (2001)
2868	Pb (model)	galena	Elizabeth Hill silver deposit (na)	110000	Thorpe et al. (1992)
2867	Pb (model)	galena	Elizabeth Hill silver deposit (na)	98042069B	Huston et al. (2002)
2861	Pb (model)	galena	Elizabeth Hill silver deposit (na)	99044045	Huston et al. (2002)

NOTE: na not available

shown on the map) was dated at 2924 ± 5 Ma (Nelson, 1998). Arndt et al. (1991) used SHRIMP U–Pb zircon geochronology to date a ferrogabbro pegmatite from the intrusion at 2925 ± 16 Ma. However, four of the seven zircon grains that were within error of the concordia curve had $^{207}Pb/^{206}Pb$ ages of between 2946 and 2931 Ma. In view of the later precise dating of the intrusive granitoid dyke (*Agi*), mentioned above, this indicates that the age of the Munni Munni Intrusion is slightly older than 2925 Ma. Sm–Nd mineral isochron ages (Table 4) reported by Hoatson et al. (1992) range from 2935 to 2915 Ma. Sm–Nd data from the Munni Munni Intrusion (Hoatson et al., 1992, table 26) permit calculation of whole-rock Nd T_{DM} model ages of approximately 3200 Ma, which are similar to Nd T_{DM} model ages for the Cherratta Granitoid Complex and the Whundo Group (Sun and Hickman, 1998).

Donaldson (1974) described the Munni Munni Intrusion as a layered intrusion consisting of a lower 2 km-thick ultramafic zone overlain by a 3.5 km-thick gabbroic zone. He recognized more than 40 cyclic units in the ultramafic zone, in which peridotite layers graded upwards into clinopyroxenite. Fine-scale layering in the clinopyroxenite consists of olivine-rich layers alternating with pyroxenite at intervals of 200 mm to 2 mm. Donaldson (1974) stated that the upper gabbroic zone of the intrusion was not rhythmically layered, but the rock was locally laminated by virtue of oriented plagioclase laths.

Subsequent studies of the Munni Munni Intrusion (Hoatson and Keays, 1989; Hoatson et al., 1992; Barnes and Hoatson, 1994; Hoatson and Sun, 2002) have indicated that the intrusion is a funnel-shaped or boat-like structure, plunging moderately to the south-southwest. As noted below, the ultramafic and gabbroic zones of the intrusion are separated by a unit of porphyritic (large euhedral hypersthene grains) websterite that contains laterally extensive PGE mineralization. Hoatson and Sun (2002) interpreted this unit as a product of mixing between the ultramafic and gabbroic zones, and described an erosional contact with the underlying ultramafic zone. Barnes and Hoatson (1994) interpreted the isolated northerly trending metapyroxenite (*AaUx*) dyke on the western side of the intrusion as a possible feeder conduit to the central and upper parts of the intrusion. The metapyroxenite and metagabbro unit along the eastern margin of the intrusion truncates layering in the ultramafic zone, and is here interpreted to be related to the porphyritic websterite in the central part of the intrusion. Certain localities along the eastern contact show this marginal phase of the Munni Munni Intrusion to be brecciated and intruded by granitoid material (Figs 6 and 7), but no granitoids younger than the mafic–ultramafic intrusion have been dated in the Cherratta Granitoid Complex. The present interpretation is that this late granitoid material is the product of melting along the contact of the Munni Munni Intrusion, and is probably related to the micro-granite dykes (*Agi*) in the intrusion a short distance to the west.

Metamorphosed gabbro and minor dolerite and microgabbro (*AaUo*) make up the upper zone of the Munni Munni Intrusion. The rocks are massive, jointed at 0.5 to 2 m intervals, and weather to form dark-grey to black bouldery hills and ridges. Rare, weakly developed mineral layering is present, and is generally defined by plagioclase-rich layers 1–10 cm thick. The rocks are petrographically similar to gabbro, dolerite, and micro-gabbro in the Radio Hill Intrusion.

Metamorphosed leucogabbro (*AaUl*) units differ from units mapped as metagabbro by containing more plagioclase, and consequently being paler coloured when broken or observed in clean outcrops. Like all types of metagabbro, leucogabbro forms bouldery hills and cannot

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Figure 6. Pyroxene-rich gabbro at the eastern margin of the Munni Munni Intrusion, brecciated and intruded by a leucocratic granitoid locally generated by contact melting of the Cherratta Granitoid Complex (MGA 486900E 7664200N)

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Figure 7. Gabbro of the Munni Munni Intrusion brecciated and intruded by late-stage granitoid partial melt (MGA 486400E 7660700N)

be distinguished by photointerpretation. Microscopic examination shows that the metamorphosed leucogabbro is composed of saussuritized plagioclase, tremolite, clinopyroxene, chlorite, traces of brown hornblende, and variable amounts of calcite. Leucogabbro forms a significant proportion of the Munni Munni Intrusion, possibly resulting from more differentiation than in the smaller bodies. Hoatson and Sun (2002) stated that the gabbroic part of the Munni Munni Intrusion also includes gabbronorite and magnetite gabbro.

The lower ultramafic zone of the Munni Munni Intrusion is layered due to variations in the proportions of olivine and pyroxene. Olivine-rich layers were mapped as serpentinized peridotite (*AaUp*), and include metamorphosed dunite, lherzolite, wehrlite, and olivine websterite. Pyroxene-rich layers include metamorphosed clinopyroxenite, websterite, and orthopyroxenite (*AaUx*). The alternating layers of these rock types have weathered to produce a low strike-ridge topography in which the pyroxene-rich layers are typically recessive. Detailed descriptions of the ultramafic zone are provided by Donaldson (1974), Hoatson et al. (1992), and Hoatson and Sun (2002).

Metapyroxenite (*AaUx*) is common within the ultramafic zone of the Munni Munni Intrusion. Unlike metagabbro and massive serpentinite, metapyroxenite generally forms low, weathered outcrops. Metapyroxenite of the Munni Munni Intrusion (*AaUx*) forms about 70% of the 1850 m-thick ultramafic zone, and includes clinopyroxenite, websterite, and orthopyroxenite. The ultramafic and gabbroic zones of the intrusion are separated by a unit of porphyritic (large euhedral hypersthene grains) websterite that contains laterally extensive PGE mineralization. Hoatson and Sun (2002) interpreted the unit as a product of mixing between the ultramafic and gabbroic zones, and described an erosional contact with the underlying ultramafic zone. Metapyroxenite of the layered intrusions is typically fine- to medium-grained, with an allotriomorphic granular texture, and is mainly composed of secondary amphibole (actinolite or tremolite) and minor chlorite, talc, and epidote. Relict pyroxene is rarely preserved. Opaque minerals form disseminated anhedral grains and discontinuous layers along grain boundaries.

The eastern margin of the Munni Munni Intrusion is marked by a narrow ridge of metamorphosed pyroxenite and pyroxene-rich gabbro (*AaUxo*). Donaldson (1974) described the unit as a pyroxenite composed of altered clinopyroxene (largely replaced by fibrous amphibole, chlorite, and iron oxide), carbonate, perthite, and quartz, with local biotite, hornblende, and iron–titanium oxides. Hoatson and Sun (2002) separated the unit into a southeastern porphyritic websterite (underlying the gabbroic zone) and a northeastern contaminated gabbro (discordant to layering in the ultramafic zone). Exposures northeast of Munni Munni Creek (Fig. 6) show veins of granitoid intruding the pyroxenite, and blocks of pyroxenite within the marginal granitoid. This relationship initially indicates that the Munni Munni Intrusion is older than the adjacent granitoids of the Cherratta Granitoid Complex, but the veining may have resulted from remelting of the granitoids against the mafic–ultramafic intrusion. This possibility is strengthened by a date of 3068 ± 4 Ma (Nelson, 1998, p. 96–98) on a sample of tonalite (GSWA 142661) collected 2 km to the south.

Quartz diorite and amphibole syenogranite (*AaUdq*) are unconformably overlain by the Fortescue Group in the southern part of the Munni Munni Intrusion, west and southwest of Zebra Hill. Hoatson and Sun (2002) referred briefly to this unit, recording a compositional range from granophyric gabbro to quartz syenite, and suggested that these are the most evolved rocks of the exposed part of the Munni Munni Intrusion.

Maitland Intrusion (Aal, Aald, Aall, Aalo, Aalx, Aalus)

The Maitland Intrusion (*AaI*) is chiefly composed of metagabbro with minor dolerite and leucogabbro (*AaIo*), metamorphosed leucogabbro (*AaIl*), and anorthosite (not mapped separately). Ultramafic rocks (*AaIus* and *AaIx*) are poorly exposed in the central part of the outcrop area, and metadolerite (*AaId*) is a very minor component of the intrusion.

Metamorphosed leucogabbro (*AaIl*) contains more plagioclase than is present in metagabbbro, and consequently the rock is paler coloured when broken or when it is present in clean outcrops. Like all types of metagabbro, leucogabbro of the Maitland Intrusion forms bouldery hills and cannot be distinguished by photointerpretation.

Mapping evidence indicates that the intrusion formed as a sheet-like body emplaced into the Whundo Group, and was subsequently folded and intruded by later granitoids of the Cherratta Granitoid Complex. On its western side, the intrusion is intensely deformed along the Maitland Shear Zone, which is interpreted to have formed at about 2930 Ma (see **D_5 (c. 2930 Ma)**). These relationships indicate that the intrusion is at least 2930 Ma in age, but no direct dating has been undertaken.

Hoatson and Sun (2002) described the Maitland Intrusion as mainly composed of a bimodal cyclic sequence of gabbro and subordinate anorthosite units, with the ultramafic rocks forming intrusive plugs. Age relationships between the mafic and ultramafic rocks are therefore different from those in the Munni Munni Intrusion. No mineralization of economic grade has been discovered in the intrusion. A marginal eastern zone of pyroxene-rich gabbro contains about 0.5% sulfides (Hoatson and Sun, 2002), and 2 km south of Yannery Well a quartz vein through pegmatite and anorthositic gabbro contains visible malachite (shown as a Cu occurrence on the map).

Other mafic and ultramafic intrusive rocks (not stratigraphically subdivided)

Metamorphosed gabbro, dolerite, peridotite, and pyroxenite (Ao, Aod, Aog, Aol, Aoz, Aus, Aux)

Mafic intrusive rocks form dykes and sills within the greenstone belts and the granitoids on PINDERI HILLS. Most

of these rocks are probably related to the mafic volcanic rocks of the greenstones, but metapyroxenite (*Aux*), metadolerite (*Aod*), metagabbro (*Aog*), and metaleucogabbro (*Aol*) are also components of major easterly trending dykes south of the Munni Munni Intrusion and in the Weelarra Hill area. These dykes intrude the c. 2925 Ma Munni Munni Intrusion, and are unconformably overlain by the c. 2760 Ma Hardey Formation. The rocks are typically massive and jointed at 0.5 to 2 m intervals; their resistance to weathering causes the intrusions to form ridges, as at Zebra Hill. The mineral compositions and textural features of these rock types are similar to those of the same rock types in the mafic–ultramafic intrusions (see above).

Metamorphosed gabbro and dolerite (*Ao*) generally form sills within the greenstones. The gabbro is typically medium or coarse grained and has a primary assemblage of pyroxene and plagioclase that has been variably altered to actinolite–tremolite, chlorite, serpentine, quartz, epidote, sericite, carbonate, clinozoisite, and opaques. Despite saussuritization and carbonation, an original hypidiomorphic texture is generally well preserved. Some gabbro outcrops are extensively silicified (*Aoz*), for example 11 km southwest of Weelarra Hill, and this alteration is probably related to Cainozoic weathering processes.

Serpentinite (*Aus*) forms deformed xenoliths within banded grey granite–tonalite gneiss (*AgCn*) about 6 km south of Whundo, and is assumed to have been derived by granitoid intrusion, alteration, and deformation of peridotite in the adjacent greenstone succession.

Granitoid rocks

Pinderi Hills contains the southern part of the Cherratta Granitoid Complex (*AgC*), the Yannery Granite (*Agya*) in northeastern Pinderi Hills, and various smaller granitoid outcrops that have been mapped lithologically and without stratigraphic assignment. The granitoids have intrusive contacts with adjacent greenstones, and have locally detached and enveloped sections of the greenstone succession. Many of the granite–greenstone contacts are faulted and sheared. Available geochemical data indicate a wide range of granitoid compositions, ranging from tonalite–trondhjemite–granodiorite (TTG) to monzogranite and syenogranite.

Cherratta Granitoid Complex (AgC, AgCp,AgCm, AgCmh, AgCx, AgCt, AgCn, AgCnh, AgCf)

On Pinderi Hills, the Cherratta Granitoid Complex (*AgC*) is unconformably overlain by the Fortescue Group, and to the north on Dampier it is bounded by the Sholl Shear Zone. In northeastern Pinderi Hills, the Maitland Shear Zone separates it from the greenstones of the Sholl domain (Fig. 4), although small stocks of monzogranite and syenogranite assigned to the complex locally intrude the greenstones. Some of the oldest granitoid components of the complex (3150–3060 Ma) are restricted to the area east of the Munni Munni Intrusion, but small inliers of the Cherratta Granitoid Complex in the valley of the Fortescue River expose 3236 Ma granitoids (Nelson, 1998). Most of the Cherratta Granitoid Complex comprises 2990–2940 Ma monzogranite and granodiorite.

Porphyritic syenogranite and monzogranite (*AgCp*) form extensive outcrops 10 km east-southeast of Zebra Hill, 3 km south-southwest of Zebra Hill, around Brill Pool and Leopold Well, and in the headwaters of Armstrong Creek. The rock is medium grained, foliated to weakly gneissic, and contains megacrysts of microcline up to 10 cm long and 6 cm wide. Plagioclase and quartz are the dominant constituents, and hornblende is present in most exposures. On Dampier, a sample of porphyritic hornblende granodiorite, collected near Karratha Homestead, was dated at 2994 ± 2 Ma (Nelson, 1997, GSWA 118974).

Foliated granite to granodiorite (*AgCm*) is a widespread component of the Cherratta Granitoid Complex, particularly around the Munni Munni Intrusion and the headwaters of Armstrong Creek. Additionally, various granitoids that have intruded the Whundo Group and the Maitland Intrusion are included within the unit. SHRIMP U–Pb zircon geochronology has established that the unit includes rocks ranging from 3068 to 2966 Ma (Nelson, 1998, 1999). The rock is locally sparsely porphyritic and weakly banded. Hornblende- and biotite-rich monzogranite (*AgCmh*) outcrops around the site of the old Cherratta Homestead in northern Pinderi Hills, and 2 km south of Cadgerina Pool. It typically forms massive hilly outcrops, and is foliated and locally weakly banded. In the field, it is distinguished from other granitoids of the complex by its abnormally high hornblende (variably replaced by actinolite) content, and by magnetism due to disseminated magnetite. The hornblende and actinolite crystals are orientated in the plane of the foliation. The rock is generally medium- to coarse-grained monzogranite, but local granodiorite is also present. In thin section it consists of plagioclase, microcline, quartz, hornblende–actinolite, chloritized biotite, sphene, apatite, epidote, and opaques. Some hornblende crystals have relict cores of pyroxene, but this alteration may have been late magmatic. The rock has not been dated, but field relations suggest its age may be similar to that of the porphyritic syenogranite and monzogranite (*AgCp*).

Mixed granitoid rock and greenstone (*AgCx*) units outcrop around Leopold Well and Weelarra Hill in northeastern Pinderi Hills. This type of rock formed where mafic rocks such as basalt, gabbro, and dolerite were extensively intruded by the Cherratta Granitoid Complex. Larger greenstone xenoliths have been mapped as foliated and sheared metabasalt with sheared veins and sheets of microgranite and pegmatite (*Abgp*) or strongly foliated amphibolite (*Aba*). The association of these various units indicates a remnant greenstone belt, and coincides with a zone of relatively high magnetic anomalies.

Metamorphosed tonalite (*AgCt*) outcrops as inliers around Tarlwa Pool on the Fortescue River, east of Yathala Hill, and 6 km south of Whundo. The Tarlwa Pool rock is a foliated hornblende–biotite tonalite consisting of sericitized plagioclase with quartz and biotite. Biotite is

partly chloritized, and associated with hornblende and clinozoisite. Nelson (1998) dated a sample (GSWA 142535 shown on the map) at 3236 ± 3 Ma, using the SHRIMP U–Pb zircon method. About 6 km south of Whundo, a zone of tonalite is exposed on both sides of the Maitland River, and is interlayered with banded grey monzogranite–granodiorite gneiss (*AgCn*). Smith et al. (1998) dated a fine-grained, plagioclase-phyric tonalite (sample JS33) from this area at 3114 ± 5 Ma (SHRIMP U–Pb zircon method). This tonalite contains numerous greenstone xenoliths that are interpreted to have been derived through lit-par-lit intrusion of the Whundo Group.

Banded grey monzogranite–granodiorite gneiss (*AgCn*), with xenoliths of amphibolite-facies mafic gneiss and sheets of leucocratic gneiss, forms excellent rocky exposures in the bed of the Maitland River south of Whundo, and outcrops extend east of the river to an area about 10 km south-southeast of Whundo. A large easterly trending belt of the gneiss is also exposed in northwestern PINDERI HILLS, south and east of Yanyare River. This 20 km-long gneiss belt includes large greenstone xenoliths, mixed granitoids, and greenstones (*AgCx*), hornblende- and biotite-rich granitoid gneiss (*AgCnh*), and sheared metabasalt with sheared veins and sheets of microgranite and pegmatite (*Abgp*). As noted above, this assemblage indicates that a greenstone belt once existed in northeastern PINDERI HILLS. The Maitland River outcrops were sampled for SHRIMP U–Pb zircon geochronology, and Nelson (1999, p. 119–121) dated the gneiss at 3130 ± 4 Ma. Other zircon populations, dated at 3149 ± 15 and 3107 ± 9 Ma are interpreted to represent minor granitoid components of the banded gneiss.

Hornblende–biotite tonalite to granite (*AgCf*) is the oldest component of the Cherratta Granitoid Complex, and outcrops only as inliers within the Fortescue Group of southwestern PINDERI HILLS. Nelson (1998) dated a sample (GSWA 142535) of foliated hornblende–biotite tonalite from this area at 3236 ± 3 Ma. Granitoids with an age of of c. 3240 Ma have been dated across the northern half of the Pilbara Craton, indicating a widespread felsic magmatic event, probably related to a 3280–3240 Ma mantle plume that caused rifting and separation of the WPGGT from the EPGGT (Van Kranendonk et al., 2002; Hickman, in prep. b). The tonalite is accompanied by units of hornblende monzogranite, orthogneiss, and amphibolite, but intrusive relations are uncertain.

Unassigned granitoids (Agi, Agm)

Monzogranite to quartz diorite dykes (*Agi*) intrude the Munni Munni Intrusion, and a sample (GSWA 142436) from one of these was dated at 2924 ± 5 Ma (Nelson, 1998). The sample dated is a fine-grained, epidotized, feldspar-rich monzonite (a full description is provided in Nelson, 1998), but other granitoid dykes of the same suite include pegmatitic granite, biotite–hornblende monzogranite to granodiorite, and extremely fine-grained rhyolite.

Foliated monzogranite and granodiorite (*Agm*) bodies have been mapped within the Radio Hill and Maitland Intrusions. As noted above, the monzogranite and granodiorite near Radio Hill may be a late-stage differentiated component of the Radio Hill Intrusion. No petrography is available.

Yannery Granite (Agya)

The Yannery Granite (*Agya*) is a newly named granitoid intrusion situated immediately to the south of the North Whundo Intrusion (*AaN*) in northeastern PINDERI HILLS. The Yannery Granite (*Agya*) outcrops over an area of 15 km^2, intrudes the Whundo Group, and is intruded by the Cooya Pooya Dolerite (*AFdc*). The granitoid is lithologically similar to monzogranite and granodiorite (Agm) related to the Radio Hill Intrusion (see **Radio Hill Intrusion**), which suggests that it might likewise be genetically related to the adjacent North Whundo Intrusion (*AaN*).

The compositional range of the Yannery Granite (*Agya*) has not been precisely established, but field observations and limited petrography (two samples) indicate that it is chiefly composed of monzogranite and syenogranite. The rock is fine to medium grained, non-foliated, and contains chlorite pseudomorphs that have replaced hornblende. It is moderately to highly magnetic in hand specimen, and significantly more magnetic than adjacent metabasalt on images from airborne magnetic surveys. In thin section, samples of the intrusion consist of either perthite or antiperthite with interstitial quartz and K-feldspar, minor chlorite, and trace opaque minerals (Watmuff, 1997). The interstitial chlorite forms rosettes containing iron oxide, but has more commonly replaced amphibole. Amphibole has also been pseudomorphed by either quartz–carbonate–chlorite or chlorite–quartz–biotite–leucoxene assemblages. Igneous opaque minerals are altered to rutile and leucoxene.

Structure of the West Pilbara Granite–Greenstone Terrane

The Archaean greenstones (Pilbara Supergroup) and granitoids of PINDERI HILLS area are part of the West Pilbara Granite–Greenstone Terrane. The tectonic evolution of this terrane occurred between 3270 and c. 2920 Ma (Van Kranendonk et al., 2002), and was separate and distinctly different from that of the unconformably overlying Hamersley Basin (post-2770 Ma). A structural description of the WPGGT requires reference to the lithostratigraphy of the Pilbara Supergroup, but for reasons given previously (see **Regional geological setting**) this stratigraphy is not shown on the PINDERI HILLS map reference. The greenstone stratigraphy of PINDERI HILLS is shown on Figure 5, and is summarized in Table 2. Additional information has been provided by Hickman (1997, 2001) and Van Kranendonk et al. (2002). The structural geology of the Hamersley Basin on PINDERI HILLS is described later in these Explanatory Notes.

Tectono-stratigraphic domains

The WPGGT is divided into four granitoid complexes and three tectono-stratigraphic domains (Fig. 4; Hickman,

2001). Each of the three domains has a different lithostratigraphy and structural history from the other two, but certain later deformation events are common to all the domains. PINDERI HILLS covers parts of the Sholl domain and the Cherratta Granitoid Complex (Fig. 4). On PINDERI HILLS, the Sholl domain is entirely composed of the 3125–3115 Ma Whundo Group, whereas the Cherratta Granitoid Complex contains 3236–2940 Ma granitoids (see **Cherratta Granitoid Complex**).

The Sholl domain and the Cherratta Granitoid Complex are separated by the Maitland Shear Zone (MSZ), except that marginal plutons of the granitoid complex locally intrude the Sholl domain. The age of the latest movement (see **D_5 (c. 2930 Ma)**) on the MSZ is interpreted to be c. 2930 Ma, based on the observation that the zone of large c. 2925 Ma mafic–ultramafic intrusions crosses it without visible deformation. However, the MSZ may have originated at about 3015 Ma, during D_3 (see below), when the Whundo Group of the Sholl domain was thrust southwards against the older components of the Cherratta Granitoid Complex.

The dominant structures of the Sholl domain are D_3 thrusts and D_4 northeasterly trending, tight to open folds (see below). The eastern part of the Cherratta Granitoid Complex is dominated by a tectonic foliation that dips northwards in the southeast of PINDERI HILLS, northeastwards near the Munni Munni Intrusion, and eastwards in the vicinity of the old Cherratta Homestead. This progressive change in orientation coincides with that of the adjacent MSZ, and the foliation is most strongly developed close to the MSZ. This indicates that the foliation, as mapped, may be a composite structure that was formed during both D_3 and D_5 (see below). In contrast, the western part of the Cherratta Granitoid Complex is dominated by a west-southwesterly striking tectonic foliation that is parallel to local lithological boundaries between different granitoids and between granitoids and large greenstone enclaves of the dismembered Weelarra greenstone belt (Fig. 5). No geochronological data are available from this western part of the complex, impeding structural correlation with eastern PINDERI HILLS.

Deformation events

PINDERI HILLS covers a relatively small section of the WPGGT, and excludes the oldest part of the terrane. Consequently, D_1 and D_2 structures of the WPGGT (Hickman, 2001, 2002) are not present on PINDERI HILLS. Deformation events on PINDERI HILLS are numbered according to structural correlation's with other parts of the WPGGT, as summarized in Van Kranendonk et al. (2002). This has resulted in different deformation event numbers from those applied on ROEBOURNE (Hickman, 2002), where events in the Mallina Basin were included in the deformational history.

The earliest deformation event recognized on PINDERI HILLS caused tectonic duplication of the lower Whundo Group 5 km south of Whundo. Northerly dipping thrusts of this area pre-date intrusion of monzogranite that Smith et al. (1998) dated at 3013 ± 4 Ma. These faults are tentatively correlated with D_3 structures of the WPGGT (Van Kranendonk et al., 2002).

D_3 (c. 3015 Ma)

About 5 km south of Whundo, D_3 thrusts duplicate mafic, ultramafic, and felsic rocks in the lower part of the Whundo Group. As noted above, these structures pre-date c. 3013 Ma, but they are folded by the 2945–2930 Ma D_4 Bradley Syncline (Fig. 5). The thrusts are parallel to gneissic banding in monzogranite–granodiorite gneiss (*AgCn*) in the adjacent part of the Cherratta Granitoid Complex. The protoliths of this gneiss crystallized between 3149 and 3107 Ma (Nelson, 1999, p. 119–121), but the gneissic fabric is absent from a c. 2988 Ma granodiorite (Nelson, 1999, p. 112–114) 6 km to the northwest. The easterly trending belt of monzogranite–granodiorite gneiss (*AgCn*) and mixed granitoids and greenstones (*AgCx*) between the Yanyare River and Yathala Hill has a strong easterly striking tectonic fabric of unknown age.

D_4 (c. 2945–2930 Ma)

The D_4 event formed major northeasterly trending, tight to open folds such as the Bradley Syncline. Farther north, on DAMPIER, D_4 folds are oblique to the Sholl Shear Zone (SSZ) and related strike-slip faults of the WPGGT, and are interpreted to have formed in response to northwest–southeast compression prior to, or during, the onset of major faulting across the SSZ. D_4 structures in the WPGGT are chronologically correlated with the major D_3 folds in the Mallina Basin (Smithies, 1998a) and interpreted to be equivalent to the phase 4 structures of Krapez and Eisenlohr (1998). Geochronology (Smithies, 1998b) has established the age of these structures in the Mallina Basin at younger than 2938 ± 4 Ma, and in the WPGGT they are cut by c. 2930 Ma D_5 structures.

D_5 (c. 2930 Ma)

The easterly to north-northwesterly striking Maitland Shear Zone truncates D_4 folds on DAMPIER (Hickman, 2001). A parallel tectonic foliation (S_5) is developed in the adjacent greenstones of the Whundo Group and in the Cherratta Granitoid Complex, for example, in scapolite-bearing calc-silicate schist (*Alas*) and quartz–feldspar rock (*Alf*) 3 km north of Elizabeth Hill. Shearing of the western margin of the Maitland Intrusion suggests either that this intrusion is older than the indicated 2925 Ma age of the Munni Munni Intrusion, or that movement on the MSZ also occurred after 2925 Ma, possibly related to D_6.

D_6 (c. 2920 Ma)

In the northern part of the WPGGT, the latest movement on the SSZ was dextral and accounted for 30–40 km of displacement of the Whim Creek greenstone belt (Smithies, 1998a; Hickman, 2001). As noted above (see **D_5 (c. 2930 Ma)**), the MSZ may have been reactivated during this event, but otherwise there are no visible D_6 structures on PINDERI HILLS. Emplacement of the mafic–ultramafic intrusions of the WPGGT at c. 2925 Ma was

probably controlled by northeasterly striking faults of the Central Pilbara Tectonic Zone (see **Mafic–ultramafic intrusions of the Pilbara Supergroup**), but it is unclear if this was also related to the northwest–southeast compression of D_6.

Metamorphism of the West Pilbara Granite–Greenstone Terrane

Greenstone xenoliths within the Cherratta Granitoid Complex and greenstones of the Whundo Group immediately north of the Maitland Shear Zone have been metamorphosed to amphibolite facies, but most of the Whundo Group has been metamorphosed to greenschist facies. Granitoids of the Cherratta Granitoid Complex show evidence of retrogression from amphibolite facies.

Hamersley Basin

The Hamersley Basin is a late Archaean to early Palaeoproterozoic tectonic unit that unconformably overlies the WPGGT and other terranes of the Pilbara Craton. The lithostratigraphy of the Hamersley Basin consists of three groups that together make up the Mount Bruce Supergroup. Only the oldest group of this succession, the Fortescue Group, is preserved on PINDERI HILLS.

Fortescue Group

The Fortescue Group is the oldest of the three groups in the late Archaean to early Palaeoproterozoic Hamersley Basin. Collectively, these groups constitute the Mount Bruce Supergroup, a succession of volcanic and sedimentary rocks up to 10 km thick that covers an area of about 100 000 km^2 (Trendall, 1990). The Mount Bruce Supergroup occupies about 65% of the Pilbara Craton, and unconformably overlies the granite–greenstone terranes. The age of the dominantly volcanic Fortescue Group is c. 2770–2630 Ma (Arndt et al., 1991; Nelson et al., 1992; Wingate, 1999). On PINDERI HILLS, all rocks in the Fortescue Group are metamorphosed to prehnite–pumpellyite facies (Smith et al. 1982). The contact between the Fortescue Group and the granite–greenstones is an angular unconformity. A polymictic conglomerate, containing subrounded clasts derived from the underlying granite-greenstones, locally marks the base of the Fortescue Group, but is generally too thin and irregular to be represented at map scale.

The Fortescue Group on PINDERI HILLS comprises a mixed assemblage of mafic to felsic volcanic and sedimentary rocks and is subdivided into the Mount Roe Basalt and the Hardey, Kylena, Tumbiana, and Maddina Formations. The volcanic rocks of the Mount Roe Basalt – Hardey Formation succession at the base of the Fortescue Group are bimodal (Arndt et al., 1991), whereas volcanic rocks within the Kylena, Tumbiana, and Maddina Formations represent four separate phases of mafic to felsic volcanism and exhibit mixed calc-alkaline and tholeiitic affinities (Kojan and Hickman, 1998).

Blake (1993) and Thorne and Trendall (2001) discussed the regional stratigraphy and tectonic evolution of the Fortescue Group. An important feature is the extent to which regional faults controlled the locations of depositional basins. Blake (1993) emphasized this by pointing out that deposition of the lower part of the Fortescue Group took place in several north-northeasterly trending rifts formed by west-northwest – east-southeast extension. Some of the faults were pre-Fortescue Group structures that were reactivated at about 2770 Ma. GSWA mapping in the west Pilbara has provided additional evidence in support of fault-controlled deposition for the Mount Roe Basalt and the Hardey Formation (Hickman, 2002; Strong et al., in prep.).

Arndt et al. (2001) attributed Fortescue Group volcanism to melting of the lithosphere above three successive mantle plumes. However, Thorne and Trendall (2001) argued against the Fortescue Group being a plume-related continental flood basalt province, partly on the basis of its lithological diversity and partly on the duration of deposition (approximately 140 million years).

Mount Roe Basalt (AFr, AFrc, AFrs, AFrb, AFrf)

On PINDERI HILLS, undivided rocks of the Mount Roe Basalt principally comprise flows of massive, vesicular, and glomeroporphyritic basalt (*AFr*). The formation is almost entirely restricted to northwestern PINDERI HILLS, although it is also thinly developed in the extreme northeastern area of the sheet, south of East Well. In thin section, vesicular basalt typically contains rare, squat subhedral phenocrysts of plagioclase and clinopyroxene, and vesicles filled by quartz and calcite, in a groundmass rich in plagioclase laths, with interstitial chlorite and epidote (after mafic phases and glass). The glomeroporphyritic rocks differ from the vesicular variety only in that they contain abundant clots of plagioclase, up to 2 cm in size. Both the vesicular and glomeroporphyritic basalt show local development of pillows. Some outcrops of basalt show extensive brecciation and development of hyaloclastite that, together with the presence of pillowed basalt, indicates deposition in a subaerial to shallow-marine environment.

Sedimentary rocks in the formation include polymictic conglomerate interbedded with sandstone (*AFrc*) southeast of East Well, and interbedded tuffaceous sandstone, siltstone, shale, and conglomerate (*AFrs*) northwest of Moondle Hill. At both localities these clastic units immediately overlie the unconformity at the base of the formation.

Basaltic breccia (*AFrb*) and andesite and dacite (*AFrf*) constitute thin units at or close to the top of the formation west of the Yanyare River.

Hardey Formation (AFh, AFhc, AFhx, AFhs, AFhj, AFhy, AFhyh)

The Hardey Formation (*AFh*) conformably overlies the Mount Roe Basalt in northwestern and northeastern PINDERI HILLS, and elsewhere unconformably overlies the WPGGT. The lower part of the formation is mainly

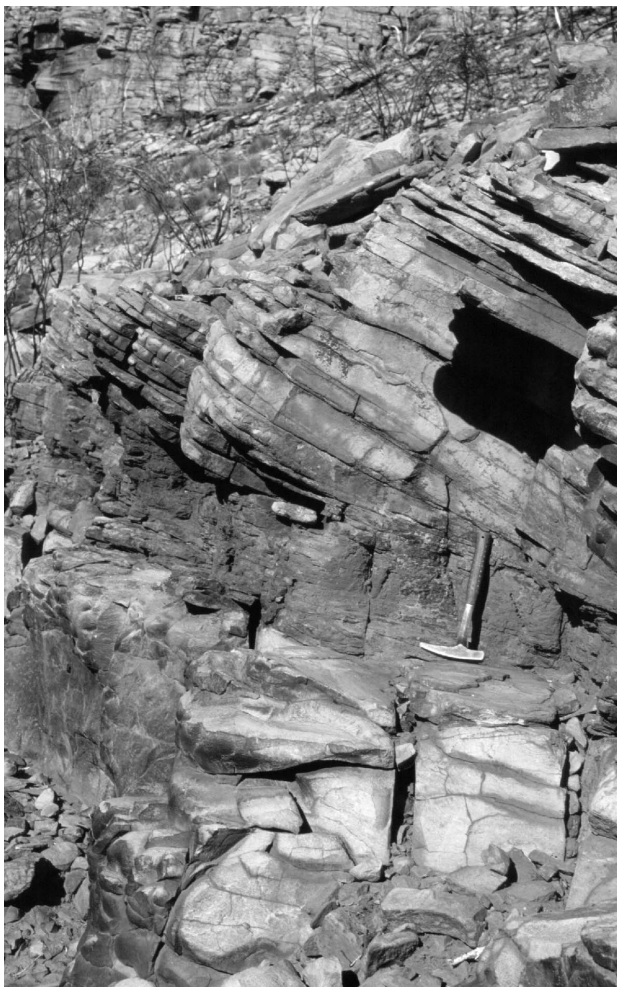

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Figure 8. Cross-bedded sandstone of the Hardey Formation close to the unconformity with underlying granitoid of the Cherratta Granitoid Complex (MGA 447700E 7657800N)

composed of poorly to moderately sorted, medium- to coarse-grained sandstone, conglomerate, siltstone, shale, and tuff (*AFh*). Cross-bedding is locally well preserved (Fig. 8), and Thorne and Trendall (2001) recorded southerly directed palaeocurrents in the area around Yannery Hill mine.

At the base of the Hardey Formation, there are locally lenticular units of polymictic conglomerate (*AFhc*), including boulders of vesicular and glomeroporphyritic basalt that establish erosion of the underlying Mount Roe Basalt. About 6.5 km south of Whundo, the base of the Hardey Formation contains tuff, tuffaceous sandstone, and minor conglomerate (*AFhx*); this unit is also present southeast of Whundo, but is generally too thin to show at the scale of the map.

Medium- to coarse-grained, poorly sorted sandstone, siltstone, and minor shale and conglomerate (*AFhs*) is an important component of the Hardey Formation east and southeast of Whundo. In the same area, the formation includes the Coolajacka Member (*AFhj*) comprising fine-grained ultramafic lava. This member is intruded by the Cooya Pooya Dolerite (*AFdc*), and both units form dark-brown to black hilly outcrops. The Coolajacka Member is a fine-grained, silicified, pyroxene-rich, and commonly olivine-bearing rock with quartz xenocrysts. The quartz xenocrysts were derived from sandstone of the Hardey Formation. This fine-grained, silica-contaminated ultramafic rock is intruded by dykes and sills of Cooya Pooya Dolerite (*AFdc*), and clasts of ultramafic rock from the Coolajacka Member are recorded from overlying beds of the Lyre Creek Member on Cooya Pooya (Hickman, in prep. a).

The upper part of the Hardey Formation includes the Lyre Creek Member (*AFhy*), comprising felsic tuff and agglomerate, and volcaniclastic sandstone and local conglomerate containing clasts of rhyolitic to andesitic composition. Good exposures of the Lyre Creek Member are provided by railway cuttings along the Robe River Railway (Fig. 9). The Lyre Creek Member locally includes hornfelsed felsic volcanic and sedimentary rock (*AFhyh*).

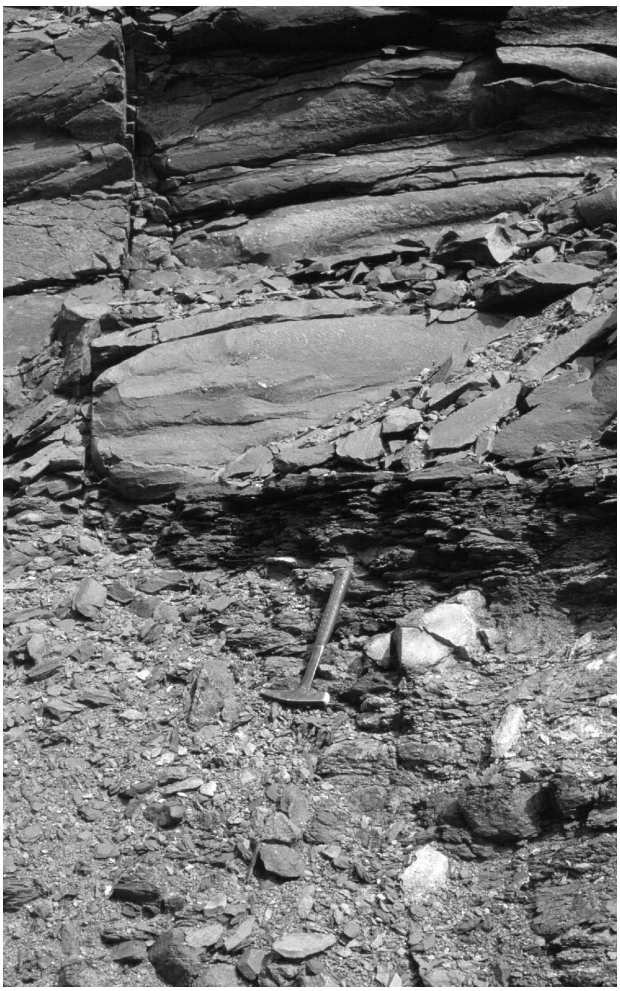

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Figure 9. Massive volcaniclastic sandstone of the Lyre Creek Member, Hardey Formation, overlying weathered and altered basalt exposed in a railway cutting (MGA 498400E 7649700N)

Arndt et al. (1991) noted that the Lyre Creek Member stratigraphically overlies the Mount Roe Basalt, and dated widely separated samples of the latter at 2775 ± 10 and 2763 ± 13 Ma. However, their attempt to directly date the depositional age of the Lyre Creek Member was unsuccessful, with only clastic zircons ranging in age from c. 3240–2940 Ma being recorded. These zircon grains were probably derived during eruption through unconformably underlying units such as the c. 3240–2940 Ma Cherratta Granitoid Complex and the c. 3130–3115 Ma Whundo Group.

Kylena Formation (AFk, AFkf)

The Kylena Formation (*AFk*) is a succession of fine-grained massive and amygdaloidal basalt, basaltic andesite, and dacite, with local high-Mg basalt, high-Mg andesite (not distinguished on the map), and rhyolite flows. Thorne and Trendall (2001) provided a comprehensive description of the formation, including its volcanic facies and petrography. On Pinderi Hills, the thickness of the formation ranges from 300 to 520 m.

Individual volcanic units have been mapped and interpreted using a combination of petrography, whole-rock geochemistry, and gamma-ray spectrometric images (Kojan and Hickman, 1998). These detailed investigations confirm a previous observation (Meakins, 1990) that many rocks classified as basaltic andesite on the basis of silica content are in reality silicificied basalts. Such rocks exhibit typical basalt mineralogy (Radke, 1997), plot as basalt on Jensen diagrams, and contain typical basalt values for Ni, Cr, and V. However, the trace element geochemistry of the rocks mapped as andesite, dacite, and rhyolite cannot be explained by secondary alteration (Kojan and Hickman, 1998). Figure 10 shows vertical geochemical variations in the Kylena and Maddina Formations (Kojan and Hickman, 1998). In the Kylena Formation, upward increases in SiO_2, K_2O, and Th, combined with decreases in FeO, MgO, and Cr, reveal a vertical change from mafic to felsic rocks.

On Pinderi Hills, the upper part of the formation is composed of andesite and dacite, with minor basalt, dolerite, and rhyolite (*AFkf*). This felsic unit is clearly identified on regional gamma-ray spectrometric images on account of the elevated concentrations of potassium, uranium, and thorium. The distribution of radioactive elements is controlled by stratigraphy, which indicates that the gamma-ray spectrometric images closely define primary vertical geochemical variations (Kojan and Hickman, 1998). Some felsic volcanic rocks display distinctive spherulitic textures visible in hand specimen. A railway cutting on the Robe River Railway contains good exposures of the contact between the rhyolite and overlying volcaniclastic sandstone (*AFtsv*) of the Tumbiana Formation (Fig. 11).

Cooya Pooya Dolerite (AFdc)

The Cooya Pooya Dolerite (*AFdc*) is a fine- to medium-grained plagioclase-rich and biotite-bearing dolerite sill. The intrusion is of regional extent, extending from Armstrong Creek to western Mount Wohler, a distance of 130 km. Across this area the sill transgresses and splits into several sheets, so that in places it occurs in the lower part of the Hardey Formation, but elsewhere it locally intrudes the Kylena Formation (*AFk*), as at Black Rock Pool (Fig. 12). Observations on Cooya Pooya (Hickman, in prep. a) indicate that the Cooya Pooya Dolerite and the Kylena Formation are the same age, the dolerite sill being one of the feeders to the lower basaltic lavas of the Kylena Formation.

Tumbiana Formation (AFt, AFtb, AFtsv, AFtc, AFtss, AFtt, AFtsl)

Thorne and Trendall (2001) stated that the Kylena and Tumbiana Formations are conformable in the northwestern Pilbara, but on Cooya Pooya there is an angular unconformity at this contact, and erosion of the Kylena Formation has locally resulted in the Tumbiana Formation directly overlying the Hardey Formation (Hickman, in prep. a). Structural evidence on Pinderi Hills (see **D_{10} (c. 2770–2700 Ma)**) also suggests deformation of the Kylena Formation prior to deposition of the Tumbiana Formation.

The Tumbiana Formation outcrops along the northern slopes of the Chichester Range, and is a distinctive formation in the field and on aerial photographs due to a closely interbedded sandstone, siltstone, basaltic to andesitic tuff, and stromatolitic limestone and dolomite. Thorne and Trendall (2001) provided a detailed description of the various sedimentary and volcanic facies that make up the formation, and interpreted these to include coastal and nearshore shelf sediments (sandstone, siltstone, and carbonate rocks), offshore shelf sediments (black argillite), and subaerial basalt and tuff.

On Pinderi Hills, the Tumbiana Formation is 190–250 m thick, and is divided into lower and upper lithological assemblages of approximately equal thickness. In the Fortescue River – Booyeema Creek area of southwestern Pinderi Hills, a thin unit of generally highly altered basalt (*AFtb*), previously included in the Kylena Basalt by Williams (1968), outcrops at the base of the formation. This basalt is now assigned to the Tumbiana Formation because it is interpreted to mark the beginning of a mafic–felsic cycle overlying the Kylena Formation. Elsewhere, the base of the formation consists of volcaniclastic sandstone with minor tuff and carbonate rocks (*AFtsv*), or dark-grey siliceous stromatolitic dolomite and limestone beds within carbonate-rich tuff, mudstone, and siltstone (*AFtc*). This stromatolitic unit is correlated with the Meentheena Member of the east Pilbara (Awramik and Buchheim, 2001), although the Meentheena Member of the east Pilbara contains more carbonate rocks. Stromatolitic beds constitute only a minor part of the succession; however, where exposed, these typically form small but prominent dark-brown to black escarpments between recessive fine-grained clastic sedimentary rocks. Awramik and Buchheim (2001) interpreted the Meentheena Member as a lacustrine deposit, and commented that it represents one of the most laterally extensive ancient lakes, or lake systems, known.

Volcaniclastic sandstone (*AFtsv*) at the base of the Tumbiana Formation in the headwaters of Munni Munni

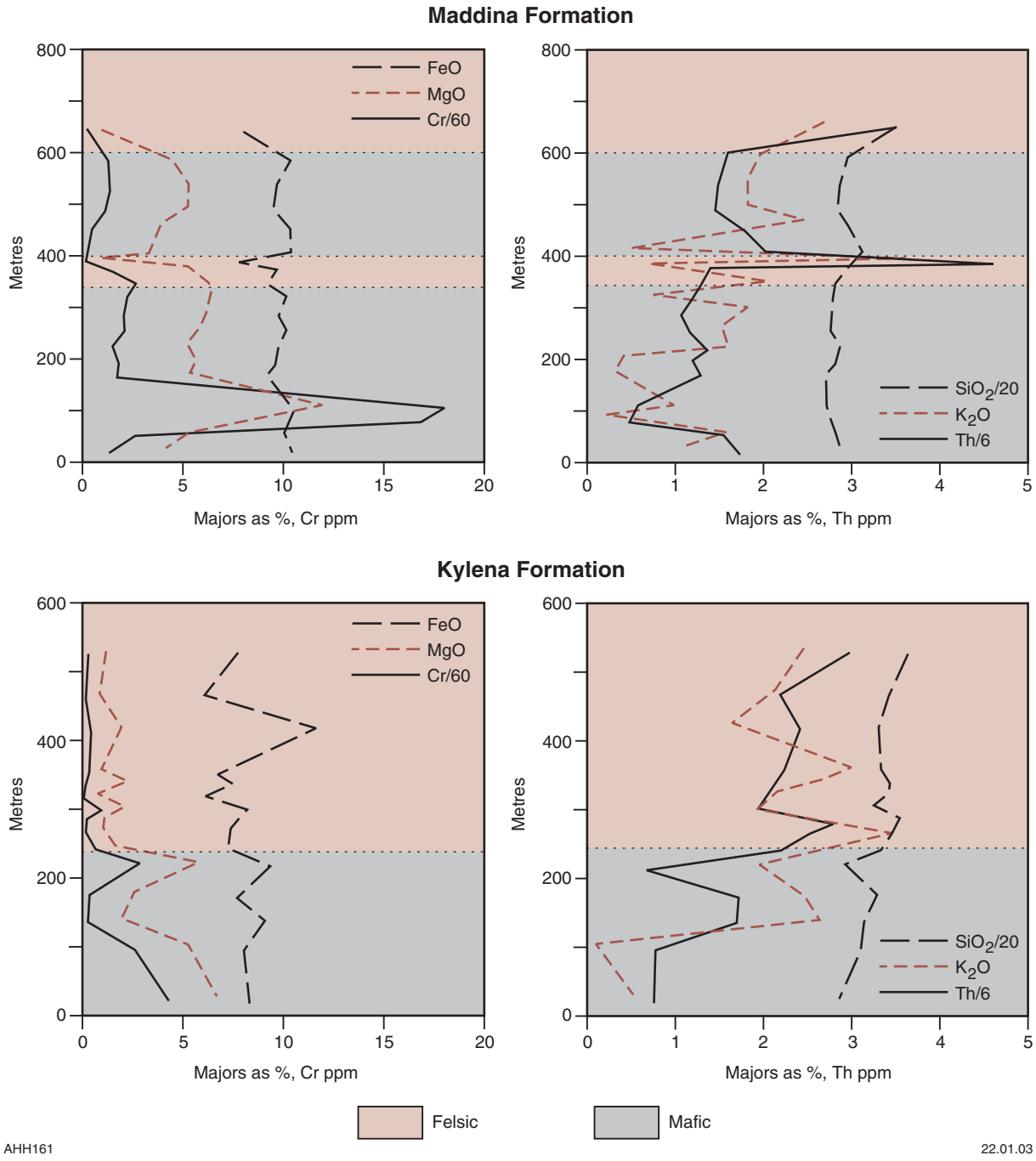
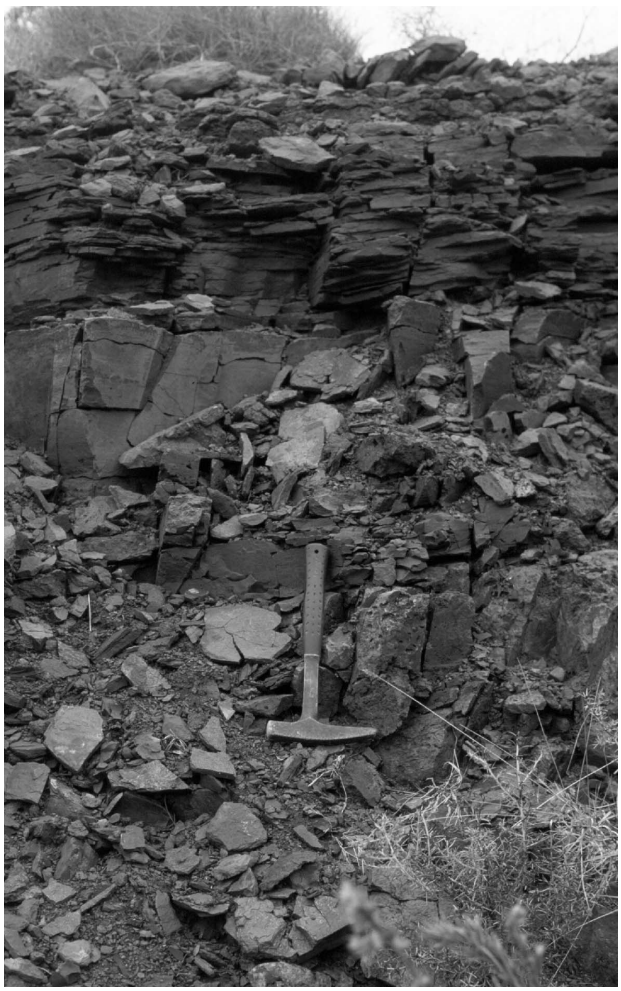


Figure 10. Vertical variations in FeO, MgO, Cr, SiO_2, K_2O, and Th content within the Maddina and Kylena Formations on Pinderi Hills (after Kojan and Hickman, 1998)

Creek (MGA 447000E 7664500N) contains lithic clasts of dacite that are interpreted to have been derived by erosion of the underlying Kylena Formation.

The upper part of the formation is composed of a basal sandstone–siltstone unit (*AFtss*) that is overlain by a thick unit of tuff and tuffaceous siltstone, commonly with accretionary lapilli (*AFtt*). This latter unit contains a far more arenaceous unit of siltstone and tuff (*AFtsl*) and this is locally pyritic. The sandstone–siltstone unit (*AFtss*) in the central part of the Tumbiana Formation is a distinctive stratigraphic marker that extends eastwards across Cooya Pooya (Hickman, in prep. a). A dark-grey (locally black) sandstone–siltstone unit (*AFtss*) forms the uppermost unit of the Tumbiana Formation on Pinderi Hills, and outcrops in the headwaters of Coondinnar Creek (MGA 498500E 7634300N) and other tributaries north of the Portland River on eastern Pinderi Hills. Basalt (*AFtb*) forms the basal unit of the Tumbiana Formation in southwestern Pinderi Hills, but, farther east, a thin and laterally impersistant basalt unit also occurs at the top of the formation.



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Maddina Formation (AFm, AFmm, AFmbi, AFmfi, AFmfr)

The Maddina Formation (*AFm*) is the highest stratigraphic formation of the Fortescue Group that is exposed on PINDERI HILLS, and outcrops in the broad, east-south-easterly plunging Coolbung Hill Syncline (Williams, 1968) in the southern part of the sheet area (Fig. 5). The formation is approximately 740 m thick in sections along and east of the Robe River Railway (Kojan and Hickman, 1998), but Thorne and Trendall (2001) recorded a thickness range to 1100 m at other localities. The Maddina Formation is a succession of volcanic rocks ranging in composition from high-Mg basalt to rhyolite. Its composition is similar to that of the Kylena Formation, but in contrast to the single mafic to felsic cycle of that formation, two such cycles are developed in the Maddina Formation (Kojan and Hickman, 1998). Figure 10 shows vertical geochemical variations in the Kylena and Maddina Formations (Kojan and Hickman, 1998). Vertical trends in the Maddina Formation are less marked than in the Kylena Formation, but three important features are revealed. Firstly, the unit of high-Mg basalt (Figs 13 and

Figure 11. (left) Rhyolite of the upper Kylena Formation overlain by volcaniclastic sandstone of the lower Tumbiana Formation in a railway cutting (MGA 487200E 7639400N)

Figure 12. (below) Basalt of the Kylena Formation intruded by underlying dolerite of the Cooya Pooya Dolerite at Black Rock Pool (MGA 475900E 7662400N)

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Figure 13. (above) Massive high-Mg basalt of the lower Maddina Formation exposed in a railway cutting (MGA 484700E 7632300N)

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Figure 14. (left) Close-up view at same location as Figure 13, showing massive high-Mg basalt with scattered vesicles of pale-green chlorite (MGA 484700E 7632300N)

14) that is present 100 m above the base of the formation has high contents of MgO and Cr; secondly, felsic rocks at 380 m mark the top of a lower mafic to felsic cycle; and thirdly the top of the formation contains felsic rocks.

On the Roy Hill 1:250 000 sheet, MacLeod and de la Hunty (1966) subdivided the succession currently assigned to the Maddina Formation into three members of the 'Mount Jope Volcanics' (name no longer used), and Hickman (1983) redefined these as formations, from bottom to top, as the 'Nymerina Basalt', the 'Kuruna Siltstone', and the 'Maddina Basalt'. As noted above (see **Fortescue Group**), separation of the Nymerina and Maddina Basalts was subsequently found to be difficult in areas of the Hamersley Basin where the intervening Kuruna Siltstone is absent. Consequently, Thorne and Tyler (1997a) redefined the Maddina Basalt to include all rocks previously assigned to the Kuruna Siltstone and the Nymerina Basalt, and the latter name ceased to be applied. However, recognition of the two volcanic cycles on Pinderi Hills indicates that more detailed regional mapping of the upper Fortescue Group, including the application of data from remote sensing techniques such as airborne gamma-ray spectrometry, could again require division of the Maddina Formation into two volcanic formations, even where the 'Kuruna Siltstone' (currently Kuruna Member) is absent. On Pinderi Hills, such a

separation would be at the boundary between felsic (*AFmfr* and *AFmfi*) and dominantly mafic (*AFm* and *AFmbi*) units south of the Portland River. The U–Pb zircon date of 2717 ± 2 Ma (Nelson, 1998, p. 133–135) obtained on the Maddina Formation was obtained on dacite from the top of the lower cycle at Booloomba Pool. The upper cycle has not been dated, but Arndt et al. (1991) dated the overlying Jeerinah Formation, 25 km west of PINDERI HILLS, at 2684 ± 6 Ma.

Much of the Maddina Formation outcrop on PINDERI HILLS is predominantly composed of massive flows of basalt, local vesicular and amygdaloidal basalt, and minor andesite, dacite, and rhyolite (*AFm*). Where field observations, petrography, geochemistry, and gamma-ray spectrometric data indicate andesitic to dacitic volcanic units, these are shown on the map. Basaltic andesite with minor basalt and andesite (*AFmbi*) forms thick sequences of flows in the central part of the lower cycle and the lower part of the upper cycle. The petrography and whole-rock geochemistry of both basalt and basaltic andesite, and associated metasomatized and altered variants, is very similar to the corresponding lithologies mapped and sampled from the Kylena Formation. Vesicles and amygdales, together with carbonate alteration, are less prevalent than in the Kylena Formation, where sericite alteration is more abundant (Radke, 1997). The lower Maddina Formation includes a thin lenticular unit of high-Mg basalt (*AFmm*) that contains chloritized mafic phenocrysts in a matrix of plagioclase and clinopyroxene. Sericite alteration of plagioclase is generally best developed marginal to chlorite-filled vesicles (Radke, 1997). Samples of this rock plot in the komatiite field on a Jensen plot (Kojan and Hickman, 1998). The high-Mg basalt (*AFmm*) unit is well exposed in a cutting on the Robe River Railway (Figs 13 and 14).

Rhyolite and dacite (*AFmfr*) and andesite and dacite (*AFmfi*) comprise the uppermost units of the lower and upper cycles of the Maddina Formation. Both the dacite and rhyolite are massive pale-grey rocks. Dacite and rhyolite of the lower Maddina Formation form a continuous outcrop from south of Booloomba Pool northwards and eastwards along both sides of the Portland River. The rhyolite unit (*AFmfr*) locally forms prominent cliffs with massive columnar jointing, as for example at Booloomba Pool where the dated sample (GSWA 144993, incorrectly shown as 144992 on the PINDERI HILLS map) was collected. The dacite here comprises mainly potash feldspar and plagioclase, and has a granophyric and tridymitic devitrification texture. Biotite crystals have been largely replaced by chlorite. Mild carbonate and sericite alteration is also present (Radke, 1997). Andesite and dacite (*AFmfi*) form low hills on the southern boundary of PINDERI HILLS. The profile of the hills in this area closely coincides with the Hamersley Surface (see **Physiography**), and as a result, the andesite and dacite are extensively leached and locally silicified.

Structure of the Hamersley Basin

The structural geology of the Hamersley Basin on PINDERI HILLS includes open folds, faults, and dykes of various orientations. Some of these structures are probably superimposed on underlying rift structures that were active during deposition of the Mount Roe Basalt and the Hardey Formation (Blake, 1993). On DAMPIER (Hickman, 2001), the earliest examples of the structures that are preserved in the Fortescue Group were assigned to D_{10}, with an age range of 2770–2750 Ma. However, the minimum ages of most of the structures on PINDERI HILLS are unknown because they deform all stratigraphic levels of the Fortescue Group.

Deformation events

D_{10} (c. 2770–2700 Ma)

Blake (1993) recognized a period of west-northwesterly – east-southeasterly crustal extension during deposition of the Mount Roe Basalt and the overlying Hardey Formation. The resulting structures were northeasterly trending normal faults and mafic dykes. Extrusion of flood basalts (Mount Roe Basalt) was followed by the development of extensional intracratonic sedimentary basins (Hardey Formation). The north-northeasterly trending Pinderi Hills dyke (Fig. 5), north of the Munni Munni Intrusion, may be a feeder to the Mount Roe Basalt, but this is uncertain because there are other dolerite dykes of the same orientation that intrude the Fortescue Group to at least the level of the Tumbiana Formation. Pre-Hardey Formation ultramafic–mafic dykes that intrude the c. 2925 Ma Munni Munni Intrusion may be related to extrusion of the Mount Roe Basalt, but these dykes have an easterly trend that is inconsistent with the extension described by Blake (1993). It is possible that these major easterly trending dykes are only slightly younger than the major mafic–ultramafic intrusions.

East–west thickness variations in the Hardey Formation are a notable feature on PINDERI HILLS. The Hardey Formation is relatively thick between the Yanyare Fault (Williams, 1968) and the western margin of the Munni Munni Intrusion, and in a second area east of the Zebra Hill Fault (Fig. 5; Williams, 1968). This suggests east–west variations in basin depth, due either to rifting or to differential erosion of underlying units. The area east of the Zebra Hill Fault contains a thick development of the Hardey Formation as far east as central MOUNT WOHLER, indicating that the Zebra Hill Fault coincides with a D_{10} rift fault, with downthrow to the east. A similar rift fault may have existed on the western side of the Munni Munni Intrusion, approximately along the trend of the Pinderi Hills dyke. The Yanyare Fault separates a northwestern area underlain by 200 m of Mount Roe Basalt (Hickman, 2001) from a southeastern area in which the Hardey Formation unconformably overlies the Cherratta Granitoid Complex without intervening Mount Roe Basalt. This suggests either that at the time of the Mount Roe Basalt deposition the Yanyare Fault coincided with a northwest-facing scarp, or that, following volcanism, upthrow to the southeast led to complete erosion of the basalt prior to deposition of the Hardey Formation. Subsequent south-eastern downthrow took place along the fault, and part of this movement probably occurred during deposition of the Hardey Formation. The northeasterly trending zone of mafic–ultramafic intrusions, including the Munni Munni and Maitland Intrusions, appears to have been a topographic high during deposition of the Hardey

Formation. In southeastern PINDERI HILLS, the deep diamond drillhole MF-1 (CRA Exploration Pty Ltd, 1987), 3 km north-northeast of Cooribin Pool, intersected an approximately 1000 m succession of the Hardey Formation concealed by the Maddina, Tumbiana, and Kylena Formations. This succession is far thicker than that of the Hardey Formation exposed in central-eastern PINDERI HILLS, and is here interpreted to have been deposited in a rift-controlled basin south of the Portland Fault (see the diagrammatic section A–B on the PINDERI HILLS map).

East of PINDERI HILLS, on COOYA POOYA, GSWA mapping (Hickman, in prep. a) has identified north-northeasterly trending open folds that deform the Kylena Formation but pre-date the Tumbiana Formation; this results in an angular unconformity between these formations. On PINDERI HILLS, northeasterly trending open folds are well developed in the lower part of the Fortescue Group (Kylena Formation downwards), whereas the main trend of folds in the Tumbiana Formation and higher stratigraphic units is northwesterly. The northeasterly trending folds are here interpreted to relate to the D_{10} rift system, whereas the northwesterly trending folds (D_{11}) post-date the Tumbiana Formation. However, centroclines that resulted from $D_{10} - D_{11}$ interference around the headwaters of Booyeema Creek suggest some continuation of folding on D_{10} trends after 2720 Ma.

D_{11} (1830–1780 Ma)

D_{11} (not equivalent to D_{11} on DAMPIER; Hickman, 2001) chiefly involved open folding of the Fortescue Group about northwesterly trending axes, and is restricted to southern PINDERI HILLS. The Coolbung Hill Syncline (Williams, 1968) is the major D_{11} structure of this area, and to the south of PINDERI HILLS deforms the lower part of the Hamersley Group (Williams et al., 1968). D_{11} folds are interpreted to belong to the 1830–1780 Ma Capricorn Orogeny (Occhipinti et al., 2001), based on a similar trend to structures of this generation in the Hamersley Range (Thorne and Tyler, 1997b). Visible deformation along the Portland Fault is also considered to be of this age. On regional gravity data and drilling 2.5 km west-southwest of Recorder Pool, the exposed fault is interpreted to overlie an earlier pre- or syn-Hardey Formation fault (see the diagrammatic sections on the PINDERI HILLS map). Northwesterly to northerly trending dolerite dykes in southern PINDERI HILLS are correlated with D_5 dykes in the MOUNT BRUCE 1:250 000 sheet area that Thorne et al. (1996) interpreted to be younger than 1840 Ma. East-northeasterly trending dolerite dykes on PINDERI HILLS are correlated with the Mundine Well Suite of Hickman and Lipple (1975) that Wingate and Giddings (2000) dated at 755 Ma.

Archaean–Proterozoic intrusions

Minor intrusions (d, dx, q, g)

Massive, medium- to coarse-grained dolerites (*d*) of uncertain, and varying, ages form dykes across most of PINDERI HILLS. Most dykes strike northeasterly, but D_{11} (see **Deformation events**) northwesterly and northerly striking dykes are also present (see above). Some east-striking dolerite dykes east of Munni Munni Creek and in northwestern PINDERI HILLS may include pre-Fortescue Group intrusions, but are younger than the c. 2925 Ma Munni Munni Intrusion. In areas of Cainozoic cover, the dykes are recognizable as aeromagnetic lineaments. Easterly trending pyroxenite and pyroxene-rich dolerite dykes (*dx*) intrude the Maitland Intrusion, and may be related to composite pyroxenite (*Aux*), gabbro (*Aog*), and dolerite (*Aod*) dykes south and east of the Munni Munni Intrusion. Numerous dykes and veins of granite (*g*) intrude the Munni Munni Intrusion, and Nelson (1998, p. 90–92) dated one of these at 2924 Ma. Quartz veins (*q*) of unknown age outcrop in many parts of PINDERI HILLS. Quartz veins typically intrude faults and are up to 20 m thick, but are lenticular along strike.

Cainozoic rocks

Cainozoic deposits cover about 20% of PINDERI HILLS. Two general ages of Cainozoic units are present: older clastic and chemical deposits that have been eroded by the present drainage system, and recent alluvial, colluvial, eluvial, and eolian deposits that are still in the process of formation. The older Cainozoic deposits are associated with previous palaeosurfaces such as the Hamersley Surface (Campana et al., 1964), and the Peawah, Millstream, and Yule Surfaces (Kriewaldt and Ryan, 1967). The age of the Hamersley Surface is imprecisely defined, and this surface probably developed following separation of Australia from Gondwana, and reached maturity between the Late Cretaceous and the Palaeocene (Cockbain and Hocking, 1990). Cockbain and Hocking (1990) concluded that the extensive deposits of calcrete and silcrete associated with the major palaeodrainages of Western Australia are primarily Eocene. Thus, ferricrete (*Czrf*) and silicified saprolite (*Czrw*) associated with the Hamersley Surface on PINDERI HILLS are here interpreted to be mainly Eocene.

Cockbain and Hocking (1990) recorded four stages of climatic evolution during the Cainozoic, and these were accompanied by fluctuations in sea level. Dissection of the Hamersley Surface related to marine regressions resulted in Miocene to early Pleistocene land surfaces, with extensive valley-fill deposits such as partly consolidated colluvium (*Czc*) and alluvial calcrete (*Czak*).

Eocene to Early Pleistocene

Clastic and chemical deposits (Czag, Czak, Czc, Czcb, Czck, Czrb, Czrf, Czrk, Czrw)

Eocene to early Pleistocene clastic and chemical deposits have been eroded by the present drainage system. Dissected deposits of Cainozoic alluvial gravel deposits (*Czag)* are exposed in beds up to 5 m thick in the banks of larger drainages. These old alluvial deposits are a concealed part of the regolith in the coastal plain, and have locally been used as a source of gravel for road construction. Alluvial calcrete (*Czak*) is distributed along

drainages, particularly where these contain alluvium derived from mafic or ultramafic units. Dissected colluvium (*Czc*) is locally divided into colluvium with a gilgai surface (*Czcb*) overlying basaltic units on the plateau of the Chichester Range, and calcrete on colluvium derived from ultramafic rocks (*Czck*), as is present along the northwestern margin of the Munni Munni Intrusion. The colluvium with a gilgai surface (*Czcb*) forms large, flat expanses of clay soil on high, poorly drained areas of the Hamersley Surface (see **Physiography**), and includes residual material derived from the chemical weathering of adjacent basalt, particularly above the Maddina Formation.

Four dissected Cainozoic residual units are mapped on PINDERI HILLS. On the Kylena Formation, south and southwest of the Munni Munni Intrusion, hill tops are locally capped by residual clay (deeply weathered basalt and andesite) containing rock fragments (*Czrb*). Being of similar composition to colluvium with a gilgai surface (*Czcb*), this unit also includes gilgai. Outcrops of residual ferricrete and ferruginous duricrust (*Czrf*) are locally preserved along the watershed between the Maitland and Fortescue river catchments, and are remnants of the Hamersley Surface (see **Physiography**). A closely related unit, saprolite (*Czrw*) developed immediately beneath the Hamersley Surface, is composed of deeply weathered and variably silicified andesitic to dacitic volcanic rock. Outcrops of this unit are widespread in southeastern PINDERI HILLS, but are also mapped around the headwaters of Armstrong and Booyeema creeks. Residual calcrete, consisting of massive, nodular, and cavernous limestone (*Czrk*), overlies amphibolite (*Aba*) and hornblende- and biotite-rich monzogranite (*AgCmh*) west of the old Cherratta Homestead. Residual calcrete (*Czrk*) is also developed on other granitoids of the Cherratta Granitoid Complex, typically between drainages and in the vicinity of dolerite dykes. The distinction between residual calcrete (*Czrk*) and alluvial calcrete (*Czak*) can be difficult, particularly in areas mapped by photointerpretation.

Recent deposits

Alluvial, colluvial, eluvial, and eolian deposits (Qaa, Qac, Qao, Qab, Qw, Qwb, Qc, Qcb, Qcd, Qrg, and Qs)

Present-day drainage systems contain alluvial clay, silt, and sand in channels on floodplains, and sand and gravel in rivers and creeks (*Qaa*). Alluvial clay, silt, and sand forms overbank deposits on floodplains (*Qao*), and locally includes brown soil and expansive clay or 'gilgai' (*Qab*) where the floodplain deposits include a substantial amount of clastic material derived from mafic or ultramafic sources. In wet weather such areas are generally impassible by vehicle, and in dry weather the surface of the ground is broken by expansion crevices and depressions known as 'crabholes'.

In areas immediately adjacent to rivers, alluvial floodplains also include small, abundant, scattered lacustrine or claypan deposits (*Qac*) consisting of clay, silt, and evaporite in shallow depressions. These deposits form where floodwaters have temporarily ponded before evaporating, or where local heavy rain has resulted in small playa systems.

Sheetwash, including sand, silt, and clay (*Qw*), is deposited on distal outwash fans and includes some gilgai (*Qwb*). Colluvium (*Qc*) is a widespread unit on PINDERI HILLS, occurring on scree slopes and in deposits of coarse, pebbly sand fringing the hills. Whereas colluvial fans commonly exhibit a well-defined radial drainage system of small gullies that originate from adjacent hills, the lower slopes (typically 0–5°) of the sheetwash fans do not have well-developed discrete drainage lines. Clay and silt within the sheetwash deposits commonly occupy claypans or areas that are temporary shallow lakes after periods of flooding. The composition of colluvial units depends on the lithology of source rocks in the adjacent hills. Where the colluvium is adjacent to dolerite units (*AFdc* or *d*), and therefore composed entirely of dolerite fragments, it is mapped as *Qcd*, for example 10 km south-southwest of Weelarra Hill.

Eluvial sand over granitoid rocks (*Qrg*) is a quartzo-feldspathic residual deposit derived from underlying granitoid bedrock or nearby outcrops. In northwestern PINDERI HILLS, between Beedina Hill and Yanyare River, sheets of eolian sand (*Qs*) have been deposited by reworking of local quartzofeldspathic residual sand (*Qrg*).

Economic geology

Some of the earliest mineral discoveries in Western Australia were made in the west Pilbara. In 1872, copper and lead were discovered southwest of Roebourne, and in 1877 auriferous quartz veins were discovered west of Roebourne (Maitland, 1909). Between 1911 and 1913, copper was found at Whundo and Yannery Hill on PINDERI HILLS, and these deposits were subsequently mined. More recently, PGE mineralization has been discovered in the Munni Munni Intrusion, and trial mining of high-grade silver mineralization has taken place at Elizabeth Hill. The distribution and geology of metallic mineral deposits in the west Pilbara has been summarized by Ruddock (1999).

Gold

Several small abandoned gold workings were visited during mapping of PINDERI HILLS, but no gold production has been officially recorded. Partly collapsed shafts about 3.5 km south of Whundo are based on mineralized shears through amphibolite-facies mafic and ultramafic rocks of the Nallana Formation, the basal formation of the Whundo Group. Minor malachite is present in the workings and adjacent waste dumps, but the primary target of some of the old mines was probably gold. Another gold prospect is located close to the northeastern corner of the sheet area near East Well. Ruddock (1999) described the East Well mineralization as consisting of gold and pyrite in quartz veins through sheared and altered metagabbro. Ruddock (1999) also referred to old alluvial gold workings about 2 km south of Whundo, and suggested that the gold may have been derived from erosion of basal sections of the nearby Hardey Formation, which elsewhere contains local placer deposits. The alluvial workings south of Whundo

were not inspected during the PINDERI HILLS mapping. Diamond drillhole MF–1 (CRA Exploration Pty Ltd, 1987) intersected placer gold mineralization in concealed Hardey Formation, 3 km north-northeast of Cooribin Pool, but gold contents were not considered high enough to merit further exploration.

Silver

In 1987, AGIP Australia Limited discovered high-grade silver mineralization in the northern part of the Munni Munni Intrusion, close to the northerly trending Munni Munni Fault. In 1996, East Coast Minerals and Legend Mining carried out drilling, and trial mining commenced in April 1999.

The Elizabeth Hill silver deposit is located where the southerly dipping contact between the Munni Munni Intrusion and granitoids of the Cherratta Granitoid Complex is intersected by the northerly trending Munni Munni Fault. Previous descriptions of the deposit have been provided by Barnes (1995), Ferguson (1999), and Marshall (2000). The mineralization is in a series of southerly plunging pods or shoots within the shear system of the Munni Munni Fault. This fault locally intersects stratiform Cu–Ni–PGE in basal pyroxenite of the Munni Munni Intrusion, with the result that base metals are also present in the deposit. Marshall (2000) described the deposit as a 10–15 m-wide, near-vertical vein system, with shoots that plunge shallowly to the south. The veins consist of carbonate–quartz breccia with clasts predominantly of pyroxenite, and lesser granitoid rocks. Silver occurs as native silver in veinlets, sheets, crystals, globules and dendrites, and as Ag sulfides and sulfosalts associated with base metal sulfides within a coarse-grained calcite vein stockwork. The selvages of the shoots include anastomozing quartz–carbonate and sulfide veins and stringers in silicified, carbonatized, and chloritized country rock. Marshall (2000) concluded that the geometry of the vein structure and textures in the deposit indicate that Elizabeth Hill is primarily a hydrothermal carbonate–quartz vein system typical of deposition in a low-pressure and low- to moderate-temperature regime. The age of the silver mineralization is later than the 2925 Ma Munni Munni Intrusion, and therefore younger than any dated granitoids in the Cherratta Granitoid Complex. Galena from the deposit has a Pb model age of c. 2868 Ma (Thorpe et al., 1992) that can be interpreted as the maximum age of the mineralization. Tectonothermal events in the northern Pilbara Craton after 2868 Ma are recorded at c. 2850 Ma and c. 2770–2740 Ma. The 2850 Ma event that was associated with intrusion of 'tin granites' in the east Pilbara has not been identified in the west Pilbara, and therefore the Elizabeth Hill silver mineralization was most probably related to hydrothermal activity within the D_{10} rift system (see **D_{10} (2770–1700 Ma)**). Elizabeth Hill is only 2 km east of the Pinderi Hills dyke, which may have intruded one of the major fractures of the rift system. In this situation, the Munni Munni Fault may have been a conduit from the Pinderi Hills fracture, with the Elizabeth Hill mineralization being controlled by the southerly dipping contact of the Munni Munni Intrusion.

Platinum group elements

Donaldson (1974) undertook petrological research on the Munni Munni Intrusion, comparing it with the layered mafic complexes at Skaergaard, Bushveld, and Stillwater. In the early 1980s, Hunter Resources commenced a program of PGE exploration that targeted all known areas of layered mafic intrusions in the west Pilbara. Hunter Resources focused initially on the Munni Munni Intrusion and explored the mafic–ultramafic contact areas using the Bushveld and Stillwater models of PGE mineralization. Investigations by the BMR at Munni Munni commenced in 1983 as part of an assessment of PGE potential in layered mafic intrusions of the west Pilbara (Hoatson et al., 1992; Hoatson, 1994). The study included 1:20 000-scale geological mapping, petrology, whole-rock and mineral geochemistry, geochronology, geophysics, and remote sensing. Hunter Resources located the Munni Munni Reef (or Hunter's Reef) in 1984 by surface sampling and trenching. Follow-up drilling between 1985 and 1988 delineated a subeconomic PGE resource in the central zone of the reef (about 700 m strike length); the reef extends for about 7.5 km along the contact zone. Minor PGE occurrences were also located at Munni Munni South and Judys Reef (also referred to as northeast Munni Munni) close to Elizabeth Hill. Hoatson and Sun (2002) reviewed mineralization in the mafic–ultramafic intrusions of the west Pilbara and described the Munni Munni Intrusion as containing the largest known resource of PGEs in an Australian layered intrusion. They recognized four different styles of PGE mineralization, the most important being within porphyritic websterite at the top of the ultramafic zone (see **Munni Munni Intrusion**). Highest PGE contents are developed at the base of a 5 to 15 m-thick zone of disseminated Cu–Ni sulfides typically within 20 m of the overlying ultramafic rock – gabbro contact. Williams et al. (1990) reported a potential resource of 20 to 30 Mt of ore at a grade of 2.9 ppm Pt + Pd + Au, 0.3% Cu, and 0.2 % Ni. Hoatson and Sun (2002) stated that the PGE layer is typically 2 to 5 m thick, with some drilling intersections being up to 13 m thick. Hoatson and Keays (1989) suggested that the PGE mineralization resulted from crystal fractionation and magma mixing.

Exploration of the Maitland Intrusion has revealed local anomalous concentrations of PGEs and gold, but no mineralization approaching economic grades. The North Whundo Intrusion contains no ultramafic components, and only minor Cu mineralization has been identified at its northern contact with metabasalt of the Whundo Group.

Copper and zinc

Volcanic massive sulfide (VMS) deposits have been mined at Whundo, West Whundo, and Yannery Hill, where mineralization is contained within metamorphosed felsic volcanic and sedimentary rocks of the c. 3120 Ma Tozer Formation of the Whundo Group. Recent reviews of VMS deposits in the west Pilbara have been provided by Barley (1992), Downes et al. (1998), Collins and Marshall (1999), and Ferguson (1999). These deposits formed from hydrothermal fluids (as syngenetic accumulations of

sulfide and sulfate minerals) that were most probably generated by magmatic (subvolcanic) heat sources.

The Whundo mineralization was discovered in 1911, and consists of two deposits 350 m apart, Whundo and West Whundo. There was some early copper production prior to 1920, and in the 1950s cupreous ore was extracted for agricultural use. Between 1964 and 1966, Westfield Minerals (WA) NL undertook further exploration of the Whundo–Yannery area, and during 1970–71 additional drilling was carried out by joint venture partner Consolidated Goldfields. Following a feasibility study in 1975, openpit mining of Whundo by Whim Creek Consolidated NL in 1976 yielded 6200 t of supergene oxide ore at 26.98% Cu. Noranda Australia Limited carried out further exploration (as joint venture partner) in 1982–83 to test for downdip extensions of ore at Whundo, and undertook more drilling in 1989. A drill-indicated resource for Whundo was estimated at 1.16 Mt averaging 2.08% Cu, 1.33% Zn, and 11 g/t Ag. West Whundo resources have been quoted as 2 Mt of sulfides at an average grade of 2% Cu, 1.3% Zn, and 11 g/t Ag (Davies and Blockley, 1990). Following mining, zinc-rich material remains in stockpiles on site, and resources at West Whundo remain undeveloped. Total production from Whundo has been 7358.74 t of copper ore and concentrates, plus 1066.92 t of cupreous ore (Ruddock, 1999).

Stratabound copper–zinc mineralization at Whundo is in chlorite–muscovite–quartz schist near the contact between felsic volcanic rocks of the Tozer Formation and metabasalt of the Nallana Formation. Roberts (1974) recognized three types of sulfide mineralization: layered pyrite, sphalerite, and chalcopyrite; massive pyrite and pyrrhotite, with minor sphalerite and chalcopyrite; and pyrite plus chalcopyrite in veins, layers, and stringers. Supergene and oxidized ore contains malachite, azurite, cuprite, and chalcocite.

The Yannery Hill mine opened in 1913 and 476.76 t of copper ore and concentrates, with an average grade of 42.5% Cu, was produced until 1920. In the 1950s and1960s a total of 1911.8 t of cupreous ore was extracted (Ruddock, 1999). Copper–zinc mineralization at Yannery Hill is hosted by variably pyritic chloritic schist within metamorphosed (greenschist–amphibolite transition facies) volcanogenic sedimentary rocks of the Tozer Formation, Whundo Group. Other local lithologies include quartz–sericite schist and chlorite–quartz–sericite schist with local porphyroblasts of andalusite. Primary Cu–Zn sulfide mineralization appears to have been concentrated in one stratabound unit, 1–3 m thick, that has been extensively folded within the trough of a northwest-plunging syncline. Thickening of the unit in fold cores controlled the geometry of most stopes. Ore minerals are secondary, and include malachite, chalcocite, and cuprite within massive limonite (Marston, 1979). Geological relations to the Whundo copper mine, 900 m to the southwest, are unclear. Mineralization is similar at Yannery Hill and Whundo (Marston, 1979), and both deposits occur in the lower part of the Tozer Formation in the axial region of the Bradley Syncline. Local northerly striking faults may provide a structural connection between the deposits, but poor exposure obscures this. The mineralization and folding at Yannery Hill are abruptly truncated by unconformably overlying c. 2760 Ma sandstone of the Hardey Formation (Fortescue Group).

Small copper deposits have been mined 3.5 km south of Whundo (see **Gold**) and 4 km west of Whundo (Maitland copper mine). The Maitland copper mine (disused) is located in sheared pyroxenite on the northern side of the Maitland Shear Zone. Ruddock (1999) reported historical production as 37.99 t of cupreous ore at an average grade of 8.08% Cu. Marston (1979) provided a brief description of the deposit.

A copper occurrence 14 km southwest of Zebra Hill was recorded during the mapping of PINDERI HILLS. The mineralization is visible as malachite within the Kylena Formation. Other minor copper occurrences were noted in the Maitland and Munni Munni Intrusions, and 4 km southwest of Whundo.

Copper–nickel

During exploration of the Munni Munni Intrusion in 1970–71, AGIP Australia Limited discovered minor Cu–Ni mineralization in the marginal pyroxenite and gabbro of the intrusion at Munni Munni North, at the Cadgerina Dyke deposit, and at Munni Munni South. In 1972, minor copper mineralization was located at North Whundo near the northern margin of the North Whundo Intrusion. More details of these subeconomic deposits have been provided by Marston (1979, 1984), Hoatson et al. (1992), and Ruddock (1999).

Chromium

Minor occurrences of chromite have been noted during exploration for PGE, the most significant being those located north of (structurally below) the porphyritic websterite unit of the Munni Munni Intrusion (Ruddock, 1999). This occurrence is not shown on the map.

Chrysotile asbestos

Seams of chrysotile asbestos in serpentinized peridotite of the Munni Munni Intrusion have been worked on a small scale, but no production figures are available.

Talc

Small occurrences of massive talc were noted in altered ultramafic rocks 4 km southwest of Whundo, and at a locality, not shown on the map, 1 km west of the main PGE prospect in the Munni Munni Intrusion. This talc occurrence lies at the contact between mineralized porphyritic websterite and overlying metagabbro.

Building stone

Well-bedded sandstone of the Hardey Formation has been quarried at two localities (one shown on the map) east of the Yannery Hill mine, and is used for decorative facing

stone and as flagstones. This rock is locally known as ‘Karratha stone’, and has been extensively used in the Karratha–Roebourne area, including the stone entrance gates to Karratha Airport, the entrance to the Karratha Industrial Estate, in bridges and waterfalls in council parks, and in a mural footpath at Roebourne Police Station. Dolerite of the Cooya Pooya Dolerite has been mined for dimension stone at a locality (not identified on the map) 200 m west of the Hamersley Iron Railway (MGA 494770E 7670800N). Both deposits are recorded in the database provided in Ruddock (1999).

Road building and construction materials

Road building and construction materials include river gravels, mostly obtained from localities along the rivers, and colluvium and weathered rock, which are typically available close to wherever gravel roads require maintenance or construction projects exist.

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Appendix

Gazetteer of localities mentioned in the text

Locality	*MGA coordinates*	
	Easting	*Northing*
Armstrong Creek	463000	7672000
Beedina Hill	464800	7674300
Booloomba Pool	475000	7624100
Booyeema Creek	455000	7638000
Brill Pool	468100	7666300
Cadgerina Dyke	480700	7666600
Cadgerina Pool	482000	7668000
Cherratta Homestead (old)	479700	7676400
Cooribin Pool	483300	7624400
East Well[b]	498720	7675850
Elizabeth Hill[a] (prospect)	487000	7667900
Judy's Reef[a] (prospect)	487650	7666750
Karratha Homestead[a]	465800	7691600
Leopold Well	459550	7674600
Mackies Well	483850	7677000
Maitland copper mine	488240	7669050
Moondle Creek	465600	7673000
Moondle Hill	463990	7676450
Munni Munni North[a] (prospect)	486200	7667900
Munni Munni South[a] (prospect)	482100	7654850
North Whundo[a] (prospect)	495500	7678150
Pinderi Hills dyke	484000	7669300
Radio Hill[a] (mine)	486200	7679600
Tarlwa Pool	451700	7632000
Weelarra Hill	465200	7669600
West Whundo (mine)	492000	7668900
Whundo (mine)	492460	7669100
Yannery Hill (mine)	493050	7669750
Yannery Well	489000	7674100
Yathala Hill	467950	7670300
Zebra Hill	483700	7656500

NOTE: (a) outside PINDERI HILLS
(b) incorrectly shown as Last Well on map

PINDERI HILLS

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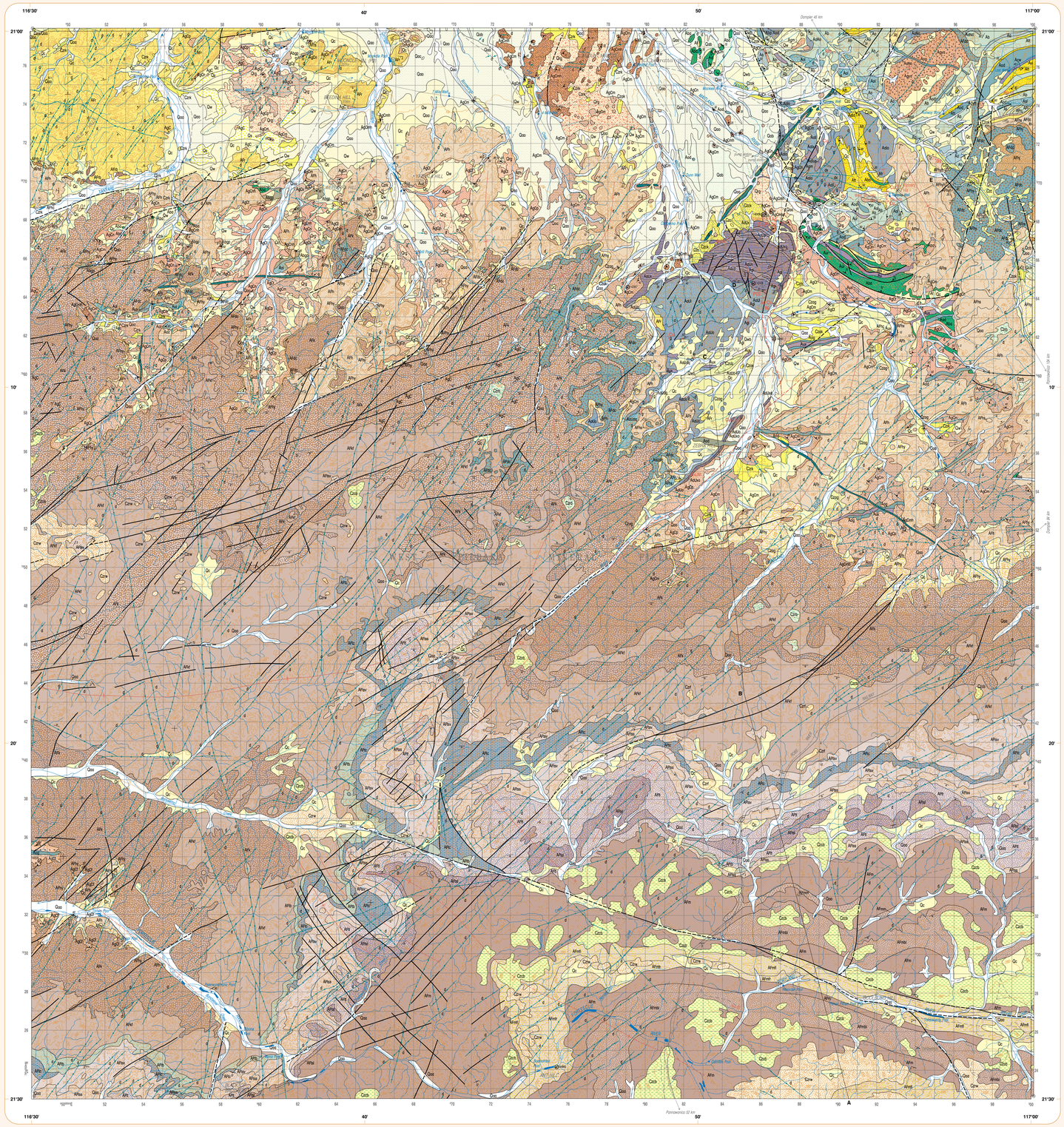
116°30'
40'
50'
117°00'
21°00'
21°30'
20'
10'
Dampier 45 km
Pomoonkurra 52 km
Pomoonkurra 158 km
Dampier 84 km
PORTLAND RIVER
ROBE RIVER RAILWAY
MAITLAND RIVER
Munni Munni Creek
ZEBRA HILL
Maitland Shear Zone
WESTERN HILL
EASTERN HILL
Munni Munni Rock
Munni Munni Pool
Munni Munni Well
Munni Munni Rockhole
Munni Munni Intrusion
Zebra Rock
Zebra Well
Zebra Rockhole
Zebra Pool
Zebra Hill
Zebra Hill Well
Zebra Hill Rockhole
Zebra Hill Pool
Maitland Rockhole
Maitland Pool
Maitland Well
Maitland Intrusion
Maitland River
Maitland Rock
Maitland Hill
Maitland Hill Well
Maitland Hill Rockhole
Maitland Hill Pool
Maitland Hill Intrusion
Maitland Hill Rock
Maitland Hill Creek