EXPLANATORY NOTES

Department of
Mineral and Petroleum Resources

GEOLOGY OF THE ROEBOURNE 1:100 000 SHEET

by A. H. Hickman

1:100 000 GEOLOGICAL SERIES

Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF THE ROEBOURNE 1:100 000 SHEET

by
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Perth 2002

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REFERENCE
The recommended reference for this publication is:
HICKMAN, A. H., 2002, Geology of the Roebourne 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 35p.

National Library of Australia Card Number and ISBN 0 7307 5710 2

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: J. Johnston
Cartography: L. Cosgrove
Desktop publishing: K. Noonan
Printed by Optima Press, Perth, Western Australia

Published 2002 by Geological Survey of Western Australia

Copies available from:
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Cover photograph:
View of the Harding River at Harding Dam, showing the black rocky hills typical of outcrops of the Cooya Pooya Dolerite (MGA 05 10900E 76 80250N)

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by

A. H. Hickman

Abstract

The ROEBOURNE 1:100 000 sheet is located in the northwestern part of the Archaean Pilbara Craton, and covers parts of the West Pilbara Granite–Greenstone Terrane (WPGGT), the Mallina Basin, and northern exposures of the Hamersley Basin.

In the WPGGT, deposition of volcanic and sedimentary rocks of the Roebourne Group commenced shortly before 3270 Ma. Between 3270 and 3260 Ma the Karratha Granodiorite intruded the base of this succession. The Roebourne Group and the Karratha Granodiorite are separated from the 3125–3115 Ma Whundo Group by the Sholl Shear Zone, a major strike-slip fault that strikes east–west across the southern third of the sheet area. The Whundo Group is an approximately 10 km-thick succession of volcanic rocks that is dominantly composed of tholeiitic basalt, but also includes calc-alkaline volcanic rocks. Unconformably overlying the Roebourne and the Whundo Groups is the c. 3020 Ma Cleaverville Formation consisting of banded iron-formation, chert, and fine-grained clastic sedimentary rocks. The Cleaverville Formation is present on both sides of the Sholl Shear Zone, indicating that most strike-slip movement took place before 3020 Ma. The Roebourne Group was intruded by a major layered mafic–ultramafic intrusion, the Andover Intrusion, prior to c. 3000 Ma.

The volcanic and sedimentary rocks of the Mallina Basin unconformably overlie the Cleaverville Formation and the Whundo Group. On ROEBOURNE the volcanic Whim Creek Group is c. 3010 Ma, and is unconformably overlain by the volcanic and sedimentary, c. 2975–2950 Ma, Bookingarra Group. Major episodes of granitoid intrusion occurred between 3016 and 2930 Ma, and a layered mafic–ultramafic intrusion (Sherlock Intrusion) intruded eastern ROEBOURNE between c. 2950 and 2925 Ma. A phase of dextral movement on the Sholl Shear Zone, involving 30–40 km displacement of the Mallina Basin succession, occurred between 3010 and 2920 Ma.

A total of nine deformation events are recognized prior to the c. 2770–2760 Ma deposition of the lower Fortescue Group. The first major tectonic event was at about 3160 Ma when the upper part of the Roebourne Group was thrust southwards across the lower part over an area of at least 1750 km^2. Subsequent deformation included the development of the Sholl Shear Zone, and later regional upright folding at 2950–2930 Ma.

Major erosion of the WPGGT and Mallina Basin between 2940 and 2770 Ma was followed, at about 2770 Ma, by deposition of the Fortescue Group at the base of the Hamersley Basin succession. Early deposition of basaltic and sedimentary rocks of the Fortescue Group was controlled by a northeasterly striking rift system.

Mineralization — copper and gold — was first discovered on ROEBOURNE between 1872 and 1888. Subsequent mineral exploration revealed many more deposits of gold, copper, lead, and vanadium–titanium. Small-scale production of pegmatite minerals and semi-precious stone has also been recorded, and the area holds potential for platinum group elements.

KEYWORDS: Archaean, Pilbara Craton, West Pilbara Granite–Greenstone Terrane, Mallina Basin, Hamersley Basin, Roebourne Group, Whundo Group, Cleaverville Formation, Whim Creek Group, Bookingarra Group, Fortescue Group, tectonics, mineralization.

Introduction

The ROEBOURNE* 1:100 000 geological sheet (SF 50-3, 2356), bounded by latitudes 20°30'S and 21°00'S and longitudes 117°00'E and 117°30'E, is situated in the northwestern part of the Pilbara region (Fig. 1). It occupies the southwestern corner of the ROEBOURNE 1:250 000 sheet.

In the middle part of the nineteenth century the town of Roebourne was established inland from the port of Cossack, where space for housing was limited. The only other town on ROEBOURNE is the town of Wickham, which provides accommodation for staff of Robe River Iron Associates. Roebourne has an airport suitable for light aircraft.

The ROEBOURNE area has an active pastoral industry (cattle and sheep), and previous mining has included gold, copper, and semi-precious stone.

* Capitalized names refer to standard 1:100 000 map sheets.

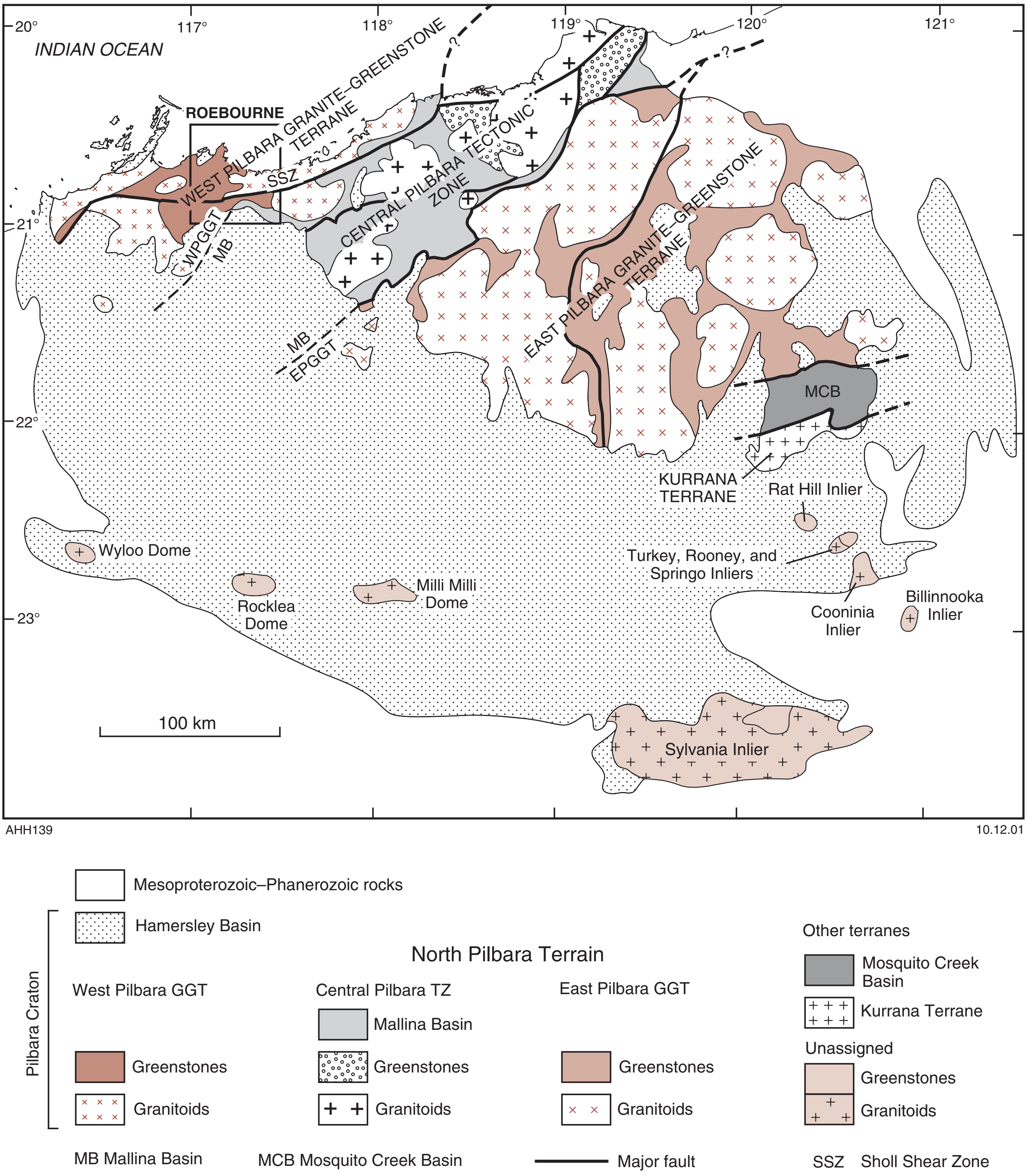

Figure 1. Regional geological setting of Roebourne within the Pilbara Craton

Climate and vegetation

Roebourne 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 from 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 the trailing southern edges of strong equatorial systems.

Summer daily maximum temperatures are generally about 35–40°C in coastal regions, and 40–45°C inland. Daily maximum temperatures during winter months are typically about 25°C, with night temperatures about 10–15°C.

ROEBOURNE occupies part of the Fortescue Botanical District (Beard, 1975), in which flora is related to topography, soil types, and proximity to the coast. Much of the coastal belt consists of tidal mud flats, with lagoons, samphire flats, and mangroves. Hypersaline conditions on the mud flats, combined with erosion and sediment reworking, preclude vegetation, but the coastline and tidal creeks are fringed by low, shrubby mangrove of *Avicennia marina* and *Rhizophora mucronata* between levels of low and high tides. Storm beaches and dunes of shelly sand support vines and rhizomatous grasses, whereas farther inland dwarf shrubs (*Acacia*) and grasses (e.g. *Triodia pungens*) populate these sandy units.

The valleys of the Harding, Jones, and George 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 ROEBOURNE, formations of the Fortescue Group form rocky dissected plateaus, 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 metamorposed volcanic and sedimentary rocks ('greenstones') in northern and western ROEBOURNE, are dominated by spinifex and scattered shrubs.

Physiography

Figure 2 summarizes the major physiographic divisions of ROEBOURNE, and closely follows divisions previously used by Hickman (1983). The present physiography of ROEBOURNE is mainly the product of the erosional and depositional processes during the Cainozoic period, but deep erosion of the Precambrian rocks also occurred as far back as the Archaean. Most of the present land surface is composed of deposits derived either from weathering of the upland areas inland, or from marine and eolian deposition along the coast.

Along the coast, a belt of marine and estuarine sediments forms tidal mud flats and mangrove swamps, flanked by supratidal deposits of shelly sand, silt, and clay. Dunes of shelly and calcareous sand rising up to 20 m above high-tide level define part of the coastline. Similar low dunes, trending parallel to the coast, lie up to 10 km inland but are commonly dissected by marine or fluvial erosion. Tidal mud flats, including mangrove swamp along the coastline and watercourse outlets, are up to 8 km wide. The mud flats are dominated by saline clay and silt, with some calcareous sand, and form large lagoons along the coast.

The alluvial–colluvial plain division (Fig. 2), inland from the coast, is a gently sloping tract of sand, silt, and clay deposited from rivers, creeks, and minor channels. Many of these drainages are short and flow from hilly areas close to the coast, but others are the distributary channels of deltas. From west to east, the main watercourses are the Harding, East Harding, Jones, George, Little George, and Little Sherlock Rivers. The rivers and larger creeks occupy wide alluvial channels containing unconsolidated sand and pebble beds.

Erosional land surfaces are separated into three divisions (Fig. 2). The low hills division comprises areas of undulating low hills, in many areas on Archaean greenstones, low 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. Neither of these divisions contains remnants of an older (pre-middle Miocene) land surface named the 'Hamersley Surface' (Campana et al., 1964). These remnants are preserved in only the more elevated areas of ROEBOURNE, and are underlain by rocks relatively resistant to erosion, such as basalts of the Fortescue Group, and gabbro and ultramafic rocks of the Andover Intrusion, south of Roebourne. The dissected plateau division rises abruptly from the plain and low hills divisions, and its boundary is typically defined by prominent cliffs or escarpments up to 100 m high. Where it is underlain by near-horizontal strata the dissected plateau contains steep V-shaped valleys, gorges, nickpoints, 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.

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 also discovered near Roebourne (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 ROEBOURNE area are listed in Kriewaldt (1964), and Hickman (1983) reviewed investigations to 1979. Hickman (2001) reviewed geoscientific investigations between 1962 and 1995 when the National Geoscience Mapping Accord (NGMA) project, between GSWA and the former Australian Geological Survey Organisation (now Geoscience Australia), commenced. The Pilbara NGMA concluded in June 2000.

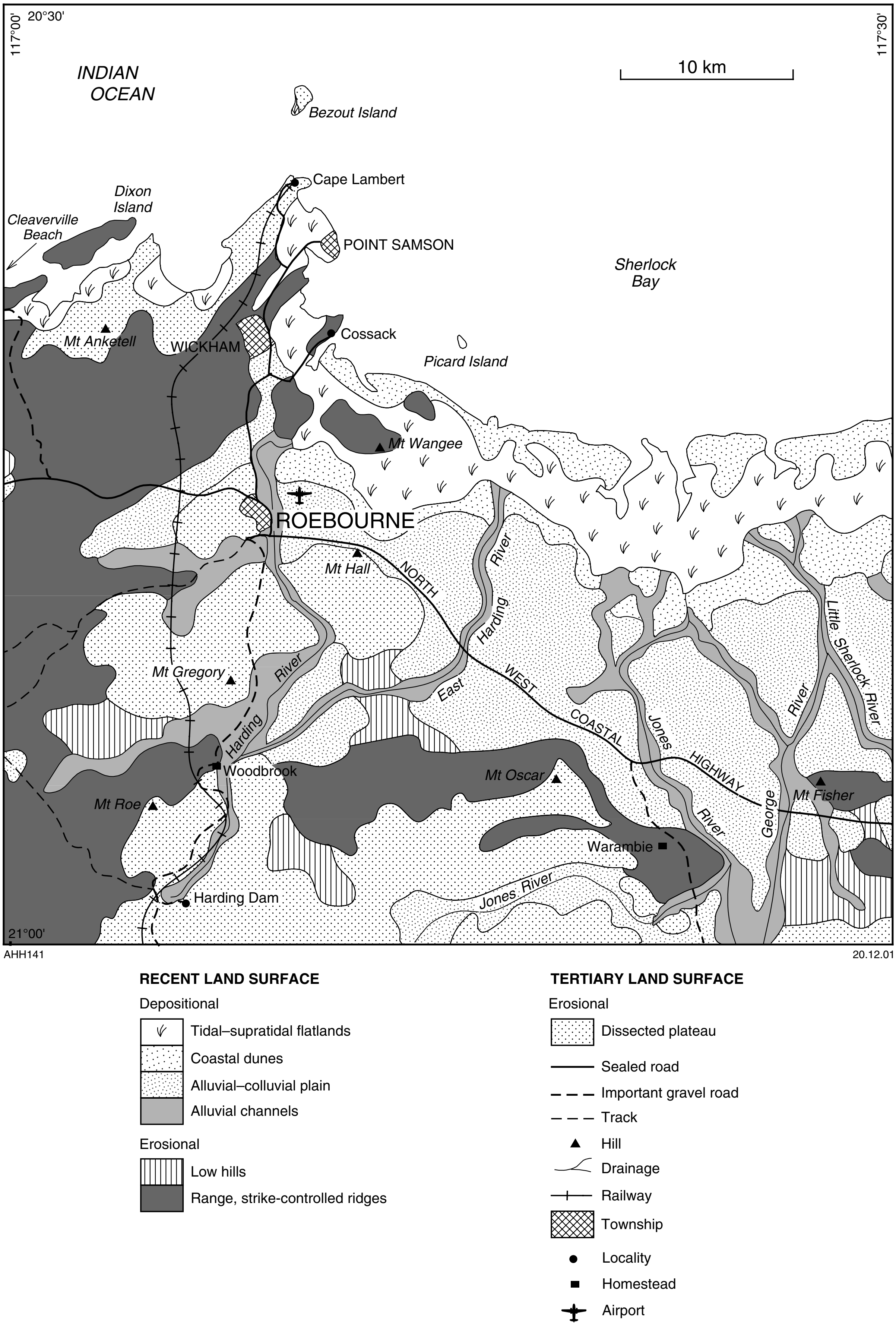

Figure 2. Physiography and access on ROEBOURNE

In 1995, GSWA mapped DAMPIER (Hickman, 1997a) and SHERLOCK (Smithies, 1997), 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 — PINDERI HILLS (Kojan and Hickman, 2000), PRESTON (Strong et al., 2000), and COOYA POOYA (Hickman, in prep.). Hickman (1997b) revised the lithostratigraphy of the Roebourne–Whundo area based on the mapping of DAMPIER, PINDERI HILLS, and ROEBOURNE.

Krapez and Eisenlohr (1998) and Smith et al. (1998) modified the sequence stratigraphy and domain interpretation of Krapez (1993) in order to subdivide the west Pilbara succession. Using available geochronology data (Horwitz and Pidgeon, 1993; Nelson, 1996, 1997; Hickman, 1997b; Smith et al., 1998), Krapez and Eisenlohr (1998) interpreted the Sholl Shear Zone to be sinistral, which has juxtaposed a 3260 Ma island-arc succession with a c. 3120 back-arc succession. They noted that this movement took place after the 'Whim Creek Basin' developed. Smith et al. (1998) placed the timing of the sinistral movement at 2991–2925 Ma, whereas Krapez and Eisenlohr (1998) put it between 3000 and 2955 Ma. However, as noted by Smithies (1998a), visible displacement of the Whim Creek Group across the Sholl Shear Zone is dextral.

Sun and Hickman (1998) reported neodymium-isotope depleted mantle model ages (Nd T_{DM}) of 3480–3430 Ma for the Roebourne Group and the Karratha Granodiorite. These ages are approximately 200 m.y. older than the emplacement ages of these rocks, suggesting that magma generation involved older basement rocks, enriched lithospheric mantle, or sedimentary rocks derived from older terrains through subduction, or a combination of these sources. These data contrast with Nd isotopic data from the Whundo Group, which indicate that the group formed from juvenile crust consistent with a subduction-zone environment, as suggested by Smith et al. (1998). Kato et al. (1998) presented lithological and geochemical data as evidence that rocks of the Cleaverville area in northwestern ROEBOURNE were formed in environments ranging from mid-oceanic spreading centres to convergent plate boundary settings.

Hickman (1999) recognized three major tectono-stratigraphic terranes in the formerly named '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 further definition was provided by Hickman (2001). The area of Archaean granitoids and greenstones in the northern part of the Pilbara Craton was referred to as the North Pilbara Terrain (Hickman et al., 2000; Hickman and Smithies, 2001; Van Kranendonk et al., in prep.), and divided into five lithotectonic elements (Fig. 1); the two most northwesterly of these divisions, the West Pilbara Granite–Greenstone Terrane (WPGGT) and the Mallina Basin, are exposed on ROEBOURNE (Fig. 1). A more detailed description of the West Pilbara Granite–Greenstone Terrane is given by Hickman et al. (in prep.).

Geological mapping of ROEBOURNE was undertaken during 1996 and 1997 using 1992 colour aerial photographs at 1:25 000 scale, and by field interpretation of multispectral Landsat Thematic Mapper images provided by Geoscience Australia. Preliminary images generated from high-resolution magnetic and radiometric 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).

Ruddock (1999) reported on the mineralization and exploration potential of the west Pilbara based on a new comprehensive dataset of mineral occurrences (provided on CD-ROM). This report was accompanied by a 1:500 000-scale geological map.

Regional geological setting

ROEBOURNE is located in the northwestern part of the Pilbara Craton (Fig. 1) and covers parts of the West Pilbara Granite–Greenstone Terrane, the Mallina Basin, and northern exposures of the Hamersley Basin. Figure 3 shows the tectono-stratigraphic domains within the WPGGT. The stratigraphy and major structures on ROEBOURNE are shown in Figure 4, and the geological history of the area is summarized in Table 1.

As ROEBOURNE was one of the first North Pilbara NGMA 1:100 000-scale sheet areas to be mapped, the map shows lithological components of the lower part of the Pilbara Supergroup in the WPGGT without stratigraphic subdivision. However, rocks of the Mallina Basin are mapped stratigraphically. A stratigraphic interpretation of the entire succession is provided in the **Simplified geology** diagram on the map, and in Figure 4.

Lithostratigraphy

On ROEBOURNE, deposition of greenstones of the Pilbara Supergroup commenced shortly before 3270 Ma. Figure 4 shows that, since ROEBOURNE was mapped, these rocks have been assigned to the Roebourne Group (Hickman, 1997b). In the area south of the Sholl Shear Zone the oldest greenstones have now been assigned to the 3125–3115 Ma Whundo Group. The 3020 Ma Cleaverville Formation, shown on the map as banded iron-formation, chert, and fine-grained clastic sedimentary rocks, unconformably overlies the Roebourne and the Whundo Groups. The Cleaverville Formation is present on both sides of the Sholl Shear Zone, indicating that most strike-slip movement took place before 3020 Ma. However, evidence from ROEBOURNE and DAMPIER (Hickman, 1997b, 2001; Smithies, 1998a) shows that a later phase of dextral movement, involving 30–40 km displacement, occurred between 3010 and 2920 Ma.

The volcanic and sedimentary rocks of the Whim Creek Group unconformably overlie the Cleaverville Formation and the Whundo Group. The Whim Creek Group (as redefined by Pike and Cas, in press) was deposited at c. 3010 Ma, and is unconformably overlain

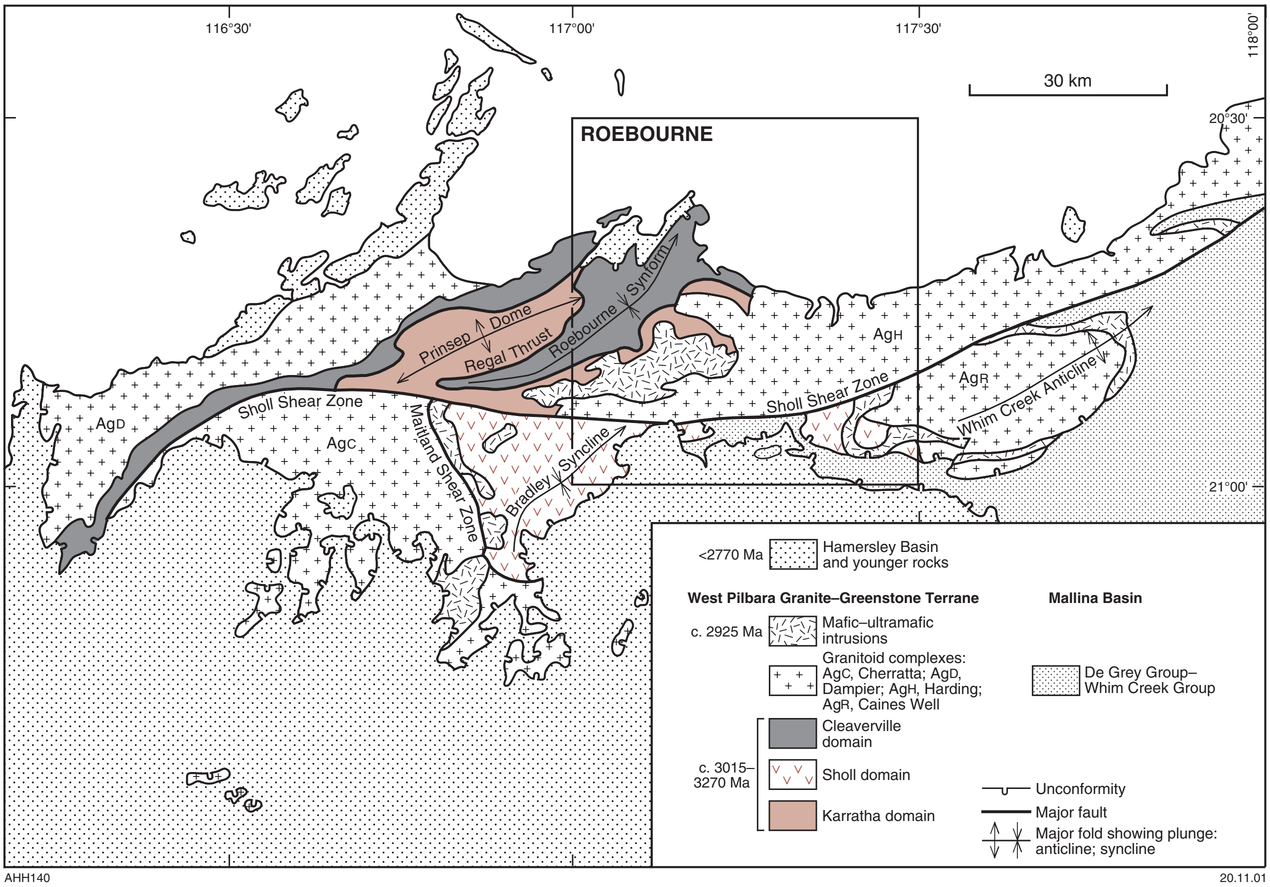

Figure 3. Tectono-stratigraphic domains of the West Pilbara Granite–Greenstone Terrane

by the c. 2975–2950 Ma Bookingarra Group which, since the map was published, has been defined to include the Louden Volcanics and the Kialrah Rhyolite (Pike and Cas, in press). Table 2 summarizes the Archaean litho-stratigraphy of ROEBOURNE.

The Fortescue Group of the Mount Bruce Supergroup unconformably overlies all the groups mentioned above. 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.

Geochronology

Precise U–Pb geochronology from ROEBOURNE is summarized in Table 3, and Table 4 lists geochronological data indicating the existence of pre-3300 Ma crustal components on ROEBOURNE. These data are referred to throughout these Notes, and are used in the map legend.

Structure

ROEBOURNE lies on the northwestern margin of the Pilbara Craton, and the structural geology of the area is dominated by northeasterly trending structures formed by successive periods of northwest–southeast to north–south extension and compression. By c. 3270 Ma, when the oldest preserved rocks of ROEBOURNE were formed, the East Pilbara Granite–Greenstone Terrane (EPGGT) was already a relatively rigid cratonic nucleus to the southeast (Van Kranendonk et al., in prep.). Tectonic processes operating after c. 3160 Ma (Table 1) involved movement of crust against and along the northwestern margin of this nucleus. As a consequence, most major structures such as thrusts, strike-slip faults, and folds in the WPGGT and the Mallina Basin have northeast–southwest trends. Granitoid complexes of the WPGGT are also elongate northeast–southwest, suggesting linear belts of felsic magmatism. Tectonic environments responsible for formation of the WPGGT are discussed by Van Kranendonk et al. (in prep.), Hickman et al. (2001), and Hickman et al. (in prep.).The evolution of the Mallina Basin is discussed by Smithies et al. (1999), Smithies and Champion (2000), and Smithies et al. (2001).

Archaean rocks

A reliable stratigraphic interpretation had not yet been developed for the metamorphosed volcanic and sedimentary rocks beneath the Whim Creek Group during the mapping of ROEBOURNE. The stratigraphic

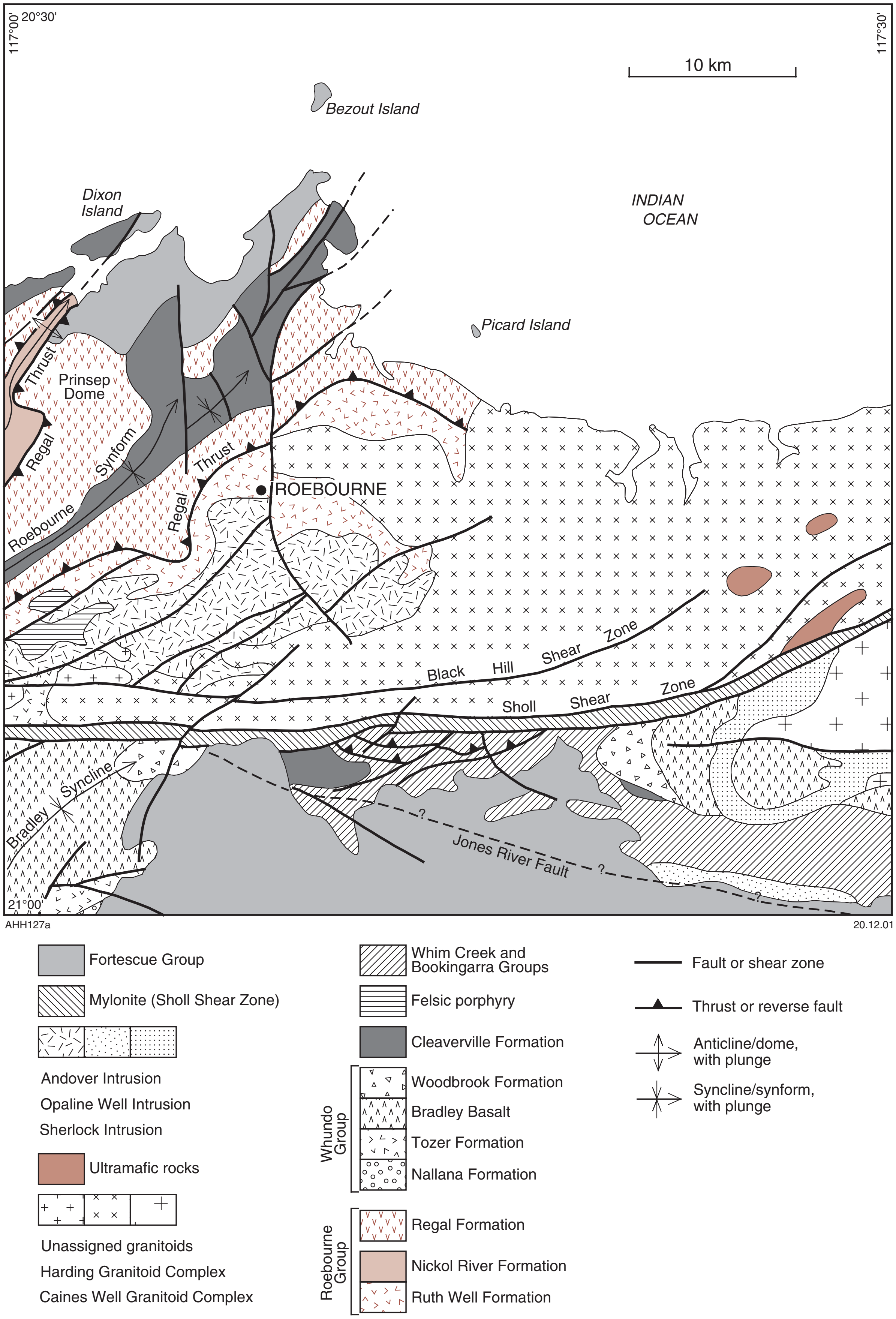

Figure 4. Stratigraphy and structural geology of ROEBOURNE

Table 1. Summary of the geological history of ROEBOURNE

Age (Ma)	*Geological event*
3724–3310	Formation of sialic crust (not exposed in WPGGT, and based on data from the EPGGT)
3300–3250	Rifting on the northwestern margin of the EPGGT; deposition of the Roebourne Group (possibly in an island arc), and intrusion of granitoids
3160–3090	D_1: Thrusting, recumbent folding and c. 3160 Ma granitoid intrusion; deposition of the Whundo Group in a rifted zone underlain by rocks no older than the Roebourne Group; intrusion of c. 3100 Ma granitoids; sinistral movement on the Sholl Shear Zone
3070–3050	Intrusion of tonalite (evidence from DAMPIER)
3070–3020	D_2: Culmination of sinistral strike-slip movement along the Sholl Shear Zone; transpressional folding and felsic magmatism; erosion
3020–3015	Deposition of the Cleaverville Formation
3015–3010	D_3: Strike-slip movement, felsic magmatism, and transpressional folding of the Whundo Group and the Cleaverville Formation; erosion
3010–2990	Deposition of the Whim Creek Group (as redefined by Pike and Cas, in press) in the early Mallina Basin, and extensive intrusion of granitoids in the WPGGT
2975–2955	Deposition of the Bookingarra Group (Mallina Basin)
2975–2955	D_4: Local thrusting and east–west folding of rocks in the Mallina Basin
c. 2955	D_5: North–south folding of rocks in the Mallina Basin (no structures on ROEBOURNE)
2950–2930	D_6 : Transpressional, northeasterly trending tight to open folding, and commencement of dextral movement along the Sholl Shear Zone; late- to post-tectonic felsic magmatism
c. 2940	D_7: Northerly to northwesterly striking strike-slip faulting (only on DAMPIER)
c. 2925	Emplacement of layered mafic–ultramafic intrusions, followed by intrusion of granitoid
c. 2920	D_8: Culmination of dextral strike-slip movement along the Sholl Shear Zone, and other easterly and northeasterly striking faults
<2920	D_9: Conjugate faulting produced by north-northwest – south-southeast compression
2920–2770	Erosion
2770–2750	D_{10}: Rifting, and deposition of the Mount Roe Basalt and Hardey Formation; intrusion of dolerite dykes
755	Intrusion of northeasterly trending dolerite dykes
545–65	Palaeozoic and Mesozoic erosion
55–present	Uplift and dissection of plateau surface, deposition of Cainozoic units

NOTES: WPGGT: West Pilbara Granite–Greenstone Terrane
EPGGT: East Pilbara Granite–Greenstone Terrane

subdivision of these lower units was delayed pending additional information from the west Pilbara mapping program. Hickman (1997b) presented a lithostratigraphic interpretation that was greatly revised from that previously published (Hickman, 1983), and this 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 SHRIMP U–Pb zircon geochronology have supported the present lithostratigraphic interpretation.

The following descriptions of Pilbara Supergroup rocks (without stratigraphic subdivision) are discussed in relation to the broad lithological grouping used in the map legend, and no age relationships are implied. Thus, lithological codes (e.g. *Ab*) apply to several units that are clearly at different stratigraphic positions. Codes that apply to granitoids, layered mafic intrusions, and the Fortescue Group, are described in order of decreasing age.

Pilbara Supergroup (not stratigraphically subdivided on the map)

Ultramafic rocks (Au, Aub, Auk, Aur, Aus, Aut, Auv, Aux)

Except for ultramafic rocks within layered mafic intrusions, almost all ultramafic rocks on ROEBOURNE outcrop north of the Sholl Shear Zone, and form parts of the Ruth Well and Nickol River Formations (Fig. 4). 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 were volcanic in origin.

On ROEBOURNE, undivided ultramafic rock (*Au*) is typically schistose close to the Regal Thrust (Figs 3 and 4). Outcrops are at Weerianna, west of Carlow Castle, and near Big Tree Well. Serpentinization, carbonation, and

Table 2. Archaean lithostratigraphy of ROEBOURNE and adjacent areas

Group	*Formation*	*Thickness (m)*	*Lithology and relationships*
Bookingarra[(a)] (new name)	Kialrah Rhyolite	0–1000	Feldspar-phyric, commonly flow-banded rhyolite. Maximum age c. 2975 Ma. Overlies or intrudes Louden Volcanics
	Louden Volcanics	0–1000	High-Mg basalt, with pyroxene spinifex texture, and undivided massive and pillow basalt
~ ~ ~ *possible low-angle unconformity* ~ ~ ~			
Whim Creek	Mons Cupri Volcanics	0–500	Felsic volcanic and volcaniclastic rocks, and dacite intrusions. Age c. 3009 Ma
	Warambie Basalt	0–500	Vesicular, amygdaloidal, and pyroclastic basalt with hyaloclastite and local pillow basalt. Basal polymictic conglomerate and sandstone
~ ~ ~ *high-angle unconformity* ~ ~ ~			
	Cleaverville Formation	1500	Banded iron-formation, chert, fine-grained clastic sedimentary rocks. Age c. 3020 Ma
~ ~ ~ *possible low-angle unconformity* ~ ~ ~			
Whundo	Woodbrook Formation	1000	Rhyolite tuff and agglomerate; minor basalt and thin banded iron-formation. Age 3117 ± 3 Ma
	Bradley Basalt	>4000	Pillow basalt, massive basalt, minor units of felsic tuff and chert. Age 3115 ± 5 Ma
	Tozer Formation	2500	Calc-alkaline volcanic rocks, including felsic pyroclastic units. Minor chert and thin banded iron-formation. Age c. 3120 Ma
	Nallana Formation	2000	Dominantly basalt, but includes minor ultramafic and felsic units. Felsic tuff dated at 3125 ± 4 Ma. Base of formation intruded by 3130 Ma granitoids and truncated by Maitland Shear Zone
~ ~ ~ *tectonic contact along Sholl Shear Zone* ~ ~ ~			
Roebourne	Regal Formation	2000	Basal peridotitic komatiite overlain by pillow basalt and local chert units. Intruded by microgranite and c. 3015 Ma felsic porphyry
~ ~ ~ *tectonized contact along Regal Thrust* ~ ~ ~			
	Nickol River Formation	100–500	Banded chert and iron-formation, ferruginous clastic sedimentary rocks, quartzite, felsic volcanic and carbonate rocks, volcanogenic sedimentary rocks and local conglomerate. Schist protolith less than 3269 ± 2 Ma, and rhyolite dated at 3251 ± 6 Ma
	Ruth Well Formation	1000–2000	Basalt and extrusive peridotite with thin chert units. Intruded by granodiorite and tonalite dated at 3270 ± 2 Ma

NOTE: (a) Bookingarra Group defined (Pike and Cas, in press) since map was published

silicification have been superimposed on strongly sheared rocks which, on the basis of their stratigraphic equivalence to less deformed rocks in other areas, probably originated as komatiite.

Intercalated ultramafic and mafic rocks and thin chert units (*Aub*) outcrop at Weerianna. The chert represents interflow sedimentary rock separating tholeiitic and ultramafic or high-Mg basalt lava flows, and is locally fuchsitic. The ultramafic and mafic rocks are foliated, and include chlorite schist. Silicification and quartz veining are widespread, and both this unit and ultramafic schist immediately to the east contain old gold workings.

Metamorphosed komatiite with olivine spinifex texture (*Auk*) is wel exposed at two localities on ROEBOURNE. Large plates of serpentinized olivine are exposed on the southern side of the Northwest Coastal Highway at Mount Hall, and also 2 km northwest of Mount Wangee (Figs 5 and 6). Both localities show well-preserved sheaf and

Table 3. Precise U–Pb zircon geochronology (SHRIMP unless otherwise indicated) on rocks from ROEBOURNE and adjacent parts of DAMPIER and SHERLOCK

Age (Ma)	*Lithology/formation*	*Location (MGA)* Easting	Northing	*Sample*	*Reference*
3269 ± 2	schist, Nickol River Formation	05010	77057	136819	Nelson (1998, p. 99–101)
3265 ± 4	granodiorite	04974	76910	JS43	Smith et al. (1998)
3128 ± 6	rhyolite, Tozer Formation	04929	76789	N4325	Smith (1997)
3125 ± 4	dacite tuff, Nallana Formation	04915	76850	114350	Nelson (1996, p. 164–167)
3122 ± 7	rhyolite, Tozer Formation	04917	76782	114358	Nelson (1997, p. 134–137)
3118 ± 3	rhyolite, Tozer Formation	04925	76832	114356	Nelson (1996, p. 156–159)
3118 ± 2	rhyolite tuff, Woodbrook Formation	05351	76882	144256	Nelson (1998, p. 114–116)
3117 ± 3	welded tuff, Woodbrook Formation	05088	76869	127378	Nelson (1998, p. 111–113)
3116 ± 3	dacite, Whundo Group	05484	76861	144210	Nelson (1998, p. 117–119)
3115 ± 5	felsic tuff, Bradley Basalt	05015	76863	114305	Nelson (1996, p. 160–163)
3112 ± 6[(a)]	felsic tuff, Tozer Formation	04973	76859	W197	Horwitz and Pidgeon (1993)
3024 ± 4	mylonite, Sholl Shear Zone	04948	76893	JS25	Smith et al. (1998)
3023 ± 9	dacite, north of Sholl Shear Zone	04955	76902	118976	Nelson (1997, p. 175–178)
3022 ± 12	sandstone, Cleaverville Formation	05021	77143	127330	Nelson (1998, p. 52–55)
3021 ± 3	porphyry sill, Ruth Well Formation	05198	77091	144224	Nelson (1999, p. 157–159)
3018 ± 3[(b)]	sandstone, Cleaverville Formation	05169	76867	142830	Nelson (1998, p. 63–65)
3018 ± 2	porphyry sill, Regal Formation	05016	77112	127327	Nelson (1998, p. 136–138)
3016 ± 4	Harding Granitoid Complex	05117	76937	168936	Nelson (2001, p. 178–180)
3015 ± 5[(b)]	sandstone, Cleaverville Formation	05090	77125	136899	Nelson (1998, p. 120–122)
3014 ± 2	quartz–feldspar porphyry	04969	76930	118979	Nelson (1997, p. 179–182)
3014 ± 6	granophyre sill, Cleaverville Formation	05170	76872	127320	Nelson (1998, p. 183–186)
3009 ± 4	welded tuff, Mons Cupri Volcanics	05544	76821	141936	Nelson (1998, p. 56–58)
2975 ± 4	Kialrah Rhyolite	05367	76819	144261	Nelson (1998, p. 129–132)
2970 ± 5	Harding Granitoid Complex	05079	76915	142430	Nelson (1999, p. 108–111)

NOTES: (a) Conventional U–Pb zircon date
(b) SHRIMP U–Pb–Th baddeleyite date
SHRIMP: Sensitive high-resolution ion microprobe

random spinifex textures, and individual olivine plates (pseudomorphed by serpentine and tremolite) are up to 30 cm long. Layers of different spinifex texture indicate that the ultramafic flows are up to 2 m thick. Random spinifex texture overlies sheaf spinifex texture indicating that the flows are right-way-up (Arndt, 1986). Rocks showing sheaf spinifex texture consist mainly of tremolite, serpentine, chlorite, and a pale yellow, birefringent phyllosilicate (possibly vermiculite). Serpentine and tremolite or vermiculite have replaced olivine blades. Tremolite and serpentine also form very fine intergrowths, and chlorite forms randomly oriented flakes. Opaque minerals are disseminated through the rock as anhedral grains and granular aggregates, and as discontinuous linings along narrow fractures or veinlets. Some of the opaque minerals have a translucent, reddish-brown outer margin, suggesting they are iron oxides such as hematite.

A thin section of random spinifex texture in a rock from Mount Hall reveals a fine-grained mosaic of tremolite crystals in which larger platy olivine is pseudomorphed by serpentine and chlorite. The olivine pseudomorphs have a random orientation and produce a well-developed spinifex texture. The tremolite crystals exhibit vague prismatic shapes and have a random orientation, filling angular interstices between the elongate aggregates of chlorite and serpentine. Opaque minerals are similar to those in rocks displaying sheaf spinifex texture.

Table 4. Geochronological data supporting the existence of pre-3270 Ma source rocks in the evolution of the West Pilbara Granite–Greenstone Terrane on ROEBOURNE and DAMPIER

Age (Ma)	*Method*	*Material*	*Rock unit/age*	*Sample*	*Reference*
3494 ± 15	Sm–Nd	rock	Karratha Granodiorite, 3261 Ma	JS17	Smith et al. (1998)
3479 ± 13	Sm–Nd	rock	granodiorite, 3265 Ma	JS43	Smith et al. (1998)
3461 ± 8	$^{207}Pb/^{206}Pb$	zircon	Cleaverville Formation, 3022 Ma	127330	Nelson (1998, p. 52–55)
3449 ± 5	$^{207}Pb/^{206}Pb$	zircon	Nallana Formation, 3125 Ma	114350	Nelson (1996, p. 164–167)
c. 3430	Sm–Nd	rock	Nickol River Formation, 3251 Ma	118975	Sun and Hickman (1998)
3391 ± 15	Sm–Nd	rock	mylonite, 3050–2920 Ma	JS25	Smith et al. (1998)
3311 ± 8	$^{207}Pb/^{206}Pb$	zircon	Karratha Granodiorite, 3261 Ma	JS17	Smith et al. (1998)
c. 3298	Sm–Nd	rock	dacite, 3023 Ma	118976	Sun and Hickman (1998)
3287 ± 17	$^{207}Pb/^{206}Pb$	zircon	Cleaverville Formation, 3022 Ma	127330	Nelson (1998, p. 52–55)

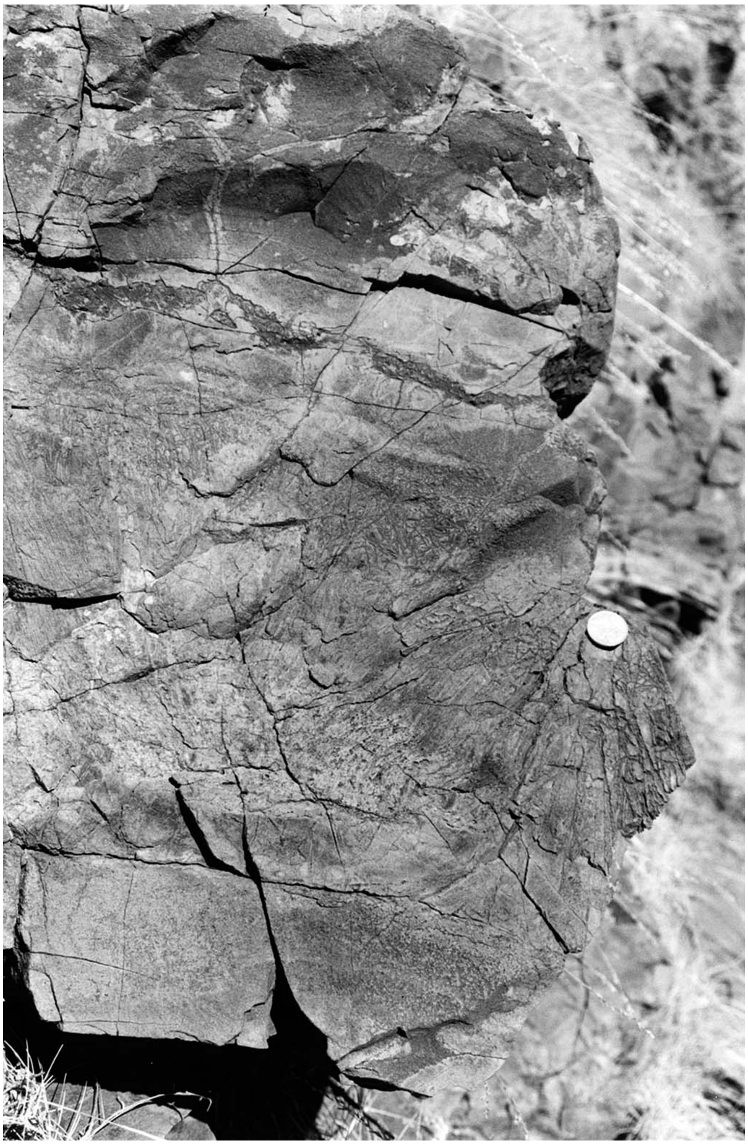

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Figure 5. Spinifex-textured ultramafic lava flow at Mount Wangee. Random spinifex texture (near coin) overlies bladed sheaf spinifex texture (below coin), indicating that the flows, which dip to the left, are right-way-up. The chilled top of the flow (above coin) overlies the random spinifex, and a cumulate-textured zone underlies the zone of bladed olivine. Coin, 3 cm diameter (MGA $_{05}$20500E $_{77}$09200N)

Serpentinite (*Aus*), representing metamorphosed peridotite, was mapped in three areas 5 km west of Carlow Castle, 2 km north of Mount Wangee, and west of Mount Hall. The unit west of Carlow Castle is a massive serpentinite that locally contains thin veinlets of chrysotile asbestos. This rock may have originated as a peridotite sill; no features characteristic of extrusive peridotites (e.g. flow margins, interbedded chert units, and spinifex textures) were observed. The Mount Wangee outcrop contains a 10 m-thick ferruginous chert which, in view of the association of the unit with komatiite (*Auk*), indicates that the serpentinite is probably an altered ultramafic lava. Microscopic examination of this serpentinite reveals a felted intergrowth of serpentine minerals and finely divided opaque minerals. The opaque minerals outline former anhedral crystals with a grainsize typically between 1 and 1.5 mm. These pseudomorphs contain serpentine similar to the interstitial serpentine. Some of the pseudomorphs have lamellar textures and could represent altered pyroxene crystals, whereas others contain irregular fractures and probably represent altered olivine crystals. Small aggregates of granular birefringent carbonate are disseminated through the rock. Although most of the opaque minerals form fine intergrowths with the serpentine, some form larger disseminated grains ranging up to 0.5 mm in size. The serpentinite west of Mount Hall is chiefly fine grained and schistose, but locally contains relict olivine spinifex texture. Rare, thin silicified layers

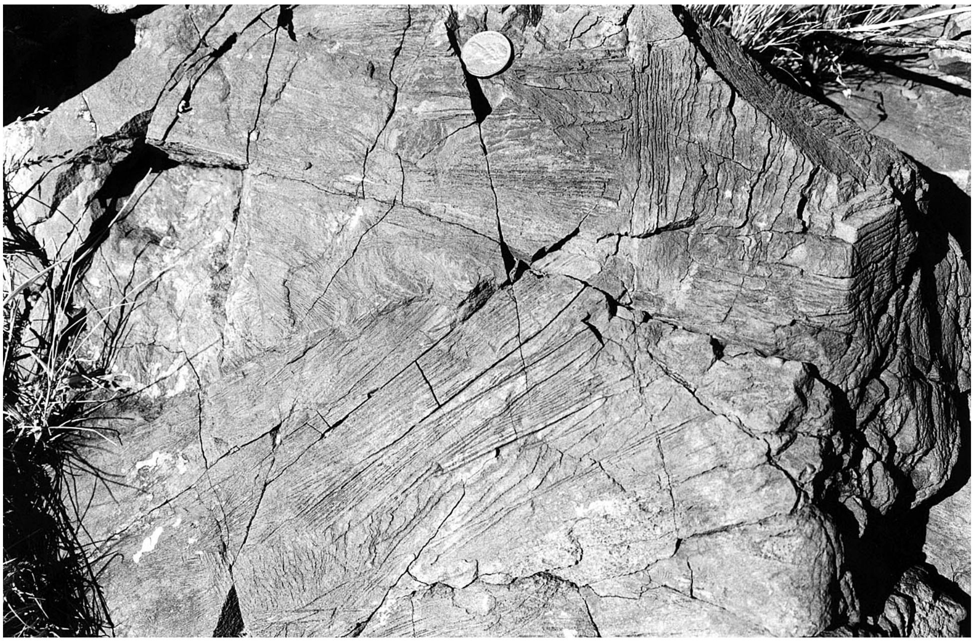

Figure 6. Close-up of bladed olivine spinifex texture at Mount Wangee. Blades of olivine, pseudomorphed by serpentine, tremolite, and chlorite, are up to 30 cm long. Coin, 3 cm diameter (MGA 05 20500E 77 09200N)

may represent altered flow margins, and the serpentinite in this area is interpreted to be deformed komatiite.

Serpentinized peridotite units forming large parts of the Andover Intrusion (*AaAp*) are mapped separately and described later (see **Mafic–ultramafic intrusions**).

Tremolite–chlorite schist (*Aur*) is poorly exposed 3 km west-southwest of Black Hill Well, where it is interleaved with mylonite of the Black Hill Shear Zone. The rock is strongly foliated and variably silicified, and includes zones of talc–chlorite schist too thin to show on the map.

Talc–chlorite schist (*Aut*) is exposed 3 km west-southwest of Black Hill Well, and 1 km east of Black Hill Well. The larger, more westerly, outcrops are compositionally layered, and include some units of talc–chlorite–tremolite schist and some layers of massive serpentinite. The rocks are interpreted to be a sheared assemblage of ultramafic flows in the Ruth Well Formation. To the south, the unit is truncated by the Black Hill Shear Zone, and to the north it is intruded by monzogranite of the Harding Granitoid Complex, and by gabbro of the Andover Intrusion. The small outcrops east of Black Hill Well are talc–chlorite schist intruded by the Harding Granitoid Complex.

Metamorphosed lava ranging from peridotite to high-Mg basalt (*Auv*) outcrops 3 km southwest of Rea Well. The unit includes ultramafic tuff, which in thin section contains flattened lapilli 1–5 mm in diameter composed of chlorite, tremolite, talc, and opaque minerals.

Metamorphosed pyroxenite (*Aux*) outcrops in three areas, north of Mount Wangee, 4 km west of Carlow Castle, and 2 km north of Woodbrook. The units north of Mount Wangee are fine-grained rocks interlayered with komatiite, and could be metamorphosed volcanic or intrusive units. In thin section the rock consists mainly of actinolite crystals intergrown with less abundant interstitial plagioclase. The actinolite is prismatic and is thought to be a replacement product of original pyroxene crystals. The actinolite has a fibrous internal texture and also contains rare intergrowths of remnant pyroxene. Concentrations of plagioclase are interstitial to the actinolite crystals and generally have a finely granular character. The plagioclase shows moderate alteration to fine granular epidote. Calcite forms irregular and discontinuous veins, and opaque minerals are disseminated as small, anhedral grains and aggregates.

About 4 km west of Carlow Castle a unit mapped as metapyroxenite, but which includes serpentinite, outcrops to the south of metabasalt; this ultramafic unit is interpreted to be an eastern continuation of the serpentinized peridotite sill (*Aus*) mapped 2 km to the southwest. The Woodbrook exposures of metapyroxenite are massive and medium grained, and are more typical of pyroxenite layers in the Andover Intrusion (*AaAx*). However, because these outcrops are isolated from the main outcrop of the Andover Intrusion, and no connection is evident from aeromagnetic data, it is possible that the pyroxenite near Woodbrook is part of an unrelated minor intrusion.

Mafic volcanic rocks (Ab, Aba, Abgp, Abm, Abs, Abt)

As elsewhere in the West Pilbara Granite–Greenstone Terrane, mafic volcanic rocks are the most common components of the greenstone successions on ROEBOURNE. Most of the mafic rocks are tholeiitic (Glikson et al., 1986), and geochronology on intercalated felsic and sedimentary rocks (Nelson, 1996, 1997, 1998) indicates that the unassigned mafic volcanic rocks in the lower part of the Roebourne Group are c. 3270–3250 Ma, and that volcanic rocks in the Whundo Group are 3125–3115 Ma. However, metabasalt of the Regal Formation in the upper part of the Roebourne Group (Fig. 4), has not been directly dated. This formation is separated from dated parts of the Roebourne Group by the regionally extensive Regal Thrust (see **Structure**), but Hickman (1997b) concluded that the Ruth Well and Regal Formations were separate ultramafic–mafic volcanic cycles within an originally continuous stratigraphic succession. This interpretation suggests that the Regal Formation is not much younger than c. 3250 Ma. An alternative interpretation, not adopted here, is that the Regal Formation is of similar age to the Cleaverville Formation (Ohta et al., 1996; Kiyokawa and Taira, 1998).

Undivided basaltic rock (*Ab*) is widespread on ROEBOURNE, and consists mainly of massive or pillowed basalt that has been metamorphosed to greenschist facies. Pillows are common between Woodbrook and the southwestern corner of the sheet area (Figs 7 and 8), south of Cleaverville, and in the Roebourne–Wickham area. 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 basaltic unit (*Ab*) unit locally includes komatiitic basalt. In the southwest of ROEBOURNE, the lower section of the Bradley Basalt (Fig. 4) contains flows of variolitic basalt, pyroxene spinifex-textured basalt and amygdaloidal komatiitic basalt. Most basalt of this unit is a fine-grained assemblage of amphibole (actinolite, tremolite, or hornblende), quartz (largely secondary), albite, epidote, chlorite, and minor sericite, sphene, clinozoisite, and carbonate and opaque minerals. Relict clinopyroxene phenocrysts are locally preserved, but replacement by amphibole is normally complete. Plagioclase is extensively albitized.

Foliated amphibolite-facies metabasalt (*Aba*) forms most of the upper part of the Roebourne Group about 10 km west of Roebourne. 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 opaque minerals. 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. Amphibolite-facies metabasalt (*Aba*) southeast of Mount Fisher is intruded by the Sherlock Intrusion and unconformably overlain by the Whim Creek Group. Geochronology (Nelson, 1998, p. 117–119) on a thin felsic unit within the amphibolite indicates that it belongs to the Whundo Group.

Foliated and sheared amphibolite-facies metabasalt, with sheared veins and sheets of microgranite and pegmatite (*Abgp*), is restricted to the upper part of the Roebourne Group, about 9 km west-northwest of Carlow Castle. About 3 km north of Big Tree Well a foliated sill of felsic porphyry, which represents a northeastern extension of the granitic sheets, was dated at 3018 ± 2 Ma (Nelson, 1998). This is interpreted as the age of formation of the metabasalt with veins and sheets of microgranite (*Abgp*), although shearing (which affects both the amphibolite and the granitic components) took place later.

Metamorphosed high-Mg basalt (*Abm*) outcrops north of Mount Wangee, where it is interlayered with komatiite (*Auk*), ferruginous chert (*Acf*), and silicified interflow sedimentary rocks. In outcrop the high-Mg basalt is a dense, fine-grained mafic to ultramafic rock without easily visible spinifex texture, but locally with well-developed variolitic texture. In thin section the rock consists of a fine intergrowth of actinolite and epidote in which there are areas containing feldspar and actinolite–epidote pseudomorphs replacing an acicular mafic mineral, probably pyroxene. Relict pyroxene is preserved in some samples and, with its alteration products of actinolite and epidote, locally defines a microscopic spinifex texture. Traces of disseminated calcite are present in most samples.

Mafic schist (*Abs*) outcrops in the Sholl Shear Zone between White Quartz Hill and Mount Ada, and at another locality 2 km west of Woodbrook. The schist is strongly sheared metabasalt derived by tectonic displacement of parts of the Whim Creek and Whundo Groups. These mafic schist units in shear zones have very similar mineralogy to amphibolite schist (*Aba*).

Metamorphosed basaltic tuff (*Abt*) outcrops along the contact between the Regal and Cleaverville Formations 7 km west-southwest of Wickham, and between 2 and 5 km southwest of Woodbrook. Small outcrops are also present in the Sholl Shear Zone, 4 km east of Woodbrook. The unit at the base of the Cleaverville Formation near Wickham includes a basal massive mafic tuff, successively overlain by accretion lapilli tuff of mafic to intermediate composition, laminated fine-grained tuff, and interbedded mudstone, shale, and chert. The chert is typically ferruginous, but grey-and-white banded chert and finely laminated black chert are locally exposed. Basaltic tuff to the west of Woodbrook includes reworked, cross-bedded mafic to intermediate tuff (MGA 075869) that immediately underlies felsic tuff of the Woodbrook Formation (Hickman, 1997b). About 4 km east of Woodbrook, well-bedded but sheared mafic tuff is preserved in the Sholl Shear Zone. Sparse accretion lapilli are present in the tuff, which may belong to the Warambie Basalt of the Whim Creek Group.

Felsic volcanic rocks (Af, Afa, Afr, Aft)

Although a minor component of the greenstones on ROEBOURNE, felsic volcanic rocks not assigned to a stratigraphic formation are exposed southwest of

Figure 7. Pillow lava in the Bradley Basalt, 2.5 km northwest of Harding Dam. Pillow structures, 1–2 m in diameter, show that the lava flows, which dip approximately 55° towards the northeast (left in picture), are right-way-up (MGA 0508900E 7682000N)

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Figure 8. Pillow lava in the Bradley Basalt, 2.5 km northwest of Harding Dam, showing way-up criteria. The pillows possess convex tops (towards left on photograph) and flatter bottoms with 'tail' structures (towards right on photograph) where a pillow rests on the V-shaped join between underlying pillows (MGA 0508900E 7682000N)

Woodbrook, at De Witt Hill, and northwest of Big Tree Well.

Undivided metamorphosed felsic volcanic rocks (*Af*) outcrop northwest of Big Tree Well, close to the western boundary of the sheet. The unit consists of massive, weakly foliated, fine- to medium-grained rocks rich in quartz. Bedding and pyroclastic textures are absent. It is uncertain if this unit is a volcanic rock, a volcanogenic sedimentary rock, or an intrusive rock related to quartz–feldspar porphyry (*Apf*) that outcrops to the northeast.

Metamorphosed rhyolite (*Afr*) outcrops at De Witt Hill and 4 km west of Harding Dam. The rock at De Witt Hill is schistose and porphyritic, and in thin section consists of quartz and sericitized plagioclase with minor chlorite. Sericitic patches within the fine-grained felsic matrix define a remnant tuffaceous texture of shards and pumice lapilli. A date of 3118 ± 2 Ma obtained by Nelson (1998, p. 114–116) indicates that the rhyolite belongs to the Whundo Group. To the west of Harding Dam, tuffaceous and porphyritic rhyolite lies at the top of a unit correlated with the Tozer Formation of the Whundo Group. The rhyolite contains thin beds of fine-grained silicified felsic tuff or volcanogenic sedimentary rock, partly replaced by chert.

Metamorphosed rhyolite and dacite tuff (*Aft*) forms large outcrops southwest of Woodbrook, and in an area 6 km west of Harding Dam. Lenses of agglomerate, too thin to map separately, are included in a unit of felsic tuff 4 km south of Bradley Well, but a thicker unit of felsic agglomerate (*Afa*) is distinguished on the map 2 km west-southwest of Woodbrook. The well-preserved coarse pyroclastic texture and wedge-shaped nature of this agglomerate indicate a locally developed explosive felsic volcanic centre. About 5 km south-southeast of Bradley Well exposures in a small valley west of a track along a powerline show beds of felsic tuff and agglomerate that contain graded bedding (upward fining) and fine-scale cross-bedding. Fine-grained reworked tuff displays intraformational convolutions and load structures (Figs 9 and 10). Reworking of the tuff suggests a relatively shallow-water depositional environment.

Felsic tuff from a locality 4 km west-southwest of Woodbrook in thin section consists of devitrified felsic glass, with abundant chlorite, minor quartz and feldspar, and accessory leucoxene, titanite, zircon, carbonate, and sericite. Fragments within the tuff include pumice, flow-banded lava, and porphyritic and spherulitic lava. This rock was dated by Nelson (1998, p. 111–113) at 3117 ± 3 Ma.

Clastic sedimentary rocks (As, Asc, Asf, Asi, Asq, Ass, Ast)

Metamorphosed clastic sedimentary rocks that are not stratigraphically assigned form a minor part of the greenstone succession on ROEBOURNE. Since the map was completed, a regional stratigraphic reinterpretion of the west Pilbara (Hickman, 1997b) has assigned most of these units either to the Nickol River Formation or to the Cleaverville Formation.

Undivided metamorphosed sedimentary rocks (*As*) outcrop 2 km northwest of Rea Well, 9 km southwest of Wickham and, based on photointerpretation, are mapped on Dixon Island. The Rea Well exposures are within the shear zone along the Regal Thrust, and consist of sheared metamorphosed sandstone, siltstone, and shale veined by quartz. The undivided metamorphosed sedimentary rocks (*As*) southwest of Wickham were not visited, but are interpreted to be metamorphosed fine-grained clastic sedimentary rocks similar to those along strike to the north.

Metaconglomerate (*Asc*) is exposed about 0.5 km southwest of Big Tree Well, where it forms part of a thick clastic sedimentary unit composed principally of metamorphosed sandstone, with minor conglomerate and siltstone (*Ast*), metamorphosed felsic volcaniclastic rock (*Asf*), and minor schistose metasandstone and metasiltstone (*Ass*) and quartzite (*Asq*). In the area west and

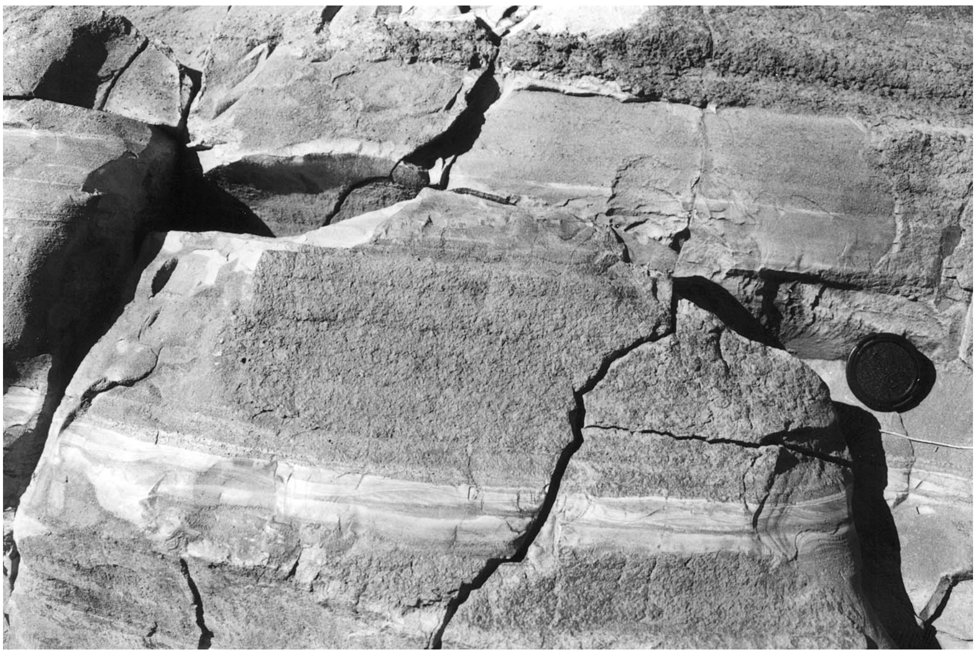

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Figure 9. Graded bedding in reworked rhyolite tuff in the Bradley Basalt. In the centre of the view, an upward-fining bed, 20 cm thick, overlies a thinner, fine-grained bed with well-preserved cross-bedding. Lens cap, 6 cm diameter (MGA 0505500E 7684300N)

Figure 10. Reworked rhyolite tuff in the Bradley Basalt, showing deformed load structures and fine-scale cross-bedding. This 25 cm-thick fine-grained bed shows exceptionally well-preserved sedimentary structures. Lens cap, 6 cm diameter (MGA 0505500E 7684300N)

north of Big Tree Well, all these units have, subsequent to production of the map, been correlated with the Nickol River Formation (Hickman, 1997b). However, in other areas these lithologies are also present in other formations. For example, metamorphosed felsic volcaniclastic rocks (*Asf*) form part of the Cleaverville Formation 5 km west of Wickham, quartzite (*Asq*) is a component of the Ruth Well Formation at Mount Wangee and Mount Hall, and the metamorphosed sandstone unit (*Ast*) locally forms thin beds at or near the base of the Cleaverville Formation.

The metaconglomerate (*Asc*) southwest of Big Tree Well contains angular and subrounded boulders of black chert, quartz–sericite schist, and smaller fragments of fuchsitic schist, and vein quartz. This rock is similar to a metaconglomerate 2 km north of Lower Nickol mining centre on DAMPIER (Hickman, 2001), which consists of angular to subrounded pebbles and boulders (up to 15 cm in diameter) of chert and fuchsitic schist in a poorly sorted sandstone matrix. Both units are currently interpreted to lie at the top of the Nickol River Formation, but indicate local erosion of older components of the Roebourne Group. An alternative interpretation is that they belong to a younger formation that unconformably overlies the Nickol River Formation.

Metamorphosed sandstone, with minor conglomerate and siltstone (*Ast*) forms a low, 5 km long, northeasterly striking ridge north of Big Tree Well. This unit is less than 400 m wide, fault-bound, and separates two large exposures of metabasalt on the northwestern and southeastern limbs of the Prinsep Dome (Hickman, 2001). Stratigraphic relationships are discussed under **Structure**. The metamorphosed sandstone is coarse grained, and includes pebble beds and thin units of ferruginous conglomerate. At the northeastern end of the ridge, a small abandoned quarry (MGA 0502750E 7713800N) exposes metamorphosed sandstone containing lenticular beds of chert-pebble conglomerate. The succession dips south-southeast, but well-preserved cross-bedding reveals that the succession is inverted, and youngs towards the northwest. Similar exposures are present 1 km northeast of the quarry, and may exist on Dixon Island (based on photointerpretation). About 2.5 km to the southwest of the quarry, quartzite (*Asq*) is folded against a major zone of shearing and mylonitization on the southeastern side of the ridge. This zone is interpreted to be a continuation of the Regal Thrust, separating amphibolite facies metabasalt to the southeast from greenschist facies rocks to the northwest (see **Structure**). Thin units of metamorphosed sandstone and siltstone (*Ast*) in association with banded iron-formation and ferruginous chert outcrop 5 km southwest of Wickham, 3 km south of Wickham, and on the southern side of the Cleaverville promontory. The depositional age of sandstone from the Cleaverville locality was interpreted by Nelson (1998, p. 52–55) to be less than 3058 ± 7 Ma using SHRIMP U–Pb zircon geochronology. However, a younger population of detrital zircons with discordant analyses gave a weighted mean ^{207}Pb/^{206}Pb ratio corresponding to a date of 3022 ± 12 Ma, and this could indicate the maximum depositional age of the sandstone. The sandstone also contained older detrital zircons, the oldest having a ^{207}Pb/^{206}Pb model age of 3461 Ma, almost 200 m.y. older than any rock yet identified in the West Pilbara Granite–Greenstone Terrane.

Schistose metasandstone and metasiltstone (*Ass*) form isolated outcrops 2 km southwest of Big Tree Well. The unit includes arkosic and fine-grained ferruginous sedimentary rocks that have been sheared and silicified.

Stratigraphically above these rocks is a unit of metamorphosed felsic volcaniclastic rock (*Asf*) that forms a northerly striking ridge south of Big Tree Well. At the southern end of this outcrop, the unit is composed of quartz–mica schist that locally possesses a flaggy layering. In thin section the rock is dominated by polygonal, granoblastic quartz and lepidoblastic white mica and minor amounts of rutile, apatite, and trace zircon. Nelson (1998, p. 99–101) obtained a SHRIMP U–Pb zircon date of 3269 ± 2 Ma for the rock. In northern outcrops, about 0.5 km south of Big Tree Well, the unit is interbedded with chert, and shows deformed clastic textures. Clasts of chert are stretched parallel to bedding, and produce a tectonic lineation plunging northeastwards. Metamorphosed felsic volcaniclastic rock (*Asf*) also forms units in the Cleaverville Formation 5 km west of Wickham. In outcrop, the western unit is bedded, and contains relict grains of quartz in an altered quartzo-feldspathic matrix. In thin section, it is composed of quartz and sericite with accessory leucoxene, rutile, and graphite. About 25% of the rock consists of detrital quartz grains and lithic fragments. Shard-like textures are also visible. Using the SHRIMP U–Pb zircon method Nelson (1998, p. 120–122) dated the depositional age of the rock at 3015 ± 5 Ma, but two older detrital zircons gave concordant analyses indicating source rocks of c. 3251–3236 Ma. A thin section from the eastern unit indicates that this includes crystal-vitric tuff, with sericitized feldspar and quartz phenocrysts in a laminated sericitized matrix.

About 7 km southwest of Wickham, the felsic volcaniclastic units (*Asf*) are underlain by metamorphosed ferruginous clastic sedimentary rocks (*Asi*). The unit includes metamorphosed shale and minor siltstone with interbedded chert and banded iron-formation. In the Mount Ada area, about 18 km south of Roebourne, units of metamorphosed ferruginous clastic sedimentary rocks (*Asi*) are interbedded with banded iron-formation (*Aci*), jaspilite (*Acj*), and minor felsic volcanic rocks (*Af*), and intruded by sills of dolerite (*Aod*). A thin felsic volcaniclastic unit, 500 m north of Mount Ada, was dated at 3018 ± 3 Ma using SHRIMP U–Pb zircon geochronology (Nelson, 1998, p. 63–65). An adjacent intrusive granophyre was dated at 3014 ± 6 Ma (Nelson, 1997, p. 183–186) using the same method.

Quartzite (*Asq*) forms part of the greenstone succession at Mount Hall and Mount Wangee. The Mount Hall quartzite is bedded but tectonically flattened, and overlies ferruginous chert and komatiite. The most westerly outcrops of the unit, about 1 km west-northwest of Mount Hall, are mylonitized and partly converted to chert. The Mount Wangee quartzite is pale cream, laminated, and interbedded with ferruginous chert and minor grey chert.

Chert (Ac, Acb, Acf, Aci, Acj, Acw, Acx)

Chert is widespread in the greenstones of ROEBOURNE, although units greater than 10 m in thickness are restricted to the Cleaverville – Dixon Island, Point Samson – Wickham – Paradise Well, Weerianna – Carlow Castle, and Mount Ada areas. Most chert units are colour banded at 1–10 mm intervals, with major bedding planes at 10 cm to 1 m intervals. The colours, compositions, and origins of the cherts are extremely varied, and many are interpreted to be secondary silicification products derived from fine-grained clastic sedimentary rocks (including carbonaceous shale), reworked fine-grained felsic tuff, carbonate sedimentary rocks, and intensely brecciated and sheared rocks, especially sedimentary, ultramafic, and mafic volcanic rocks. Primary cherts, formed during deposition, are probably restricted to some units of grey-and-white banded chert (*Acw*) and to some of the iron-rich cherts (*Aci, Acf, Acj*).

Most undivided chert (*Ac*) units are either non-banded or consist of several different interbedded chert types. Brecciation and late quartz veining is common, and many of these internally complex cherts are probably silicified shear zones. Chert of this type is exposed 3 km and 5 km north of Big Tree Well, and 1 km west of Mount Hall. Chert derived from silicification of interflow sedimentary rocks outcrops within a thick basaltic succession 3 km north of Bob Well. Chert of uncertain composition is mapped along the northern coast of Dixon Island, an area not visited during the mapping. Kiyokawa and Taira (1998) mapped the Dixon Island chert as including ferruginous chert, laminated black chert, shale, and reworked felsic tuff with extensive secondary silica enrichment. They reported that the organic carbon content of the black chert is about 1–2% by weight. An underlying vein system of intrusive black chert was interpreted as syn-depositional, and of hydrothermal origin.

Units of black chert (*Acb*), sufficiently large to show on the map, outcrop 1 km south, and 1.5 km southwest of Big Tree Well, and are interpreted to be silicified carbonaceous shales. The chert is banded by weakly defined alternating black and dark grey layers, but some components are homogeneous and have quartz veinlets. Similar Archaean black chert in the east Pilbara (near Marble Bar) contains microfossils (Schopf, 1993), but no work has been reported on the Big Tree Well black chert. Immediately overlying felsic volcaniclastic rock was dated at 3269 ± 2 Ma (Nelson, 1998, p. 99–101) using the SHRIMP U–Pb zircon method.

Ferruginous chert, interlayered with metamorphosed banded iron-formation and fine-grained clastic sedimentary rocks (*Acf*), outcrops from Wickham southwestwards to the western margin of the sheet, around Cleaverville, and at Mount Wangee. The protoliths are interpreted to be iron-rich shale and siltstone, minor carbonate rocks, and BIF.

Banded iron-formation with minor ferruginous chert (*Aci*) forms thick units at Cleaverville, Dixon Island, between Point Samson and Paradise Well, and at Mount Ada. Smaller outcrops are mapped north and south of De Witt Hill, 2 km northeast of Bob Well, and 3 km south of Mount Roe. Iron minerals, predominantly magnetite, hematite, and goethite, make up about 50% of the rock and are interlayered with quartz at 1–10 mm intervals. The rock is typically almost black, and forms units up to 50 m thick in which BIF is interbedded with red jasper, shale, or mudstone. At depth, the shale and mudstone are black or dark grey, but surface exposures are commonly pale grey, brown, or cream to off-white due to bleaching.

Sugitani et al. (1998) presented evidence that banded iron-formation near Roebourne is a shallow-water deposit.

Jaspilite (*Acj*) is a variety of iron formation containing alternating layers of magnetite and red jasper. The only outcrop of the unit *Acj* distinguished on the map is at Mount Ada, although minor jaspilite is also present within banded iron-formation (*Aci*) of other areas.

Grey-and-white banded chert (*Acw*) outcrops between Point Samson and Wickham, 7 km west-southwest of Wickham, 4 km northwest of Roebourne, 6 km north of Roebourne, and 2 km west of Paradise Well. Most of these chert units are probably silicified fine-grained clastic sedimentary rocks or tuff, but some may have originated as primary hydrothermal deposits (Sugitani, 1992). Alternating white and grey layers, typically 1–10 mm thick, are mostly sharply defined but some colour grading is locally present. This may represent graded bedding in the fine-grained clastic protoliths; consistent way-up evidence is rarely visible.

Brecciated chert and totally silicified mafic cataclastic rocks (*Acx*) form ridges between Weerianna and Carlow Castle, and smaller outcrops 2 km and 3 km north of Paradise Well. The Weerianna – Carlow Castle outcrops are associated with shearing and mylonitization along the Regal Thrust, whereas the Paradise Well units lie along a fault on the southeastern limb of the Roebourne Synform (Fig. 4). At Weerianna, the unit is an almost black, cherty microbreccia that is net-veined by quartz with local gossanous lenses. In thin section, the rock is a quartz-rich mylonitic chert, with evidence of intense cataclasis. It consists of a very finely granular, cherty-textured quartz mosaic with a grain size of less than 0.05 mm. Although most of the rock consists of very finely granular-textured quartz, it is transected by some slightly coarser grained quartz veins ranging up to 0.1 mm in width. Much of the quartz forms strongly deformed mosaics, supporting field evidence that the rock is an intensely granulated, mylonitized rock. Angular, turbid inclusions, up to 1 mm in diameter, locally preserve a remnant fragmental texture. Carbonate (probably dolomite) and epidote are disseminated through the rock as small crystals intergrown with the quartz. Many of these crystals have a fine sieve texture and much of the epidote has a turbid character. Euhedral opaque grains (probably pyrite) are also disseminated through the rock. Some quartz veins contain a carbonate with high refractive indices that could be siderite. The rock is transected by narrow veinlets with a microstylolitic character that are generally lined with chlorite and very finely divided opaque material. Chlorite is present as disseminated flakes and fine-grained aggregates. Geochemical analysis of samples of the brecciated chert collected during the mapping gave amounts of Ni, Cr, and V characteristic of mafic igneous rocks.

In the Carlow Castle area the brecciated chert units (*Acx*) consist of intensely brecciated grey, grey-and-white banded, and ferruginous chert intruded by veins of black tectonic chert. Pale grey to cream, and locally green coloured, chert containing a fine-scale, wispy layering is interpreted to be silicified mylonite. Colour variations are interpreted to be due to a range of protoliths for these cataclastic rocks. The Regal Thrust has locally replaced most of the Nickol River Formation, which elsewhere includes various types of chert, metamorphosed clastic sedimentary rocks, metabasalt, and ultramafic rocks. About 1 km west of Carlow Castle green, fuchsitic chert that has been prospected as a potential source of semi-precious stone is probably a sheared and silicified ultramafic rock.

Pilbara Supergroup

Whim Creek Group

The Whim Creek Group (Fitton et al., 1975) has been redefined (Pike and Cas, in press) since publication of ROEBOURNE. However, all references made herein are to the group as it appears on the map legend, unless otherwise specified. The Whim Creek Group is the main component of the Whim Creek greenstone belt (Hickman, 1977). Centred on Whim Creek, the belt is up to 15 km wide, 70 km long, and trends in an easterly to north-easterly direction. On SHERLOCK, the belt is fault-bound against rocks of the De Grey Group to the south and east, and its northwestern margin is a faulted unconformity against rocks of the Caines Well Granitoid Complex. Only the western part of the belt is exposed on ROEBOURNE. South of Mount Fisher, the Whim Creek Group unconformably overlies rocks of the Cleaverville Formation and the Whundo Group. A few kilometres to the east, on SHERLOCK, volcaniclastic rocks near the base of the Whim Creek Group have been dated at 3009 ± 4 Ma (Nelson, 1998, p. 56–58) using the SHRIMP U–Pb zircon method.

On ROEBOURNE the basal formation of the Whim Creek Group is the Warambie Basalt (Fitton et al., 1975). This passes upwards into metamorphosed felsic volcanic and metasedimentary rocks of the Mons Cupri Volcanics (Fitton et al., 1975). In the main part of the Whim Creek greenstone belt, on SHERLOCK, this formation is overlain by coarse- to fine-grained volcaniclastic and sedimentary rocks of the Cistern Formation (Miller and Gair, 1975), which in turn is overlain by fine-grained, deep-water sedimentary rocks of the Rushall Slate (Hickman, 1977). However, the Cistern Formation and the Rushall Slate are absent on ROEBOURNE, leaving the Mons Cupri Volcanics unconformably overlain by pillowed and spinifex-textured ultramafic and basaltic rocks of the Louden Volcanics (Hickman, 1983).

Both the Cistern Formation and the Rushall Slate were originally assigned to the Whim Creek Group (Fitton et al., 1975; Hickman, 1977), but recent evidence (Pike and Cas, in press) has resulted in the separation of these formations, along with the Louden Volcanics and the Mount Negri Volcanics (Miller and Gair, 1975), into the Bookingarra Group (Pike and Cas, in press). Pike and Cas (in press) suggested that the earliest volcanism of the Loudens and Mount Negri Volcanics was synchronous with deposition of the Rushall Slate.

Warambie Basalt (ACw, ACwh, ACws, ACwt, ACwx, ACwy)

Over most of southeastern ROEBOURNE the Warambie Basalt (*ACw*) represents the lowest part of the Whim Creek

Group (Fitton et al., 1975). However, on SHERLOCK, where the formation is much thinner, Smithies (1997) showed that basaltic rocks are locally interleaved with the Mons Cupri Volcanics (*ACf*). Felsic volcanic units also alternate with polymictic basaltic conglomerate of the Warambie Basalt near Webster Well in southeastern ROEBOURNE. In the area between Warambie and Mount Ada, in southeastern ROEBOURNE, the Warambie Basalt unconformably overlies both the Cleaverville Formation (c. 3020 Ma) and the Woodbrook Formation (c. 3115 Ma), and locally includes basal polymictic conglomerate (*ACwx*) containing boulders of metabasalt, felsic volcanic and intrusive rocks, and banded iron-formation. The matrix of this unit is fragmental and composed of altered basaltic material. The Warambie Basalt was deposited on the erosional unconformity that separates the West Pilbara Granite–Greenstone Terrane from the Mallina Basin.

Undivided Warambie Basalt (*ACw*) includes weakly metamorphosed vesicular basalt, basaltic tuff, sandstone, and local conglomerate. Flows of vesicular basalt (*ACwy*), in many areas with pillows or a glomeroporphyritic texture, form the bulk of the formation near Warambie and south of Mount Ada. Closer to the Sholl Shear Zone, in the area northeast of Mount Ada, the lowest parts of the Warambie Basalt are chiefly composed of basaltic tuff and vesicular basalt (*ACwt*) with thick intercalations of sandstone, conglomerate, and semipelitic sedimentary rock (*ACws*). There are no exposures of any of these rocks to the north of the Sholl Shear Zone, supporting evidence from DAMPIER (Hickman, 2001) that faulting along the shear zone, which was mainly strike-slip, also included north-side-up movement. The observation that coarse clastic sedimentary rocks are almost entirely restricted to the area immediately south of the shear zone suggests that the latter coincided with an east–west trending belt of south-facing fault scarps during deposition of the Warambie Basalt. In this environment, the conglomerate and sandstone were proximal alluvial and colluvial deposits derived through active erosion of an upland area to the north. Dolerite intrusions (*Aod*) along the Sholl Shear Zone, combined with locally large volumes of pyroclastic material in the Warambie Basalt to the south, further suggest that deep crustal fracturing along the Sholl Shear Zone may have resulted in a linear belt of fissure eruptions. If dextral movement on the Sholl Shear Zone (see **Structure**) commenced during deposition of the Warambie Basalt, the Mount Ada – Warambie section of the fault would have been in an extensional pull-apart environment that could have promoted local volcanism.

In thin section, the tholeiitic basalt of the formation shows a moderate degree of alteration, including intergranular patches of carbonate, chlorite, serpentine, and zoisite enclosed by an interlocking network of sericitized and carbonated plagioclase.

Pelitic schist with minor chert and metabasalt (*ACwh*) was mapped 1.5 km west of De Witt Hill. The schist overlies basaltic tuff (*ACwt),* and includes thin quartzo-feldspathic beds, which thin section evidence suggests is either altered felsic tuff or metamorphosed volcaniclastic sedimentary rock.

Mons Cupri Volcanics (ACft, ACfw)

On SHERLOCK, the Mons Cupri Volcanics (Fitton et al., 1975) reach a maximum thickness of around 1 km, but on southeastern ROEBOURNE the formation is less than 200 m thick. In outcrops around Webster Well and Warambie the formation is almost entirely composed of rhyolite, rhyolite and dacite tuff, and felsic volcaniclastic rocks (*ACft*). About 7 km west of Warambie, the formation includes a unit of grey-and-white banded chert and silicified tuffaceous siltstone and shale (*ACfw*).

The unit (*ACft*) is well exposed 1.5 km west of Warambie, where rock types include rhyolite, tuff, and volcaniclastic sedimentary rock. In thin section, the rhyolite is an altered rock with plagioclase phenocrysts in a matrix of fine-grained quartz intergrown with irregular patches of sericite and clay. The plagioclase phenocrysts have been largely replaced by finely divided sericite. The tuff is a fragmental rock containing angular clasts and probable pumice lapilli ranging up to a few millimetres in size in a very fine grained, cherty matrix. The clasts and pumice lapilli generally have irregular shapes, and some are shard-like. Most of these have been replaced by a very pale green chlorite. A small number of lithic clasts containing feldspar laths are also present. The volcaniclastic sedimentary rock consists mainly of volcanic rock clasts up to 5 mm in size with a range of textures. Most of the lithic clasts consist of very fine grained plagioclase with a small number of plagioclase and quartz phenocrysts.

About 7 km west of Warambie, the chert unit (*ACfw*) separates felsic volcanic and volcaniclastic rocks (*ACft*) from overlying high-Mg basalt of the Loudens Volcanics, and consists of grey-and-white chert and quartzite overlying silicified fine-grained felsic tuff and tuffaceous siltstone. Fine-scale cross-bedding in less silicified sections of the chert show that the succession youngs southwards towards the Louden Volcanics. In thin section, the rock from immediately beneath the chert contains plagioclase phenocrysts in a fine-grained felsic matrix composed mainly of small, randomly oriented plagioclase laths intergrown with granular plagioclase and quartz. The plagioclase phenocrysts exhibit euhedral to subhedral lath shapes and show only mild alteration to sericite. The rock contains irregular patches and discontinuous vein-like bodies of coarser grained quartz which, in some cases, is associated with small amounts of calcite. Chlorite generally forms pale green interstitial intergrowths with the plagioclase-rich matrix.

Formations stratigraphically overlying the Whim Creek Group

Louden Volcanics (Aeh, Ael, Aes, Aey)

On ROEBOURNE, the Louden Volcanics outcrop south of the Sholl Shear Zone, between Mount Ada and the south-eastern corner of the sheet area. The formation includes high-Mg basalt with well-developed spinifex textures (*Aeh*), and vesicular and aphyric basalt with flows of spinifex-textured basalt (*Aey*). About 1 km south of Warambie, the vesicular and aphyric basalt unit (*Aey*) includes spinifex-textured pillow basalt. Basalt of both types (*Aey*, *Aeh*) typically displays conchoidal fracturing in outcrop. Komatiitic rocks with olivine spinifex texture are rare and form layers that are not sufficiently thick or continuous to be represented at map scale. Thick units of pillow basalt (*Ael*) and metamorphosed sedimentary rocks including sandstone, tuffaceous sandstone, shale, and calcite-cemented volcaniclastic sandstone (*Aes*) outcrop about 4 km southwest of Mount Ada.

The total thickness of the Louden Volcanics in southeastern ROEBOURNE is about 1000 m. The formation is interpreted to unconformably overlie the Mons Cupri Volcanics because this formation is not preserved between Mount Ada and De Witt Hill, and because in most areas flows of the Louden Volcanics dip more steeply than underlying flows of the Warambie Basalt. In thin section, most samples from the Louden Volcanics contain a very fine grained groundmass of devitrified glass, pyroxene, and plagioclase, now partially altered to chlorite, carbonate, Fe-hydroxides, and clay minerals. Phenocrysts of acicular pyroxene up to 10 cm in length are common. In many samples, pseudomorphs after euhedral pyroxene phenocrysts have a distinct chlorite core rimmed by carbonate or clinopyroxene. The original mineralogy was probably of orthopyroxene or olivine, rimmed by clinopyroxene. Some ultramafic cumulates contain abundant phenocrysts of olivine, commonly enclosed by orthopyroxene, which is in turn rimmed by clinopyroxene.

Kialrah Rhyolite (Ak)

The Kialrah Rhyolite (*Ak*), first recognized and defined by Hickman (1997b), is a thick unit of flow-banded and porphyritic rhyolite stratigraphically above the Louden Volcanics. The formation outcrops about 2 km south of Warambie Homestead, and has a visible strike length of 5 km. However, aeromagnetic data and field observations suggest that the formation may be laterally equivalent to undated rhyolite porphyry that intrudes the Whim Creek Group farther east. Contacts between the Kialrah Rhyolite and the Louden Volcanics have not been observed, but flow-banding in the rhyolite is more steeply inclined to the south than the dip of flows in the Louden Volcanics. This indicates an unconformity, but an intrusive relationship is also possible. A sample (GSWA 144261) of the rhyolite that was collected during the mapping was subsequently dated using the SHRIMP U–Pb zircon method (Nelson, 1998, p. 129–132). His preferred interpretation of the 36 analyses on 32 zircons was that the maximum age of the rock was 2975 ± 4 Ma, and that a smaller, younger, population of zircons could mark a disturbance event at 2943 ± 7 Ma. The formation is locally intruded by a gabbro sill (*Aaoo*) that is interpreted to belong to the Opaline Well Intrusion, and the younger zircon ages could record this event.

The rhyolite consists of plagioclase phenocrysts within a fine-grained groundmass consisting of plagioclase laths intergrown with finely granular felsic minerals, including quartz and K-feldspar. The matrix also exhibits a fine, radiating spherulitic texture, with spherulites consisting mainly of K-feldspar. The rock contains irregular patches, up to several millimetres across, of intensely pleochroic green chlorite, which is generally surrounded by finely granular quartz. Titanite, partly altered to leucoxene, is intergrown with the chlorite.

Mafic–ultramafic intrusions

Andover Intrusion (AaAo, AaAob, AaAl, AaAd, AaAp, AaAx, AaAus, AaAy)

The Andover Intrusion is the largest mafic–ultramafic intrusion of the northwest Pilbara, and occupies an area of about 200 km^2 southeast and southwest of Roebourne. No detailed description of the intrusion has been published. Hickman (1983) referred to it as the 'Mount Hall – Carlow Castle Complex', and described it as consisting of sheets of dunite, peridotite, pyroxenite, gabbro, and minor anorthosite. Mapping on ROEBOURNE indicates that the intrusion is a lopolith, or funnel-shaped body, which intruded the Ruth Well Formation and was subsequently intruded by late components of the Harding Granitoid Complex. A monzodiorite that intrudes the Andover Intrusion was dated by Nelson (2001) at 3016 ± 4 Ma using the SHRIMP U–Pb zircon method, indicating that the Andover Intrusion is older than 3016 Ma. Nelson (2001) interpreted slightly younger concordant or slightly discordant analyses from four of the 21 zircon analyses as resulting from loss of radiogenic lead. The $^{207}Pb/^{206}Pb$ model ages of these four zircon grains range between 3001 and 2991 Ma. Therefore, an alternative, if less probable, intepretation of the data is that the age of granitoid intrusion was about 2990 Ma (a common age for granitoid intrusion in the Cherratta and Dampier Granitoid Complexes), and that the c. 3016 Ma population of grains is xenocrystic. In either interpretation the Andover Intrusion is older than 2990 Ma, and therefore older than other dated mafic–ultramafic intrusions of the west Pilbara, which are generally about 2925–2890 Ma (Arndt et al., 1991; Frick et al., 2001). Like the c. 3010 Ma Warambie Basalt, the Andover Intrusion is located near an east–west bend in the otherwise east-northeast striking Sholl Shear Zone, and may have been intruded in a local extensional environment during dextral strike-slip movement.

The Andover Intrusion is elongate east-northeast to west-southwest, and is estimated to have a total thickness of about 3000 m. The northeastern part of the intrusion is dominated by serpentinized peridotite and dunite (*AaAus*), and minor metapyroxenite (*AaAx*), whereas metamorphosed gabbro with minor dolerite, norite, and anorthosite (*AaAo*), and leucogabbro (*AaAl*) are the main components west of the Harding River. The original large-scale layering has been partly obscured by late-stage discordant intrusion of gabbro and leucogabbro, and by fragmentation of parts of the intrusion by granitoid intrusions. Thus, the structure of the intrusion is far more complex than that of the much better documented Munni Munni Intrusion, which lies about 30 km southwest of ROEBOURNE. In the latter, Hoatson et al. (1992) described a lower ultramafic zone of peridotite and pyroxenite, overlain by a thick upper zone of gabbroic rocks. In the Andover Intrusion, however, mapping of layering close to the Harding River indicates that the thick ultramafic zone of the northeast is locally underlain by gabbro. The absence of a lower gabbroic zone east of the Harding River may be due either to removal of the lower gabbro by granitoid intrusion, or to lateral heterogeneity across the intrusion.

Serpentinized peridotite and dunite units (*AaAus)* are relatively massive and form dark coloured hills and ridges. Serpentinization of the peridotite layers has generally completely replaced primary olivine, but opaque minerals commonly define the boundaries of pseudomorphs. Relict olivine and clinopyroxene are locally preserved. Minor mineral constituents of serpentinite are talc, hornblende (after pyroxene), tremolite, chlorite, and biotite. Meta-peridotite, slightly serpentinized (*AaAp*), is restricted to the northeastern part of the intrusion. Metapyroxenite (*AaAx*) generally forms low, weathered outcrops. The rock is fine- to medium-grained, with an allotriomorphic–granular texture, and is chiefly composed of secondary amphibole (actinolite or tremolite) with minor chlorite, talc, and epidote. Relict pyroxene is very rarely preserved. Opaque minerals form anhedral, disseminated grains and discontinuous layers along grain boundaries and cleavage planes.

Metamorphosed gabbro (*AaAo*) and leucogabbro (*AaAl*) are massive, jointed at 0.5 to 2 m intervals, and form dark grey to black, bouldery hills and ridges. A rare, weakly developed mineral layering is generally defined by plagioclase-rich layers 1–10 cm thick. In thin section, 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 gabbro contains minor quartz. Metamorphosed leucogabbro differs from metagabbro in containing more plagioclase. Microscopic examination reveals saussuritized plagioclase, tremolite, clinopyroxene, chlorite, traces of brown hornblende, and variable amounts of calcite.

Metamorphosed gabbro and dolerite containing angular blocks of metabasalt (*AaAob*) outcrops 5 km northwest of Woodbrook. The unit probably formed by fragmentation of basaltic wallrocks followed by injection of gabbro into the resulting breccia. The observation that only basalt forms clasts within the breccia indicates formation more or less in situ.

A rock interpreted to be metamorphosed granophyre (*AaAy*) forms small rubbly outcrops 1.5 km north of Black Hill Well, but the intrusive relationships of this marginal component of the Andover Intrusion to quartz–feldspar porphyry (*Apf*) are unclear.

Opaline Well Intrusion (AaOb, AaOo, AaOd, AaOus)

On Roebourne, the Opaline Well Intrusion intrudes the Whim Creek Group, the Louden Volcanics, and the Kialrah Rhyolite. It is not a single intrusive body, but is a suite of high-level sills between eastern Sherlock and the area south of Mount Ada, an east–west distance of approximately 70 km. On Sherlock there is evidence that the Opaline Well Intrusion pre-dates the Sherlock Intrusion (Smithies, 1998a), and it is interpreted to be of similar age to the Louden Volcanics and Kialrah Rhyolite (c. 2975–2943 Ma, see above). Metabasalt (*AaOb*) resembling parts of the Louden Volcanics is exposed west of Warambie.

Metagabbro (*AaOo*) of the Opaline Well Intrusion differs from metagabbro of the Sherlock Intrusion in that it is typically coarser grained and contains slightly more clinopyroxene, which shows a notably acicular habit. Also, the texture is distinctly inequigranular, with intergranular spaces between clinopyroxene and plagioclase euhedra filled with very fine grained plagioclase, clinopyroxene, quartz, and sericite. In some samples, intergranular quartz and quartz–feldspar granophyric intergrowth comprise up to 10% of the rock. Metadolerite and microgabbro (*AaOd*) forms sills in the Louden Volcanics west of Warambie and west of Mount Oscar.

On Sherlock, gabbroic rock of the Opaline Well Intrusion grades into peridotitic gabbro and peridotite, with an increase in the proportion of clinopyroxene and the addition of olivine and minor ortho-pyroxene. Aeromagnetic data indicate that a large outcrop of massive serpentinite (*AaOus*), about 2 km southwest of Koogebuntare Well, is the only exposure of a 15 km-long ultramafic sill along the southern margin of the Kialrah Rhyolite. In thin section, the rock is a peridotite, and consists mainly of olivine and clinopyroxene crystals showing alteration to serpentine, along with smaller amounts of talc, tremolite, and chlorite. The former olivine and pyroxene form anhedral crystals, although some of the pyroxene has vague prismatic shapes. Serpentine group minerals are also interstitial to the former olivine and serpentine crystals, whereas talc and tremolite are generally pseudomorphs after crystals, or marginal alteration products of crystals. Minor chlorite is also present as pale green, weakly pleochroic aggregates. Rare, intensely pleochroic, reddish-brown biotite crystals are less than 0.2 mm in length. Opaque minerals are disseminated through the rock as euhedral to subhedral crystals and as irregular granular aggregates.

Sherlock Intrusion (AaSo, AaSob, AaSs, AaSuo, AaSy)

The most westerly outcrops of the Sherlock Intrusion are located at Mount Fisher near the eastern margin of Roebourne. Farther east, on Sherlock, the intrusion is exposed along a strike length of 70 km, and it essentially rims the Caines Well Granitoid Complex. Throughout the greater part of the intrusion the main rock type is metagabbro (*AaSo*). This rock is medium- to coarse-grained, massive, and outcrops as dark ridges. In thin section, subhedral to euhedral clinopyroxene is seen to be the main mafic phase, and commonly lies within an interlocking network of plagioclase euhedra or, less commonly, displays a subophitic texture. In some samples, early formed subhedral to euhedral phenocrysts of orthopyroxene were noted. Quartz and patches of quartz–plagioclase granophyric intergrowth, are inter-granular phases that become common in plagioclase-rich leucogabbro, and abundant in granophyric gabbro. Metamorphosed gabbro and minor metadolerite contain-ing angular fragments of metabasalt (*AaSob*) outcrop 2 km east of Mount Fisher. This rock is lithologically similar to metamorphosed gabbro and dolerite (*AaAob*) in the Andover Intrusion.

About 3 km east of Mount Fisher the lower part of the intrusion is composed of weakly metamorphosed plagioclase-bearing olivine clinopyroxenite and olivine gabbro (*AaSuo*). In outcrop, the rock is almost black, and forms low rubbly outcrops partly covered by thin residual calcrete. In thin section, the rock consists mainly of olivine and clinopyroxene anhedra that are poikilitically enclosed by large plagioclase crystals. Under crossed polarizers the plagioclase crystals extinguish over a relatively large area. This produces a typical cumulate texture in which the olivine and clinopyroxene represent the cumulate phase and the plagioclase a later interstitial crystallizing component. Plagioclase shows some alteration to fine-grained clay intergrown with localized birefringent sericite. Olivine shows slight alteration to serpentine along fractures. Much of the plagioclase also has a somewhat turbid character, possibly due to the development of very finely granular epidote. Opaque minerals are disseminated through the rock as small grains and as localized finely granular aggregates intergrown with serpentine developed along fractures in olivine. Some of the disseminated opaque grains have marginal intergrowths of reddish-brown biotite. Minor biotite was also noted as individual crystals intergrown with clinopyroxene. Close to the overlying metagabbro layer of the intrusion, the proportions of plagioclase and pyroxene increase relative to olivine.

Granophyre (*AaSy*) forms the upper part of the intrusion 2 km east-southeast of Mount Fisher. The rock forms low, pale reddish-brown outcrops reflecting its mineralogy of K-feldspar, plagioclase, and quartz. In thin section, the rock consists mainly of a granophyric feldspar and quartz intergrowth containing disseminated feldspar and quartz grains. The feldspar is mainly potash feldspar, although minor plagioclase is also present as prismatic crystals. The large quartz phenocrysts are generally recrystallized, and tend to have concentrations of chloritized biotite around their outer margins. Chlorite is disseminated through the rock as pale green, weakly pleochroic grains and angular aggregates, which are generally thought to represent altered biotite. Opaque minerals are disseminated through the rock as anhedral grains many of which tend to be intergrown with chlorite.

About 1 km northeast of Mount Fisher, the northern margin of the Sherlock Intrusion is composed of plagioclase–hypersthene gneiss (*AaSs*). This unusual rock is interpreted to be a mylonitized gabbro, possibly including amphibolite (*Aba*) that the gabbro intrudes. Aeromagnetic data suggest that the gneiss is adjacent to a concealed easterly striking fault. In outcrop, the plagioclase–hypersthene gneiss unit (*AaSs*) is a finely laminated mafic gneiss containing magnetite-rich layers and blocks of amphibolite. In thin section, the rock consists of a granular mosaic of plagioclase and hypersthene with a typical grain size of about 0.1 to 0.2 mm. In one sample, the hypersthene crystals are larger and have a well-developed sieve texture enclosing plagioclase crystals. The rock is strongly banded. Bands vary between 0.5 and 3 mm, produced by variations in the proportions of hypersthene and plagioclase, and by variations in grain size between bands. The plagioclase tends to have turbid cores produced by alteration to very fine grained, turbid epidote. The plagioclase also shows very minor alteration to sericite or clay. The hypersthene is generally fresh, although it shows some marginal alteration to ill-defined brown phyllosilicates, as well as possible amphibole and a birefringent phyllosilicate. Locally, well-developed reddish-brown biotite is interstitial to the hypersthene crystals. The rock also contains a small number of pale green amphibole crystals. The rock is transected by a few veins, approximately perpendicular to banding, which are filled with epidote and chlorite. Minor opaque minerals are disseminated through the rock as subhedral crystals.

Granitoid rocks

ROEBOURNE contains parts of two granitoid complexes (Harding and Caines Well Granitoid Complexes), but only the former is exposed on the sheet. Additionally, some granitoid intrusions (*Agg*, *Agm*) that are isolated within greenstones, and not obviously related to larger named granitoids, have been mapped lithologically. The Karratha Granodiorite (*Agka*) is not exposed, but is shown on the diagrammatic section. As indicated in the map legend, the age of the granitoids ranges from 3270 Ma to approximately 2970 Ma. Until a granitoid (part of *AgHd*) intruding the Andover Complex was dated (Nelson, 2001) it was assumed that such granitoids and pegmatitic granitoids (*AgHd* and *AgHu*) were younger than 2925 Ma (see **Mafic–ultramafic intrusions**), but the new data now indicate that at least some of these rocks are older than 2990 Ma.

Karratha Granodiorite (Agka)

The Karratha Granodiorite (*Agka*) is not exposed on ROEBOURNE, but is interpreted to underlie the southeastern limb of the Prinsep Dome (Fig. 4 and Diagrammatic section on the map). It is the oldest identified granitoid unit of the West Pilbara Granite–Greenstone Terrane. U–Pb zircon geochronology (Nelson, 1998; Smith et al., 1998) has established that its components crystallized at 3270–3260 Ma, and Sm–Nd isotopic analyses have given Nd T_{DM} model ages of 3480–3430 Ma (Sun and Hickman, 1998). The c. 200 m.y. difference between the emplacement age and the Nd T_{DM} model ages indicates that magma generation involved older crust or enriched lithospheric mantle. A sample (JS17) dated by Smith et al. (1998), contained near-concordant zircon cores with $^{207}Pb/^{206}Pb$ ages up to 3311 Ma, thereby supporting the involvement of older crust in magma generation. Samples collected on DAMPIER show that the Karratha Granodiorite ranges from allotriomorphic granular tonalite to granodiorite (Hickman, 2001).

Unassigned granitoids and felsic intrusive rocks (Agm, Agg, Apf)

North of the Sholl Shear Zone, on both ROEBOURNE and DAMPIER, irregular stocks and sheets of monzogranite and granodiorite (*Agm*) outcrop in greenstones now assigned to the Roebourne Group (Hickman, 1997b). The rocks are typically equigranular, medium grained and tectonically foliated. Compositional banding is visible in many outcrops and minor shear zones are locally present. West of Black Hill Well, monzogranite and granodiorite (*Agm*) may include parts of the c. 3270–3260 Ma Karratha Granodiorite (see above). However, fine- to medium-grained biotite monzogranite locally intrudes the c. 3014 Ma quartz–feldspar porphyry (*Apf*) 1.5 km east of Rea Well, establishing that younger granitoids, probably related to c. 2970 Ma monzogranite of the Harding Granitoid Complex, are also present. A sample of mylonitized granitoid (JS25) from the Sholl Shear Zone on DAMPIER included a range of zircon $^{207}Pb/^{206}Pb$ ages from 2959 to 3044 Ma (Smith et al., 1998). If this mylonitized granitoid were derived from rocks related to adjacent monzogranite and granodiorite (*Agm*), then this unit may also include c. 3015 Ma granitoids belonging to the Harding Granitoid Complex (see below).

Foliated granodiorite with local compositional banding (*Agg*) is exposed south and east of Black Hill Well. Banded granodiorite, 3 km east of Black Hill Well is intruded by gabbro of the Andover Intrusion. At several localities the granodiorite is strongly foliated and contains greenstone xenoliths. The rock has not been dated, but it is similar to parts of the Karratha Granodiorite, and may be of approximately the same age.

Quartz–feldspar porphyry (*Apf*) intrudes the greenstone succession north of the Sholl Shear Zone and north and west of Black Hill Well. It also forms sills 3 km north of Big Tree Well and 3 km northwest of Mount Wangee. A sill in the area north of Big Tree Well was dated at 3018 ± 2 Ma (Nelson, 1998, p. 136–138), and a sample from near Mount Wangee was dated at 3021 ± 3 Ma (Nelson, 1999, p. 157–159), both results using the SHRIMP U–Pb zircon method. On DAMPIER quartz–feldspar porphyry, from a locality 7 km west-southwest of Rea Well, was dated at 3014 ± 2 Ma (Nelson, 1997, p. 179–182), also using the SHRIMP U–Pb zircon method. Contacts between the porphyry and the Andover Intrusion are obscured by scree. Outcrops of the porphyry 1 km west of Rea Well exhibit flow banding, and in thin section this rock contains felsic spherulites. Elsewhere, the porphyry typically contains plagioclase, quartz, and K-feldspar, with minor chlorite, and rare epidote, carbonate, sericite, and zircon. Quartz and plagioclase are highly strained in the sample collected from a locality 7 km west-southwest of Rea Well, and lamellar twin planes in plagioclase are curved and broken. This is attributed to shearing related to movement on the Sholl Shear Zone to the south.

Harding Granitoid Complex (AgHd, AgHm, AgHmh, AgHmx, AgHn, AgHu)

The Harding Granitoid Complex (*AgH*) is almost entirely concealed by Cainozoic alluvial and marine deposits. Aeromagnetic data indicate that it extends approximately 130 km in an east-northeast direction, between Roebourne and Port Hedland, covering the eastern portion of the sheet north of the Sholl Shear Zone. Bouguer anomalies (Blewett et al., 2000) suggest that the complex is 40–80 km wide, including its offshore extent. At the southern margin of the complex, the Sholl Shear Zone is a 1 km-wide belt of mylonitized granitoids and tectonic lenses of sheared greenstones that separates the complex from the Whundo Group, the Whim Creek Group, and, in eastern ROEBOURNE, from the Caines Well Granitoid Complex.

Between White Quartz Hill and the area south of Black Hill Well, the complex is composed of weakly foliated to compositionally banded monzogranite and granodiorite, with minor tonalite (*AgHm*). A sample of massive monzogranite collected 4 km southeast of Black Hill Well was dated at 2970 ± 5 Ma (Nelson, 1999, p. 108–111), using the SHRIMP U–Pb zircon method. This sample also contained a population of zircon xenocrysts dated at about 3018 Ma, which is the approximate age of two older samples collected from the Harding Granitoid Complex (Nelson, 1997, p. 138–141; Nelson, 2001), and similar to the age of quartz–feldspar porphyry intrusions (see above). The rock southeast of Black Hill Well has subsequently provided a Nd T_{DM} model age of 3309 Ma (Hickman, et al., in prep.). This age is similar to a Nd T_{DM} model age of 3276 Ma (Sun and Hickman, 1998) from gneiss of the complex at Forestier Bay, 60 km east of Roebourne, on SHERLOCK. The crystallization age of the Forestier Bay rock was 3014 ± 3 Ma (Nelson, 1997, p. 138–141). At White Quartz Hill, and immediately north of the Sholl Shear Zone, the complex contains foliated hornblende-, diopside-, and biotite-rich monzogranite (*AgHmh*) that has been tectonized to form a feldspar–quartz–diopside gneiss (*AgHn*).

North of Bradley Well, the Sholl Shear Zone contains several outcrops of sheared monzogranite and granodiorite with numerous mafic xenoliths (*AgHmx*) and lenses of metamorphosed gabbro and dolerite (*Ao*).

The Harding Granitoid Complex intrudes the Andover Intrusion. In the vicinity of Mount Gregory, pegmatitic granodiorite and diorite (*AgHd*) has locally assimilated parts of the gabbro in the Andover Intrusion. A sample of monzodiorite collected 1.5 km west of Mount Gregory was dated by Nelson (2001) at 3016 ± 4 Ma using the SHRIMP U–Pb zircon method. Pegmatitic fine- to medium-grained muscovite granite (*AgHu*) forms several small stocks in the Andover Intrusion south of Mount Hall, and is probably related to numerous dykes and veins of pegmatite (*p*) and granite (*g*) in this area. This interpretation implies that the muscovite granite (*AgHu*) is one of the youngest components of the Harding Granitoid Complex because the granite and pegmatite bodies occupy northeasterly striking faults that post-date intrusion of pegmatitic granodiorite and diorite (*AgHd*).

Rocks of shear zones and minor intrusions

Mylonite (Amm)

Mylonite (*Amm*), representing intensely sheared granitoids and greenstones, is found along the Sholl Shear Zone, which is locally up to 2 km wide. The mylonite is dominantly silicic, and represents extremely sheared granitoids, with layers of amphibolite. Good exposures of mylonite are located 5 km west of White Quartz Hill, north of Bradley Well, and in the Black Hill Shear Zone south of Black Hill Well. Mylonite units, too thin to map at 1:100 000 scale, lie along strike-slip faults and thrusts (see **Structure**), and within greenstones they can be mafic in composition.

Metamorphosed mafic intrusive rocks (Ao, Aod, Aog)

Mafic intrusive rocks form dykes and sills within the greenstone belts and the granitoids on ROEBOURNE. Most of these rocks are probably related either to the mafic volcanic rocks of the greenstones or to later layered mafic intrusions. The rocks are typically massive and jointed at 0.5 – 2 m intervals; their resistance to weathering causes the intrusions to form ridges.

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 opaque minerals. Despite saussuritization and carbonation, an original hypidiomorphic texture is generally well preserved.

Metadolerite (*Aod*) generally forms sills or dykes less than 100 m thick, and is vertically differentiated in places. The rock is medium grained, with altered phenocrysts of plagioclase or pyroxene in a groundmass of altered plagioclase laths and pyroxene. Secondary mineralogy is similar to that of the basaltic rocks. Metagabbro (*Aog*) is lithologically similar to gabbro of the mafic–ultramafic intrusions.

Structure

The structural geology of pre-Fortescue Group rocks on ROEBOURNE is best described in relation to the area's regional tectonic setting within the northern part of the Pilbara Craton (Fig. 1). The NGMA geological remapping of the west Pilbara has led to a new tectonic interpretation of the granite–greenstones of the north Pilbara (see **Regional geological setting**). Description of the structure of the area requires reference to the stratigraphy of this part of the West Pilbara Granite–Greenstone Terrane, but for reasons given previously (see **Regional geological setting**) this stratigraphy is not shown on the ROEBOURNE map. Figure 3 presents a tectono-stratigraphic interpretation of ROEBOURNE, based on the recent mapping and geochronology. The tectono-stratigraphic domains shown on Figure 3 are described by Hickman (2001). The greenstone stratigraphy of ROEBOURNE is shown on Figure 4, and summarized in Table 2. Additional information is provided by Hickman (1997, 2001) and Van Kranendonk et al. (in prep.).

The Sholl Shear Zone bisects the WPGGT (Fig. 1), and is a major structural break with a long history of displacement and reactivation (Table 1). Over most of its length (at least 250–350 km, depending on geophysical interpretation) it is a near-vertical zone of mylonite and schist 1000 to 2000 m wide. Dextral displacement (30–40 km) of the c. 3010 Ma Whim Creek Group is seen north of Whim Creek (Smithies, 1998a), and Hickman (2001) mapped dextral displacement of c. 2925 Ma layered intrusions southwest of Roebourne. Other evidence (Van Kranendonk et al., in prep.) indicates that dextral movement was late in the history of the Sholl Shear Zone, and minor compared to earlier sinistral movement which may have been 150–200 km

Stratigraphic differences between rocks north and south of the Sholl Shear Zone are accompanied by Sm–Nd evidence that the Roebourne and Whundo Groups were formed in different tectonic environments (Sun and Hickman, 1998). Additional Sm–Nd data (Van Kranendonk et al., in prep.; Hickman et al., in prep.) support reworking of 3500–3300 Ma crustal material north of the shear zone, but indicate that to the south, only crust younger than c. 3300 Ma existed in the area of the Central Pilbara Tectonic Zone, including the Mallina Basin. This suggests that EPGGT crust, or crust of similar age, underlies the northern area, but must be thin or even absent to the south. Van Kranendonk et al. (in prep.) concluded that the Sholl Shear Zone approximately coincides with a post-3300 Ma terrane boundary, but pointed out that at least 80% of the rocks now separated by the Sholl Shear Zone were formed in approximately their current relative positions, and consequently post-date this old boundary. Thus, the WPGGT is an essentially coherent geological unit that developed across this boundary, and largely concealed the components of two older terranes.

Deformation event D_1 (c. 3160–3130 Ma)

The earliest recognizable tectonic structures in the WPGGT are low-angle thrusts and recumbent folds, apparently produced by southerly directed thrusting. The largest fault is the Regal Thrust, recognized from mapping on DAMPIER (Hickman, 1997a,b, 2001). The Regal Thrust is an early (D_1) layer-parallel shear zone that separates the Nickol River Formation from the Regal Formation over an area measuring 70 km in an east-northeast direction, and 25 km in a north-northwest direction. The thrust is folded by the Prinsep Dome and by the Roebourne Synform (Fig. 4).

Sun and Hickman (1998) found the chemistry of the Regal Formation to be MORB-like, which is inconsistent with a normal stratigraphic position above clastic sedimentary rocks of the Nickol River Formation. They suggested an explanation for this anomaly might be that the formation was obducted onto the Nickol River Formation. In this case, the Regal Thrust would form the base of the obducted slab.

A bedding-parallel tectonic foliation (S_1), preserved in metasedimentary rocks of the Nickol River Formation and in metabasalt of the Regal Formation, is interpreted to have initially formed parallel to the D_1 thrusts, but was reactivated by bedding-parallel shearing during later tectonic events.

D_1 structures have not been recognized in the Whundo Group, suggesting that they formed prior to 3130 Ma. A thermotectonic event in the Karratha Granodiorite at 3160–3150 Ma (Smith et al., 1998; Kiyokawa and Tairo, 1998) may have coincided with D_1.

D_2 (c. 3070–3020 Ma)

Evidence for major strike-slip movement on the Sholl Shear Zone includes the stratigraphic and geochemical differences between the rocks on either side of it (see above), the length and width of the shear zone (described above), and the possibility that the Roebourne Group might be equivalent to the c. 3260–3235 Ma Sulphur Springs Group of the EPGGT (Sun and Hickman, 1998). Measurable strike-slip movement of 30–40 km took place during D_8, and is dextral along the Sholl Shear Zone. The major stratigraphic mismatch between the Roebourne Group and the Whundo Group across the Sholl Shear Zone cannot be explained by this amount of dextral displacement.

Direct evidence for earlier sinistral movement is provided by asymmetric feldspar porphyroclasts within fine-scale lamination in mylonite (*Amm*) in the shear zone (Hickman, 2001). These shear-sense indicators consistently point to sinistral movement along the foliation planes of the mylonite. This lamination was subsequently deformed by tight to isoclinal folds indicating dextral strike-slip movement (Hickman, 2001). Less conclusive evidence for pre-Whim Creek Group sinistral movement is provided by the outcrop distribution of the c. 3020–3015 Ma Cleaverville Formation. A large outcrop of this formation lies immediately south of the shear zone at Mount Ada, whereas outcrops of the same formation immediately on the northern side of the zone are restricted to the Maitland River area (DAMPIER) approximately 60 km to the west. Allowing for the post-3010 Ma dextral displacement of 30–40 km (see above), this observation implies 3020–3010 Ma sinistral displacement of approximately 100 km. Although indicative of substantial sinistral movement, interpretation of this observation is complicated by the fact that the present outcrop distribution of the Cleaverville Formation results from D_6 folding (see below) and post-3015 Ma granitoid intrusion.

Stratigraphic similarities and indistinguishable isotopic data in the Cleaverville Formation on both sides of the Sholl Shear Zone are in marked contrast to the stratigraphic mismatch of older units. This indicates that the period of greatest strike-slip movement occurred prior to deposition of the Cleaverville Formation. SHRIMP $^{207}Pb/^{206}Pb$ model ages on detrital zircons in samples of the Cleaverville Formation (see above) indicate that igneous source rocks for the clastic sediments of the formation included units between c. 3070 and 3020 Ma, in addition to older units such as the Roebourne Group and the Whundo Group. The absence of Whundo Group rocks north of the Sholl Shear Zone suggests that major movement occurred after 3115 Ma. This movement (D_2) may have coincided with igneous activity between c. 3070 and 3020 Ma. Igneous rocks of this age include c. 3068 Ma tonalite in the Cherratta Granitoid Complex (Nelson, 1998, p. 96–98) and c. 3021 Ma intrusive porphyry (*Apf*) on ROEBOURNE (see above).

D_3 (c. 3015–3010 Ma)

At Mount Ada, east-southeasterly trending, upright, tight to isoclinal D_3 folds in the Cleaverville Formation deform a sill of 3014 Ma granophyre (Nelson, 1997, p. 183–186), and these fold structures are unconformably overlain by the c. 3010 Ma Warambie Basalt. The folding is interpreted to be transpressional, and related to sinistral strike-slip movement on the Sholl Shear Zone. As most sinistral movement along the Sholl Shear Zone pre-dated deposition of the Cleaverville Formation, the folding at Mount Ada was formed by a separate event.

D_4 (c. 2990–2960 Ma)

East of Mount Ada the c. 3010 Ma Warambie Basalt succession is tectonically repeated by northerly dipping thrusts. These structures are truncated by the Sholl Shear Zone, and are therefore interpreted to pre-date dextral movement. The thrusts may be equivalent to 'Phase 3' structures that Krapez and Eisenlohr (1998) recognized in the Whim Creek area. Originally easterly trending folds in the Mallina Basin (D_1 of Smithies, 1998b) may belong to the same event. These correlations suggest that D_4 compression and thrusting towards the south occurred between 2990 and 2960 Ma.

D_5 (pre-2950 Ma)

Northerly trending folds recognized in the Mallina Basin (D_2 of Smithies, 1998b; Smithies and Farrell, 2000) and assigned to D_5 by Van Kranendonk et al. (in prep.) have not been recognized on ROEBOURNE.

D_6 (c. 2950–2940 Ma)

The D_6 event formed major northeasterly trending, upright, tight to open folds such as the Roebourne Synform and Bradley Syncline (Fig. 4). These structures are chronologically correlated with major folds in the Mallina Basin (D_3 of Smithies, 1998a), and are equivalent to Phase 4 structures described by Krapez and Eisenlohr (1998). Geochronology in the Mallina Basin (Smithies, 1998b) establishes that the age of these structures is 2950–2930 Ma. The D_6 folds are oblique to the Sholl Shear Zone and to other strike-slip faults in the WPGGT and Central Pilbara Tectonic Zone. The folds are probably transpressional folds within a post-2950 Ma, east–west belt of dextral strike-slip movement.

D_7 (c. 2940 Ma)

Hickman (2001) described the north-northwesterly striking Maitland Shear Zone on DAMPIER as a D_7 structure. This major shear zone appears to have no equivalent structures on ROEBOURNE. On DAMPIER, the Maitland Shear Zone truncates major, northeasterly trending D_6 folds of the Mount Sholl area.

D_8 (c. 2920 Ma)

The main phase of dextral strike-slip movement on the Sholl Shear Zone post-dated deposition of the Whim Creek Group (Smithies, 1998a), but may have commenced during deposition of the Warambie Basalt (see above). On DAMPIER, the Sholl Shear Zone displaces the c. 2940 Ma Maitland Shear Zone (Hickman, 2001), and truncates the Bullock Hide Intrusion, which is interpreted to have an age of c. 2925 Ma. On ROEBOURNE, a subsidiary dextral strike-slip fault, the Black Hill Shear Zone, displaces the Andover Intrusion by 10 km south of Roebourne. As noted by Krapez and Eisenlohr (1998), zircon geochronology on several rock units close to the Sholl Shear Zone has revealed a metamorphic disturbance event at about 2920 Ma. This could have coincided with peak D_8 dextral movement in the area. Minor D_8 structures in the Sholl Shear Zone include dextral drag folding and isoclinal folding of S_2 mylonite lamination, and associated small-scale faulting and brecciation.

D_9 (<2920 Ma)

In southwestern ROEBOURNE, and on DAMPIER (Hickman, 2001), the Sholl Shear Zone and earlier structures are deformed by a conjugate system of north-northeasterly striking sinistral faults and west-northwesterly striking dextral faults. Northeasterly striking faults that deform the Andover Intrusion are assigned to D_9. The precise age of D_9 faults is unknown, but well-developed conjugate structures have not been observed in the Fortescue Group, implying an age between 2920 Ma and 2770 Ma.

Metamorphism

Greenstones of the Roebourne Group north of the Sholl Shear Zone have been metamorphosed to amphibolite facies, whereas south of the shear zone the Whundo Group has been metamorphosed to lower greenschist facies. This difference is attributed to a component of reverse movement on the northerly inclined Sholl Shear Zone.

The granitoid complexes contain greenstone enclaves that are metamorphosed to amphibolite facies, and the granitoids show evidence of retrogression from amphibolite facies.

Mount Bruce Supergroup

Fortescue Group

The Fortescue Group is the oldest of three groups in the Late Archaean to 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. 2770–2680 Ma (Arndt et al., 1991; Nelson et al., 1992; Wingate, 1999). On ROEBOURNE, 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.

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. NGMA mapping in the west Pilbara has provided additional evidence in support of fault-controlled deposition for the Mount Roe Basalt and the Hardey Formation. On ROEBOURNE, pre-Fortescue Group faults such as the Sholl Shear Zone, the Regal Thrust, and the concealed Jones River Fault (Fig. 4) appear to have been reactivated and influenced lower Fortescue Group volcanism and sedimentary deposition.

Mount Roe Basalt (AFr, AFra, AFrc, AFrs)

On ROEBOURNE, undivided rocks of the Mount Roe Basalt principally comprise flows of massive, vesicular, and glomeroporphyritic basalt (*AFr*). 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 which, together with the presence of pillowed basalt, indicates deposition in a subaerial to shallow marine environment. The presence of channel-fill conglomerate and sandstone in the succession confirms this interpretation.

Basaltic agglomerate (*AFra*) is restricted to an outcrop 2 km northeast of Mount Anketell, where it unconformably overlies basaltic tuff (*Abt*) and ferruginous chert (*Acf*) of the Cleaverville Formation. Sedimentary rocks in the formation include polymictic conglomerate interbedded with sandstone (*AFrc*), and interbedded sandstone, conglomerate and shale (*AFrs*). This last unit (*AFrs*) outcrops in a fault zone 5 km west-southwest of Mount Anketell. This northeasterly striking fault zone locally marks the northwestern limit of outcrops of Mount Roe Basalt, and may have produced a southeast-facing fault scarp during deposition of the formation. About 2 km northwest of Mount Anketell, polymictic conglomerate and interbedded sandstone outcrop over an area about 1.5 km^2, and are also located southeast of this fault zone. At the eastern end of this large hilly outcrop, the basal section of the conglomerate contains rounded boulders of basalt and rare metagabbro in a sandy, mafic tuffaceous matrix. These beds are overlain by finer grained conglomerate that, in addition to the basaltic clasts, also

Figure 11. Conglomerate in the Mount Roe Basalt near Mount Anketell. The largest boulders (pale colour) are composed dominantly of monzogranite (MGA 0504150E 7714700N)

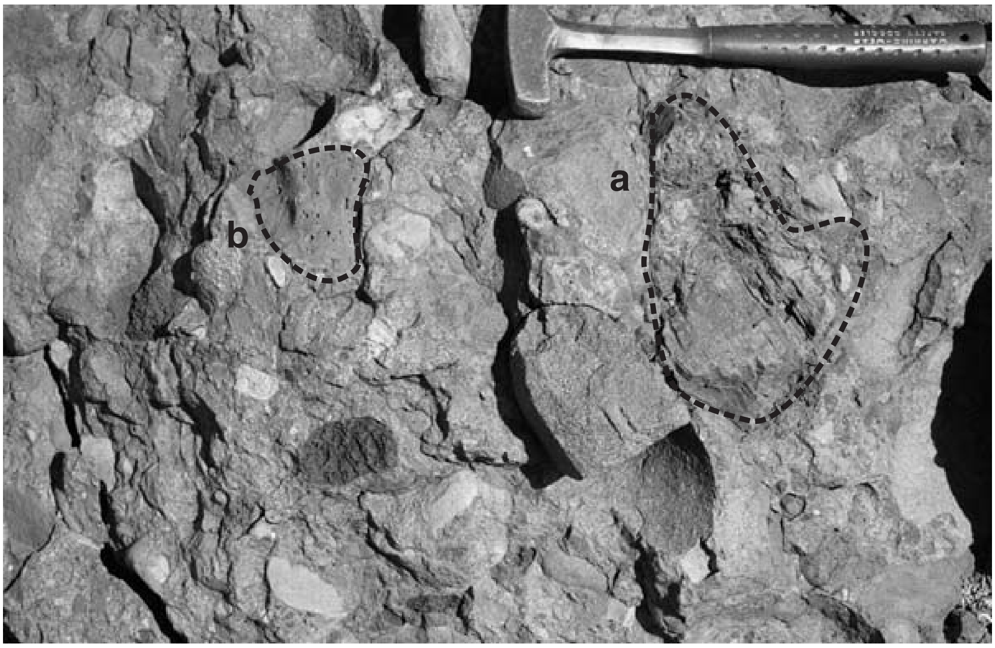

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Figure 12. Conglomerate in the Mount Roe Basalt near Mount Anketell, including small boulders of banded iron-formation (a) and vesicular basalt (b). Other boulders and pebbles include quartzite, metabasalt, monzogranite, and chert (MGA 0504150E 7714700N)

contains boulders and pebbles of vein quartz and quartzite. Close to the stratigraphic top of the 100 m-thick succession, the conglomerate includes beds of fine-grained clastic sedimentary rock, and conglomerate clasts include monzogranite, ferruginous chert, banded iron-formation, and quartzite (Figs 11 and 12). Such boulders in the conglomerate confirm active and deep erosion of the WPGGT during deposition of the Mount Roe Basalt, and transport of granite clasts for at least 10 km, probably from the Dampier Granitoid Complex to the northwest.

About 2 km east of Mount Roe, conglomerate locally forms the base of the formation, and overlies steeply dipping beds of the Whundo Group (chiefly metamorphosed rhyolite and dacite tuff (*Aft*) and well-bedded basaltic tuff (*Abt)* in this area) with high angular unconformity. In this area, which is the type area of the Mount Roe Basalt, the formation is estimated to be at least 500 m thick, and was deposited on very uneven topography. This appears to be well illustrated 3 km south of Mount Roe where a ridge of almost vertically dipping and northerly striking banded iron-formation, chert, and volcaniclastic sandstone (*Aci* on map) protrudes as an inlier through the gently easterly dipping Mount Roe Basalt. The banded iron-formation is interpreted to belong to the Cleaverville Formation, and the fact that its strike is perpendicular to the strike of the Whundo Group to the west and south suggests an unconformity between these two WPGGT units. However, the stratigraphic significance of the outcrop is uncertain due to the absence of a high magnetic anomaly that would be expected if the Mount Roe Basalt were underlain by an extensive unit of banded iron-formation. Alternative explanations could be either that the banded iron-formation and chert form a relatively thin unit in the Whundo Group, locally rotated by a northerly striking fault, or that the outcrop is part of an immense raft of Cleaverville Formation within the Mount Roe Basalt.

Hardey Formation (AFh, AFhc, AFhh, AFhq, AFhs, AFhy)

The Hardey Formation (*AFh*) overlies the Mount Roe Basalt in southern ROEBOURNE, and is mainly composed of poorly to moderately sorted, medium- to coarse-grained arkose, conglomerate, siltstone, shale, and fine- to medium-grained tuffaceous sedimentary rocks and tuff. At the base of the formation are locally lenticular units of polymictic conglomerate (*AFhc*), indicating an erosional break above the Mount Roe Basalt. On ROEBOURNE, the thickness of the Mount Roe Basalt varies from 0 to about 500 m, indicating local erosion of this formation before deposition of the Hardey Formation. On southeastern ROEBOURNE, the Hardey Formation directly overlies the Opaline Well Intrusion and the Kialrah Rhyolite, and on southwestern ROEBOURNE, at the southern margin of the sheet area, the Mount Roe Basalt is less than 50 m thick. Vesicular and non-vesicular clasts of Mount Roe Basalt in polymictic conglomerate (*AFhc*) at the southern end of Pinanular Pool, 2.5 km north of Harding Dam, are evidence for erosion of the Mount Roe Basalt. The basalt makes up about 70% of the clasts in the conglomerate, some of which are rounded boulders up to 0.5 m across; clasts of other rock types include vein quartz, chert, and minor quartzite. The conglomerate and sandstone association in this area resembles an upward-fining alluvial fan deposit (Hickman, 1990). A basalt-boulder conglomerate directly overlies leached, saprolitic Mount Roe Basalt 2 km south of Mount Ada, and was mapped southeastwards for a distance of 2 km. The matrix of the conglomerate is composed of basaltic fragments. More extensive exposures of conglomerate are situated 4 km south-southeast of Mount Ada, but this is not a basal unit. The conglomerate here is a matrix-supported polymictic conglomerate interbedded with sandstone.

Medium- to coarse-grained, poorly sorted sandstone, siltstone, and minor shale and conglomerate (*AFhs*) is the dominant lithological association in the Hardey Formation northeast and southwest of Harding Dam. A unit of siltstone, shale, and minor tuffaceous sandstone (*AFhh*), 20 m thick, is present within the sandstone, siltstone, shale, and conglomerate unit (*AFhs*) 6 km northeast of Harding Dam. About 3 km east-northeast and 8 km east of Harding Dam, the top of the clastic succession is overlain by the Lyre Creek Member (*AFhy*), described by Thorne and Trendall (2001). On southern ROEBOURNE, this member of the Hardey Formation is a succession of basaltic to intermediate tuff and lapilli tuff, with minor tuffaceous sandstone and conglomerate. On PINDERI HILLS, PRESTON, and COOYA POOYA, the formation is composed of intermediate to felsic pyroclastic rocks and volcaniclastic sedimentary rocks. On southern ROEBOURNE, the Lyre Creek Member is overlain by the Cooya Pooya Dolerite (*AFdc* and *AFdcu*). Mapping on COOYA POOYA (Hickman, in prep.) indicates that the Cooya Pooya Dolerite includes extrusive ultramafic rocks. Small, isolated units of quartzite (*AFhq*) within the Cooya Pooya Dolerite are metamorphosed rafts of sandstone from the Hardey Formation.

Cooya Pooya Dolerite (AFdc, AFdcu)

Prior to the recent mapping, the Cooya Pooya Dolerite (*AFdc*) was thought to be a dolerite sill of regional extent, but field and laboratory evidence (Hickman, in prep.) now indicates that the unit is composed of intrusive and extrusive rocks. On southern ROEBOURNE, the basal unit is a fine-grained, silicified, pyroxene-rich, and commonly olivine-bearing rock with quartz xenocrysts (*AFdcu*). 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 dolerite (*AFdc*), and clasts of the ultramafic rock are recorded from the Lyre Creek Member of the Hardey Formation (Hickman, in prep.). This ultramafic unit is now interpreted to be extrusive and, being underlain and overlain by sections of the Hardey Formation, is now interpreted to be part of the Hardey Formation (Hickman, in prep.). The dolerite that forms the upper part of the Cooya Pooya Dolerite, and dykes within the ultramafic unit, is a fine- to medium-grained plagioclase-rich and biotite-bearing dolerite (*AFdc*). Some of the most accessible exposures of the Cooya Pooya Dolerite are at Harding Dam.

Structure

Structures affecting the Fortescue Group include northeasterly striking faults (D_{10}) at Cleaverville, Wickham, and in the area between Woodbrook and Warambie. 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). Major faults, such as the Sholl Shear Zone, also appear to have been reactivated during rifting at c. 2770–2750 Ma (Strong et al., in prep.). The Fortescue Group is gently folded in southern ROEBOURNE, possibly due to post-depositional subsidence within the rift basins.

Archaean–Proterozoic intrusions

Granophyric quartz diorite (Agdqy)

A small area of granophyric quartz diorite (*Agdqy*) forms a ridge immediately to the west of Cossack. In the field, the rock resembles parts of the Gidley Granophyre that outcrop on the Burrup Peninsula, about 50 km to the west. The rock contains partly melted granite xenoliths and large feldspar xenocrysts. On the southern side of Nanny Goat Hill, the granophyric quartz diorite overlies, and is assumed to have intruded, sandstone, conglomerate, and shale that are tentatively assigned to the Mount Roe Basalt (*AFrs*).

Minor intrusions (d, q, g, p, fb)

Massive, medium- to coarse-grained dolerite (*d*) of uncertain, and probably varying, ages forms dykes across most of ROEBOURNE. Almost all the dykes strike northeast, and this suite intrudes the Fortescue Group. In areas of Cainozoic cover, the dykes are recognizable as magnetic lineaments. Numerous dykes and veins of pegmatite (*p*) and granite (*g*) intrude the Andover Intrusion south of Mount Hall, and are probably related to younger granitoids in the Harding Granitoid Complex, in particular pegmatitic muscovite-bearing granitoid (*AgHu*). The dykes occupy northeasterly striking faults that post-date intrusion of metamorphosed pegmatitic granodiorite and diorite (*AgHd*), and are probably of D_9 age (see **Structure**). Quartz veins (*q*) of unknown age outcrop in many parts of ROEBOURNE. Quartz veins typically intrude faults, and are up to 20 m thick, but are lenticular along strike. Large quartz veins (*q*) are present along the Sholl Shear Zone, for example at White Quartz Hill, and mineralized quartz veins intrude the Andover Intrusion south of Carlow Castle, and at the Andover lead mine (not shown on the map), 4 km north-northwest of Woodbrook. Silicified fault breccia (*fb*) mapped along a northerly striking fault immediately north of Wickham is a massive, grey chert breccia.

Cainozoic rocks

Cainozoic deposits cover about 50% of ROEBOURNE, and overlie mainly granitoid units. Three main categories of Cainozoic units are present: Eocene to early Pleistocene clastic and chemical deposits that have been eroded by the present drainage system; recent alluvial, colluvial, eluvial, and eolian deposits; and recent marine, estuarine and coastal eolian deposits.

Eocene to early Pleistocene deposits

Clastic and chemical deposits (Czaa, Czab, Czaf, Czag, Czak, Czc, Czrf)

Eocene to early Pleistocene clastic and chemical deposits have been eroded by the present drainage system. Dissected deposits of Cainozoic alluvium (*Czaa*) are preserved in small deltas where the George and East Harding Rivers discharge into lagoons along the coast. Upstream, high-level alluvial gravel deposits (*Czag*) are exposed in beds up to 5 m thick in the banks of larger drainages. These old alluvial deposits form a concealed part of the regolith in the coastal plain, and have locally been used as a source of gravel for road construction. They are typically overlain by overbank (*Qao*) deposits (see below), and are related to finer grained deposits of consolidated alluvial sand, silt, and clay with a gilgai surface (*Czab*) that occupy abandoned alluvial channels on floodplains. Calcrete of alluvial origin (*Czak*) is best developed along the upper reaches of Jones River, where the catchment area is dominated by mafic and ultramafic rocks of the Fortescue Group. Dissected colluvium, containing clay, silt, sand, and gravel (*Czc*) was mapped 2 km southeast of Wickham. Ferricrete (*Czrf*) is locally developed on and adjacent to banded iron-formation and ferruginous chert (*Aci, Acf*) between Point Samson and Paradise Well. A related alluvial deposit containing pisolitic limonite (*Czaf*) outcrops in dissected mesas between 1 and 3 km northeast of Paradise Well. This rock is similar to the Eocene Robe Pisolite in the western part of the Pilbara Craton.

Recent deposits

Alluvial, colluvial, eluvial, and eolian deposits (Qaa, Qal, Qac, Qao, Qaoc, Qab, Qas, Qw, Qwb, Qc, Qcq, Qrg, 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 sand and gravel in levees and sandbanks (*Qal*) is exposed along the lower sections of major drainages such as the Harding and Jones Rivers. 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 deposits in shallow depressions. These deposits form where floodwaters have temporarily ponded before evaporating, or where local heavy rain has resulted in small playa systems. Where numerous closely spaced small claypans are present in areas of alluvial sand, silt, and clay on floodplains (*Qao*), these deposits and the lacustrine or claypan deposits (*Qac*) are combined and mapped as mixed floodplain and claypan deposits (*Qaoc*). Coastal sand deposits of mixed alluvial and eolian origin (*Qas*) form irregular low dunes and sandbanks within and along the inner margins of lagoons. These deposits are most extensively developed where deltas enter lagoons and alluvial deposits have been eroded, probably by a combination of wind and wave action, and then redeposited along the coast.

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 ROEBOURNE, occurring on scree slopes, and in deposits of coarse, pebbly sand fringing the hills. Colluvial fans commonly exhibit a well-defined radial drainage system of small gullies that originate from adjacent hills, whereas 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 quartz veins (*q*), and therefore composed entirely of quartz fragments, it is mapped as *Qcq*. Eluvial sand over granitoid rocks (*Qrg*) is a quartzofeldspathic residual deposit derived from underlying granitoid bedrock or nearby outcrops. Eolian sand (*Qs*) forms unstable dunes in the vicinity of Wickham. The sand is red to yellow due to iron staining of quartz grains and contains few or no shell fragments (unlike sand of the coastal dunes).

Marine, estuarine, and coastal eolian deposits (Qhmm, Qhms, Qhmu, Qpmb)

Quaternary deposits of marine, estuarine, and eolian origin form in the coastal belt of lagoons, mangrove swamps, and sand dunes, and on islands immediately off the coast. The oldest deposit is a siliceous limestone consisting of lime-cemented, shelly sand, dune sand, and beach conglomerate (*Qpmb*). This limestone is commonly exposed as rock platforms, reefs, and offshore bars within the tidal zone, but it is also preserved inland, where it forms old coastal dunes and strand lines. Unconsolidated shelly sand (*Qhms*) forms coastal dunes and old beach deposits. At Cleaverville, this unit was mined as a source of limesand (Hickman, 1983).

Tidal mudflat deposits are composed of supratidal to intertidal silt and mud (*Qhmu*), and mud and silt in tidal creeks fringed by stands of mangroves (*Qhmm*). The lagoonal mudflats are highly saline due to slow evaporation of ponded seawater, whereas the mud and silt deposits of the mangroves are less saline due to better drainage and repeated flushing by tides.

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 southwest of ROEBOURNE at Whundo and Yannery Hill on PINDERI HILLS, and these deposits were subsequently mined. The distribution and geology of metallic mineral deposits in the west Pilbara is summarized by Ruddock (1999).

Gold

West and southwest of Roebourne, gold has been mined at Weerianna, Carlow Castle, Fortune – Good Luck, and Sing Well. Except for the Fortune – Good Luck mineralization, all these deposits are situated in sheared mafic or ultramafic rocks of the Roebourne Group, within or immediately beneath the Regal Thrust (see **Structure**). Although the age of the Regal Thrust is interpreted to be 3160–3130 Ma, at least some of the gold mineralization appears to be younger and related to reactivation during later events. At Carlow Castle, for example, the main vein system strikes north, at an oblique angle to the silicified shear zone in metasedimentary and mafic rocks of the Nickol River Formation immediately to the north. The workings on the northern side of Cherratta Road are based on steeply inclined limonitic quartz veins that strike north and dip 75° to the east within brecciated metabasalt. About 300 m to the east, old workings immediately south of the road follow a 0.5 to 1 m-wide lode that dips southwestwards at between 45° and 75° within metabasalt. The oxidized supergene mineralogy of the deposits is limonite, cuprite, malachite, and azurite, but chalcocite, covellite, bornite, and chalcopyrite were identified in the workings at about 20 m depth. Descriptions of the workings are provided by Finucane et al. (1939).

The Fortune and Good Luck deposits are situated about 3–4 km south of Carlow Castle, and are closely associated with metagabbro of the Andover Intrusion. The Fortune group of workings lies on an easterly striking fault zone within the gabbro, and therefore gold mineralization here post-dates the Andover Intrusion. Production data for the deposits are provided by Ruddock (1999).

About 7 km west-southwest of Carlow Castle, the Sing Well workings focused on an east-northeastward striking belt of faulting and shearing immediately beneath the Regal Thrust. On ROEBOURNE, the mineralization is hosted by talc–carbonate schist intruded by felsic dykes. Lodes consist of ultramafic schist with gossanous quartz veinlets; a sample (GSWA 116996) from one of these lodes contained 60 g/t Au.

The Weerianna mining centre is situated 4 km west of Roebourne, with one of the the larger mines (Hillside) being located at the northern end of a chert breccia (*Acx*) ridge, a few hundred metres south of the North West Coastal Highway. Here, gold occurs in quartz veins and veinlets within mafic and ultramafic schist containing talc–chlorite(–carbonate). The veins strike between north and east-northeast, and surface inspection indicated that the main ore zone dips 70° to the east. A sample of gossan collected from the mine dump during mapping contained 10.4 g/t Au, 3.9 ppm Ag, 1.10% Co, 0.64% As, and 0.74% Cu. Other mines in the group were based on northeasterly striking quartz veins through sheared mafic and ultramafic rocks. Descriptions of the old workings are provided by Finucane et al. (1939).

Most gold mines of the Lower Nickol mining centre, southwest of Big Tree Well, are located on DAMPIER, but the more easterly workings extend onto ROEBOURNE. Primary gold mineralization of these easterly workings, northeast of the Lydia mine (DAMPIER), was in northeasterly striking lodes and quartz veins within schistose metasedimentary rocks. At the Lydia mine, a 15–20 cm-wide quartz vein dips 80° towards 155° through arenaceous schist. The Lower Nickol gold deposits lie beneath the Regal Thrust, and on the southern side of a later east-northeasterly striking shear zone that extends northeast to Dixon Island. This late faulting probably took place between the D_6 and D_8 deformation events (see **Structure**).

Copper and lead

Copper was mined at Carlow Castle, southwest of Roebourne, between 1899 and 1957. During this period, total recorded production was 165.63 t of copper from 1066.97 t of ore, and smaller tonnages were obtained from nearby Au–Cu workings at Fortune and Good Luck (Ruddock, 1999). All these deposits are in faults and minor shear zones veined by quartz. Descriptions of the deposits are provided by Finucane et al. (1939) and Hickman (1983). About 1 km south of Weerianna Hill, the Lilly Blanche mine produced 1030.25 t copper ore containing 193.01 t copper (Marston, 1979). The mine (not shown on the map) exploits a cupriferous quartz–limonite vein in metamorposed leucogabbro. Smaller copper workings are present at the Ena mine a few hundred metres to the south of the Lilly Blanche (Marston, 1979; Ruddock, 1999).

A prospective area for Cu–Pb–Zn mineralization lies along the Orpheus fault system within the Whundo Group. At Orpheus (DAMPIER), close to the western boundary of ROEBOURNE, Dragon Resources discovered Cu–Zn(–Ag–Au) mineralization in 1995 (Ruddock, 1999). The present mapping on ROEBOURNE has revealed that the Orpheus mineralization extends at least 2.5 km east-northeast to the Bradley Well area. Samples of gossan and quartz (GSWA 127364–127369) contained up to 14.5% Zn, 2.2% Pb, 840 ppm Ag, 1.1 g/t Au, and 0.2% Cu. Cu–Zn mineralization along the Orpheus fault system takes the form of sulfide lenses and sulfidic quartz veins in sheared metabasalt. The age of the faulting is about 2950–2920 Ma (D_6–D_8), but the Cu–Zn mineralization may have been tectonically mobilized from concealed volcanogenic massive sulfide (VMS) deposits in the Whundo Group.

Lead has been mined at the Andover lead mine (not shown on the map), about 3.5 km northwest of Woodbrook. The deposit was first discovered in 1872, and forms a prominent northerly striking quartz–pegmatite vein through granite and gabbro. Galena is still visible in the old workings, and other minerals include sphalerite, smithsonite, and malachite (Ruddock, 1999). Recorded production between 1948 and 1952 was 44.17 t of lead. Richards et al. (1981) dated the galena at 2026 Ma, but this age may be too young due to contamination by relatively young radiogenic lead.

Copper–nickel(–platinum group elements)

The Andover Intrusion is similar in size to the Munni Munni Intrusion, which contains substantial platinum group element (PGE) mineralization (Ruddock, 1999). However, exploration of the Andover Intrusion between 1986 and 1988 failed to find PGE mineralization (Ruddock, 1999). The reason for this is uncertain, although the present mapping has shown that prospective contacts between ultramafic rocks and gabbro in the Andover Intrusion are locally intrusive rather than various levels in a layered series.

Vanadium–titanium

Titaniferous magnetite layers in the Andover Intrusion southwest of Roebourne have been explored for vanadium and titanium, but the deposits were too small and discontinuous for economic mining (Ruddock, 1999). The deposits were recently quarried as a source of heavy aggregate to protect submarine natural gas pipelines on the Northwest Shelf.

Asbestos (chrysotile)

Several old workings and test pits for chrysotile are located in serpentinized peridotite of the Andover Intrusion. Archer (1979a) stated that only minor production has been recorded.

Semi-precious stone

Bright green chert has been excavated near Carlow Castle as a source of ornamental stone. The chert is in sheared rocks of the Nickol River Formation adjacent to an ultramafic unit within the Regal Formation. The green colour of the chert is due to a chromium impurity.

Pegmatite minerals

Southeast of Roebourne, near Mount Hall, pegmatite dykes within the Andover Intrusion have been mined for beryl (Ellis, 1962), tantalum, and tin (Hickman, 1983). The dykes strike northeast within the ultramafic zone of the intrusion, and are related to larger bodies of intrusive granite belonging to a late phase of the Harding Granitoid Complex.

Sand

Eolian sand has been obtained from sand pits 3 km north of Wickham, possibly for house foundations and fill.

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. About 2 km west of Wickham there is a large rock quarry in the Mount Roe Basalt. This operation has supplied ballast material for the Robe River Railway and for a variety of other local uses (Archer, 1979b).

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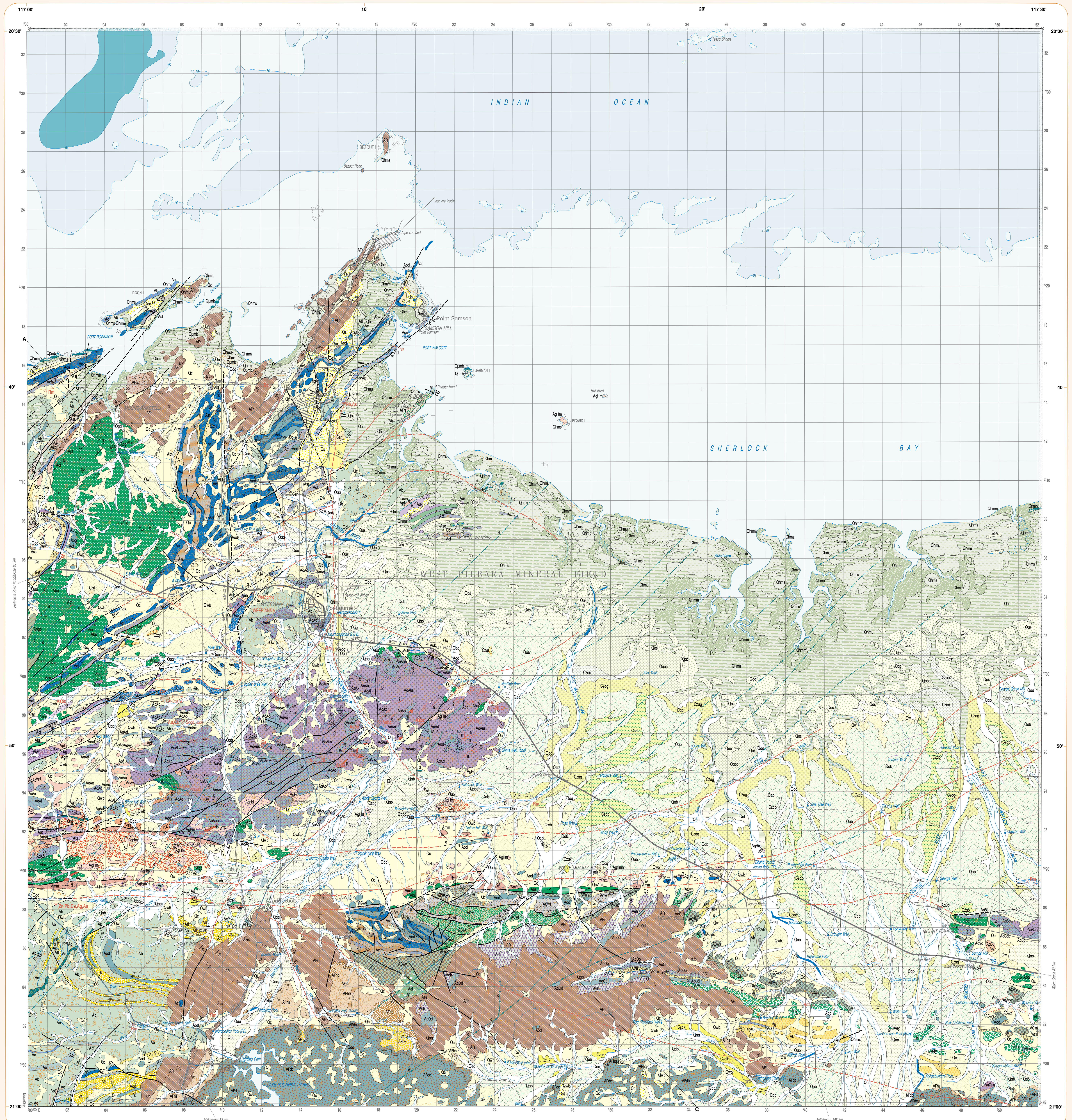
Appendix

Gazetteer of localities mentioned in the text

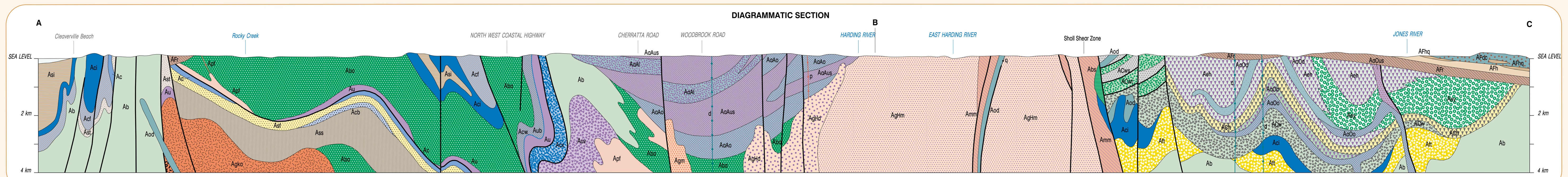
Locality	*MGA coordinates* *Easting*	*Northing*
Andover lead mine	510520	7691475
Big Tree Well	501650	7708250
Black Hill Well	505038	7693455
Bradley Well	537838	7682455
Carlow Castle	506884	7698925
Cleaverville	502900	7716400
Cossack	519600	7713400
De Witt Hill	535000	7688200
Dixon Island	506000	7719000
Fortune (Au–Cu)	507849	7696935
Good Luck (Au–Cu)	507989	7697655
Good Luck Well	570635	7683845
Harding Dam	510900	7680250
Koogebuntare Well	551100	7679900
Lilly Blanche mine	512000	7702650
Lower Nickol mining centre (DAMPIER)	497300	7705500
Lydia mine (DAMPIER)	499500	7706500
Mount Ada	516838	7686555
Mount Anketell	506900	7713800
Mount Fisher	556713	7683468
Mount Gregory	513100	7693450
Mount Hall	520838	7701355
Mount Oscar	532250	7687500
Mount Roe	508938	7686355
Mount Wangee	520500	7709200
Nanny Goat Hill	519700	7713900
Orpheus (DAMPIER)	499700	7687300
Paradise Well	504000	7700800
Point Samson	520500	7718600
Rea Well	504200	7718600
Roebourne	515138	7703155
Sing Well	497129	7694805
Warambie	538838	7683755
Webster Well	551650	7682800
Weerianna	510138	7703855
Weerianna Hill	512538	7703955
White Quartz Hill	529638	7690055
Wickham	514000	7714000
Woodbrook Homestead	512300	7788200

ROEBOURNE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



DIAGRAMMATIC SECTION



QUATERNARY — CAINOZOIC

Qhmm	Marine mud and silt; intertidal with mangroves
Qhms	Shelly sand in coastal dunes and old beach deposits; contains Anadara granosa
Qhmu	Silt and mud in supratidal to intertidal flats and lagoons
Qpmb	Coastal limestone — lime-cemented shelly sand, dune sand, and beach conglomerate
Qaa	Alluvial sand and gravel in rivers and creeks; clay, silt, and sand in channels on floodplains
Qal	Alluvial sand and gravel in levees and sandbanks associated with deltas
Qac	Clay and silt in claypan and coastal lacustrine deposits
Qao	Overbank deposits; alluvial sand, silt, and clay on floodplains adjacent to main drainage channels
Qaoc	Alluvial sand, silt, and clay; mixed floodplains deposits (Qao) characterized by numerous small claypans
Qab	Alluvial sand, silt, and clay in floodplains, with gilgai surface in areas of expansive clay
Qas	Coastal sand deposits of mixed alluvial and eolian origin
Qw	Low-gradient sheetwash deposits — silt, sand, and pebbles in distal outwash fans; no defined drainage
Qwb	Sand, silt, and clay in distal outwash fans, with gilgai surface in areas of expansive clay
Qc	Colluvium — sand, silt, and gravel in outwash fans; scree, talus; proximal mass-wasting deposits
Qcq	Quartz debris adjacent to large quartz-veins
Qrg	Quartzofeldspathic eluvial sand, with quartz and rock fragments; overlying and derived from granitoid rock
Qs	Eolian sand — red-yellow, wind-blown sand; local sand ridges
Czaa	Consolidated alluvial sand, silt, and clay; dissected by present-day drainage
Czab	Variably consolidated alluvial sand, silt, and clay, with gilgai surface, in abandoned alluvial channels; locally dissected by present-day drainage
Czaf	Pisolitic limonite deposits, developed along palaeodrainage lines; dissected by present-day drainage
Czag	Alluvial gravel deposits; unrelated to recent drainage; dissected
Czak	Dissected valley calcrete; massive, nodular, and cavernous limestone; variably silicified
Czc	Colluvium — dissected consolidated clay, silt, and sand, and gravel deposits; derived from adjacent rock outcrop
Czrf	Ferricrete; includes ferruginous duricrust and pisolitic ironstone; residual origin; dissected by present-day drainage
d	Dolerite dyke, interpreted beneath regolith from aeromagnetic data where dashed
q	Quartz vein
g	Granite vein
p	Pegmatite
fb	Fault breccia along or adjacent to faults; silicified

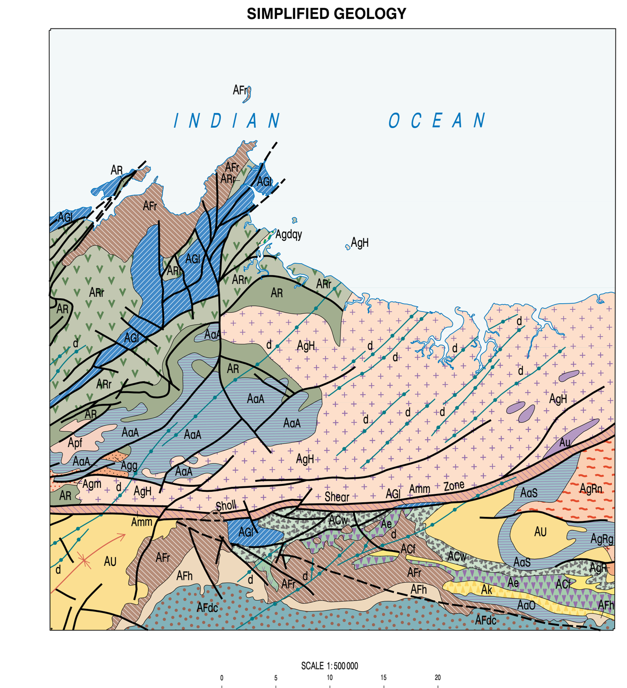
PHANEROZOIC — ARCHAEAN

Aqday Granophyric quartz diorite

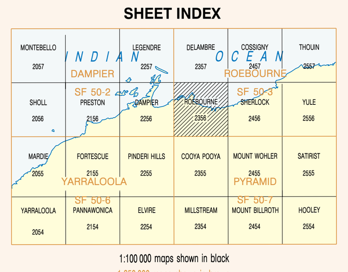
Map symbols

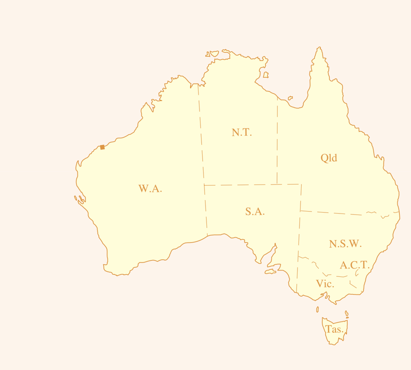
Geological boundary — exposed; concealed	
Fault — exposed; concealed; concealed, interpreted from aeromagnetic data, position uncertain; mylonite; horizontal relative displacement	
Fold, showing axial trace and generalized plunge direction — anticline; exposed, concealed; syncline; exposed, concealed	
Small-scale fold axis, showing trend and plunge — S-vergence	
Bedding, showing strike and dip — inclined; vertical; overturned	
Igneous layering, showing strike and dip — inclined	
Way-up indicator — pillow structure; sedimentary structure; graded-bedding; cross-bedding	
Metamorphic foliation, showing strike and dip — inclined; vertical	
Cleavage, showing strike and dip — inclined	
Shear-sense indicator — sinistral	
Lineation, showing trend and plunge — inclined	
Aeromagnetic lineament	
Isotopic age determination site with identification number	127320
Highway with national route marker; bridge	
Formed road	
Major track	
Track	
Fence, generally with track	
Railway	
Powerline, generally with track	
Townsite — population between 1000 – 10 000	WICKHAM
Townsite — population less than 1000	Roebourne
Homestead	
Building	
Yard	Yd
Microwave repeater station	
Horizontal control; major, minor	
Contour line, 20 metre interval	80
Watercourse with ephemeral pool or waterhole	P
Bathymetric contour (m); accurate, inferred	10
Gas pipeline	
Water pipeline	
Bore, well	B W
Windpump	
Dam, tank	Dam T
Rockhole, soak	Rockhole Soak
Rock, exposed	
Abandoned	(abd)
Position doubtful	(PD)
Prominent submerged reef	
Mining centre	WEERIANNA
Mine (gold, unless otherwise indicated)	Fortune
Opencut	
Quarry or pit	
Prospect	
Made ground	
Mining area — ore stockpiles	
Geochemical anomaly from gossan assay (>1000 ppm; except for Mo and W >50 ppm; Bi, Ag >100 ppm; Au >500 ppb)	*
Mineral occurrence	•
Arsenic	As
Asbestos, chrysotile	Asbc
Chromium	Cr
Copper	Cu
Corundum	Crn
Gemstones	Gs
Gold	Au
Iron	Fe
Lead	Pb
Nickel	Ni
Road material	Rm
Rock, crushed aggregate	Rc
Sand	Sv
Silver	Ag
Titanium	Ti
Vanadium	V
Zinc	Zn

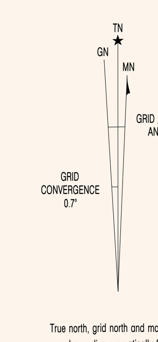
SIMPLIFIED GEOLOGY



SHEET INDEX







True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 1999 and moves easterly by about 0.1° in 2 years.

Department of Industry and Resources
CLIVE BROWN, M.L.A. MINISTER FOR STATE DEVELOPMENT
JIM LIMERICK DIRECTOR GENERAL

Geological Survey of Western Australia
TIM GRIFFIN DIRECTOR

NGA
PRODUCT OF THE NATIONAL GEOSCIENCE AGREEMENT

SCALE 1:100 000

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

TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM
BATHYMETRIC DATUM: LOWEST LOW SEA LEVEL

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

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

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

Geology by A. H. Hickman, 1996–97
Edited by N. Tetlaw and C. Brien
Cartography by D. Ladbrook and B. Williams
Topography from the Department of Land Administration Sheet SF 50-3, 2356, with modifications from geological field survey
Bathymetric data supplied by the Department of Transport, and is not to be used for navigation purposes
Published by the Geological Survey of Western Australia. Digital and hard copies of this map are available from the Information Centre, Department of Industry and Resources, 100 Plain Street, East Perth, WA, 6004. Phone (08) 9222 3459, Fax (08) 9222 3444
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The recommended reference for this map is:
HICKMAN, A. H., 2000, Roebourne, W.A. Sheet 2356: Western Australia Geological Survey, 1:100 000 Geological Series

ROEBOURNE

SHEET 2356 FIRST EDITION 2000
Version 2—August 2003