EXPLANATORY NOTES

Department of Mineral and Petroleum Resources

ROEBOURNE
1:250 000 SHEET
WESTERN AUSTRALIA

SECOND EDITION

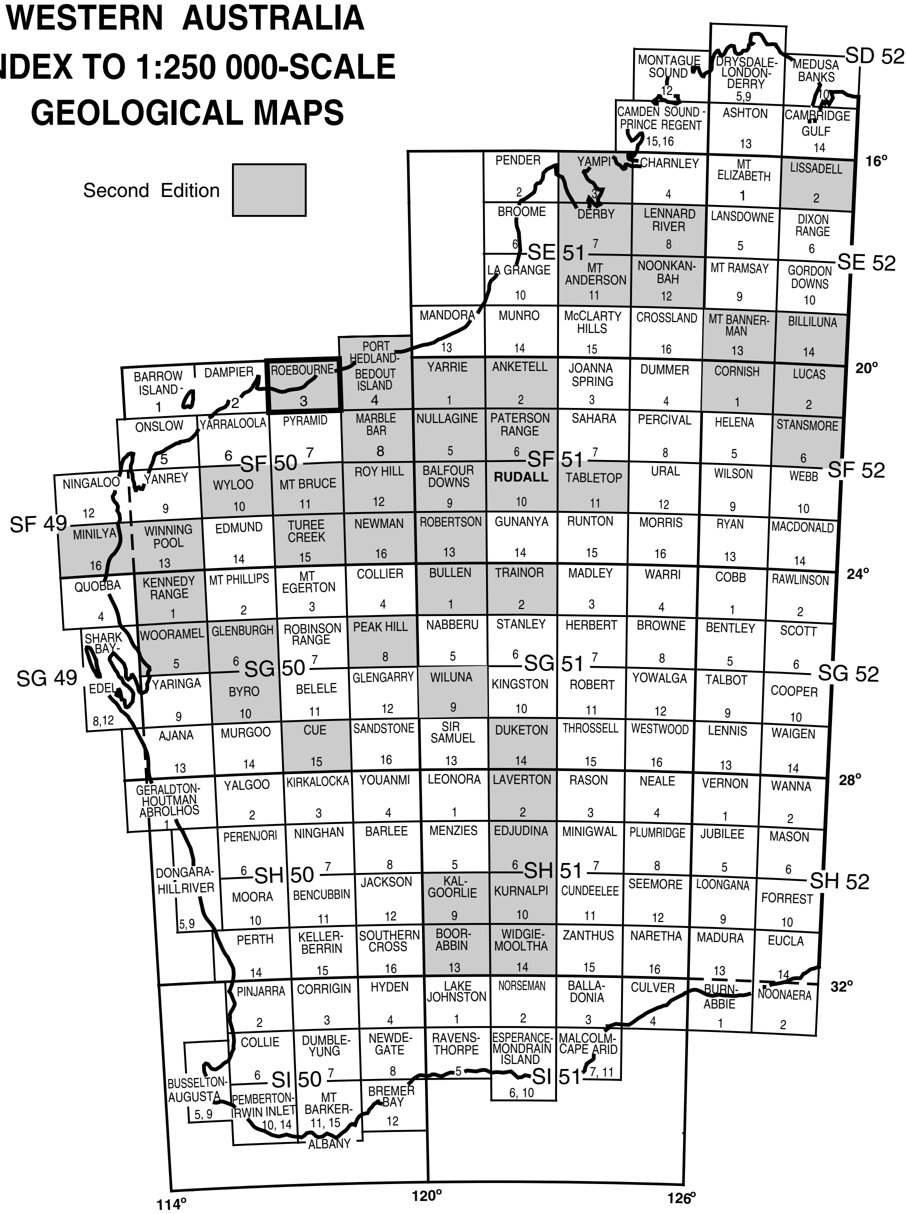
1:250 000 GEOLOGICAL SERIES

SHEET SF 50-3 INTERNATIONAL INDEX

Geological Survey of Western Australia

WESTERN AUSTRALIA
INDEX TO 1:250 000-SCALE GEOLOGICAL MAPS

Second Edition



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
1:250 000 GEOLOGICAL SERIES — EXPLANATORY NOTES

ROEBOURNE

WESTERN AUSTRALIA

SECOND EDITION

SHEET SF 50-3 INTERNATIONAL INDEX

by

A. H. HICKMAN AND R. H. SMITHIES

Perth, Western Australia 2001

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by A. H. Hickman and R. H. Smithies

ABSTRACT

The ROEBOURNE 1:250 000 sheet is located in the northwestern part of the Archaean Pilbara Craton, and covers parts of the West Pilbara Granite–Greenstone Terrane (WPGGT), Mallina Basin, and northern exposures of the Hamersley Basin.

The stratigraphic succession in the WPGGT commenced shortly before 3270 Ma, with deposition of volcanic and sedimentary rocks of the Roebourne Group. 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 volcanic, 3125–3115 Ma Whundo Group by the Sholl Shear Zone, a major fault zone interpreted to involve sinistral strike-slip movement of at least 200 km. 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 sinistral strike-slip movement took place before 3020 Ma. However, a later phase of dextral movement, involving 30–40 km displacement of the Mallina Basin succession, occurred at about 2920 Ma.

The volcanic and sedimentary rocks of the Mallina Basin unconformably overlie the Cleaverville Formation and Whundo Group. The volcanic Whim Creek Group is c. 3010 Ma and is unconformably overlain by the volcanic and sedimentary, c. 2975–2950 Ma Bookingarra Group. Both groups were faulted during dextral movement along the Sholl Shear Zone. The central and southeastern parts of the Mallina Basin are composed of the De Grey Group, dated at between 2990 and 2940 Ma. Major episodes of granitoid intrusion occurred between 3015 and 2930 Ma, and layered mafic–ultramafic intrusions intruded the area at c. 2950–2925 Ma.

A total of nine deformation events are recognized prior to earliest deposition of the c. 2770–2760 Ma 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 development of the Sholl Shear Zone, and 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.

In 1872 mineralization was first discovered on ROEBOURNE, and between 1872 and 1888 copper and gold were mined. Subsequent mineral exploration has revealed many more deposits of gold, copper, lead, zinc, nickel, and vanadium–titanium. Small-scale production of pegmatite minerals and semi-precious stones 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, De Grey Goup, Fortescue Group, tectonic events, mineralization

INTRODUCTION

The ROEBOURNE* 1:250 000 map sheet (SF 50-3) is bounded by latitudes 20°00'S and 21°00'S and longitudes 117°00'E and 118°30'E (Fig. 1). The towns of Roebourne and Wickham, and the coastal village of Point Samson, are in the southwest of the sheet area, and the settlement of Whim Creek lies in the central southern part. The North West Coastal Highway connects the major town of Karratha, to the west of ROEBOURNE, with Roebourne, and continues east, through Whim Creek, and on to the major town of Port Hedland, to the east of ROEBOURNE. The unsealed Roebourne–Wittenoom road joins the North West Coastal Highway about 25 km to the southeast of Roebourne, and links that highway with the abandoned town of Wittenoom, about 250 km to the southeast. The Great Northern Highway passes through the southeast corner of ROEBOURNE, connecting Port Hedland with Newman, about 320 km to the south of the sheet area.

Pastoral stations on ROEBOURNE include Mount Welcome, Karratha, Warambie, Pyramid, Sherlock, Mallina, Mundabullangana, Boodarie, and Indee. The northernmost portion of the Yandeearra Aboriginal Reserve, belonging to the Mugarinya Aboriginal Community, lies in the southeastern part of ROEBOURNE, on the west side of the Yule River.

The discoveries of auriferous quartz to the west of Roebourne in 1877 (Maitland, 1909) and at Mallina Homestead in 1888 were amongst the first in Western Australia. The copper mine at Whim Creek is perhaps the most famous deposit on ROEBOURNE.

CLIMATE AND VEGETATION

ROEBOURNE has a semi-arid climate with an average rainfall of between 250 and 400 mm. However, total precipitation is extremely variable from year to year, being largely dependent on the passage of tropical cyclones through the area between December and April. Such cyclones generally develop off the northwest Kimberley coast and move southwestward parallel to the Pilbara coastline. Some continue westward into the Indian Ocean, and have no effect on the Pilbara, but others swing southward and southeastward, crossing the coast and bringing rapid, heavy rainfall and strong winds to country along their paths. Rainfall in excess of 100 mm in 24 hours is common during the passage of a cyclone. Outside the cyclone season, longer periods of low to moderate rainfall commonly occur during May and June. This precipitation is associated with southeasterly moving cloud banks, related either to the northern margins of low-pressure systems or to 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). Flora is closely 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 intertidal zones are fringed by low, shrubby mangrove of *Avicennia marina* and *Rhizophora mucronata*. Storm beaches and dunes of shelly sand support vines and rhizomatous grasses, whereas farther inland, dwarf shrubs (*Acacia* species) and grasses (e.g. *Triodia pungens*) populate these sandy units.

Extensive river floodplains contain poorly drained, red earthy sands, red earths, and expansive silty clay (gilgai). Beard (1975) described this country as short grass savanna

* Capitalized names refer to standard map sheets. Where 1:100 000 and 1:250 000 scale sheets have the same name, the 1:250 000 sheet is implied.

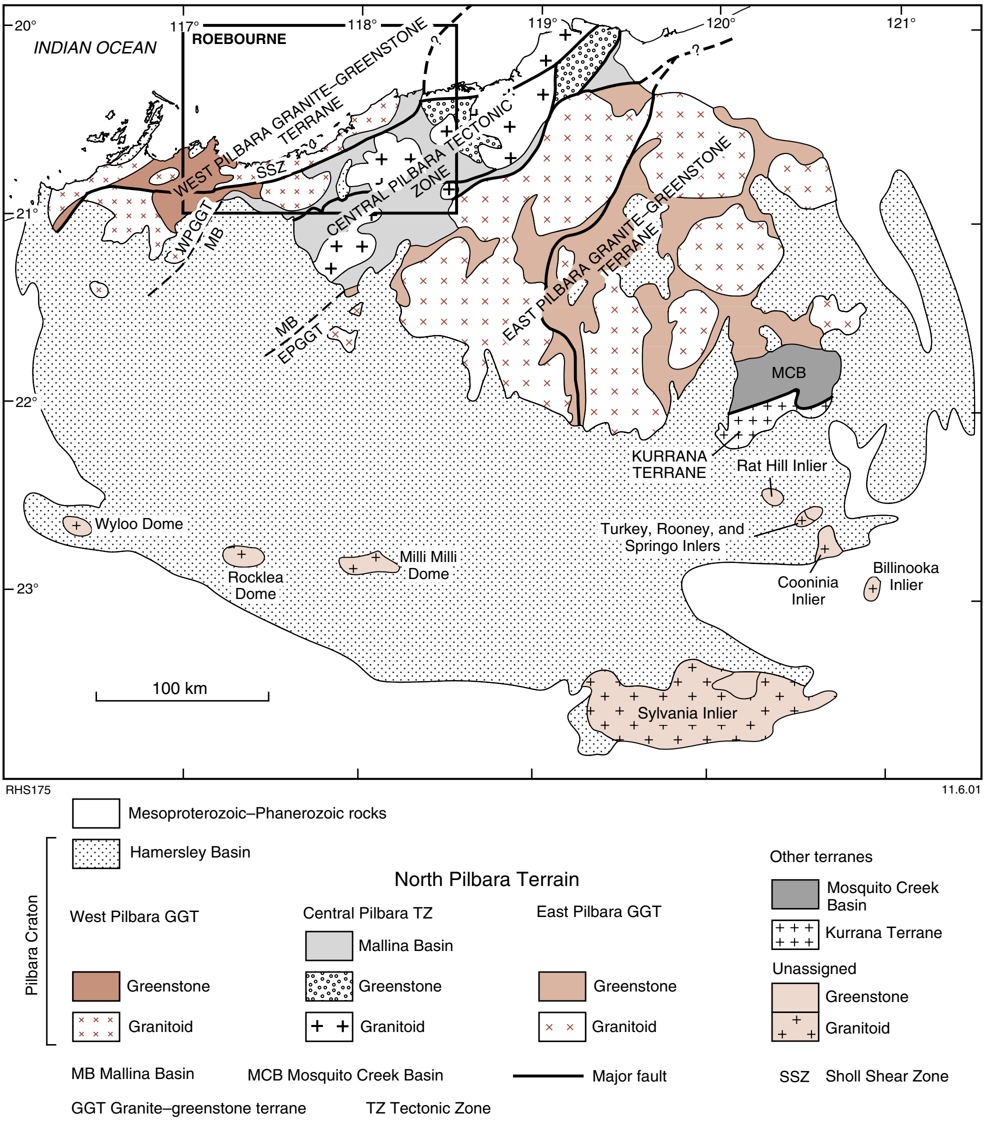

Figure 1. Regional geological setting of ROEBOURNE

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.

Low hills and ridges, corresponding to outcrops of metamorphosed volcanic and sedimentary rocks ('greenstones'), are dominated by spinifex and scattered shrubs. Here, trees and other grasses are concentrated along the banks of rivers and creeks.

PHYSIOGRAPHY

Over half of ROEBOURNE is covered by part of the North West Shelf section of the Indian Ocean. A series of islands lies parallel to the west Pilbara coastline that trends in an east-

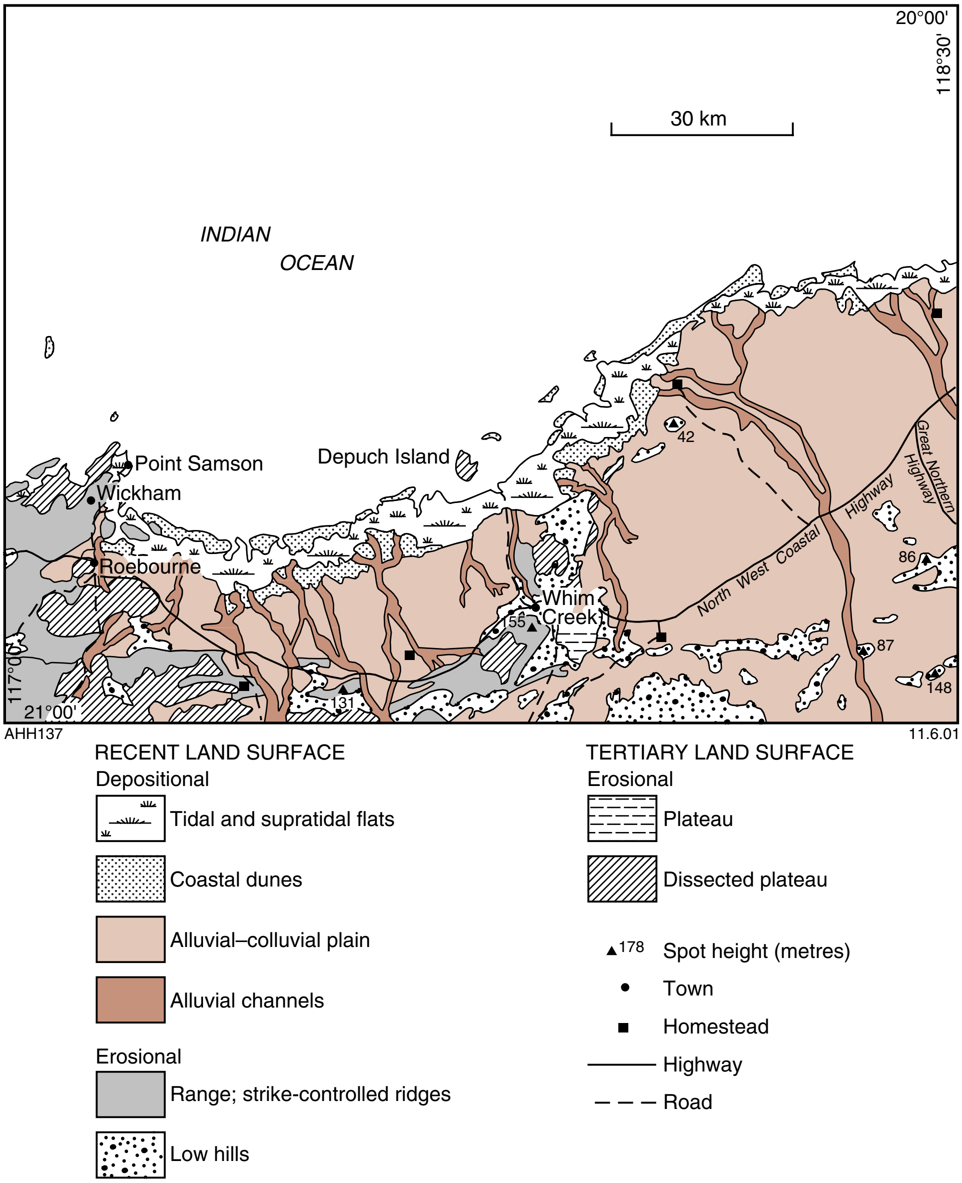

Figure 2. Physiography and access

northeast direction across the southern part of ROEBOURNE. The largest and most prominent of these is Depuch Island, which covers an area of about 10 km^2. Figure 2 summarizes the major physiographic divisions of ROEBOURNE, and closely follows divisions previously used by Hickman (1983). The area's physiography is mainly the product of the erosional and depositional processes during the Cainozoic, 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, form 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 run from hilly areas close to the coast, but others are distributary channels of deltas. The best examples of deltaic deposits are located in eastern ROEBOURNE, along the lower reaches of the Yule and Turner rivers. East-southeasterly trending longitudinal dunes, up to about 15 m in height, are found on the Yule River floodplain in the southeastern part of the sheet area.

From west to east, the main watercourses are the Harding, East Harding, Little Sherlock, Sherlock, Peawah, Yule, and Turner rivers. The rivers and larger creeks occupy wide alluvial channels containing unconsolidated sand and pebble beds.

Erosional land surfaces are separated into four 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’ by Campana et al. (1964). These remnants are preserved only in the more elevated areas of ROEBOURNE, and are underlain by rocks relatively resistant to erosion, such as basalts of the Fortescue Group and Mount Negri Volcanics, 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 stata, the dissected plateau contains steep V-shaped valleys, gorges, nick-points, dendritic drainage patterns, and abrupt margins. However, where the underlying rocks are more steeply dipping, variations in resistence to weathering result in dip slopes and some strike control of drainage. The plateau division, which is distinguished southeast of Whim Creek, shows only limited evidence of dissection of the ‘Hamersley Surface’.

PREVIOUS INVESTIGATIONS

Geological interest in the west Pilbara dates back to 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). Early geological investigations of the area are summarized in the first edition explanatory notes for ROEBOURNE (Ryan, 1966). More recent accounts are given in Smithies (1997b, 1998a), Hickman (1999), and Smithies et al. (1999), and references therein, and are summarized below.

Woodward (1911) placed all sedimentary components of the Whim Creek Group into the Nullagine Beds. These beds included all the older, post-granite, sedimentary and volcanic rocks of Western Australia and were considered to be Palaeozoic in age. David (1932) reassigned the beds to the Proterozoic, whereas Finucane and Sullivan (1939) correlated the upper sedimentary part of the Whim Creek Group with the Archaean 'Mosquito Creek Series'.

Ryan and Kriewaldt (1964) suggested that the volcano-sedimentary stratigraphy of the western Pilbara region developed as a single subsiding trough in which clastic material was derived from essentially contemporaneous, stable volcanic margins. The northeastern margin lay in the Mons Cupri – Roebourne region whereas the Teichmans region (SATIRIST 1:100 000 map sheet) represented the southeastern margin. The entire volcano-sedimentary sequence was redefined as the Roebourne Group, and appears as such on the first edition of ROEBOURNE (Ryan et al., 1965). The group was equated with the 'Warrawoona succession' of the east Pilbara.

Further mapping of the western Pilbara region (Fitton et al., 1975) led to a major revision of the stratigraphy. Felsic to intermediate volcano-sedimentary rocks on SHERLOCK (1:100 000) were considered to be much younger than those of the 'Warrawoona succession', and were redefined as the 'Whim Creek Group'. Voluminous basalts (including high-Mg basalts of the Negri Volcanics), which overlie felsic to intermediate rocks in the Whim Creek area, were excluded from the group based on locally unconformable contact relationships. An angular unconformity was identified in the southeast of the Whim Creek greenstone belt, between low-grade metamorphic rocks (Warambie Basalt), considered to represent the base of the Whim Creek Group, and amphibolite facies rocks, considered to correlate with the Warrawoona Group of Hickman and Lipple (1975).

A thick but poorly outcropping sequence of shale and fine-grained to coarse-grained sandstone, immediately to the south of the Whim Creek greenstone belt, was called the Mallina Formation, and was correlated with shale around the Whim Creek mine in the upper part of the Whim Creek Group (Fitton et al., 1975). Sandstone beneath the Mallina Formation was called the Constantine Sandstone, and was thought to be a facies equivalent of tuffaceous and clastic units below the shale at Whim Creek. This increased the outcrop extent of the Whim Creek Group beyond the confines of the (later defined) Whim Creek greenstone belt, and a suggested correlation of the Mallina Formation with Hickman and Lipple's (1975) Mosquito Creek Formation, of the eastern Pilbara, gave the group regional significance.

Hickman (1977, 1983) remapped the Whim Creek area and redefined the Whim Creek Group. He suggested that the Mallina Formation and Constantine Sandstone were older than the Whim Creek Group, and placed them in the Gorge Creek Group, which separated the redefined Whim Creek Group from the Warrawoona Group. Subsequent studies (Krapez, 1984) confirmed earlier suggestions (Fitton et al., 1975) of a regional unconformity within the Gorge Creek Group, leading Hickman (1990) to relocate the Mallina and Mosquito Creek Formations and the Lalla Rookh and Constantine Sandstones into what he termed the De Grey Group. However, it has recently been suggested that, in the western part of the Pilbara Craton, rocks of the De Grey and Whim Creek Groups are time equivalent facies of the same depositional basin (Smithies, 1997b; Smithies et al., 1999), supporting earlier stratigraphic correlations by Fitton et al. (1975) and Horwitz (1990).

REGIONAL GEOLOGICAL SETTING

ROEBOURNE is located in the northwestern part of the Pilbara Craton (Fig. 1). The Archaean rocks of the craton can be divided into two components — granite–greenstone terrain of the North Pilbara Terrain, which formed between c. 3600 and c. 2800 Ma (Hickman, 1983, 1990; Barley, 1997), and unconformably overlying volcano-sedimentary sequences (Mount

Bruce Supergroup) of the c. 2800–2400 Ma Hamersley Basin (Trendall, 1995). The North Pilbara Terrain contains five lithotectonic elements (Van Kranendonk et al., in prep.), the two most northwesterly of which, the West Pilbara Granite–Greenstone Terrane (WPGGT) and the Mallina Basin, are exposed on ROEBOURNE (Fig. 1). ROEBOURNE also covers the lower formations of the Hamersley Basin succession.

In the north and northeast of the craton, the East Pilbara Granite–Greenstone Terrane (EPGGT) consists of large domal granitoid–gneiss complexes partially surrounded by belts of tightly folded and near-vertically dipping volcanic and sedimentary rocks that are typically metamorphosed at the greenschist facies (i.e. greenstones). In the WPGGT, however, the granitoid–gneiss complexes are not domal, but intrude the greenstone belts along more discordant contacts.

The stratigraphy and major structures on ROEBOURNE are shown on the interpretative bedrock geological map on ROEBOURNE, and the geological history of the area is summarized in Table 1. The stratigraphic succession in the WPGGT commenced with the deposition of the Roebourne Group shortly before 3270 Ma. This group is separated from the 3125–3115 Ma Whundo Group by the Sholl Shear Zone, which is a major fault zone interpreted to involve strike-slip movement of about 200 km (Hickman, in prep.a). Unconformably overlying the Roebourne and Whundo Groups is the 3020 Ma Cleaverville Formation consisting of banded iron-formation (BIF), 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. However, evidence from ROEBOURNE and DAMPIER (Hickman, 1997, 2001; Smithies, 1998a) shows that a later phase of dextral movement, involving 30–40 km displacement, occurred at about 2920 Ma.

The volcanic and sedimentary rocks of the Whim Creek greenstone belt unconformably overlie the Cleaverville Formation and Whundo Group. The Whim Creek Group (as redefined by Pike and Cas, in press) is c. 3010 Ma in age, and is unconformably overlain by the c. 2975–2950 Ma Bookingarra Group (Pike and Cas, in press). The central and southeastern parts of the Mallina Basin are composed of the De Grey Group, dated at between 2990 and 2940 Ma (Smithies et al., 1999). Parts of the Bookingarra and De Grey Groups are considered to be laterally equivalent.

The Fortescue Group of the Hamersley Basin succession unconformably overlies all the groups mentioned above. Published geochronology (Arndt et al., 1991; Wingate, 1999) indicates that deposition commenced at about 2770 Ma. 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.

TECTONIC EVOLUTION

The structural geology of ROEBOURNE is controlled by the location of the area on the northwestern margin of the Pilbara Craton. By c. 3270–3250 Ma, when the oldest preserved rocks of ROEBOURNE — the Roebourne Group and the Karratha Granodiorite — were formed, the EPGGT was already a relatively rigid cratonic nucleus to the southeast (Van Kranendonk et al., in prep.). Tectonic processes operating between c. 3160 and 2920 Ma (Table 1) involved episodes of northwest–southeast or north–south extension and compression 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. Most granitoids in the WPGGT were intruded between 3015 and 2970 Ma, a

Table 1. Summary of the geological history of ROEBOURNE

Age (Ma)	*Geological event*
3724–3310	Formation of EPGGT sialic crust (not exposed in WPGGT)
3300–3250	Rifting on the northwestern margin of the EPGGT (possibly related to a subduction zone to the northwest); 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 southeast of the Roebourne Group (possibly an arc environment); intrusion of c. 3100 Ma granitoids; sinistral movement on the Sholl Shear Zone
3070–3050	Intrusion of tonalite
3070–3020	D_2: Culmination of sinistral strike-slip movement along the Sholl Shear Zone; upright, tight to isoclinal 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 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 De Grey Group and Bookingarra Group in the 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; erosion
2955–2945	Intrusion of Peawah Granodiorite and Portree Granitoid Complex into rocks of the Mallina Basin
2945–2940	Renewed extension across the Mallina Basin and redeposition within the Mallina Basin
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: Strike-slip movement on the Maitland Shear Zone, and along faults within the Cherratta Granitoid Complex
c. 2925	Emplacement of layered mafic–ultramafic intrusions, followed by intrusion of granite
c. 2920	D_8: Dextral strike-slip movement along the Sholl Shear Zone, and other east–west 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 (outside ROEBOURNE)
545–65	Palaeozoic and Mesozoic erosion
55–present	Uplift and dissection of plateau surface, deposition of Cainozoic units

period that coincides with felsic volcanism in the Whim Creek and Bookingarra Groups on the northwestern margin of the Mallina Basin. The alignment of structures and linear zones of magmatism in the WPGGT are here attributed to deep rifting, after deposition of the Roebourne Group, and possibly initiated by a mantle plume (Van Kranendonk et al., in prep.).

The geological evolution of the WPGGT has previously been attributed to subduction-related environments. Krapez and Eisenlohr (1998) proposed that the Roebourne Group formed in ophiolitic, island-arc and intra-arc environments, whereas they interpreted the Whundo Group to be of continental back-arc origin. However, evidence that the Roebourne Group was deposited on, or immediately adjacent to, older crust, probably the EPGGT, precludes an oceanic island-arc setting. This evidence includes Nd T_{DM} model ages of between 3494 and 3479 Ma from the Karratha Granodiorite (Smith et al., 1998), which is intepreted to be consanguinous with felsic volcanic rocks in the Roebourne Group, and by Nd T_{DM} model ages of c. 3430 Ma from the Nickol River Formation of the Roebourne Group (Sun and Hickman, 1998). The c. 200 Ma difference between crystallization ages and the Nd T_{DM} model ages indicates that magma generation involved older crust or enriched lithospheric mantle. The Roebourne Group, like the Sulphur Springs Group in the EPGGT, may be the product of a mantle plume erupted beneath, and contaminated by, continental crust of the EPGGT (Van Kranendonk et al., in prep.). The c. 3130–3115 Ma Whundo Group has provided Nd T_{DM} model ages of 3250–3150 Ma (Sun and Hickman, 1998). The relatively small difference between the depositional age and the Nd T_{DM} model ages indicates that the Whundo Group is unlikely to have been deposited on thick crust older than the Roebourne Group (Sun and Hickman, 1998). However, the volcanic rocks of the Whundo Group are calc-alkaline (Glikson et al., 1986), were contemporaneous with granitoid intrusion between c. 3130 and 3090 Ma (Nelson, 1997, 1999; Smith et al., 1998), and contain xenocrystic zircon as old as 3449 ± 5 Ma (Nelson, 1996). These features establish some degree of derivation from older crust. The present interpretation is that the Whundo Group was deposited in a northeasterly trending rift basin between the EPGGT to the southeast and a proto-WPGGT (Roebourne Group and Karratha Granodiorite overlying older crust) to the northwest.

The evolution of the Mallina Basin is discussed by Smithies et al. (1999) and Smithies and Champion (2000), who suggested an intracontinental rift setting punctuated by at least three periods of magmatism and deformation.

ARCHAEAN ROCKS

PILBARA CRATON

Based on correlations between well-exposed rock successions in the eastern part of the craton and lithologically similar sequences in the western part (Fitton et al., 1975; Hickman, 1983), the greenstones were collectively assigned to the Pilbara Supergroup by Hickman (1983). Four lithostratigraphic groups were defined, recording about 600 m.y. of greenstone evolution. From oldest to youngest, these include the predominantly mafic and ultramafic volcanic rocks of the Warrawoona Group, and the predominantly sedimentary and felsic volcanic rocks of the Gorge Creek, De Grey, and Whim Creek Groups. All the Pilbara granite–greenstone rocks on ROEBOURNE have been metamorphosed.

Recent mapping and sensitive high-resolution ion microprobe (SHRIMP) U–Pb dating have led to major revisions of the stratigraphy of the Pilbara Craton that are of particular relevance to the geology of ROEBOURNE. Two new groups (Roebourne and Whundo) have been defined in the western part of the craton for rocks that were formerly part of the Warrawoona Group

(Hickman, 1997), and these comprise the bulk of the outcropping rocks of the Pilbara Supergroup in the western part of ROEBOURNE. Early correlations between rocks of the Whim Creek Group, in the central southern part of the sheet area, and De Grey Group, in the southwest of ROEBOURNE (Fitton et al., 1975), have been largely substantiated (Smithies et al., 1999).

Since the second edition of ROEBOURNE was published (Hickman and Smithies, 2000), the Whim Creek Group has been divided, with the addition of the Bookingarra Group (Pike and Cas, in press). Table 2 shows this revision, but these Notes describe the stratigraphic succession as presented on the map.

Roebourne Group (*AR*)

Table 2 summarizes the lithostratigraphy of the Roebourne Group (Hickman, 1997). Field relations and geochronological data have established that basal mafic and ultramafic metavolcanic rocks of the Ruth Well Formation are the oldest preserved components (Hickman, 1997). These rocks are undated, but must be older than c. 3270–3250 Ma, the age of conformably overlying felsic metavolcanic and metasedimentary rocks of the Nickol River Formation and coeval, intrusive granitoid rocks of the Karratha Granodiorite (Nelson, 1998; Smith et al., 1998; Hickman, 1999). The Ruth Well Formation includes metabasalt, serpentinized peridotitic komatiite, talc–chlorite schist, grey-and-white banded chert, and black chert. The overlying Nickol River Formation contains grey-and-white banded chert, ferruginous chert, fine-grained clastic sedimentary rocks, quartzite, felsic volcanic rocks, metamorphosed carbonate sedimentary rocks, and conglomerate.

The Regal Formation overlies the Nickol River Formation and has been assigned to the Roebourne Group (Hickman, 1997). This stratigraphic assignment was based on the lithological similarity of the Regal Formation (peridotitic komatiite, metabasalt, and chert) to the Ruth Well Formation. However, the contact between the Regal Formation and the Nickol River Formation is invariably tectonized. Hickman et al. (2000) named the regional tectonic contact the Regal Thrust, and noted that it can be traced over a large area, but the amount of lateral movement is unknown. Sun and Hickman (1998) also found the chemistry of the Regal Formation to be mid-oceanic-ridge basalt (MORB)-like, which is inconsistent with a normal stratigraphic position above metamorphosed clastic sedimentary rocks of the Nickol River Formation. Sun and Hickman (1998) suggested that either the Regal Formation was obducted onto the Nickol River and Ruth Well Formations, or that the Regal Formation was not part of the Roebourne Group. Stratigraphic redefinition of the Regal Formation has been deferred pending reliable geochronological data.

Ruth Well Formation (ARw, ARwc, ARwu)

The Ruth Well Formation is composed of a lower unit of serpentinized peridotite and spinifex-textured peridotitic komatiite (*ARwu*), and an overlying metabasalt with units of serpentinized peridotite and chert (*ARw*). At Mount Wangee, northeast of Roebourne, the formation includes relatively thick ferruginous and grey-and-white banded chert with minor quartzite (*ARwc*). The dominant rock type of the formation on ROEBOURNE is metamorphosed, massive and pillowed basalt — good exposures are present on Weerianna Hill (immediately west of Roebourne) and in the Carlow Castle area. Mapping indicates that most of the basalt has been metamorphosed to greenschist facies, although amphibolite-facies metabasalt is present along the northern side of the Sholl Shear Zone.

Flow tops within the basaltic units are typically difficult to recognize, except where there are interflow sedimentary rocks or altered flow-top breccias. Alteration in the upper sections

Table 2. Archaean lithostratigraphy of Roebourne

Group	*Formation*	*Thickness (m)*	*Lithology and relationships*
De Grey	Unassigned wacke	uncertain	Wacke. Age 2945–2940 Ma
~ *possible local unconformity* ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~			
	Mallina Formation	2 000 – 10 000	Shale, silstone, and wacke, minor chert. Age 2970–2955 Ma
	Constantine Sandstone	0 – 3 500	Quartzite, sandstone, and shale. Age 2970–2955 Ma
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ *Bookingarra Group and lower De Grey Group may be laterally equivalent* ~ ~ ~ ~ ~ ~ ~ ~ ~			
Bookingarra[a] (new name)	Kialrah Rhyolite	0 – 1 000	Feldspar-phyric, commonly flow-banded rhyolite. Maximum age c. 2975 Ma. Overlies or intrudes Louden Volcanics
	Mount Negri Volcanics	1 000	Variolitic and vesicular basalt
	Louden Volcanics[b]	0 – 1 000	High-Mg basalt with pyroxene spinifex texture, and undivided, massive and pillow basalt
	Rushall Slate	0–200	Laminated shale and siltstone, locally graphitic, and minor sand-stone. Includes the Comstock Member, comprising high-Mg and vesicular basalt
	Cistern Formation	0–800	Clastic and volcaniclastic rocks, including wacke, sandstone, silt-stone, and conglomerate. Age <2978 ± 5 Ma
~ *possible low-angle unconformity* ~			
Whim Creek	Mons Cupri Volcanics	0 – 1 000	Felsic volcanic and volcaniclastic rocks, and dacite intrusions. Age c. 3009 Ma
	Warambie Basalt	0–500	Vesicular, amygdaloidal, and pyroclastic basalt with hyalo-clastite and local pillow basalt. Basal polymictic conglomerate and sandstone
~ *high-angle unconformity* ~			
Gorge Creek	Cleaverville Formation	1 500	BIF, chert, fine-grained clastic sedimentary rocks. Age c. 3020 Ma
~ *possible low-angle unconformity* ~			
Whundo	Woodbrook Formation	1 000	Rhyolite tuff and agglomerate; minor basalt and BIF. Age 3117 ± 3 Ma
	Bradley Basalt	>4 000	Pillow basalt, massive basalt, minor units of felsic tuff and chert. Age 3115 ± 5 Ma
	Tozer Formation	2 500	Calc-alkaline volcanics, including felsic pyroclastic units. Minor chert and thin BIF. Age c. 3120 Ma
	Nallana Formation	2 000	Dominantly basalt, but includes minor ultramafic and felsic units. Felsic tuff dated at 3125 ± 4 Ma.

Table 2. (continued)

Group	*Formation*	*Thickness (m)*	*Lithology and relationships*
			Base of formation intruded by c. 3130 Ma granitoids and truncated by Maitland Shear Zone
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ *tectonic contact along Sholl Shear Zone* ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~			
Roebourne	Regal Formation	2 000	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, BIF, ferruginous clastic sedimentary rocks, quartzite, felsic volcanic rocks, 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	1 000 – 2 000	Basalt and extrusive peridotite with thin chert units. Intruded by granodiorite and tonalite dated at 3270 ± 2 Ma

NOTES: (a) Bookingarra Group defined (Pike and Cas, in press) since ROEBOURNE map was published
(b) Louden Volcanics and Mount Negri Volcanics may be partly equivalent

of flows has mainly involved silicification and epidotization. Depending on the metamorphic grade, most metabasalt consists of a generally fine-grained assemblage of amphibole (actinolite, tremolite, or hornblende), quartz (chiefly secondary), albite, epidote, chlorite, and minor sericite, sphene, clinozoisite, carbonate minerals, and opaque minerals. Relict clinopyroxene phenocrysts are locally preserved, but replacement by amphibole is normally complete. Plagioclase is extensively saussuritized. Komatiite containing large plates of serpentinized olivine is exposed on the southern side of the North West Coastal Highway at Mount Hall, and also at Mount Wangee (Figs 3 and 4). Both localities show well-preserved sheaf and 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 comprise tremolite, serpentine, chlorite, and a pale-yellow, birefringent phyllosilicate (probably vermiculite). Serpentine and tremolite or vermiculite have replaced olivine blades. Tremolite and serpentine also form very fine intergrowths, and chlorite forms flakes with a random orientation. 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 rim around their outer margins, suggesting they are iron oxides such as hematite.

A thin section of random spinifex texture from Mount Hall reveals a fine-grained mosaic of tremolite crystals in which larger bladed olivine is pseudomorphed by serpentine and

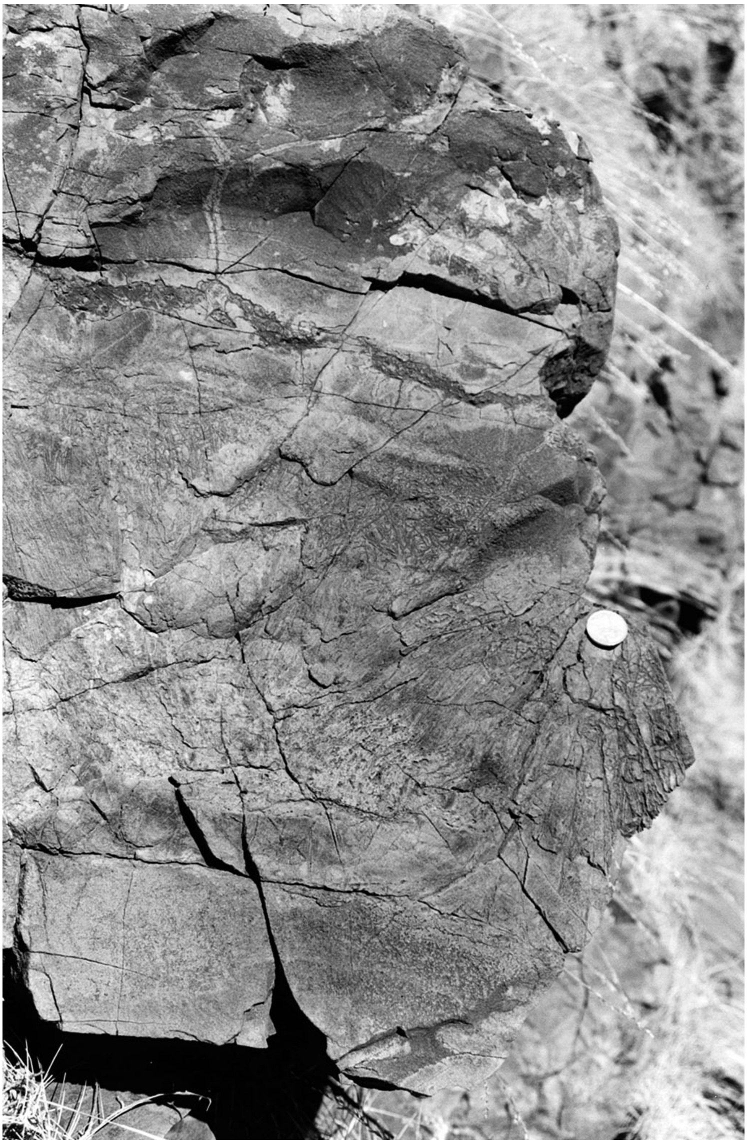

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Figure 3. Spinifex-textured ultramafic lava flow at Mount Wangee. Random spinifex texture (near coin) overlies bladed sheaf spinifex-texture (below coin), indicating that the flows, which dip to the left, are right-way-up. The chilled top of the flow (above coin) overlies the random spinifex texture, and a cumulate-textured zone underlies the zone of bladed olivine. Coin is 3 cm in diameter (MGA 0520500 7709200). Photograph rotated 90° for ease of interpretation

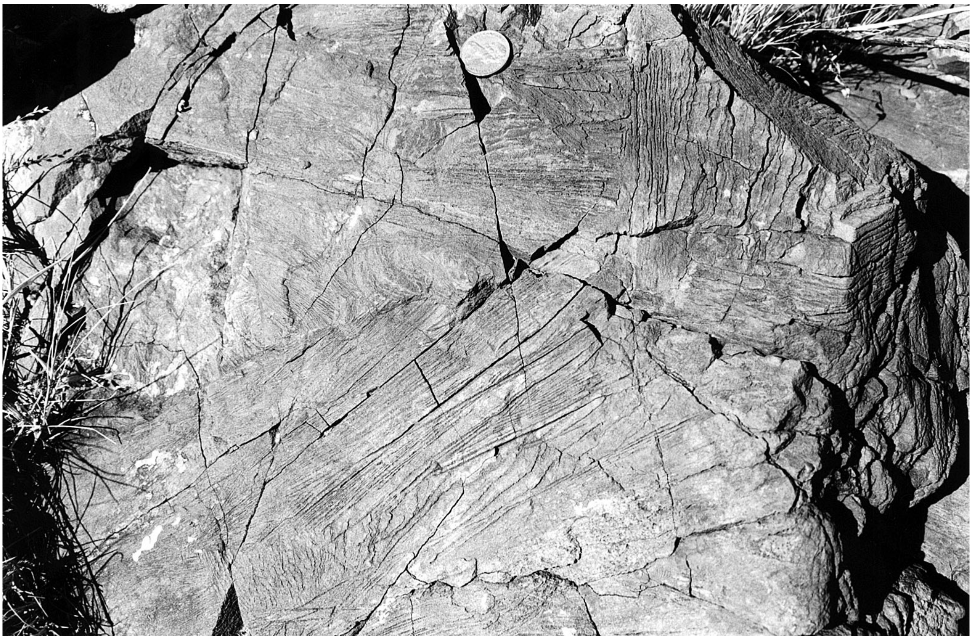

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Figure 4. Close-up of bladed olivine-spinifex texture at Mount Wangee. Blades of olivine, pseudomorphed by serpentine, tremolite, and chlorite, are up to 30 cm long. Coin is 3 cm in diameter (MGA 0520500 7709200)

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.

Nickol River Formation (ARn, ARnc, ARnx)

On ROEBOURNE, the Nickol River Formation is exposed on both limbs of the Roebourne Synform, but is extensively deformed adjacent to the Regal Thrust (see **Structure**, p. 34). In almost all areas, the formation is mapped either as undivided metamorphosed chert, BIF, ferruginous clastic sedimentary rocks, carbonate rocks, quartzite, conglomerate, felsic volcanic and intrusive rocks, and felsic volcanogenic sedimentary rocks (*ARn*), or as brecciated chert and silicified mafic rock (*ARnx*). Greater lithological subdivision is shown on the ROEBOURNE 1:100 000-scale map (Hickman, 2000). Brecciated chert and silicified mafic rock (*ARnx*) outcrop from Weerianna (west of Roebourne) southwestward to Carlow Castle, and farther west almost to the boundary of ROEBOURNE. The rock varies from a moderately deformed banded chert to a finely granular silicic breccia with thin layers of mylonite. Relatively undeformed grey-and-white banded chert (*ARnc*) is restricted to a ridge 3 km northwest of Roebourne.

Within the undivided Nickol River Formation (*ARn*), metamorphosed volcanogenic sandstone and siltstone underlie the Regal Thrust around the northeastern closure of the Prinsep Dome, 8 km south of Cleaverville. The unit is chiefly composed of quartz–sericite schist, phyllite, ferruginous chert, and boudinaged quartz veins. Below this unit is a thicker succession of metasandstone containing minor conglomerate and metasiltstone that outcrops about 8 km south of Cleaverville. These rocks include silicified (cherty) breccia, grey-and-white banded chert (derived by silicification of fine-grained clastic sedimentary rock), and some mylonitic zones. Black chert, interpreted to represent silicified carbonaceous shale, also outcrops in this area. The chert is generally weakly banded as alternating black and dark-grey layers, but can also be homogeneous apart from quartz veinlets. Similar Archaean black chert in the east Pilbara, near Marble Bar, contained microfossils (Schopf, 1993), but the black chert of the Nickol River Formation appears to be more recrystallized. Ferruginous chert, interlayered with metamorphosed BIF and fine-grained clastic sedimentary rocks, forms part of the undivided Nickol River Formation west of Carlow Castle. The protoliths are interpreted to be iron-rich shale and siltstone, minor carbonate rocks, and BIF. Green chert is a minor component of the undivided formation 1 km west of Carlow Castle, where it has been examined as a source of semi-precious stone. The distinctive colour of the rock is attributed to finely disseminated chromium muscovite (fuchsite).

Regal Formation (ARr, ARru, ARrg, ARrt)

Undivided Regal Formation (*ARr*) comprises massive and pillowed basalt that in most areas has been metamorphosed to amphibolite facies. Metamorphosed gabbro and dolerite sills are present in the largest outcrops of the unit south of Cleaverville, and in the area between Wickham and Mount Wangee. The metabasalt is petrographically similar to the metabasalt in the Ruth Well Formation.

West of Weerianna, and in the Big Tree Well area south of Cleaverville, the lower part of the Regal Formation is composed of serpentinized peridotite and komatiite (*ARru*). This unit is thinner and more poorly preserved than the lower ultramafic section of the Ruth Well Formation, but the general mineralogy of the rocks is similar. Within the Roebourne Synform, the Regal Formation contains sheared metabasalt with sheared veins and sheets of micrgranite and pegmatite (*ARrg*). This unit is exposed only on the western boundary of ROEBOURNE, but is far more extensive on DAMPIER to the west. The unit lies in a zone of intense shearing and granitic intrusion, flanked to the southeast by narrow belts of mylonite. A foliated sill of quartz–feldspar porphyry, which represents a northeastern extension of the granitic sheets, has been dated at 3018 ± 2 Ma (Nelson, 1998). This is interpreted as the age of formation of this unit (*ARrg*), although shearing (which affects both the metabasalt and the granitic components) occurred later.

Metamorphosed, well-bedded basaltic tuff (*ARrt)* is restricted to the contact between the Regal Formation and the Cleaverville Formation, 7 km west of Wickham. It should be noted that, although this unit is provisionally placed in the Regal Formation by virtue of its mafic character, it also contains grey chert and ferruginous chert similar to components of the Cleaverville Formation. The lower part of the unit is a coarse mafic tuff with beds of accretionary lapilli. This passes upward into finer grained tuff and volcaniclastic siltstone and mudstone interbedded with chert. Chert beds are most common close to the basal contact of the overlying Cleaverville Formation. The most northerly outcrops of the unit (MGA 0508700E 7714300N) include finely bedded, black chert that has convoluted laminations of possible biogenic origin.

Whundo Group (*AU*)

The Whundo Group (Hickman, 1997) is an approximately 10 km-thick succession of mafic and felsic metavolcanic rocks that outcrops south of the Sholl Shear Zone between the Cherratta and Caines Well Granitoid Complexes. Geochronology on felsic volcanic rocks in the central and upper formations of the group gives a range of dates from 3125 to

3115 Ma (Horwitz and Pidgeon, 1993; Hickman, 1997; Nelson, 1997, 1998). However, the base of the Nallana Formation is intruded by c. 3130 Ma granodiorite of the Cherratta Granitoid Complex (Hickman et al., in prep.a), establishing that the lowermost sections of the Whundo Group must have been deposited before 3130 Ma. West of ROEBOURNE, the Nallana Formation is 2000 m thick and comprises metabasalt, ultramafic rocks, intermediate pyroclastic rocks, and sills of dolerite. The Tozer Formation conformably overlies the Nallana Formation and west of ROEBOURNE is about 2500 m thick. Its succession consists of alternations of metamorphosed basalt, andesite, dacite, rhyolite, and thin metasedimentary units including chert and BIF. Dates from the Tozer Formation are close to 3120 Ma. The most homogeneous formation of the Whundo Group is the Bradley Basalt, which exceeds 4000 m in thickness and conformably overlies the Tozer Formation. The bulk of the unit consists of metamorphosed, massive and pillowed basalt, but spinifex-textured high-Mg basalt is present near its base, and units of felsic tuff are intercalated with basalt and dolerite sills in the upper part of the basalt formation. A felsic tuff 1000 m above the base of the Bradley Basalt was dated at 3115 ± 5 Ma (Nelson, 1996). Units of metamorphosed rhyolite tuff and agglomerate in the uppermost 1000 m of the Whundo Group are assigned to the Woodbrook Formation (Hickman, 1997). Nelson (1998) dated a welded tuff of this formation at 3117 ± 3 Ma, supporting the interpretation of a conformable relationship with the underlying Bradley Basalt. The stratigraphic top of the Whundo Group is concealed by the Fortescue Group between Mount Ada and Mount Roe.

Nallana Formation (AUn)

On ROEBOURNE, the Nallana Formation (*AUn*) is restricted to outcrops 5 km west-southwest of Harding Dam. Here, the upper part of the formation consists of metamorphosed basalt, basaltic tuff, and thin units of felsic tuff. The stratigraphically lower section of the formation is concealed by the Fortescue Group.

Tozer Formation (AUt)

The Tozer Formation (*AUt*) is exposed 6 km west of Harding Dam, where it conformably overlies the Nallana Formation. The formation is locally composed of a 1000 m-thick succession of metamorphosed felsic tuff capped by a thin unit of silicified tuff, BIF (partly jaspilitic), and metamorphosed siltstone and shale. This unit is overlain by metabasalt assigned to the Bradley Basalt.

Felsic tuff of the Tozer Formation has plagioclase crystals set in a felsic groundmass of plagioclase, K-feldspar, and quartz. The rocks are of very low metamorphic grade, but show a moderate degree of alteration to secondary phyllosilicates and carbonate.

Bradley Basalt (AUb, AUbf)

Undivided Bradley Basalt (*AUb*) is composed of metamorphosed pillow basalt (Fig. 5), massive basalt, dolerite sills, and minor units of metamorphosed felsic tuff and chert. The formation is well exposed in the Bradley Syncline in southwestern ROEBOURNE. The central stratigraphic part of the Bradley Basalt contains several units of felsic tuff, agglomerate, and minor chert (*AUbf*), with lenticular sills of dolerite. At other stratigraphic levels within the formation, beds of reworked felsic tuff locally show well preserved, upward-fining graded bedding (Fig. 6). Fine-scale cross-bedding proves the succession to be right-way-up. Fine-grained, reworked tuff also has intraformational convolutions and load structures (Fig. 7). Reworking of the tuff by currents suggests a relatively shallow-water depositional environment.

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Figure 5. 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 508900 7682000)

Woodbrook Formation (*AUw*)

The Woodbrook Formation (*AUw*) comprises metamorphosed rhyolite tuff and agglomerate, and minor metabasalt. Units of carbonate-rich ferruginous chert and BIF are rare, and are less than 2 m thick. In thin section, a sample of welded tuff is composed of fragments of well-packed, randomly oriented devitrified glass containing quartz and feldspar phenocrysts. Some fragments are pumiceous and some show perlitic structures. Igneous textures are well preserved, although the rock has undergone weak to moderate chlorite, leucoxene, carbonate, and sericite–clay alteration.

Gorge Creek Group (*AG*)

In the east Pilbara, the Gorge Creek Group (*AG*) comprises a thick metamorphosed succession of clastic sedimentary rocks, chert, BIF, and basaltic volcanic rocks. On ROEBOURNE, only one formation, the Cleaverville Formation (Ryan and Kriewaldt, 1964), of the group is preserved.

Cleaverville Formation (AGl)

The Cleaverville Formation is composed of BIF, ferruginous chert, grey-white and black chert, and metamorphosed shale, siltstone, and minor volcanogenic sedimentary rocks (*AGl*). Excellent exposures of the formation are provided by wave-cut platforms at Cleaverville (Fig. 8). The most complete successions of the formation are preserved north and northwest of Roebourne, and in the Mount Ada area (15 km south of Roebourne). Although these

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Figure 6. 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 is 6 cm diameter (MGA 05 05500 76 84300)

outcrops lie on opposite sides of the Sholl Shear Zone (see **Structure**, p. 34), the thicknesses and lithological components of the formation in these areas are very similar. Distinctive lithologies common to both areas include jaspilite, feldspar-phyric tuff, and volcanogenic sandstone, and in both areas the formation is extensively intruded by dolerite sills. At Mount Ada the depositional age of the Cleaverville Formation is closely constrained by clastic zircons dated at 3018 ± 3 Ma (Nelson, 1998), and by an intrusive granophyre dated at 3014 ± 6 Ma (Nelson, 1997). Nelson (1998) dated a volcaniclastic metasedimentary component from northwest of Roebourne at 3015 ± 5 Ma and a sandstone near Cleaverville at 3022 ± 12 Ma.

Northwest of Roebourne, metamorphosed clastic sedimentary rocks at the base of the Cleaverville Formation suggest an erosional contact on pillow basalt of the underlying Regal Formation, but an angular unconformity has not been recognized. At Mount Ada the base of the formation is concealed by unconformably overlying Mount Roe Basalt of the Fortescue Group. Here, the formation was folded by tight to isoclinal, easterly trending folds prior to erosion and subsequent deposition of the Whim Creek Group at c. 3010 Ma.

Quartz–feldspar porphyry (*Apf*)

Quartz–feldspar porphyry, and associated metamorphosed rhyolite and dacite (*Apf*) form minor intrusions and possible extrusive units north of the Sholl Shear Zone, southwest of Roebourne. The sills intrude the Roebourne Group and are intruded by monzogranite and granodiorite (*Agm*). Intrusive relations to gabbro of the Andover Intrusion (described below) are obscured by scree, but the porphyry may be the older unit because it is tectonically foliated, whereas the rocks of the Andover Intrusion are massive. Flow-banded metarhyolite forms large exposures near the Cherratta Road, 6–10 km southwest of Carlow Castle.

A sill of quartz–feldspar porphyry intrudes the Ruth Well Formation 7 km north-northeast of Roebourne. Nelson (1999) dated this rock at 3021 ± 3 Ma, and a similar porphyry sill in the Regal Formation 5 km southeast of Cleaverville was dated at 3018 ± 2 Ma (Nelson, 1998). Microscopic examination shows the porphyry to consist of plagioclase, quartz, and K-feldspar, with minor chlorite and accessory epidote, carbonate, sericite, and zircon. Where the porphyry is foliated, quartz and plagioclase are highly strained, and lamellar twin planes in plagioclase are curved and broken.

Whim Creek Group (*AC*)

The Whim Creek Group (Fitton et al., 1975) has been redefined (Pike and Cas, in press) since the 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 a northeasterly direction from the southern margin of the sheet area to Peawah Hill. The belt is fault bounded 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. The greenstone belt partially wraps around the northeastern edge of the granitoid complex, immediately south of where both the belt and the complex abut the regional, east-northeasterly trending Sholl Shear Zone. Miller and Smith (1975) also described a sequence of metamorphosed felsic

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Figure 7. 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 is 6 cm in diameter (MGA 05 05500 76 84300)

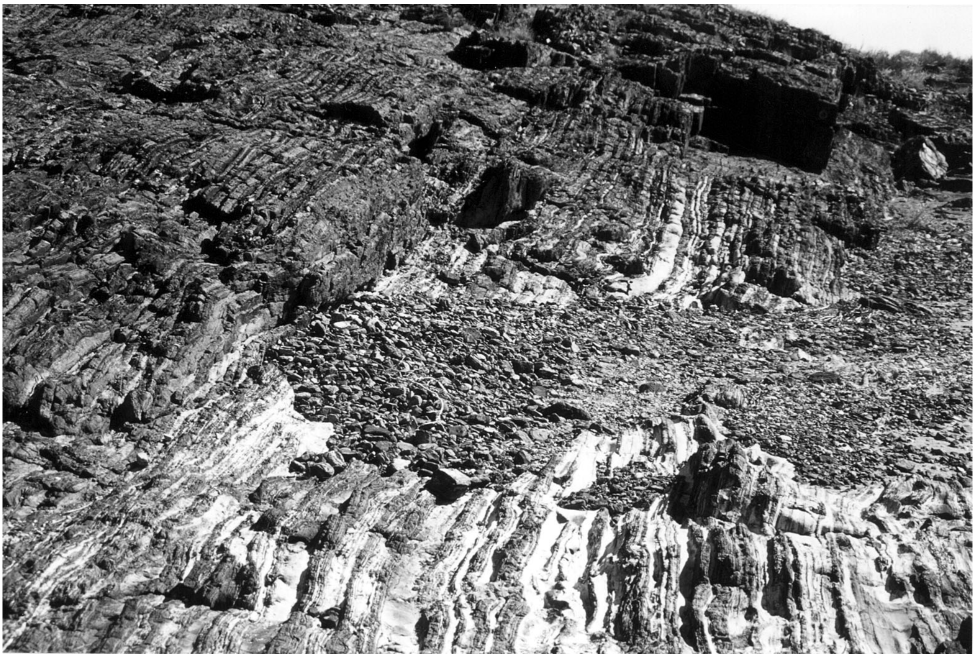

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Figure 8. Beach exposures of the Cleaverville Formation at Cleaverville. Beds of jaspilitic BIF (dark), 5–20 cm thick, alternate with bleached, fine-grained clastic metasedimentary beds. The BIF exhibits fine-scale (less than 1 mm) alternation of magnetite–hematite and chert layers (MGA 0502900 7716400)

to mafic volcanic rocks from Sherlock Bay, in the northwest, which may belong to the Whim Creek Group. Small outcrops of highly sheared felsic volcanic and volcaniclastic rocks found to the north of the Sholl Shear Zone, between Peawah Hill and Illingotherra Hill, may also belong to this group. In the southwest of the Whim Creek greenstone belt, south of Mount Fisher, the Whim Creek Group unconformably overlies rocks of the Cleaverville Formation and Whundo Group. Metamorphosed volcaniclastic rocks near the base of the Whim Creek Group have been dated at 3009 ± 4 Ma (Nelson, 1997).

The Whim Creek Group is a metamorphosed succession that passes upwards from subaqueous felsic volcanic and volcaniclastic rocks (Mons Cupri Volcanics) and interleaved basalt (Warambie Basalt), into coarse- to fine-grained volcaniclastic and sedimentary rocks (Cistern Formation), and then into fine-grained, deep-water, sedimentary rocks (Rushall Shale). A mafic volcanic succession overlies the Rushall Slate, and Hickman (1977) subdivided this into a lower spinifex-textured and locally pillowed unit (the Louden Volcanics) and an upper variolitic unit (the Negri Volcanics, later renamed Mount Negri Volcanics by Hickman, 1990). Very few stratigraphic contacts between the Louden Volcanics and the underlying rocks of the Whim Creek Group are exposed, and no clearly unconformable relationships have been substantiated. Mafic rocks interleaved with the lower part of the Rushall Slate, in the vicinity of Mons Cupri, which were previously referred to as the Comstock Andesite, are petrologically and geochemically similar to the Mount Negri Volcanics. In addition, Pike and Cas (in press) recognized peperite-like contacts, where basalt has locally intruded unlithified sediment of the Rushall Slate. This suggests that the earliest stages of magmatism that resulted in the Louden and Mount Negri Volcanics were synchronous with deposition of the Rushall Slate, although more voluminous mafic volcanism may have post-dated deposition of the slate. Accordingly, in redefining the Whim Creek Group, Pike and Cas (in press) included the Louden and Mount Negri Volcanics within the Bookingarra Group, along with the Cistern Formation and Rushall Slate (Table 2). The youngest population of detrital zircons extracted from a clastic unit of the Cistern Formation has been dated at c. 2975 Ma (Nelson, 2000). This provides a maximum age of deposition of the Bookingarra Group, and is about 35 m.y. younger than the depositional age of the redefined Whim Creek Group.

Mons Cupri Volcanics (ACf)

The basal unit of the Whim Creek Group is the Mons Cupri Volcanics (Fitton et al., 1975). These metamorphosed felsic volcanic rocks include an upper sequence containing subordinate volcaniclastic rocks, and the lower unit, which Fitton et al. (1975) called the Mount Brown Rhyolite Member. The upper sequence appears to be only of local extent, or was partly removed before deposition of the Cistern Formation. Mineralogical gradations in places make the distinction between the upper sequence and the Mount Brown Rhyolite Member difficult. The latter member consists of porphyritic rock of possible extrusive origin and lesser tuff, but also includes abundant porphyritic rocks of clearly intrusive origin. The Mons Cupri Volcanics reaches a maximum thickness of around 1 km in the Mount Brown area, but thins towards the west.

The Mount Brown Rhyolite Member ranges from a light- to dark-grey rock containing relatively few (<10%) feldspar(–quartz) phenocrysts, to a dark-grey rock containing abundant phenocrysts (>15%). Some samples of the Mount Brown Rhyolite Member are highly spherulitic, with individual spherulites ranging up to 3 mm in diameter.

Plagioclase is the dominant phenocryst phase and forms euhedral to subhedral, partially resorbed grains up to 5 mm in length. Anhedral quartz is a locally common phenocryst phase, whereas microcline is rare. Lithic fragments are locally abundant and consist of felsic volcanic rocks, pumice, and volcaniclastic rocks. The matrix of most samples comprises clay minerals, sericite, carbonate, chlorite, and iron oxides, and is a microcrystalline alteration product of devitrified glass. Rocks containing pumice fragments, abundant spherulites, and perlite textures may have a pyroclastic or tuffaceous origin, although fragmental textures are only locally preserved. Some exposures show a well developed flow-banding, which becomes increasingly contorted towards fragmental–brecciated margins, which may be flow tops. More coherent facies, of probable intrusive origin, contain an euhedral phenocryst population, fewer spherulites, and rare perlite-textures, but show no contact relationships indicative of either extrusion or deposition. It is difficult to estimate the proportion of intrusive rock in the Mons Cupri Volcanics, however, they may volumetrically dominate this unit.

The upper part of the Mons Cupri Volcanics contains a possible volcanic rock that is lithologically very similar to the phenocryst-poor Mount Brown Rhyolite Member. These are accompanied by rare volcaniclastic rocks, including generally poorly sorted, matrix-supported, fine- to medium-grained arkose, containing angular to subangular grains of quartz, feldspar (dominantly plagioclase), and locally derived lithic fragments. Contacts between the volcanic and volcaniclastic components commonly show well-developed peperite textures.

In the vicinity of Red Hill, the Mons Cupri Volcanics includes a thick sequence of black, dacitic to rhyolitic, fragmental volcaniclastic rocks of mass-flow origin. Originally mapped by Smithies (1997a) as part of the Cistern Formation, these metamorphosed turbidites form individually structureless layers up to 10 m thick, which together form a stacked sequence up to 80 m thick. The turbidites locally contain up to 70% angular pumice fragments in a very fine grained matrix (?former ash), and are interpreted to result from synvolcanic recycling of unconsolidated 'juvenile' volcanic debris. An age of 3009 ± 4 Ma was obtained from these rocks by Nelson (1997).

Warambie Basalt (ACw, ACws)

The Warambie Basalt (*ACw*) was considered by Fitton et al. (1975) to represent the lowest part of the Whim Creek Group. However, Smithies (1997a) showed that the metabasalt and associated metamorphosed mafic breccia and conglomerate is interleaved with the Mons Cupri Volcanics (*ACf*) in the area between the Sherlock River and Mount Fraser. The Mons Cupri Volcanics pinch out immediately to the west of this area, where the Warambie Basalt sits unconformably on amphibolite of the Whundo Group. In the area between Warambie and Mount Ada, in the southwestern part of ROEBOURNE, the Warambie Basalt unconformably overlies both the Cleaverville Formation and Woodbrook Formation.

On ROEBOURNE, most exposures of the Warambie Basalt are mapped as metamorphosed basalt and minor metasedimentary rocks (*ACw*). The metabasalt is a vesicular and glomeroporphyritic tholeiitic basalt commonly showing a moderate degree of alteration, including intergranular patches of carbonate, chlorite, serpentine, and zoisite enclosed by an interlocking network of sericitized and carbonated plagioclase. Blocky flow-tops are commonly preserved. Metamorphosed fragmental basalt, mafic breccia, basaltic tuff, and conglomerate units are interleaved with metamorphosed basalt flows. They contain an altered matrix of chlorite, quartz, and iron oxides. Angular clasts in the breccia are up to 15 cm in size and are either compositionally similar to the matrix, or composed of plagioclase porphyry. Some of the breccia units may be flow-top breccias. Conglomerate is matrix supported and contains subangular to subrounded clasts, up to 1 m in diameter. Most of the conglomerates are polymictic, with clasts of basalt, granite, and boulders of felsic plagioclase porphyry that are petrographically identical to the Mount Brown Rhyolite Member. In the Mount Ada area, the Warambie Basalt includes metamorphosed units of sandstone, conglomerate, and semi-pelitic rocks (*ACws*) that are most thickly developed immediately adjacent to the Sholl Shear Zone. This may be due to syndepositional faulting along the shear zone, with relative upthrow of the northern block.

Cistern Formation (ACc)

The Cistern Formation (*ACc*) was originally defined by Miller and Gair (1975) as a thin (about 30 m) sandstone unit lying at the top of the Mons Cupri Volcanics (*ACf*). Smithies (1997a) redefined the formation to include a locally thick (200–300 m), upward-fining package of metamorphosed volcaniclastic rocks, including conglomerate, poorly sorted sandstone, siltstone, and laminated shale, which was formally placed within the upper portion of the Mons Cupri Volcanics by Fitton et al. (1975) and Hickman (1977). The redefined unit hosts the base metal mineralization at Mons Cupri.

The Cistern Formation is locally absent, and in such areas the Rushall Slate (*ACr*) lies conformably or disconformably on the Mons Cupri Volcanics. The Cistern Formation is best represented in the area north of Opaline Well. Contacts between the formation and the Mons Cupri Volcanics may be transitional as there are rare lenses of metamorphosed felsic volcanic or volcaniclastic rock in the lower portion of the former formation. However, it is not certain that these felsic volcanic or volcaniclastic lenses are related to the Mons Cupri Volcanics, or represent a younger volcanic episode. The base of the Cistern Formation is typically marked by an oligomictic, matrix-supported, boulder conglomerate, or a coarse-grained volcanolithic sandstone. Boulder conglomerate also forms discontinuous lenses, a few metres thick, throughout the formation and locally reaches a thickness of about 200 m. Clasts in the conglomerate are commonly subrounded to subangular, up to 30 cm in diameter, and are dominantly locally derived overwhelmingly from the Mount Brown Rhyolite Member. Rare granite and basalt clasts may have been derived from the Caines Well Granite Complex and Warambie Basalt respectively.

A lithologically variable, metamorphosed package comprising interbedded sandstone, shale, and minor poorly sorted, ?tuffaceous rock overlies the conglomerate. Most of the rocks in this package are quartz rich and show clear evidence for reworking. The sandstones are typically medium-grained, matrix supported rocks with poorly sorted, angular to subrounded grains of feldspar, quartz, and lithic fragments. They fine upwards to well-laminated mudstone (Fig. 9). The youngest population of detrital zircons obtained from these rocks indicates that deposition occurred after 2978 ± 5 Ma (Nelson, 2000).

To the north of Opaline Well, the Cistern Formation includes rare metabasalt units up to 50 m thick. These units are conformable within the formation, commonly vesicular and spinifex textured, and are locally connected to stratigraphically lower mafic igneous intrusions (Opaline Well Intrusion) via thin dykes. The metabasalt units are possibly flows, but unambiguous contact relationships have not been found.

Rushall Slate (ACr)

The Rushall Slate (*ACr*) is locally preserved on the northeastern and southwestern sides of a domal feature between Whim Creek and Mons Cupri, to the south of Mount Negri, and

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Figure 9. Interbedded sandstone and laminated shale to mudstone in the Cistern Formation, Bookingarra Group

on the northeastern and southwestern sides of a domal feature between Good Luck Well and Opaline Well. Contacts with the Cistern Formation are conformable and, in places, gradational. Contacts with the Mons Cupri Volcanics are mostly fault bounded, but sharp and conformable or disconformable contacts are observed. The Rushall Slate reaches a maximum thickness of around 200 m, and is relatively uniform. It consists mostly of well-laminated, metamorphosed shale, but minor, thin (0.5 – 1.5 cm but up to 30 cm) interlayers of medium-grained metasandstone occur near the base, as do thin layers of metabasalt. The metamorphosed shale is composed of very fine grained sericite, chlorite, and quartz, is heavily dusted with iron oxides and pyrite, and is iron stained. Graded bedding is locally well developed. The rock shows a prominent schistosity defined by the alignment of mica. Marston (1979) and Barley (1987) noted the presence of tuffaceous interbeds and chert within the shale, with associated massive sulfide mineralization at Whim Creek and Salt Creek.

Comstock Member (ACrc)

A thin band of vesicular metabasalt and high-Mg metabasalt (*ACrc*) is exposed near the base of the Rushall Slate at Mons Cupri and about 8 km to the southwest. This metabasalt was referred to as the Comstock Andesite Member by Miller and Gair (1975), but was renamed the Comstock Member by Smithies (1997a). The metabasalt is fine grained, locally vesicular, variolitic and pyroxene-spinifex textured, and is generally chloritized and ferruginized. Geochemically the rock is virtually identical to the metabasalt of Mount Negri Volcanics, to which it possibly correlates.

De Grey Group (*AD*)

Rocks of the De Grey Group (*AD*) are in faulted contact with the southern and eastern margin of the Whim Creek greenstone belt, and dominate outcrop in the eastern part of ROEBOURNE. To the south of the Whim Creek greenstone belt, rocks of the De Grey Group are subdivided into either the Mallina Formation or the underlying Constantine Sandstone. Both formations were originally named and defined by Fitton et al. (1975), and are interpreted to include metamorphosed turbidite deposits (Hickman, 1977; Eriksson, 1982; Barley, 1987; Horwitz, 1990). The Mallina Formation is primarily a metamorphosed sequence of interbedded, well-graded, medium- to fine-grained wacke and shale, with rare, thick, massive units. In contrast, the Constantine Sandstone is generally a medium- to coarse-grained, poorly sorted, metamorphosed subarkose to wacke with conglomerate layers, and is considerably more thickly bedded than the Mallina Formation. To the east of Mallina Station, the distinction between the Mallina Formation and Constantine Sandstone is not always clear and it is likely that the two formations are locally gradational. As a result, many rocks of the De Grey Group in that area are not assigned to either formation.

Estimates of the maximum thickness of the Mallina Formation vary from 2.5 km (Fitton et al., 1975) to 10 km (Miller and Gair, 1975), and the maximum thickness of the Constantine Sandstone has been estimated to be about 3.5 km (Smithies, 1998b). The maximum age of the De Grey Group in the western part of the Pilbara Craton is constrained by an age of c. 3015 Ma from an underlying felsic volcanic sandstone on MOUNT WOHLER, to the south (Smithies, 1998b). A maximum depositional age of c. 2990 Ma for the Constantine Sandstone was obtained from detrital zircons in a sample from SHERLOCK (Nelson, 2000). Zircon xenocrysts in granites that have intruded the Mallina Formation and Constantine Sandstone are assumed to have been derived from these formations, and thus indicate a maximum depositional age of c. 2970 Ma (Hickman et al., in prep.b). The age of detrital zircons from a wacke unit near Egina Well (SATIRIST) shows that sediment deposition also occurred at c. 2940 Ma (Nelson, 1999; Smithies et al., 1999). However, the bulk of the De Grey Group was deposited before intrusion of the c. 2950 Ma Peawah Granodiorite and Portree Granitoid Complex.

Constantine Sandstone (ADc, ADcq, ADcs)

The Constantine Sandstone (*ADc*) outcrops in the hinge zone of the Croydon Anticline, about 2 km to the southwest of Toweranna Well, in the south central part of ROEBOURNE. The formation also forms a prominent east-northeasterly trending ridge that marks the trace of the Mallina Shear Zone to the north of Toweranna Well. The rock is generally a poorly to moderately well-sorted, medium- to coarse-grained, metamorphosed subarkose (*ADcq*). Grains of quartz and lesser feldspar are angular to subrounded, and generally supported by a matrix of quartz, sericite, chlorite, feldspar, and clay minerals. Fuchsitic chert and black chert fragments are locally common. Grain-size grading is uncommon and in places poorly developed. Towards the top of the Constantine Sandstone, medium-grained, poorly sorted, metamorphosed arkose and shale are interbedded with subarkose (*ADcs*). The metamorphosed shale is laminated on a scale of 1–5 mm. The proportion of shale and arkose increases upward towards a gradational contact with the Mallina Formation.

Mallina Formation (ADm)

Interbedded metamorphosed shale, siltstone, and medium- to fine-grained wacke of the Mallina Formation (*ADm*) forms most outcrops of the De Grey Group to the north of the Mallina Shear Zone, and to the west of Mallina Station. Rocks of the Mallina Formation have been recrystallized close to the Portree Granitoid Complex (Smithies, 1999).

Shale within the Mallina Formation is generally ferruginous. Angular, silt-sized grains of chert and quartz are common and plagioclase (pseudomorphed by calcite) is rare. Very fine grained mica (mainly sericite) comprise the bulk of the groundmass, and is accompanied by abundant chlorite, quartz, and minor zoisite. There is a prominent slaty cleavage defined by the alignment of mica. Carbonate minerals locally overprint the slaty cleavage and may comprise up to 50% of some rocks.

The wacke component of the Mallina Formation ranges in grain size from sand to silt, and individual beds commonly fine upward. The rocks are generally poorly sorted, and grains range from angular to subrounded. Quartz is generally more abundant than feldspar. Lithic fragments are abundant, particularly in the coarser grained rocks. The dominant lithic component is grey chert, but fragments of shale and basalt are also found. The matrix is rich in sericite and chlorite with lesser quartz, plagioclase, biotite, epidote, zoisite, and pyrite. The rocks are commonly iron stained and some are strongly carbonated.

To the south of the Mallina Shear Zone, minor hornblende- and feldspar-phyric felsic rock is locally interleaved with rocks of the Mallina Formation and unassigned rocks of the De Grey Group on a scale too fine to portray at map scale. It consists of subhedral to euhedral phenocrysts of hornblende and plagioclase (up to 3 and 5 mm in size respectively), in a medium- to fine-grained groundmass of quartz, plagioclase, and biotite. A weak to moderate mineral foliation, which parallels bedding in the surrounding sedimentary rocks, may be a flow foliation. Many units of hornblende- and feldspar-phyric felsic rock are probably intrusive, but fragmental textures, flattened shard-like features, and angular lithic clasts point to a pyroclastic origin for some units. According to Smithies and Champion (1998), these rocks are comagmatic with the Peawah Granodiorite, providing further evidence for active deposition within the Mallina Basin as late as c. 2950 Ma.

Unassigned rocks of the De Grey Group

Wacke (AD(t))

Metamorphosed, medium- to coarse-grained wacke and fine- to coarse-grained wacke (*AD(t)*) outcrops to the east of Mallina Station and to the south of the Mallina Shear Zone. In many respects, the medium- to coarse-grained wacke resembles the wacke component of the Mallina Formation, except that it is locally coarser grained and contains pebble beds and only rare interbeds of shale. It is possible that medium- to coarse-grained wacke was deposited in a slightly higher energy environment than the bulk of the Mallina Formation. However, the unit is locally associated with outcrops that can confidently be assigned to the Constantine Sandstone, and on that basis, may lie at a slightly lower stratigraphic level than the rocks of the Mallina Formation. The fact that rocks of the Mallina Formation and the medium- to coarse-grained wacke appear to be confined to opposite sides of the Mallina Shear Zone, which shows a south-side-up displacement, is consistent with the latter proposition.

The fine- to coarse-grained wacke contains abundant chert clasts and locally includes shale, subarkose, conglomerate, and pebble beds. This unit differs from the Mallina Formation in that it includes coarse-grained wacke, and differs from the medium- to coarse-grained wacke in that it locally contains a higher proportion of shale interbeds and graded bedding is commonly well developed. The fine- to coarse-grained wacke is also generally more quartz rich, sericite rich, and chlorite poor than rocks of both the Mallina Formation and the medium- to coarse-grained wacke unit.

Shale (AD(h))

Undivided metamorphosed shale (*AD(h)*) units outcrop to the south of the Mallina Shear Zone and to the east of Mallina Station. They include rare layers of metamorphosed, poorly sorted subarkose and locally ferruginous or highly chloritic shale and siltstone with rare layers of metamorphosed ironstone. It is likely that the abundance of chlorite in laminated shale and siltstone can at least partly be attributed to the sedimentary reworking of syndepositional high-Mg basalt (Smithies, 1999).

Basalt – high-Mg basalt (AD(b))

Metamorphosed basalt and high-Mg basalt (*AD(b)*) is within, and to the south of, the Mallina Shear Zone. The basalt forms isolated outcrops close to, or in contact with, fine-grained metasedimentary units of the De Grey Group. All samples are extensively to totally replaced by combinations of chlorite, serpentine, talc, carbonate, and quartz. Most samples are deformed, but locally preserved spinifex textures are diagnostic of an extrusive origin. Relict primary textures include euhedral phenocrysts of olivine and pyroxene (pseudomorphed by calcite, talc, and serpentine) up to 2 mm in size, and distinct, fine-grained, pyroxene-spinifex textures.

Other units of the Whim Creek greenstone belt

ROEBOURNE shows three formations of the Pilbara Supergroup above the Whim Creek and De Grey Groups. Detailed investigation of the Whim Creek greenstone belt (Pike and Cas, in press) has recently resulted in a redefinition of local lithostratigraphy, in which the Louden Volcanics (*Ae*, *Aes*), Mount Negri Volcanics (*At*), and Kialrah Rhyolite (*Ak*), are now placed in the newly recognized Bookingarra Group.

Louden Volcanics (Ae, Aes)

Most outcrop of the Louden Volcanics (*Ae*) is confined to the southeastern and southern parts of the Whim Creek greenstone belt, adjacent to the Loudens Fault, and to the northern contact with the Sholl Shear Zone. The Louden Volcanics are best developed in the northeast, where they are up to 1.3 km thick and include an upper unit of clastic rocks (*Aes*).

The Louden Volcanics consist predominantly of metamorphosed high-Mg basalt with well-developed, coarse pyroxene-spinifex textures, or randomly orientated, acicular pyroxene phenocrysts. Komatiitic rocks with olivine spinifex texture are rare and form layers that are not sufficiently thick or continuous to be represented at map scale. Metamorphosed aphyric basalt is common near the top of the sequence, forming cooling units up to 10 m thick. Hyaloclastite and pillowed basalt also occur at the top of the sequence, where it is locally interlayered with, and conformably overlain by, chert and clastic rocks, including conglomerate. Diorite units and ultramafic cumulates are either sills or dykes, or may represent thicker flows.

Most samples of the Louden Volcanics contain a very fine grained groundmass of devitrified glass, pyroxene and plagioclase, now partially altered to chlorite, carbonate, iron hydroxides, and clay minerals. Phenocrysts of acicular pyroxene up to 10 cm in length are common. In many cases, pseudomorphs after euhedral pyroxene phenocrysts show a distinct chloritized 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 in orthopyroxene, which is in turn rimmed by clinopyroxene.

In the northeast of the Whim Creek greenstone belt, metamorphosed clastic rocks and minor chert (*Aes*) that are interbedded with, and conformably overlie, metabasalt have been included within the Louden Volcanics. Metamorphosed, poorly sorted, medium- to fine-grained sandstone containing interbeds and lenses of shale and polymictic conglomerate dominates the sedimentary horizons. The metasandstone consists of matrix-supported, subrounded to subangular grains of quartz, with lesser plagioclase and lithic fragments. The fine-grained matrix comprises quartz, feldspar, chlorite, sericite, and clay minerals. Coarse-grained and trough cross-bedded, grain-supported quartz arenite is locally exposed. Metamorphosed polymictic conglomerate forms layers up to 100 m thick. The conglomerate is poorly sorted, matrix supported, and contains locally derived clasts of sandstone, shale, chert, quartzite, and high-Mg basalt. Chert, which forms only a very minor portion (<10 m) of the sedimentary unit, is thinly banded, red to grey, and locally brecciated. Quartzite conformably overlies the metabasalt.

Mount Negri Volcanics (At)

The Mount Negri Volcanics (*At*) are a metamorphosed basaltic succession that forms abundant outcrops at Mount Negri and between Hill Well and Mons Cupri. Variolitic basalt and vesicular basalt dominate, and pyroxene-spinifex textures are locally preserved. Variolitic basalt forms individual flows up to 15 m thick and reaches an accumulated thickness of greater than 150 m in the vicinity of Mount Negri. Dark-green, pea-sized varioles are abundant and consist of acicular clinopyroxene, interstitial plagioclase, and devitrified glass, and lie in a light-green groundmass of clinopyroxene, plagioclase, and glass. Euhedral clinopyroxene phenocrysts, up to 2 mm in length, are distributed randomly throughout varioles and groundmass. Epidote, actinolite, carbonate, and chlorite are common replacement minerals.

Kialrah Rhyolite (Ak)

The Kialrah Rhyolite (*Ak*), first recognized and defined by Hickman (1997), is a thick unit of metamorphosed, 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.

The Kialrah 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.

Unassigned units

Serpentinized ultramafic rock (Aus)

Serpentinized ultramafic rock derived from peridotite and pyroxenite (*Aus*) occurs as large xenoliths, up to 5 km long and 2 km wide, within the Caines Well Granite Complex or adjacent to the southeastern and northwestern margins of that complex. It also forms as tectonically dislocated sills and dykes within the De Grey Group in the southeast corner of ROEBOURNE. The metaperidotites range from serpentinized olivine-rich samples to granoblastic assemblages of cummingtonite, orthopyroxene, olivine (now serpentine), and spinel (hercynite). Metapyroxenite has a granoblastic assemblage of clinopyroxene, hornblende, and minor serpentine (after olivine).

Mafic–ultramafic intrusions

Fitton et al. (1975) referred to the voluminous mafic and layered mafic–ultramafic intrusions within the western Pilbara Craton collectively as the ‘Millindinna Complex’. However, Smithies (1997b), noted that intrusions assigned to this unit occur at various stratigraphic levels and are unlikely to represent a single intrusive event. He subdivided the intrusions into those emplaced between the rocks of the Whim Creek Group and the Caines Well Granitoid Complex (Sherlock Intrusion), those emplaced within the rocks of the Whim Creek Group (Opaline Well Intrusion), and those emplaced within the De Grey Group (Millindinna Intrusion). Further mapping of the De Grey Group on SATIRIST (Smithies and Farrell, 2000) revealed at least two very distinctive types of intrusions that consistently occupy different stratigraphic levels. Massive to schistose metagabbro and metamorphosed melanogabbro (unassigned gabbro) intrudes the lower exposed parts of the group, whereas a layered mafic–ultramafic intrusion(s) (Millindinna Intrusion) is found in the stratigraphic interval above the gabbros and is best exposed at Millindinna Hill (on SATIRIST). As a result, gabbro units between the Croydon Anticline and the Peawah Granodiorite, which Smithies (1997a) initially placed into the Millindinna Intrusion, are now unassigned.

Millindinna Intrusion (AaM, AaMu, AaMo)

Only the layered mafic–ultramafic intrusion(s), or their tectonically dismembered components, emplaced within the rocks of the De Grey Group (*AD*) are referred here to the Millindinna Intrusion (*AaM*). Outcrop of these rocks on ROEBOURNE is restricted to the southeastern corner, in the vicinity of Mount Dove. The rocks range in composition from peridotite (*AaMu*) to melanogabbro (*AaMo*), but are now replaced by combinations of serpentine, tremolite, talc, chlorite, epidote, and plagioclase. The intrusion is best exposed on SATIRIST, immediately to the south of ROEBOURNE, where a sill, up to 400 m thick, shows a distinct compositional layering from a basal peridotite (primarily lherzolite), upwards to pyroxenite, with a typically thin upper layer of melanogabbro. Smithies and Farrell (2000) estimated that the sill may extend up to 70 km across the southeastern half of the Mallina Basin.

Talc–carbonate schist (Aut)

Talc–carbonate schist (*Aut*), after peridotite, is a minor component of the De Grey Group in the eastern part of ROEBOURNE, and to the south of the Mallina Shear Zone. The schist is possibly a metamorphosed, carbonate-altered peridotite related to the Millindinna Intrusion.

Unassigned gabbro (Aog)

Metamorphosed, medium- to coarse-grained mesocratic to leucocratic gabbro (*Aog*) outcrops about 7 km to the east of Toweranna Well. Subhedral to euhedral hornblende, with rare clinopyroxene cores, forms an interlocking network with intergranular plagioclase and late patches of quartz–plagioclase granophyric intergrowth.

Unassigned gabbro and dolerite (Ao)

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.

Unassigned dolerite (Aod)

Medium-grained dolerite (*Aod*) is well exposed on Depuch Island, to the north of Whim Creek, and has intruded rocks of the Cleaverville Formation in the Wickham area.

Andover Intrusion (AaAo, AaAu, AaAy)

The Andover Intrusion is the largest layered intrusion of North Pilbara Terrain, 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. Recent mapping (Hickman, 2000) indicates that the intrusion is a lopolith, or funnel-shaped body, that intruded the Ruth Well Formation and was subsequently intruded by late components of the Harding Granitoid Complex. Since the publication of ROEBOURNE, one of these intrusions has been dated at 3016 ± 4 Ma (Nelson, in prep.). 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, and minor metapyroxenite (*AaAu*), whereas metamorphosed gabbro, including leucogabbro and minor anorthosite (*AaAo*), are the main components west of 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. (1993) 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 (Hickman, 2000) indicates that the thick ultramafic zone in 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. The age of the Andover Intrusion is now known to be older than 3016 Ma, based on geochronology (Nelson, in prep.), distinguishing it from other large, layered c. 2925 Ma intrusions south of DAMPIER (Arndt et al., 1991). Its maximum age is constrained only by its intrusive relationship to the c. 3270–3250 Ma Roebourne Group.

Serpentinized peridotite and dunite (*AaAu)* 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 boundaries of pseudomorphs. Relict olivine and clinopyroxene are locally preserved. Minor mineral constituents of serpentinite are talc, hornbende (after pyroxene), tremolite, chlorite, and biotite. Metapyroxenite 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 and leucogabbro (*AaAo*) 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, the gabbro has a hypidiomorphic assemblage of saussuritized plagioclase, pyroxene (variably replaced by actinolite and chlorite), and brown hornblende. Accessory minerals include sphene and carbonate, and some 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.

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 the quartz–feldspar porphyryr (*Apf*) are unclear.

Sherlock Intrusion (AaS, AaSy)

Gabbro sills and dykes of the Sherlock Intrusion (*AaS*) intrude the contact between the Caines Well Granite Complex and the Whim Creek Group (*AC*), and in marginal sections of the granite complex, are close to the contact. The rock is medium to coarse grained and typically massive, but is well foliated close to the Kents Bore Fault. Subhedral to euhedral clinopyroxene is the main mafic phase, and commonly lies within an interlocking network of plagioclase euhedra or, less commonly, displays a subophitic texture. In rare cases, early formed, subhedral to euhedral phenocrysts of orthopyroxene are found. Quartz and patches of quartz–plagioclase granophyric intergrowth are intergranular phases that become common in plagioclase-rich leucogabbro and abundant in granophyric gabbro. Granophyre (*AaSy*) forms the upper part of the intrusion 3 km northeast of George Bridge.

Opaline Well Intrusion (AaO)

Rocks that comprise the Opaline Well Intrusion (*AaO*) intrude the Whim Creek Group, or form at the contact between that group and rocks of the Sherlock Intrusion. At the contact with the Sherlock Intrusion, rocks of the Opaline Well Intrusion are commonly sheared whereas those of the Sherlock Intrusion are massive. This relationship may suggest that the intrusion of the Opaline Well Intrusion pre-dates that of the Sherlock Intrusion. Contacts with rocks of the Whim Creek Group mostly involve the Cistern Formation, particularly in the Opaline Well area.

The weakly metamorphosed gabbroic rocks of the Opaline Well Intrusion differ from the rocks of the Sherlock Intrusion in that they are coarser grained and contain 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. 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 orthopyroxene. Some of these rocks closely resemble peridotite in the Louden Volcanics. Many outcrops show 1–10 m-scale igneous layering that is conformable with the dip of sedimentary country rocks.

Mylonite (Amm)

The mylonite (*Amm*) is along the Sholl Shear Zone, which is locally up to 1 km wide. The mylonite is dominantly silicic, and represents extremely sheared granitoids, but there are also layers of amphibolite and tectonic slices of BIF and ultramafic rocks. The mylonite is composed of 0.5 – 2.0 mm-wide laminae of extremely fine grained siliceous material containing small porphyroclasts of quartz, plagioclase, microcline, and fractured garnet. Mylonite units, too thin to map at 1:100 000 scale, are along strike-slip faults and thrusts, and within greenstones they can be mafic in composition.

Granitoid rocks

Karratha Granodiorite (Agka)

On ROEBOURNE, the Karratha Granodiorite is interpreted to be concealed beneath the Roebourne Synform, as illustrated by the diagrammatic section accompanying the map. The Karratha Granodiorite (*Agka*) is the oldest identified granitoid unit of the WPGGT. SHRIMP 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). On DAMPIER (1:100 000; Hickman, 2001), the Karratha Granodiorite ranges in composition from tonalite to granodiorite.

Monzogranite and granodiorite (Agm)

North of the Sholl Shear Zone, in the area southwest of Black Hill Well, irregular stocks and sheets of the monzogranite and granodiorite (*Agm*) intrude greenstones of the Roebourne Group. The granitoids are typically equigranular, medium grained, and tectonically foliated. Compositional banding is visible in many outcrops, and minor shear zones are locally present. The unit is now interpreted to include parts of the c. 3270–3260 Ma Karratha

Granodiorite, but local intrusive relationships to quartz–feldspar porphyry (*Apf*) indicate that younger granitoids (probably related to c. 2970 Ma monzogranite of the Harding Granitoid Complex) may also be present.

Harding Granitoid Complex (AgH, AgHn)

The Harding Granitoid Complex (*AgH*) is almost entirely concealed by Cainozoic alluvial and marine deposits, but aeromagnetic data indicate that it extends approximately 130 km in an east-northeast direction, between Roebourne and Port Hedland. Bouguer anomalies (Blewett et al., 2000) suggest that the complex is 40–80 km wide, including its offshore extent. About 15 km southwest and southeast of Roebourne, outcrops of the complex are composed of weakly foliated to compositionally banded monzogranite, granodiorite, and minor tonalite (*AgH*). Gneissic, biotite-bearing granitoid rocks (*AgHn*) outcrop close to the Sholl Shear Zone between Jones Bridge and White Quartz Hill. The strong foliation in these granitoids is interpreted to result from shearing associated with movement on the shear zone. 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 and Whim Creek Groups. A sample of the less-deformed variety of monzogranite was dated at 2970 ± 5 Ma, and contained a population of zircon xenocrysts dated at 3018 ± 19 Ma (Nelson, 1999). The same rock provided a Nd T_{DM} model age of 3309 Ma (Hickman et al., in prep.a). North of Whim Creek, and immediately north of the Sholl Shear Zone, a sample of granodiorite gneiss from the Forestier Bay area was dated at 3014 ± 3 Ma (Nelson, 1997), and subsequently gave a Nd T_{DM} model age of 3276 Ma (Sun and Hickman, 1998).

Caines Well Granitoid Complex (AgR, AgRg, AgRn)

The Caines Well Granite Complex (*AgR*) outcrops between the Sholl Shear Zone and the Whim Creek greenstone belt, forming an elliptical feature rimmed by mafic rocks of the Sherlock Intrusion. Rocks of the granitoid complex vary from foliated in the southeast, along the Kents Bore Fault (formerly Bookingarra Granite; *AgRg* on map), to strongly foliated and gneissic in the west and north. Banded biotite trondhjemite gneiss (*AgRn*) is best exposed where the old North West Coastal Highway crosses the Sherlock River (MGA 562436E 7692456N) and has been dated at 3093 ± 4 Ma (Nelson, 1997). Amphibolite facies ultramafic rocks (*Aus*) around Sherlock Station are probably xenoliths within the gneiss. Foliated biotite syenogranite along the Kents Bore Fault has been dated at 2925 ± 4 Ma (Nelson, 1997). Since the publication of ROEBOURNE, a strongly foliated, locally feldspar porphyritic biotite–hornblende monzogranite that forms the main central and northern phase of the complex has been dated at 2990 ± 5 Ma (Nelson, 2000).

Peawah Granodiorite (Agpe, Agped)

The Peawah Granodiorite (*Agpe*) outcrops about 7 km to the south of Mallina Station and intruded the rocks of the De Grey Group at c. 2950 Ma. It consists of medium- to coarse-grained, generally equigranular hornblende–biotite granodiorite and subordinate tonalite. The rock contains up to 15% mafic minerals, with subhedral hornblende either interstitial to plagioclase or as aggregates with biotite, magnetite, and titanite. Biotite forms subhedral to anhedral crystals, in places partially surrounding hornblende. Microcline microperthite forms a late, minor to accessory phase. Other accessory minerals include titanite, apatite, zircon, rutile, and magnetite. The rocks typically contain abundant rounded xenoliths of gabbro and diorite (Fig. 10), interpreted to be cognate in origin.

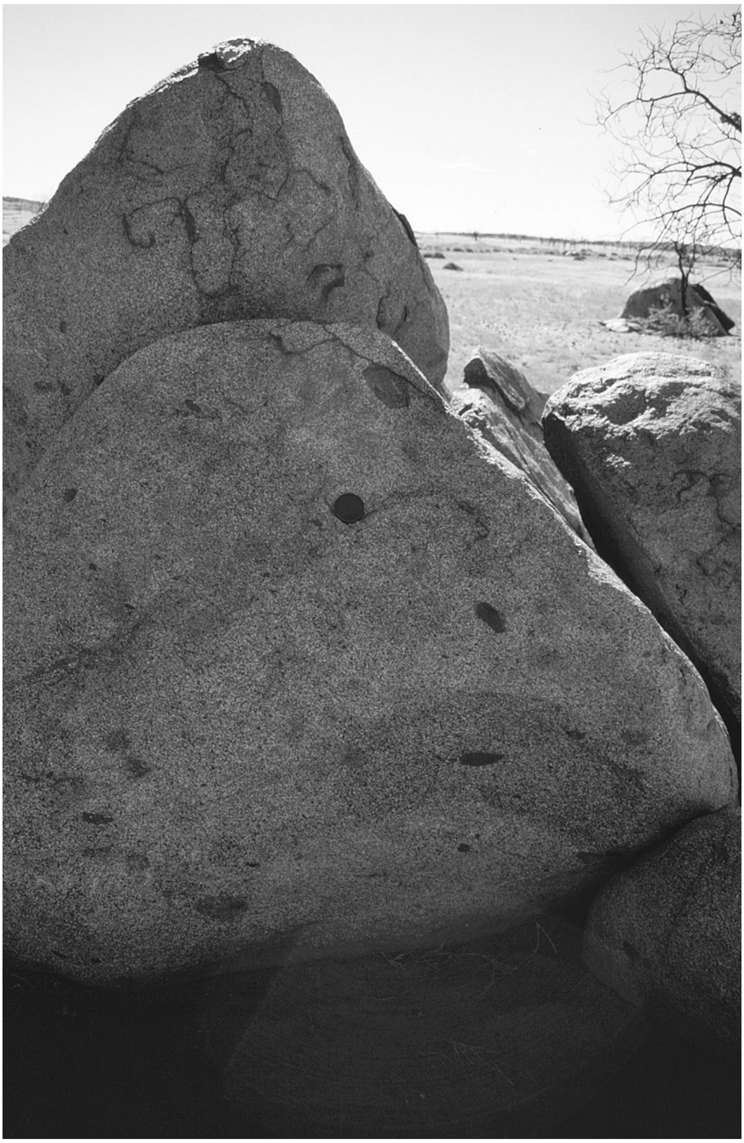

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Figure 10. Peawah Granodiorite showing abundant, rounded xenoliths ranging in composition from gabbro through diorite to granodiorite. The xenoliths are interpreted to be cognate inclusions. Lens cap is 6 cm in diameter

Seriate- to porphyritic-textured diorite and equigranular diorite (*Agped*) is found in the Millindinna Well area. They form sills and dykes within the De Grey Group, and at the contact between those rocks and the Peawah Granodiorite. The diorite also occurs as subrounded to rounded xenoliths within the Peawah Granodiorite.

Toweranna Porphyry (Apto) and unassigned granodiorite and tonalite (Agg)

Plagioclase-porphyritic, hornblende-, and biotite-bearing granodiorite (*Apto*), at Toweranna Well, and hornblende- and biotite-bearing granodiorite to tonalite (*Agg*), near Geemas Well, have intruded rocks of the De Grey Group. Both intrusive rocks closely resemble the Peawah Granodiorite in mineralogy and chemistry, and the age of the intrusion near Geemas Well (2954 ± 4 Ma; Nelson, 2000) is within error of that of the Peawah Granodiorite.

Portree Granitoid Complex (AgP, AgPam, AgPac)

The Portree Granitoid Complex (*AgP*) is a series of discrete, nested plutons that intrude the De Grey Group and are the same age as the Peawah Granodiorite. Outcrop is poor and only the northern and southern extremes of the complex are exposed. The rock is generally massive, but locally contains northerly and northwesterly trending zones of sheared rock. In the southern part of the Portree Granitoid Complex is a medium-grained, leucocratic alkali granite (*AgPam*) consisting of quartz, microcline, sodic-plagioclase, sodic-clinopyroxene, and minor biotite. Blue alkali-amphibole is a late-magmatic to subsolidus replacement of clinopyroxene. Outcrop of the northern part of the complex is of coarse-grained alkali granite (*AgPac*) containing tabular perthite, up to 1 cm in size, locally crowded with inclusions of sodic-plagioclase.

Leucogranite (Agl)

Leucogranite (*Agl*), near Opaline Well, is composed of biotite- and tourmaline-bearing, medium-grained rock that has intruded the De Grey Group on the southern edge of ROEBOURNE. The granite outcrops about 20 km southwest of Whim Creek, close to where the Loudens Fault intersects the Mallina Shear Zone. An age of 2765 ± 5 Ma (Nelson, 1997) establishes intrusion during deposition of the lower part of the Fortescue Group. The rock ranges in composition from syenogranite to monzogranite, and contains subhedral to euhedral plagioclase phenocrysts (up to 5 mm) and late-crystallizing microperthite. Biotite occurs either as an anhedral, interstitial groundmass phase, or as aggregates of larger subhedral grains associated with plagioclase. Tourmaline is present in discontinuous veins or stringers, or in orbicules up to 3 cm in diameter.

STRUCTURE

West Pilbara Granite–Greenstone Terrane

The regional setting of the WPGGT is shown in Figure 1. Whether the WPGGT is a single terrane or a composite of two terranes depends on the interpretation of the tectonic significance of the Sholl Shear Zone. Krapez and Eisenlohr (1998) and Smith et al. (1998) argued that the Sholl Shear Zone is a terrane boundary because it juxtaposes the 3270–3250 Ma Roebourne Group (interpreted by them as an island-arc succession) with the 3130–3115 Ma Whundo Group (interpreted as a back-arc succession). Smith et al. (1998) interpreted the Roebourne Group and granitoids north of the Sholl Shear Zone to be parts of an allochthonous terrane that was tectonically transported from the northern part of the North Pilbara Terrain.

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 1000–2000 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 (Hickman et al., 2000; Hickman, 2001) 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 (Hickman et al., 2000, in prep.a) 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.

D_1 (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 in the Dampier area (Hickman, 1997, 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 × 25 km, trending east-northeast. The thrust is folded by the Prinsep Dome and the Roebourne Synform (see interpreted geology map).

Sun and Hickman (1999) 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 of this anomaly might be that the formation was obducted onto the Nickol River Formation. In this case, the Regal Thrust would be the base of the obducted slab.

A bedding-parallel tectonic foliation (S_1), preserved in metasedimentary rocks of the Nickol River Formation (Hickman et al., 2000) 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 (Kiyokawa and Taira, 1998; Smith et al., 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 along the Sholl Shear Zone is dextral (D_8), and 30–40 km based on displacement of the c. 3010 Ma Whim Creek Group (see interpreted geology map) and of c. 2925 Ma layered intrusions in the DAMPIER area (Hickman, 2001). The major stratigraphic mismatch across the Sholl Shear Zone cannot be explained by this amount of dextral displacement.

Direct evidence for earlier sinistral movement is provided by feldspar porphyroclasts within fine-scale mylonite lamination 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 about 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 between outcrops of the Cleaverville Formation on both sides of the Sholl Shear Zone (see **Cleaverville Formation**) are in marked contrast to the apparently total 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 clastic zircons in samples of the Cleaverville Formation (Nelson, 1998) 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 and Whundo Groups. 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) and c. 3021 Ma intrusive porphyry north of Roebourne (Nelson, 1999).

D_3 (3015–3010 Ma)

At Mount Ada (15 km south of Roebourne), east-southeasterly trending, upright, tight to isoclinal D_3 folds in the Cleaverville Formation deform a sill of 3014 Ma granophyre (Nelson, 1997), 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.

D_4 (c. 2990–2960 Ma)

Northerly dipping thrusts in the c. 3010 Ma Warambie Basalt east of Mount Ada (Hickman, in prep.a) pre-date dextral movement on the Sholl Shear Zone, and may be equivalent to Phase 3 that Krapez and Eisenlohr (1998) recognized in the Whim Creek area. Originally east–westerly trending folds in the Mallina Basin (D_1 of Smithies, 1998b) may belong to the same event. These correlations suggest that D_3 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) may be equivalent to tight folds with northerly trending axes within gneiss of the Caines Well Granitoid Complex (see also **Mallina Basin**). Otherwise, D_5 structures have not been recognized in the WPGGT.

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 (see interpreted geology map). 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). However, geochronology in the Mallina Basin (Smithies, 1998b) establishes that the age of these structures must be 2950–2930 Ma, not 2906–2863 Ma as suggested by Krapez and Eisenlohr (1998, fig. 2). 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) describes the north-northwesterly striking Maitland Shear Zone on DAMPIER (1:100 000) 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. A parallel tectonic foliation (S_7) is developed in the adjacent greenstones of the Whundo Group, and in the granitoids of the Cherratta Granitoid Complex. The Maitland Shear Zone is truncated by dextral displacement on the Sholl Shear Zone.

D_8 *(c. 2920 Ma)*

The latest movement on the Sholl Shear Zone was dextral, and displaces c. 2925 Ma layered intrusions on DAMPIER (1:100 000; Hickman, 2001). 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 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 (1:100 000; 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 and 2770 Ma.

Mallina Basin

Rocks of the De Grey and Whim Creek Groups show a common deformation history, including early northerly trending folds and later, upright, east-northeasterly trending folds (Smithies et al., 1999).

The earliest recognized phase of deformation within the Mallina Basin (D_4 — local D_1 of Smithies, 1998b) is best developed in rocks of the De Grey Group, to the south of ROEBOURNE. This event produced large-scale, open folds, probably with an originally east–west orientation (Smithies, 1998b). Large northerly trending, upright to overturned folds, such as the Croydon Anticline (Smithies, 1998b), were produced during D_5 (D_2 of Smithies, 1998b). Outcrop of the De Grey Group, immediately to the west of the Yule River and within the Yandeearra Aboriginal Reserve, also exposes the faulted western limb of a northerly trending D_5 anticline. Rocks of the Whim Creek Group show only local evidence for this early phase of deformation (Krapez and Eisenlohr, 1998); however, gneiss within the Caines Well Granitoid Complex shows the development of tight folds with northerly trending axes consistent with deformation during D_5. Structures related to D_5 are locally truncated by the Peawah Granodiorite, and so this deformation event occurred at or before c. 2950 Ma.

In the De Grey Group, D_6 (D_3 of Smithies, 1998b) has resulted in isoclinal and locally overturned, northeasterly trending folds, and reversed (south-side-up) the originally normal displacement along early east-northeasterly trending faults such as the Mallina Shear Zone. This deformation post-dates intrusion of the Peawah Granodiorite. In the area to the south of Mallina Station, rocks of the Millindinna Intrusion have also been tightly folded during this event.

The rocks of the Whim Creek greenstone belt generally young and dip away from the Caines Well Granitoid Complex at angles less than 30°. The overall structure is a regional-scale, east-northeasterly plunging, upright D_6 anticline cored by the Caines Well Granitoid Complex.

The Mallina Shear Zone forms part of the southwestern margin of the Whim Creek greenstone belt and trends in an easterly direction across ROEBOURNE. The zone is defined as a network of anastomosing faults that form a low ridge of calcretized and silicified rocks of the De Grey Group. In the abundant low-strain areas within the shear zone, calcretized rock shows well-preserved sedimentary structures. Kinematic indicators, including S–C fabrics and fold asymmetry, tentatively show that the last movement along the shear zone was sinistral and south-side-up. The Mallina Shear Zone is interpreted as the reactivation of an early growth fault related to the development of the Mallina Basin (Smithies, 1999).

The Loudens Fault marks the southeast margin of the Whim Creek greenstone belt. Movement on the Loudens Fault was at least partly later than deposition of the Fortescue Group. Along the northwest margin of the belt, the Kents Bore Fault parallels the Mallina and Sholl Shear Zones, but is displaced by the Caines Well Fault, which has a similar northeasterly trend to the Loudens Fault. The Kents Bore Fault can be traced through the greenstone belt, where it is further dislocated by minor sinistral northeasterly trending faults, and is truncated by the Loudens Fault.

HAMERSLEY BASIN

Fortescue Group (*AF*)

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, which 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 terrains. The age of the dominantly volcanic Fortescue Group is c. 2770–2629 Ma (Arndt et al., 1991; Nelson et al., 1992, 1999; Wingate, 1999). 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–greenstone terrain is an angular unconformity. A polymictic conglomerate containing subrounded clasts derived from the underlying granite–greenstone terrain, 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.

Mount Roe Basalt (AFr, AFrb, AFrc, AFrg, AFrs, AFry)

On ROEBOURNE, most rocks of the Fortescue Group belong to the Mount Roe Basalt (*AFr*), and are locally subdivided into vesicular basalt (*AFry*) or glomeroporphyritic basalt (*AFrg*). The former contains rare squat, subhedral phenocrysts of plagioclase and clinopyroxene, and quartz–calcite filled vesicles 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 (*AFrb*), which, together with the presence of pillowed basalt, indicate deposition in a subaerial to shallow marine environment.

Sedimentary rocks associated with the basalts include polymictic conglomerate (*AFrc*), and shale, siltstone, and fine- to medium-grained, poorly sorted arkose and subarkose (*AFrs*). About 3 km to the southwest of Mons Cupri, interbedded coarse-grained and fine-grained sedimentary rocks outcrop in a narrow belt, up to 0.5 km wide and 6 km long. These rocks are faulted against the Mount Negri Volcanics, and follow the general trend of the Whim Creek greenstone belt; they are interpreted to have been deposited in a local graben.

Hardey Formation (AFh)

The Hardey Formation overlies the Mount Roe Basalt in southwestern ROEBOURNE and southeast of Whim Creek. The formation 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.

Cooya Pooya Dolerite (AFdc)

The rocks of the Hardey Formation have been locally intruded by the Cooya Pooya Dolerite (*AFdc*). In southwestern ROEBOURNE, the basal unit is a fine-grained, silicified, pyroxene-rich rock with quartz xenocrysts derived from adjacent sandstone of the Hardey Formation. Evidence of original olivine is seen in some samples. The dolerite that forms the main body of the Cooya Pooya Dolerite is a fine- to medium-grained, plagioclase-rich and biotite-bearing dolerite, with local olivine–orthopyroxene–clinopyroxene–plagioclase cumulate. Some of the most accessible exposures of the Cooya Pooya Dolerite are seen at Harding Dam (Fig. 11).

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Figure 11. Harding Dam, showing surrounding rocky black hills typical of the Cooya Pooya Dolerite (MGA 0510900 7680250)

Subsequent to the mapping of ROEBOURNE, mapping of COOYA POOYA (Hickman, in prep.b) has indicated that the Cooya Pooya Dolerite, as previously defined, includes ultramafic lava within the Hardey Formation.

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 Peninsular, about 50 km to the west. The rock contains partly melted granite xenoliths and large feldspar xenocrysts. Immediately to the north of Cossack, 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*).

Dolerite and gabbro dykes (d)

Massive, medium- to coarse-grained dolerite of uncertain, but probable Late Archaean age forms prominent outcrops at Peawah Hill and on Depuch Island, and has intruded the Portree Granitoid Complex. Aeromagnetic lineaments trend northeast and northwest and are also presumed to coincide with mafic dykes.

Quartz–tourmaline deposits (Aqt)

Close to faults and the hinge zone of major folds, clastic rocks of the De Grey Group have locally undergone boron metasomatism, such that all aluminous mineral phases have been altered to tourmaline, leaving an assemblage of quartz and tourmaline. Primary sedimentary structures, including bedding and grain-size grading, are commonly preserved. The timing of metasomatism is difficult to constrain, but tourmaline-rich quartz veins are locally associated with the c. 2935 Ma Satirist Granite, to the south of ROEBOURNE, and with the c. 2765 Ma Opaline Well Granite, about 19 km southwest of Whim Creek.

Granite and quartz dykes (g, q)

Numerous dykes and veins of granite (*g*) intrude the Andover Intrusion south of Mount Hall, and are probably related to younger granitoids in the Harding Granitoid Complex. They occupy northeasterly striking faults that post-date intrusion, and are probably of D_9 age (see **Structure**, p. 34).

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 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.

STRUCTURE

Structures affecting the Fortescue Group include northeasterly striking faults (D_{10}) at Cleaverville and in the Whim Creek area. Some of these structures are probably superimposed on underlying rift structures that were active during deposition of the Mount Roe Basalt and Hardey Formation (Blake, 1993). Major faults, such as the Sholl Shear Zone, also appear to have been reactivated during rifting at about 2770–2750 Ma (Strong et al., 2001). The Fortescue Group is gently folded in the southwestern part of ROEBOURNE and east of Whim Creek, possibly due to post-depositional subsidence within the rift basins.

CAINOZOIC DEPOSITS

Cainozoic deposits cover about 70% 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

Clastic and chemical deposits (*Czaa*, *Czag*, *Czak*, *Czc*, *Czrk*, *Czru*, *Czaf*, *Czrf*, *Czrz*)

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 as gravel beds up to 5 m thick in the banks of larger drainages. These old alluvial deposits are a concealed part of the regolith in the coastal plain, and have been used locally as a source of gravel for road construction. Calcrete of alluvial origin (*Czak*) is best developed along the upper reaches of Jones River (MGA 536700E 7792800N), 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. Silcrete and opaline silica

(*Czrz*) locally replaces quartz-rich sedimentary rocks of the De Grey Group within the Mallina Shear Zone. Siliceous cap rock over ultramafic rock (*Czru*), to the east of the Yule River, in the southeastern part of ROEBOURNE, is associated with altered outcrop of the Millindinna Intrusion. Calcrete, of residual origin (*Czrk*), locally replaces all rock types on ROEBOURNE, particularly along faults and shear zones, and is extensively developed over rocks of the De Grey Group within the Mallina Shear Zone. Where original sedimentary structures are preserved, the calcretized rock has been mapped according to the inferred protolith. Ferricrete (*Czrf*) is locally developed to the north of the Mallina Shear Zone, in the southeastern part of ROEBOURNE, where it develops over rocks of the De Grey Group along inferred contacts with the Portree Granitoid Complex. 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*, *Qao*, *Qaoc*, *Qab*, *Qw*, *Qwb*, *Qws*, *Qc*, *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*) outcrop along the lower sections of major drainages such as the Harding and Jones rivers. Alluvial clay, silt, and sand form overbank deposits on floodplains (*Qao*), and locally include gilgai (*Qab*). In areas immediately adjacent to rivers, alluvial floodplains also include small, abundant, scattered lacustrine or claypan deposits (*Qaoc*), consisting of clay, silt, and evaporite in shallow depressions.

Sheetwash, including sand, silt, and clay (*Qw*), is deposited on distal outwash fans and includes some gilgai (*Qwb*). Red to yellow quartzofeldspathic sand (*Qws*) is commonly fine grained, and has been deposited in distal outwash fans. Locally reworked by wind action, the sand deposits have been generally stabilized by extensive grass and shrub cover. Colluvium (*Qc*) is a widespread unit on ROEBOURNE, occurring on scree slopes and in deposits of coarse pebbly sand fringing the hills. The composition of colluvial units depends on the lithology of source rocks in the adjacent hills. Eluvial sand over granitoid rocks (*Qrg*) is a quartzofeldspathic residual deposit derived from underlying granitoid bedrock or nearby outcrops. Eolian sand (*Qs*) forms east-southeasterly trending, unstable dunes in the south and west of ROEBOURNE, and in the vicinity of Wickham.

Marine, estuarine, and coastal eolian deposits (*Qhm*, *Qhms*, *Qpmb*)

Quaternary deposits of marine, estuarine, and eolian origin occur 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, locally referred to as the Bossut Formation (Lindner, 1961), 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. Tidal mudflat deposits (*Qhm*) are composed of supratidal to intertidal silt and mud, and include tidal creeks fringed by stands of mangroves. 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.

Table 3. U–Pb zircon geochronology (SHRIMP) from ROEBOURNE

Age (Ma)	*Lithology, formation*	*MGA coordinates Eastings*	*Northings*	*Sample no.*
3269 ± 2	schist, Nickol River Formation	501000	7705700	136819(e)
3118 ± 2	rhyolite tuff, Woodbrook Formation	535100	7688200	144256(e)
3117 ± 3	welded tuff, Woodbrook Formation	508800	7686600	127378(e)
3116 ± 3	dacite, Whundo Group	548400	7686100	144210(e)
3115 ± 5	felsic tuff, Bradley Basalt	501500	7686300	114305(c)
3093 ± 4	Caines Well Granitoid Complex	562400	7892400	118965(d)
3022 ± 12(a)	sandstone, Cleaverville Formation	502100	7714300	127330(e)
3021 ± 3	porphyry sill, Ruth Well Formation	519600	7709100	144224(f)
3018 ± 3(a)	sandstone, Cleaverville Formation	516500	7686700	142830(e)
3018 ± 2	porphyry sill, Regal Formation	501600	7711200	127327(e)
3015 ± 5(a)	sandstone, Cleaverville Formation	509000	7712500	136899(e)
3014 ± 3	Harding Granitoid Complex	571100	7705900	118966(d)
3014 ± 6	granophyre sill, Cleaverville Formation	517000	7687200	127320(e)
3009 ± 4	welded tuff, Mons Cupri Volcanics	554450	7682100	141936(e)
2997 ± 20(a)	sandstone, Mallina Formation	587700	7682900	118969(d)
2994 ± 4(a)	sandstone, Constantine Sandstone	589190	7685490	142942(g)
2990 ± 5	Caines Well Granitoid Complex	579400	7697800	142950(g)
2978 ± 5(a)	sandstone, Cistern Formation	586750	7691490	142949(g)
2975 ± 4(b)	Kialrah Rhyolite	536700	7681900	144261(e)
2970 ± 5	Harding Granitoid Complex	507900	7691500	142430(f)
2948 ± 5	Peawah Granodiorite	603400	7678500	118967(d)
2946 ± 6	Portree Granitoid Complex	611200	7696350	142889(f)
2945 ± 6	granodiorite, Mallina Basin	580510	7678990	160498(g)
2925 ± 4	Caines Well Granitoid Complex	581500	7695250	118964(d)
2765 ± 5	Leucogranite	575250	5879500	118972(d)

NOTES: (a) maximum depositional age of clastic sedimentary rock
(b) alternative crystallization age from smaller zircon population is 2943 ± 7 Ma
(c) Nelson (1996)
(d) Nelson (1997)
(e) Nelson (1998)
(f) Nelson (1999)
(g) Nelson (2000)

GEOCHRONOLOGY

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 the ROEBOURNE. These data are referred to throughout these Notes, and are used in the map legend.

ECONOMIC GEOLOGY

Some of the earlier mineral discoveries in Western Australia were made in the west Pilbara. In 1872 copper and lead were discovered southwest of Roebourne, but the copper mine at Whim Creek is perhaps the most famous deposit on ROEBOURNE. Copper mining also took place, on a small scale, at Mons Cupri, about 5 km to the southwest of Whim Creek. Copper was also found south of DAMPIER, at Whundo and Yannery Hill on PINDERI HILLS, between 1911 and 1913, and these deposits were subsequently mined. The discoveries of auriferous quartz to the west of Roebourne in 1877 (Maitland, 1909) and at Mallina Homestead in 1888 were amongst the first in Western Australia. A brief mention

Table 4. Geochronological data providing evidence of pre-3300 Ma source rocks on ROEBOURNE

Age (Ma)	*Method*	*Material*	*Rock unit, age*	*Sample no.*
3800–3400	$^{207}Pb/^{206}Pb$	zircon	Constantine Sandstone (4 grains)	142942[d]
3487–3394	$^{207}Pb/^{206}Pb$	zircon	Mallina Formation (8 grains)	141936[a]
3461 ± 8	$^{207}Pb/^{206}Pb$	zircon	Cleaverville Formation, 3022 Ma	127330[a]
3368	Nd T_{DM}	rock	Louden Volcanics	331/338, 331/339[b]
3309	Nd T_{DM}	rock	Harding Granitoid Complex	142430[c]

NOTES: (a) Nelson (1998)
(b) Sun and Hickman (1998)
(c) Hickman et al. (in prep.)
(d) Nelson (2000)

of mineral occurrences are made here, but for a more complete account, reference is made to Ruddock (1999).

COPPER–LEAD–ZINC

The Whim Creek deposit was discovered in 1888, and was worked until the mid 1920s. A total of 79 263 t of copper ore was mined for approximately 11 500 t of contained copper from stratabound Cu–Zn mineralization near the base of the Rushall Slate. The slate defines an open, northeast-plunging syncline, and the main ore horizon is confined chiefly between two northeasterly striking faults, separated by about 500 m. The main ore horizon has a maximum thickness of 14 m, and includes the primary ore minerals pyrite, pyrrhotite, chalcopyrite, sphalerite, and minor galena (Reynolds et al., 1975). Ore reserves of copper (leachable openpit proved and probable reserves of oxide and supergene material) were estimated to be 2.53 Mt at 1.34% Cu (Straits Resources Ltd, 1997).

The Mons Cupri mine is situated about 4 km southwest of Whim Creek and was worked until 1917. Ore reserves of copper (leachable openpit proved and probable reserves of oxide and supergene material) were estimated to be 4.1 Mt at 0.75% Cu (Straits Resources Ltd, 1997).

Mineralization at Mons Cupri forms as disseminated stockworks, veins, and massive lenses of chalcopyrite, pyrite, galena, and sphalerite, contained primarily within a chalcedony–chlorite–siderite pipe. According to Miller and Gair (1975), the host is a rhyolite fragmental rock of the Mons Cupri Volcanics. Investigation of the deposit during the present study showed the host rock to comprise abundant boulder conglomerate, coarse- to medium-grained clastic and volcaniclastic rocks, and lesser felsic pyroclastic rocks. Generally, finer grained clastic rocks, including well-laminated shale (?the bedded silica cap rock of Miller and Gair, 1975), form at the top and overlie the mineralization. The host sequence has been reassigned to the Cistern Formation (Smithies, 1997a).

Gossans within the Whim Creek Group at Salt Creek (near Balla Balla Central) have been explored for their base metal potential. Drilling identified less than 500 000 t of ore with grades up to 1.3% Cu, 3.3% Pb, and 8.4% Zn. This massive sulfide mineralization forms within medium- to fine-grained tuffaceous siltstone and is overlain by basalt. Correlation of the host sequence with the Cistern Formation is suggested.

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).

A prospective area for Cu–Pb–Zn mineralization lies along the Orpheus fault system within the Whundo Group. At Orpheus, close to the western boundary of ROEBOURNE, Dragon Resources discovered Cu–Zn(–Ag–Au) mineralization in 1995 (Ruddock, 1999). The present mapping on ROEBOURNE 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) were found to contain up to 14.5% Zn, 2.2% Pb, 840 ppm Ag, 1.1 g/t Au, and 0.2% Cu. Copper–zinc 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. VMS deposits have previously been identified southwest of ROEBOURNE at Whundo and Yannery Hill (Collins and Marshall, 1999). Although most of the known Cu–Zn mineralization is in narrow shear zones and is irregular along strike, the system probably merits further investigation for its mineral potential.

Other known copper occurrences on ROEBOURNE appear to be isolated small deposits associated with lenticular quartz veins, and appear to have limited economic potential. Marston (1979) and Ruddock (1999) have provided descriptions of these deposits.

Lead has been mined at the Andover Lead Mine (not shown on map), about 3.5 km north-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)

A large body of nickel and copper mineralization known as the Sherlock Bay deposit (near Symond Well) occurs to the north of the Caines Well Granitoid Complex; outcrop is extremely poor and most geological observations come from drill core (Miller and Smith, 1975). The mineralization forms within a quartz–amphibole–magnetite–sulfide schist that forms part of a steeply northerly dipping sequence of mafic, intermediate, and felsic volcanic rocks, and gabbro. Ore minerals include pyrite, pyrrhotite, pentlandite, and chalcopyrite. An initial (non Joint Ore Reserves Committee, JORC) resource for the deposit was estimated to be 75 Mt at 0.5% Ni and 0.1% Cu (Miller and Smith, 1975). A more recent estimate has been made for an inferred resource of 16 Mt at 0.75% Ni and 0.9% Cu (Dragon Resources Ltd, 1990).

Greenstones around Quarry Well, identified from aeromagnetic images in the central eastern part of ROEBOURNE, have been explored for base metals and nickel. Although no significant mineralization was found, drilling in the region intersected a greenstone sequence lithologically and stratigraphically very similar to that in the Whim Creek greenstone belt.

Rocks of the Millindinna Intrusion, in the southeastern part of ROEBOURNE, and particularly in the vicinity of Mount Dove, to the east of Yule River, have been investigated for nickel, copper, and platinum group element (PGE) mineralization. No significant mineralization was found, although O'Shea and Davies (1987) quoted maximum values of 70 ppb Pt, 10 ppb Pd, 1600 ppm Cu, and 950 ppm Ni from composite samples taken from rocks in the region of Mount Dove.

The Andover Intrusion is similar in size to the Munni Munni Intrusion, which contains substantial 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 levels in a layered series.

GOLD(–ANTIMONY)

Gold mineralization on ROEBOURNE is present in two main types of deposit: gold and gold–copper deposits in mafic and ultramafic rocks, and gold(–antimony) deposits in metasedimentary rocks of the Mallina Basin.

West and southwest of Roebourne, gold has been mined at Weerianna, Carlow Castle, Fortune and Good Luck, and Sing Well. Except for the Fortune and 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**, p. 34). 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. For example, at Carlow Castle the main vein system strikes north, at an oblique angle to the silicified shear zone in the Nickol River Formation immediately to the north. The Fortune and Good Luck deposits are situated about 3–4 km south of Carlow Castle, and 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 c. 2925 Ma Andover Intrusion. On DAMPIER, gold mineralization at Radleys Find occurred late in the history of the Sholl Shear Zone, and may be of similar age — c. 2920 Ma if related to D_8 (see **Structure**, p. 34). Production data for the deposits near Roebourne are provided by Ruddock (1999), and geological descriptions and additional references are available in Hickman (1983).

Gold deposits hosted by sedimentary rocks of the Mallina Basin are located south and east of Whim Creek. The Toweranna mining centre lies about 15 km to the south-southeast of Whim Creek, and has yielded 4052 t of ore for a total of 161.8 kg Au. Gold mineralization forms in pyrite-rich quartz veins within, and marginal to, a coarse-grained feldspar porphyry (*Apto*) that intrudes the Mallina Formation. The porphyry intrudes the sheared axial region of the northeasterly plunging Croydon Anticline. According to Hickman (1983), a similar porphyry intrudes the axis of the anticline, 13 km to the south, suggesting that emplacement of the porphyry and the mineralization are both structurally controlled.

Gold and antimony were discovered around Mallina Homestead in 1888. Further discoveries of antimony mineralization included the Peawah prospect, about 7.5 km to the east-southeast of Mallina Homestead. This prospect lies within the Mallina Shear Zone, whereas mineralization near Mallina Homestead is within minor shear zones and quartz veins that trend parallel to the Mallina Shear Zone. All of these deposits are hosted by rocks of the Mallina Formation.

The main gold-bearing quartz reef, referred to as the Stray Shot, lies immediately north of Mallina Homestead and yielded a total of 4.0 kg Au (Hickman, 1983). Gold was not recovered from the antimony-rich lodes at Mallina Homestead and at the Peawah prospect. However, Resolute Ltd commenced exploration in 1997 and identified significant zones of gold mineralization within, and to the south of, the Mallina Shear Zone (Phaceas, 1997).

Resolute Ltd's Camel 2 prospect lies within the Mallina Shear Zone, about 5 km to the east of the Peawah prospect, and includes a zone of mineralization that is continuous over 200 m and locally reaches grades of 6.8 g/t Au over 22 m (Phaceas, 1997).

Martins lode is the main antimony-bearing deposit at Mallina and lies about 500 m east-northeast of the Mallina Homestead. Here, stringers of stibnite are disseminated throughout a fractured quartz reef, and have yielded over 2.5 t Sb (Finucane and Telford, 1939). The Peawah Prospect, about 7.5 km east-southeast of Mallina Station, has yielded 11.8 t Sb (Finucane and Telford, 1939).

VANADIUM–TITANIUM

Substantial deposits of vanadium–titanium mineralization occur within the Sherlock Intrusion. The intrusion ranges from serpentinite and pyroxenite at the base, to anorthosite, norite and gabbro, to granophyre at the top. The mineralized zones are stratiform and stratabound seams of vanadiferous titanomagnetite. The largest deposits are at Balla Balla, where there are three main mineralized zones known as Balla Balla West, Central, and East, along the northeastern boundary of the Caines Well Granitoid Complex. The total mineral resource estimate (measured and indicated resource categories) for the three zones is 64 Mt at 0.78% V_2O_5 (Tanganyika Gold NL, 1999). Further resources have been identified nearby at Balla Balla – Don Well and Balla Balla – Caines Well, where the total resource estimate (indicated and inferred resource categories) is 25.5 Mt at 0.72% V_2O_5 and 12.4% TiO_2 (Dominion Mining, 2000).

Titaniferous magnetite layers in the Andover Intrusion southwest of Roebourne have been explored for vanadium and titanium, but the deposits were found to be 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 North West Shelf.

SEMI-PRECIOUS STONE

Bright-green chert has been excavated near Carlow Castle as a source of ornamental stone. The chert forms 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, pegmatite dykes within the Andover Intrusion, near Mount Hall, have been mined for beryl (Ellis, 1962), and 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.

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Appendix 1

Gazetteer of localities

Place name	*MGA coordinates* *Easting*	*Northing*
Balla Balla Central	580600	7703500
Big Tree Well	501738	7708455
Black Hill Well	505038	7693455
Bradley Well	537838	7682455
Camel 2 prospect (Au)	619200	7688200
Carlow Castle	506884	7698925
Cleaverville	502900	7716400
Cossack	519600	7713400
Depuch Island	576139	7718155
Egina Well[(a)]	629544	7667164
Fortune (Au–Cu)	507849	7696935
Geemas Well[(a)]	580510	7678990
George Bridge	546100	7685600
Good Luck (Au–Cu)	507989	7697655
Good Luck Well	570635	7683845
Harding Dam	510900	7680250
Hill Well	578500	7685350
Illingotherra Hill	609900	7725483
Jones Bridge	537938	7688655
Mallina Station	607139	7690555
Millindinna Hill[(a)]	616949	7673468
Millindinna Well[(a)]	616839	7678355
Mons Cupri	584042	7690670
Mount Ada	516838	7686555
Mount Brown	582800	7692750
Mount Dove	651836	7684257
Mount Fisher	547600	7686850
Mount Hall	520838	7701355
Mount Negri	588027	7701349
Mount Roe	508938	7686355
Mount Wangee	520500	7707200
Opaline Well	573941	7680356
Paradise Well	503950	7700750
Peawah Hill	597300	7717100
Quarry Well	612139	7722755
Radleys Find (Au)[(b)]	489482	7688545
Red Hill	555148	7681844
Roebourne	515138	7703155
Salt Creek	573847	7704860
Sing Well[(b)]	497129	7694805
Sherlock Bay	557400	7698450
Sherlock Station	567000	7689000
Toweranna Well	591524	7679962
Warambie	538800	7683650
Warambie Homestead	538838	7683755
Weerianna	510138	7703855
Weerianna Hill	512538	7703955
Whim Creek	586738	7694955
White Quartz Hill	529638	7690055
Wickham	514000	7714000
Woodbrook	512300	7688150

NOTES: (a) SATIRIST (1:100 000) sheet coordinates
(b) DAMPIER (1:100 000) sheet coordinates

HICKMAN, SMITHIES

ROEBOURNE, WESTERN AUSTRALIA, SECOND EDITION

EXPLANATORY NOTES

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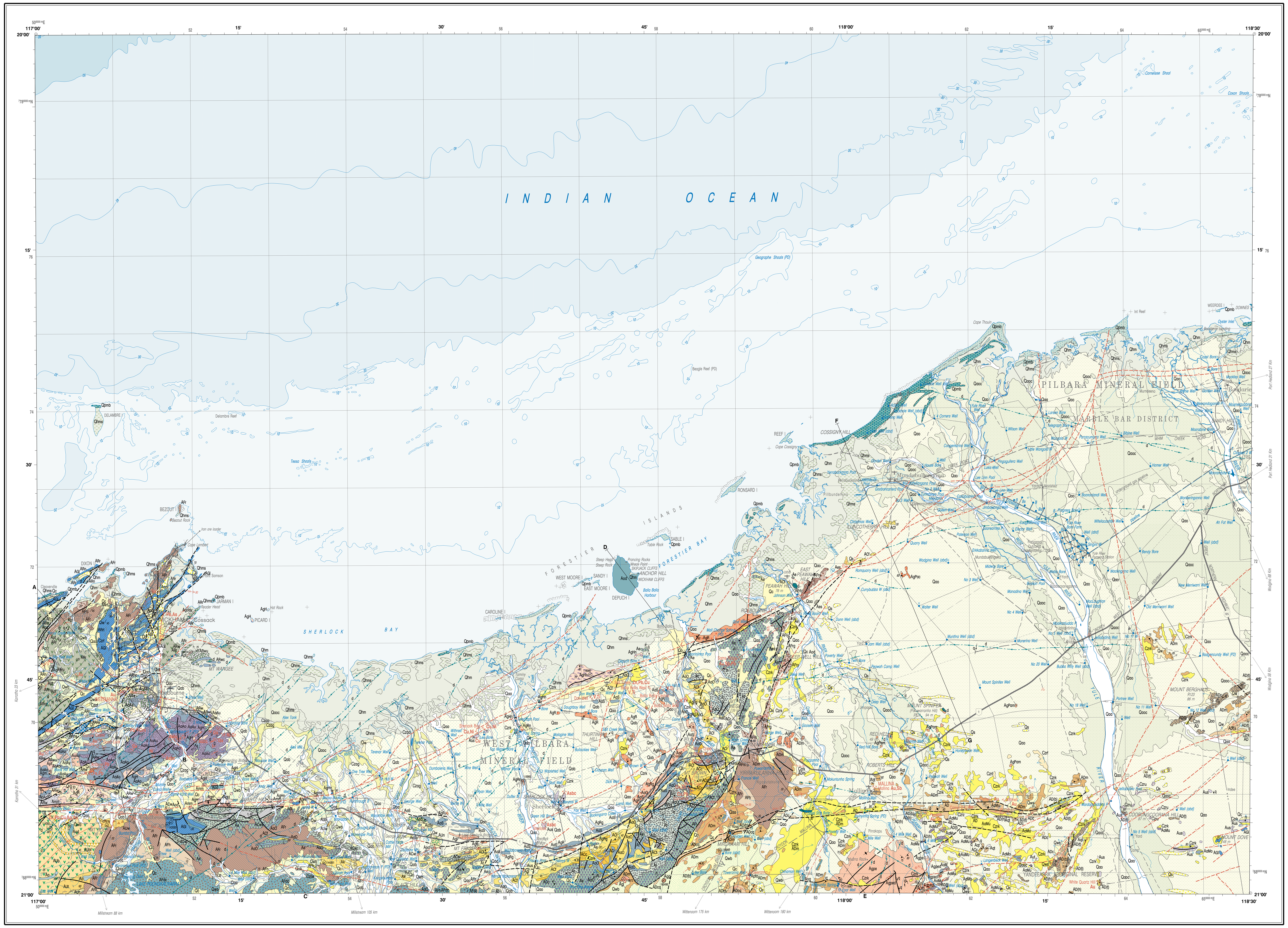
ROEBOURNE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SF 50-3



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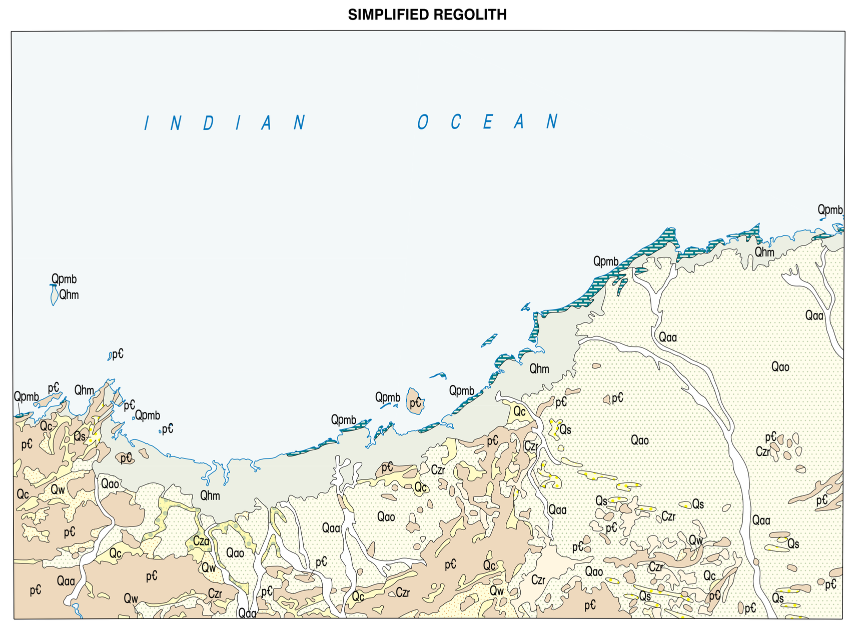

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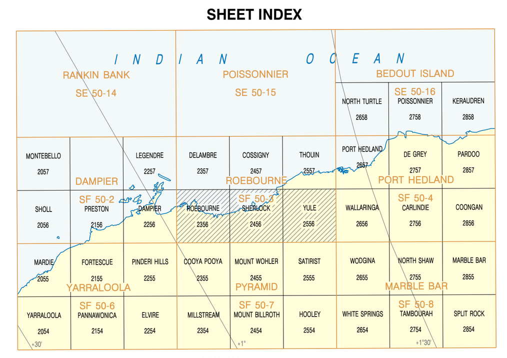

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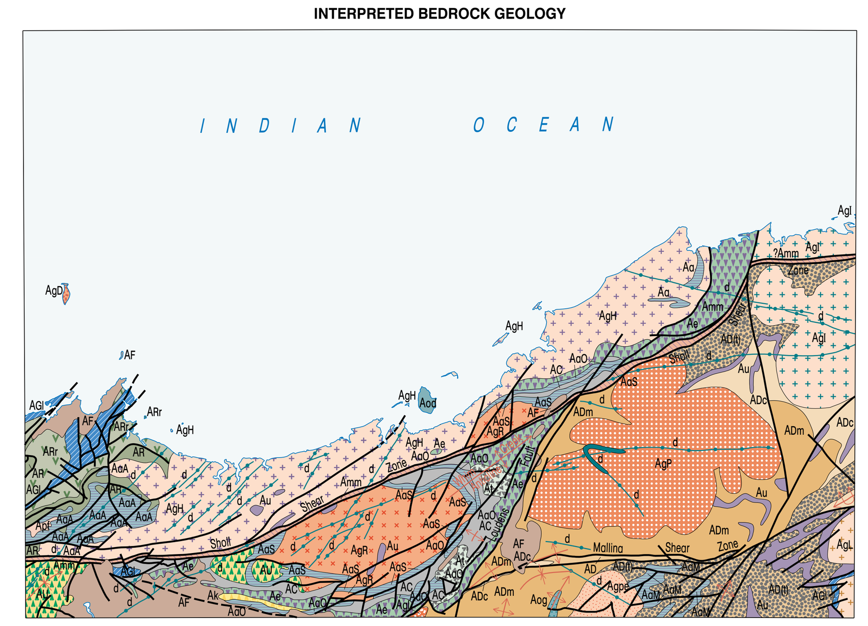

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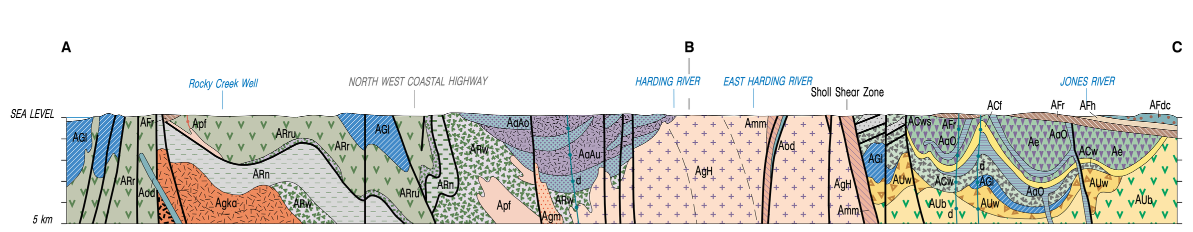
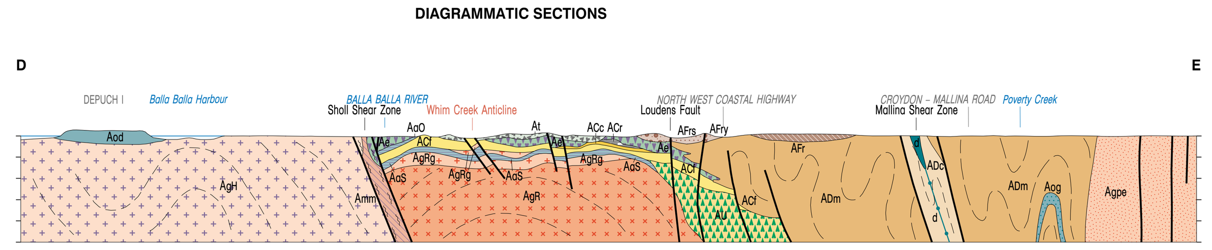
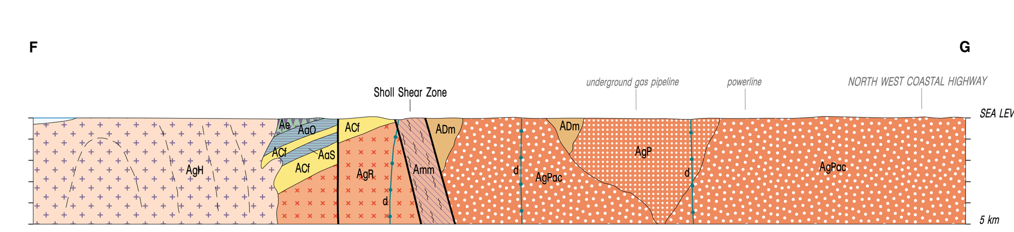






REFERENCE

PHANEROZOIC — CAINOZOIC — QUATERNARY

Qhm, Qhms, Qpmb

Qhm	Marine mud and silt on supratidal to intertidal flats; includes intertidal deposits with mangroves
Qhms	Coastal sand in beach deposits and dunes; chiefly marine sand reworked by wind, but includes some reworked alluvium near deltas; shelly sand contains *Anadara granosa*
Qpmb	Coastal limestone — lime-cemented shelly sand, dune sand, and beach conglomerate

Qaa, Qal, Qao, Qaoc, Qab; Qw, Qwb, Qws, Qc, Qrg, Qs

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 deltaic sandbanks
Qao	Alluvial sand, silt, and clay on floodplains
Qaoc	Mixed floodplain deposits with numerous small claypans
Qab	Alluvial sand, silt, and clay in floodplains, with gilgai surface in areas of expansive clay
Qw	Low-gradient sheetwash deposits — silt, sand, and pebbles on distal outwash fans; no defined drainage
Qwb	Sand, silt, and clay in distal outwash fans, with gilgai surface in areas of expansive clay
Qws	Quartzofeldspathic sand
Qc	Colluvium — sand, silt, and gravel in outwash fans; scree and talus; proximal mass-wasting deposits
Qrg	Quartzofeldspathic eluvial sand with quartz and rock fragments; overlying and derived from granitoid rock
Qs	Eolian sand — red-yellow, wind-blown sand; local ridges

Czaa, Czag, Czak, Czc, Czrk, Czru, Czaf, Czrf, Czrz

Czaa	Consolidated alluvial sand, silt, and clay; dissected by present-day drainage
Czag	Alluvial gravel, unrelated to recent drainage; dissected by present-day drainage
Czak	Alluvial calcrete; massive, nodular, and cavernous limestone; variably silicified; dissected by present-day drainage
Czc	Colluvium — dissected consolidated clay, silt, and sand, and gravel deposits; derived from adjacent rock outcrop
Czrk	Residual calcrete; massive, nodular, and cavernous limestone; mainly silicified
Czru	Siliceous caprock over ultramafic rock
Czaf	Pisolitic limonite deposits, developed over palaodrainage lines; dissected by present-day drainage
Czrf	Residual ferricrete; includes ferruginous duricrust and pisolitic ironstone; dissected by present-day drainage
Czrz	Silcrete and massive nodular silica

d	Dolerite and gabbro dykes; interpreted from aeromagnetic data where dashed
q	Quartz vein
g	Granite vein

Aqt — Quartz–tourmaline vein or replacement tourmalinite

ARCHAEAN — PILBARA CRATON

Hamersley Basin — Mount Bruce Supergroup — Fortescue Group (c. 2760 Ma; c. 2765 Ma; c. 2770 Ma)

AFdc — **COOYA POOYA DOLERITE:** fine- to medium-grained dolerite; includes ultramafic layers

AFh — **HARDEY FORMATION:** sandstone, conglomerate, siltstone, shale, and mafic to felsic tuff; includes **Lyre Creek Member**

Agdqy — Granophyric quartz diorite

Agl — Metamorphosed leucogranite; biotite (–tourmaline)-bearing; nonfoliated

AFr, AFrb, AFrc, AFrg, AFrs, AFry

AFr	**MOUNT ROE BASALT:** massive, vesicular, and glomeroporphyritic basalt
AFrb	Basaltic breccia
AFrc	Polymictic conglomerate and sandstone
AFrg	Glomeroporphyritic basalt
AFrs	Laminated shale, siltstone, and poorly sorted tuffaceous sandstone
AFry	Vesicular basalt

c. 2925 Ma — AgRg — **CAINES WELL GRANITOID COMPLEX**
BOOKINGARRA GRANITE: medium- to coarse-grained monzogranite to syenogranite; locally strongly foliated; metamorphosed

Pilbara Supergroup

Ao	Gabbro and dolerite; metamorphosed
Aod	Metadolerite

Amm — Mylonite and mylonitic gneiss; chiefly in Sholl Shear Zone

Pilbara Supergroup

AaS	**Sherlock Intrusion:** fine- to coarse-grained mafic intrusive rock; includes gabbro, olivine gabbro, leucogabbro, and granophyric gabbro; metamorphosed
AaSy	Granophyre; weakly metamorphosed
AaO	**Opaline Well Intrusion:** fine- to coarse-grained, mafic intrusive rock; includes olivine gabbro and minor pyroxenite and dunite; minor extrusive mafic rock; metamorphosed
	Andover Intrusion
AaAo	Gabbro, leucogabbro, and minor anorthosite
AaAu	Serpentinized peridotite and dunite; local metapyroxenite
AaAy	Granophyre and granophyric fine-grained monzogranite

c. 2946 Ma — **PORTREE GRANITOID COMPLEX**

AgP	Alkali granite; metamorphosed
AgPac	Alkali granite, coarse-grained; massive
AgPam	Alkali granite, medium-grained; pyroxene-bearing; foliated to massive

c. 2950–2945 Ma

Agpe	**PEAWAH GRANODIORITE:** metamorphosed medium- to coarse-grained hornblende–biotite granodiorite and tonalite
Agped	Fine- to coarse-grained diorite
Apto	**TOWERANNA PORPHYRY:** metamorphosed porphyritic granodiorite; possibly equivalent to **PEAWAH GRANODIORITE**
Agg	Metamorphosed medium- to coarse-grained hornblende–biotite granodiorite and tonalite; possibly equivalent to **PEAWAH GRANODIORITE**

Pilbara Supergroup

AaM	**Millindinna Intrusion:** ultramafic schist, tremolite- and serpentine-rich schists after peridotite, metamorphosed pyroxenite, and actinolite–chlorite schist after pyroxenite
AaMo	Melanogabbro and pyroxenite; metamorphosed
AaMu	Tremolite- and serpentine-rich schist, and serpentinite after peridotite; minor metachert, metasedimentary rock, and serpentinized high-Mg basalt
Aog	Metamorphosed medium- to coarse-grained gabbro; foliated to massive
Aut	Talc–carbonate schist; after peridotite

c. 3015–2970 Ma — **HARDING GRANITOID COMPLEX**

AgH	Metamorphosed granitoids ranging from monzogranite to tonalite; weakly foliated to banded and gneissic
AgHn	Foliated to gneissic granitoid rock; biotite-bearing; locally migmatitic

Pilbara Supergroup

2972 Ma — Ak — **KIALRAH RHYOLITE:** flow-banded porphyritic rhyolite and dacite; metamorphosed

At — **MOUNT NEGRI VOLCANICS:** metamorphosed variolitic and vesicular basalt; undivided

Ae	**LOUDEN VOLCANICS:** undivided basalt and high-Mg basalt; interbedded clastic units and chert; metamorphosed
Aes	Sandstone; fine- to coarse-grained; poorly sorted, arkosic; locally interbedded subarkose, polymictic conglomerate, and chert

<2990 Ma — De Grey Group

AD	Unassigned; sedimentary rock, and minor basalt and high-Mg basalt; metamorphosed
AD(b)	Basalt and high-Mg basalt; local ironstone, shale, and wacke
AD(h)	Shale; local ironstone; chert and arkose
AD(t)	Wacke; local pebble beds; minor shale and subarkose
ADc	**CONSTANTINE SANDSTONE:** undivided clastic rock; metamorphosed
ADcq	Quartzite; medium- to coarse-grained; minor graded beds
ADcs	Poorly sorted sandstone and shale; minor graded beds
ADm	**MALLINA FORMATION:** metamorphosed shale, siltstone, and wacke; minor chert

Whim Creek Group (3009 Ma)

ACr — **RUSHALL SLATE:** metamorphosed well-laminated shale and siltstone; locally graphitic; minor sandstone; may be equivalent to lower part of **MALLINA FORMATION**

ACre — **Comstock Member:** vesicular basalt and high-Mg basalt; metamorphosed

ACc — **CISTERN FORMATION:** metamorphosed clastic and volcaniclastic rocks, fine- to coarse-grained wacke, siltstone, and volcanolithic sandstone; includes polymictic cobble conglomerate

ACf — **MONS CUPRI VOLCANICS:** metamorphosed felsic volcanic and volcaniclastic rocks; lavas and pyroclastic rock, with feldspar and quartz phenocrysts; dacite to rhyolite composition; locally spherulitic and flow-banded

ACw	**WARAMBIE BASALT:** metamorphosed basalt and minor coarse-grained sedimentary rock
ACws	Sandstone, conglomerate, and semipelitic rock; metamorphosed

c. 3015 Ma — Apf — Quartz–feldspar porphyry, rhyolite, and dacite; chiefly intrusive; metamorphosed

Gorge Creek Group

c. 3020 Ma — AGl — **CLEAVERVILLE FORMATION:** banded iron-formation, jaspilite, chert, siltstone, shale, and minor felsic volcaniclastic rock; metamorphosed

Aus — Serpentinized ultramafic rocks; metamorphosed to amphibolite facies

CAINES WELL GRANITOID COMPLEX

AgR	Granitoid gneiss and foliated granitoid rock
AgRn	Monzogranite, strongly foliated and locally gneissic; locally migmatitic; metamorphosed to amphibolite facies

Pilbara Supergroup — Whundo Group

AU — Undivided; metamorphosed basalt and calc-alkaline volcanic rock (Section only)

c. 3115 Ma — AUw — **WOODBROOK FORMATION:** rhyolite tuff and agglomerate; minor basalt and rare thin banded iron-formation; metamorphosed

c. 3115 Ma — AUb — **BRADLEY BASALT:** pillow basalt, massive basalt, dolerite sills, and minor units of felsic tuff and chert; metamorphosed

AUbf — Felsic tuff and minor chert; metamorphosed

c. 3120 Ma — AUt — **TOZER FORMATION:** calc-alkaline volcanic rock, including basalt, andesite, and felsic pyroclastic rock; metamorphosed

AUn — **NALLANA FORMATION:** metabasalt, with minor metamorphosed ultramafic, felsic, and sedimentary units

c. 3270–3260 Ma

Agm	Monzogranite and granodiorite; local compositional banding; foliated (Section only)
Agka	**KARRATHA GRANODIORITE:** granodiorite and tonalite; foliated; local compositional banding; metamorphosed

Pilbara Supergroup — Roebourne Group (c. 3270 Ma)

ARrt — Basaltic tuff; well bedded; metamorphosed

ARr — **REGAL FORMATION:** pillowed and massive basalt, with a basal unit of peridotitic komatiite; minor chert; metamorphosed

ARrg — Foliated and sheared metabasalt with sheared veins and sheets of microgranite and pegmatite; metamorphosed to amphibolite facies

ARru — Serpentinized peridotite; locally peridotitic komatiite with olivine spinifex texture; metamorphosed

ARnx — Brecciated chert and silicified mafic rock

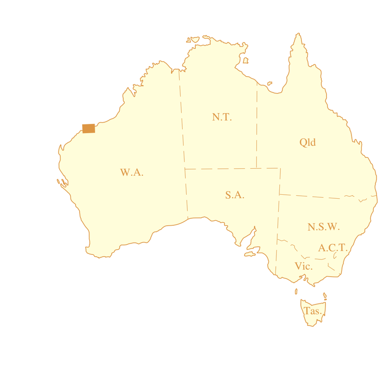
ARn — **NICKOL RIVER FORMATION:** chert, banded iron-formation, ferruginous clastic sedimentary rock, carbonate rocks, quartzite, conglomerate, felsic volcanic and intrusive rocks, and felsic volcanogenic sedimentary rock; metamorphosed

ARnc — Chert

ARw	**RUTH WELL FORMATION:** metabasalt and serpentinized peridotite, and thin chert units
ARwc	Chert, grey and white banded or ferruginous; minor quartzite; metamorphosed
ARwu	Serpentinized peridotite; locally peridotitic komatiite with olivine spinifex texture; metamorphosed

SYMBOLS

Geology by A. H. Hickman and R. H. Smithies 1995–1999



DEPARTMENT OF MINERALS AND ENERGY

NGA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SCALE 1:250 000

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

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