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GEOLOGY OF THE DAMPIER 1:100 000 SHEET

by A. H. Hickman

1:100 000 GEOLOGICAL SERIES

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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by
A. H. Hickman

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Cover photograph:
Rocky outcrop in the bed of the Maitland River east of Toorare Pool (AMG 784788). Banded granitoid gneiss of the Cherratta Granitoid Complex contains large xenoliths of sheared amphibolite. The age of the gneiss is approximately 2990 Ma, but the origin of the amphibolite (metabasalt) is uncertain.

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Abstract

Geological mapping of the DAMPIER 1:100 000 sheet, in conjunction with mapping and geochronology on the adjacent sheets of ROEBOURNE, PINDERI HILLS, and PRESTON, has resulted in a new geological interpretation of the northwest Pilbara. DAMPIER forms part of the West Pilbara Granite–Greenstone Terrane, a newly recognized and defined tectonic unit of the pre-Hamersley Basin component of the Pilbara Craton. Revision of the stratigraphy of the Archaean metamorphosed volcanic and sedimentary rocks on DAMPIER has enabled the tectonic evolution and mineral potential of the area to be better understood.

The greenstone lithostratigraphy of DAMPIER comprises the 3270–3250 Ma Roebourne Group, the 3125–3115 Ma Whundo Group, and the c. 3020 Ma Cleaverville Formation. This succession was folded, faulted, and intruded by granitoids during a sequence of magmatic and tectonic events between 3270 and 2920 Ma. 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, a major crustal dislocation with a long history of strike-slip and vertical movement, and regional upright folding at 2950–2930 Ma. A total of nine deformation events are recognized prior to earliest deposition of the Fortescue Group at c. 2770 – 2760 Ma.

Early deposition of basaltic and sedimentary rocks of the Fortescue Group on the deeply eroded surface of the West Pilbara Granite–Greenstone Terrane was controlled by a northeasterly striking rift system.

The mineralization on DAMPIER is reflected by gold mining, which dates to 1890, nickel and copper mining at Radio Hill, salt mining near Dampier, and exploration for base metals and platinum group elements.

KEYWORDS: Archaean, Pilbara Craton, West Pilbara Granite–Greenstone Terrane, lithostratigraphy, tectonic evolution, Roebourne Group, Whundo Group, Cleaverville Formation, Fortescue Group, geochronology, economic geology.

Introduction

The DAMPIER* 1:100 000 geological sheet (SF 50-2, 2256), bounded by latitudes 20°30'S and 21°00'S and longitudes 116°30'E and 117°0'E, is situated in the western part of the North Pilbara Terrain (Fig. 1). It occupies the southeastern corner of the DAMPIER AND BARROW ISLAND 1:250 000 sheet.

DAMPIER derives its name from the port of Dampier (AMG 700150†), which was built in the 1960s by Hamersley Iron Pty Ltd, and was named after the English explorer William Dampier who visited the area in 1688. Iron ore from Tom Price, Paraburdoo, and Channar, and salt from Dampier Salt Limited's seawater evaporation ponds, are shipped from the port. Development of the North West Shelf oil- and gasfields increased the total annual value of exports from Dampier, and in 1995 these exports were valued at about $A5 billion. Additionally, State energy requirements increasingly are being met through the 1500 km gas pipeline from Dampier to Perth, and the gas pipeline from Dampier to Newman, Wiluna, Leinster, and Kalgoorlie. The largest town on DAMPIER is Karratha, which was established in 1968 as a major regional administrative, commercial, industrial, and residential centre.

The combined population of Dampier and Karratha is about 12 000. Karratha Airport provides daily jet services to and from Perth and to other regional centres such as Port Hedland, Newman, and Geraldton.

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

† Localities are specified by the Australian Map Grid (AMG) standard six-figure reference system whereby the first group of three figures (eastings) and the second group (northings) together uniquely define position, on this sheet, to within 100 m.

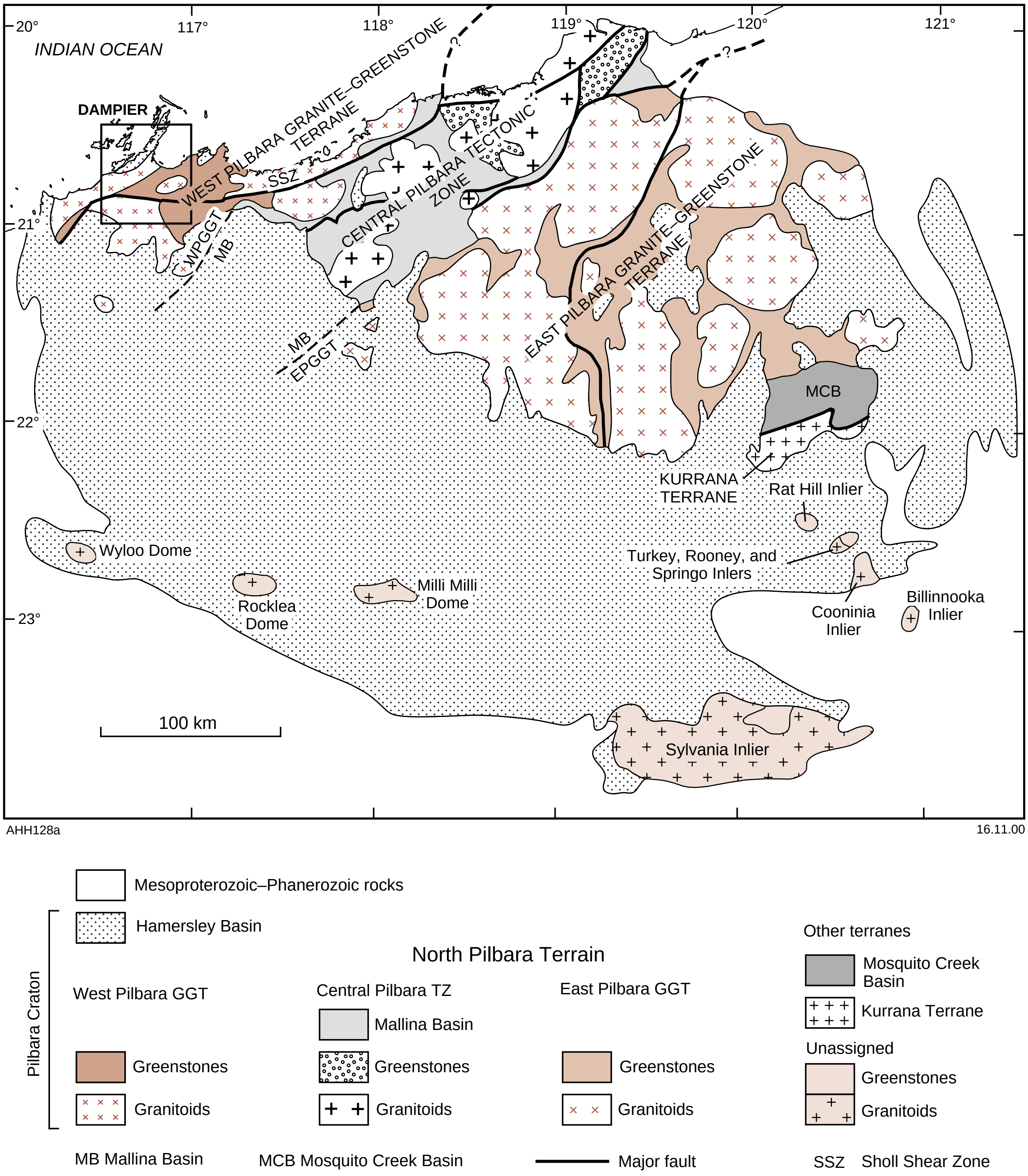

Figure 1. Regional geological setting of Dampier within the Pilbara Craton

The DAMPIER area has an active pastoral industry (cattle and sheep), as well as mining (gold, copper, nickel, semi-precious stones, and industrial minerals), fishing, and tourism. Boating and game fishing around the Dampier Archipelago are extremely popular, both for local residents and tourists.

Climate and vegetation

DAMPIER has a tropical, semi-desert climate with an average rainfall of between 250 and 300 mm; however, total precipitation is extremely variable from year to year because of tropical cyclones that pass through the area. Such cyclones generally develop off the northwest Kimberley coast during January to April, and subsequently move southwestwards and parallel to the Pilbara coastline. Some continue westwards into the Indian Ocean and have no effect on the Pilbara, but others swing southwards and southeastwards, crossing the coast and bringing rapid, heavy rainfall and strong winds along their paths. Rainfall in excess of 100 mm during 24-hour periods is common, causing rivers to flow, and then to flood parts of the coastal plain. 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.

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

The extensive plains of the Maitland, Yanyare, and Nickol rivers contain poorly drained red earthy sands, red earths, and expansive silty clay (gilgai). Beard (1975) describes this country as short-grass savanna mixed with spinifex. Fine-grained soils support grasses such as *Eragrostis setifolia* and *Triodia wiseana* (buck spinifex), whereas colluvial slopes near hills also contain *Acacia pyrifolia* (kanji), and creeks and rivers are lined with eucalypts.

In the southwestern part of DAMPIER, the northern foothills of the Chichester Range consist of a rocky dissected plateau that has large areas without soil cover. The basaltic rocks of this area have resulted in the development of hard alkaline soils and shallow loams. This country consists of plain with sparse trees that include *Eucalyptus brevifolia* (snappy gum) and *Triodia wiseana*, and scattered shrubs such as *Acacia xiphophylla* (snakewood).

Low hills and ridges, corresponding to outcrops of metamorphosed volcanic and sedimentary rocks (greenstones), for example around Mount Regal, Ruth Well, and in the southern part of DAMPIER, are dominated by spinifex and scattered shrubs. In these areas, trees and other grasses are concentrated along the banks of rivers and creeks.

Rocky terrain of the Burrup Peninsula and on the islands of the Dampier Archipelago is sparsely vegetated with spinifex and coastal flora.

Physiography

The physiography of DAMPIER is the product of the erosional and depositional processes acting on the area's bedrock geology. Thus, areas of active erosion, such as the hilly terrain of southeastern DAMPIER and the islands of the Dampier Archipelago, contain different landforms from those in areas of current and recent deposition, for example, on the coastal plain and the floodplains of the major drainages. Figure 2 shows the physiographic divisions of DAMPIER, based on criteria used across the northern part of the Pilbara region (Hickman, 1983). The same criteria and classification system have also been applied to other 1:100 000 sheets in the north Pilbara (Smithies, 1997, 1998c).

The tidal–supratidal flatlands physiographic division contains marine, eolian, and alluvial–colluvial material. Along the coast, a belt of dominantly marine sediments forms tidal mud flats and mangrove swamps, flanked by supratidal deposits of shelly sand, silt, and clay. Dunes of shelly and calcareous sand, which rise up to 20 m above high-tide level, define part of the coastline. Up to 10 km inland similar low dunes parallel the coastline, but are commonly dissected by marine or fluvial erosion. Saline tidal mud flats, dominated by clay and silt, but also with some calcareous sand, form large lagoons along the coast.

Inland from this marine environment is a gently sloping tract of sand, silt, and clay deposited from creeks and minor channels. Many of these drainages are short and originate from hilly areas close to the coast, but others are distributary channels of deltas. The best example of a deltaic coastal plain is in the western part of DAMPIER at the mouths of the Maitland and Yanyare rivers.

The alluvial plain and valley divisions occupy about 30% of the land surface on DAMPIER. They include the Maitland River floodplain and adjacent low-slope pediment plains that abut the dissected-plateau, range, and low granite-hills divisions. The alluvial plain and valley divisions are almost entirely underlain by rocks of the granitoid complexes.

The low hills division comprises areas of low rocky hills and scattered inselbergs, and rare mafic and ultramafic dykes that form narrow but prominent strike ridges.

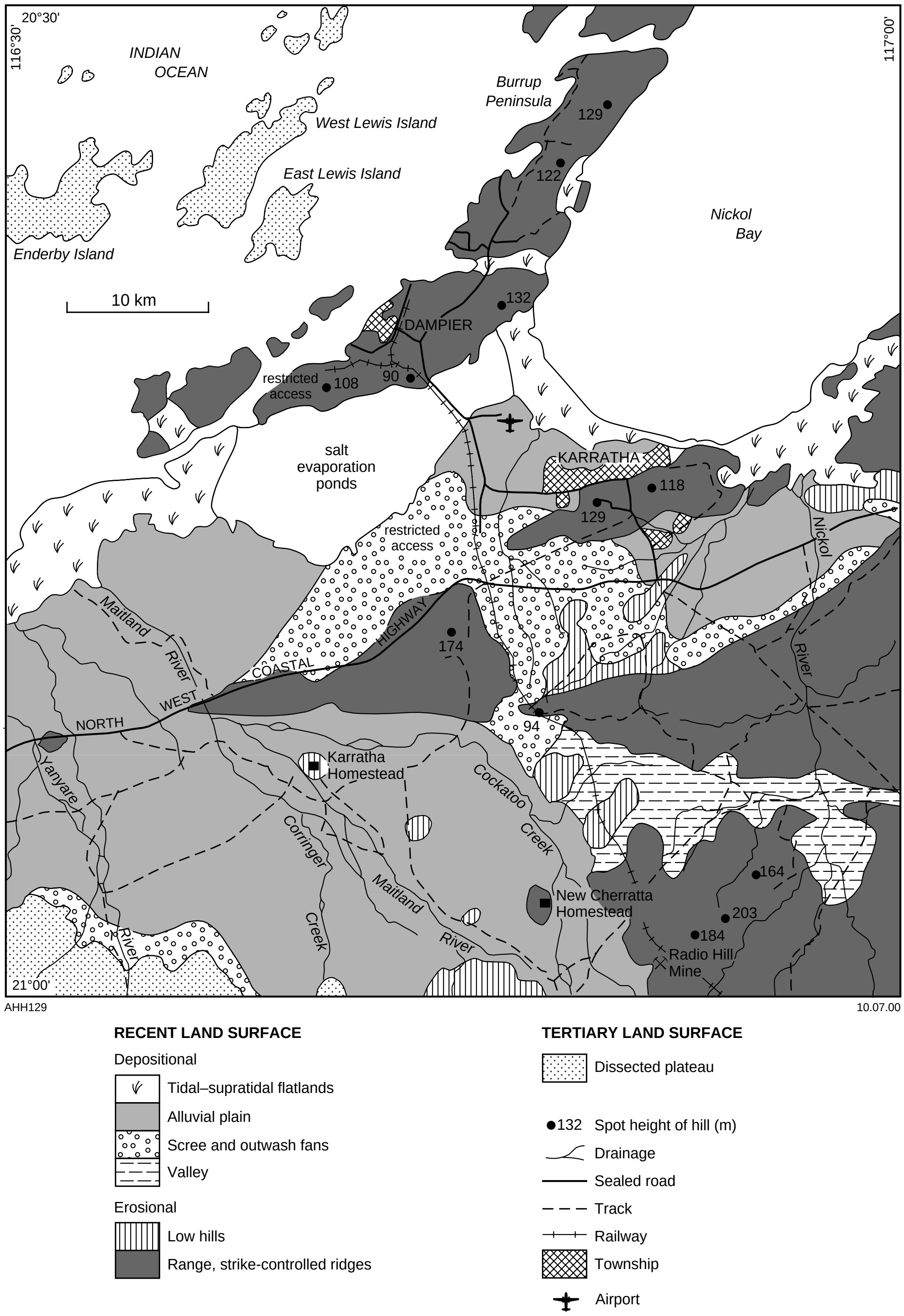

Figure 2. Physiography and access on Dampier

The range division consists of strike ridges that are separated by narrow, locally steep-sided valleys. In most areas steeply inclined greenstone belts form the ranges. Preferential weathering of the less resistant rock types has produced a trellised drainage pattern in these areas.

The dissected plateau division coincides with outcrop of the Fortescue Group in the Dampier Archipelago and in the southwest of DAMPIER. The division includes remnants of the Hamersley Surface (Campana et al., 1964), which rises abruptly from the plain and valley divisions. The boundary of the dissected plateau division is marked by prominent escarpments up to 100 m high and by cliffs up to 50 m high. The division contains steep V-shaped valleys, gorges, nick-points, and dendritic drainage patterns.

Previous investigations

Geological interest in the west Pilbara dates 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). However, prior to 1960 all geological investigations of the Dampier–Roebourne area were either of a reconnaissance nature or limited to local studies of mineral deposits. Consequently, knowledge of the regional geology of the west Pilbara was extremely limited until the Geological Survey of Western Australia (GSWA) commenced a 1:250 000-scale geological mapping program in 1962. Earlier references to the DAMPIER area are listed in Kriewaldt (1964a), and Hickman (1983) has reviewed investigations to 1979.

Based on mapping by the GSWA between 1962 and 1964 Ryan (1964), Ryan and Kriewaldt (1964), and Kriewaldt (1964a,b) interpreted the Archaean geology of the west Pilbara as a ‘geosynclinal cycle’ that culminated in the Pilbara Orogeny, with associated granitoid intrusion. In this scheme, all the volcanic and sedimentary rocks of the greenstone belts were assigned to the Roebourne Group. Banded iron-formation (BIF) at Cleaverville and west of Roebourne was named the Cleaverville Formation, and underlying volcanics were assigned to the Regal Formation. The Cleaverville Formation was tentatively correlated with BIF of the Gorge Creek Formation (described by Noldart and Wyatt, 1962) in the east Pilbara.

Ryan (1965) correlated the Roebourne Group with the Warrawoona succession of the east Pilbara. Fitton et al. (1975) partly adopted this interpretation; the main differences were that they recognized a regional mid-Archaean unconformity in the west Pilbara, splitting what had been the Roebourne Group into two successions. The lower succession comprised the Teichmans and Gorge Creek Groups, and the upper succession consisted of the Whim Creek Group and the Negri Volcanics. Fitton et al. (1975) correlated the Teichmans Group with the then newly defined Warrawoona Group (Hickman and Lipple, 1975) of the east Pilbara.

Between 1979 and 1981, the area around Dampier and Roebourne was mapped at 1:50 000 scale as part of the GSWA urban geology mapping program (Archer, 1979a,b; Biggs, 1979a,b,c, 1980). This work concentrated on the resources of industrial minerals and did not include detailed mapping of Archaean rocks in the area. Two 1:1 000 000-scale geological maps of the northern part of the Pilbara Craton were compiled by Hickman (1983): one shows outcrop lithology, and the other is a solid geology lithostratigraphic interpretation. On the latter map, the major lithological units of the west Pilbara, including those on DAMPIER, were correlated with sections of the east Pilbara stratigraphic succession (named the Pilbara Supergroup by Hickman, 1981). This correlation supported earlier suggestions (Ryan, 1965; Fitton et al., 1975) that much of the Archaean greenstone succession in the west Pilbara belonged to the c. 3500 – 3400 Ma Warrawoona Group. Hickman (1983) agreed that the Gorge Creek Group extended to the west Pilbara, but did not accept the regional mid-Archaean unconformity identified by Fitton et al. (1975). Hickman (1990) subsequently recognized the existence of a stratigraphic break in the Gorge Creek Group, and assigned the upper, coarse clastic sedimentary units to the newly defined De Grey Group.

Hudson and Horwitz (1986) correlated the Regal Formation (Ryan and Kriewaldt, 1964) with the Gorge Creek Group of the east Pilbara, and correlated the greenstones of the Mount Sholl – Whundo area with the Whim Creek Group.

Horwitz and Krapez (1991) reinterpreted the greenstone successions of the Pilbara Craton using sequence stratigraphy. Krapez (1993) provided a more detailed account of this new stratigraphic scheme, which included a division of the Pilbara granite–greenstone terrane into five tectono-stratigraphic domains. Krapez (1993) claimed that these domains were separated by northeasterly trending lineaments that coincided with major strike-slip faults, across which there was no stratigraphic continuity. In the west Pilbara, a domain boundary was interpreted east of DAMPIER between the Whim Creek Belt and the Mallina Basin. West of this boundary, the ‘Roebourne Megasequence’ was thought to be overlain by the ‘Mount Negri Megasequence’, whereas to the east the ‘Roebourne Megasequence’ was underlain by the ‘Gorge Creek Megasequence’.

The current National Geoscience Mapping Accord (NGMA) project between GSWA and the Australian Geological Survey Organisation (AGSO) commenced in 1995. In that year GSWA mapped DAMPIER and SHERLOCK, supported by data from NGMA aeromagnetic and radiometric surveys of the west Pilbara. Other west Pilbara 1:100 000-scale sheets were mapped between 1996 and 1999. Hickman (1997) revised the lithostratigraphy of the Roebourne–Whundo area, based on the mapping of DAMPIER, PINDERI HILLS, and ROEBOURNE.

Krapez and Eisenlohr (1998) and Smith et al. (1998) modified the sequence stratigraphy and domain interpretation of Krapez (1993) in order to subdivide the west Pilbara succession using the Sholl Shear Zone. Using available geochronology data (Horwitz and Pidgeon, 1993; Nelson, 1996, 1997; Hickman, 1997; Smith et al., 1998), Krapez and Eisenlohr (1998) interpreted that the Sholl Shear Zone is sinistral and has juxtaposed a

>c. 3260 Ma island arc succession with a c. 3120 back-arc succession. They noted that this movement took place after the 'Whim Creek Basin' developed. Smith et al. (1998) placed the timing of the sinistral movement at 2991–2925 Ma, whereas Krapez and Eisenlohr (1998) put it between 3000 and 2955 Ma; however, both interpretations are incorrect because visible displacement of the Whim Creek Group on SHERLOCK (approximately 30–40 km) was dextral. Smith et al. (1998) and Krapez and Eisenlohr (1998) interpret the crustal segment north of the Sholl Shear Zone to be allochthonous but not exotic (i.e. it was displaced southwestwards from the northern part of the Pilbara Craton).

Krapez and Eisenlohr (1998) presented a tectono-stratigraphic interpretation of the west Pilbara based on a hypothesis of global tectonic cycles. In the north Pilbara, two 'Megacycle Sets', spanning 3500–2775 Ma, are divided into four 'Megacycles', each of 190–175 Ma duration. Each 'Megacycle' is inferred to contain a 'Megasequence' that can be divided into supersequences or basins. Krapez and Eisenlohr (1998) admitted that this approach creates stratigraphic divisions and tectonic interpretations prior to verification and testing by observational data. Krapez and Eisenlohr (1998) reiterated that the 'domain boundaries' (Krapez, 1993) of the north Pilbara have a long history of development and reactivation, but admitted that evidence for any pre-3000 Ma history is only 'cryptic, and related to interpreted stratigraphic patterns'. The limited significance of these domain boundaries before 3000 Ma is indicated by a reconstruction of Pilbara tectonic environments between 3325 and 3135 Ma (Krapez and Eisenlohr, 1998, fig. 4). The stratigraphic and structural interpretions made by Krapez and Eisenlohr (1998) on DAMPIER are discussed in **Structure**.

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

Hickman (1999) recognized three major tectono-stratigraphic terranes in the 'north Pilbara granite–greenstone terrane' (Griffin, 1990). In Hickman's (1999) interpretation, the west and east Pilbara terranes are separated by the Mallina Basin. The boundary between the western terrane and the Mallina Basin was taken as the contact (faulted) between the Whim Creek Group and the De Grey Group. However, recent evidence from the Whim Creek area (Smithies et al., 1999; Huston et al., 2000) suggests that the Whim Creek Group forms an intrinsic part of the Mallina Basin. Thus, the basal unconformity of the Whim Creek Group is now taken as the boundary between the Mallina Basin and the western terrane. The western terrane is herein formally named the West Pilbara Granite–Greenstone Terrane (Fig. 1). A revision of the tectonic subdivision of the Pilbara Craton is provided by Hickman et al. (in prep.b) and a more detailed description of the granite–greenstone terrain of the West Pilbara Granite–Greenstone Terrane is given by Hickman et al. (in prep.a).

Geological mapping of DAMPIER was undertaken during 1995 using 1992 colour aerial photographs at 1:25 000 scale, and by field interpretation of multispectral Landsat Thematic Mapper images provided by AGSO. Preliminary images generated from high-resolution magnetic and radiometric data obtained in 1995 (part of the North Pilbara NGMA program) were also used during map compilation. These data were subsequently published by GSWA (Geological Survey of Western Australia, 1995a,b).

Regional geological setting

DAMPIER is located in the northwestern part of the Pilbara Craton, and covers parts of the West Pilbara Granite–Greenstone Terrane and Hamersley Basin (Fig. 1). This terrane is divided into four granitoid complexes and three tectono-stratigraphic domains (Fig. 3; Hickman et al., in prep.b). The main tectonic features of DAMPIER are shown in Figure 4, and the geological history of the rocks within the sheet area is summarized in Table 1.

Because DAMPIER was one of the first 1:100 000-scale maps to be published in the North Pilbara NGMA program, the map shows lithological components of the Pilbara Supergroup without stratigraphic subdivision. A stratigraphic interpretation was delayed until a wider area of the north Pilbara had been investigated. However, to understand the regional geological setting of DAMPIER it is essential to understand the area's stratigraphy. Likewise, the structural geology of the area must be viewed in a regional context.

Stratigraphy, structure, and tectonic evolution

The greenstone succession (Tables 2 and 3, and Fig. 4) comprises metamorphosed sedimentary rocks, and mafic, felsic, and ultramafic igneous rocks of the Roebourne, Whundo, and Whim Creek Groups (Hickman, 1997). Almost all granitoid rocks on DAMPIER belong to the Dampier or Cherratta Granitoid Complexes, or to the Karratha Granodiorite. The Hamersley Basin succession on DAMPIER comprises the Mount Roe Basalt, the Gidley Granophyre, and basalt, andesite, and clastic sedimentary rocks that are exposed on islands of the Dampier Archipelago.

Hickman (1997) described the local stratigraphy of the Pilbara Supergroup, recognizing and defining the Roebourne and Whundo Groups (Tables 2 and 3). A stratigraphic interpretation proposed by Krapez and Eisenlohr (1998) has not been adopted for reasons given by Hickman et al. (in prep.a). Based on field relations and geochronological data, the Roebourne Group and the

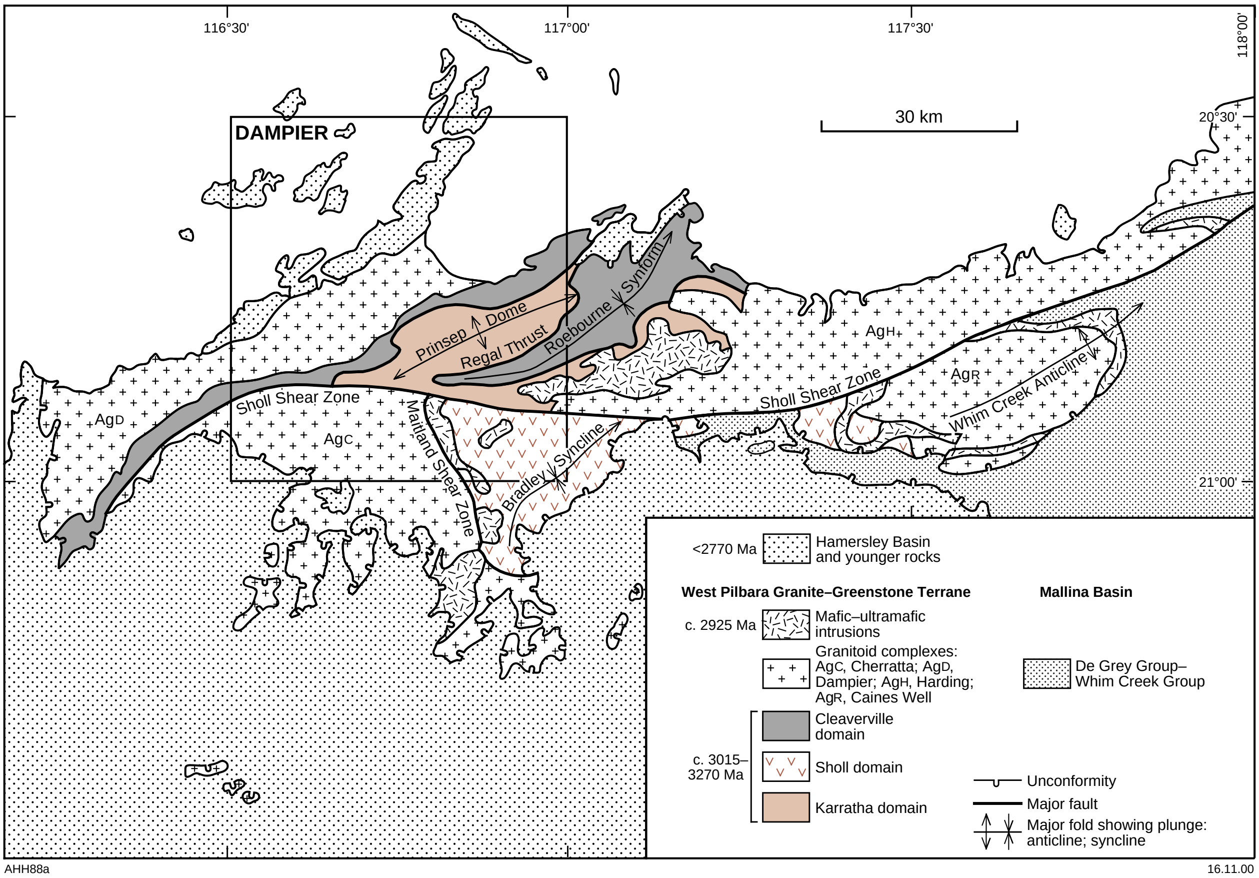

Figure 3. Tectono-stratigraphic domains of the West Pilbara Granite–Greenstone Terrane

Karratha Granodiorite formed at about 3270–3250 Ma and are the oldest preserved components of the West Pilbara Granite–Greenstone Terrane. Isotopic data (see **Geochronology**) indicate that older sialic crust, at least 3500 Ma in age, was present between 3270 and 3020 Ma, but no rocks of this age have been identified. The Whundo Group (greenstones in the southeastern part of DAMPIER) has been dated at between 3125 and 3115 Ma, and most of the granitoids of the Dampier and Cherratta Granitoid Complexes are about 2990 Ma in age. The oldest recognizable tectonic structures in the area are D_1 thrusts and recumbent folds that formed after deposition of the Roebourne Group but before deposition of the Cleaverville Formation. D_1 involved thrusting of the Regal Formation across the lower part of the Roebourne Group and across the Karratha Granodiorite. The age of this event may coincide with a c. 3160 – 3150 Ma thermotectonic disturbance recognized in the Karratha Granodiorite (Smith et al., 1998). Support for this interpretation is provided by the absence of D_1 structures in the 3125–3115 Ma Whundo Group, although this evidence is inconclusive because the Whundo Group was deposited up to 250 km from its present position relative to the Roebourne Group (see **Structure**).

Sun and Hickman (1998) reported Nd isotopic data from the Whundo Group that is consistent with juvenile crust formed in a subduction-zone environment. Krapez and Eisenlohr (1998) interpreted the Whundo Group as a back-arc rift-basin succession, although no evidence of the inferred c. 3120 Ma volcanic arc northwest of the Whundo Group has been identified. The present interpretation is that the Whundo Group was deposited in a northeasterly trending rift basin between the East Pilbara Granite–Greenstone Terrane to the southeast and a proto-West Pilbara Granite–Greenstone Terrane to the northwest. The dominantly volcanic 3125–3115 Ma ‘Whundo Basin’ has many common features with the 3010–2930 Ma volcano-sedimentary Mallina Basin that developed in a parallel zone to the southeast. Both basins probably evolved by similar northwest–southeast extension, although the Mallina Basin was certainly intracratonic. Thus, the ‘Whundo Basin’ can be regarded as a precursor to the Central Pilbara Tectonic Zone. Volcanism in the ‘Whundo Basin’ was followed by granitoid intrusion (3115–3050 Ma), strike-slip faulting (probably commencing at 3125 Ma and culminating at c. 3050 – 3020 Ma), and transpressional folding. During this 3125–3020 Ma interval, the Central Pilbara Tectonic Zone could have been at an early stage of development southeast of DAMPIER, but no direct evidence for this is currently available. At approximately 3020 Ma, the Cleaverville Formation was deposited across the West Pilbara Granite–Greenstone Terrane, the early Central Pilbara Tectonic Zone, and the western margin of the East Pilbara Granite–Greenstone Terrane.

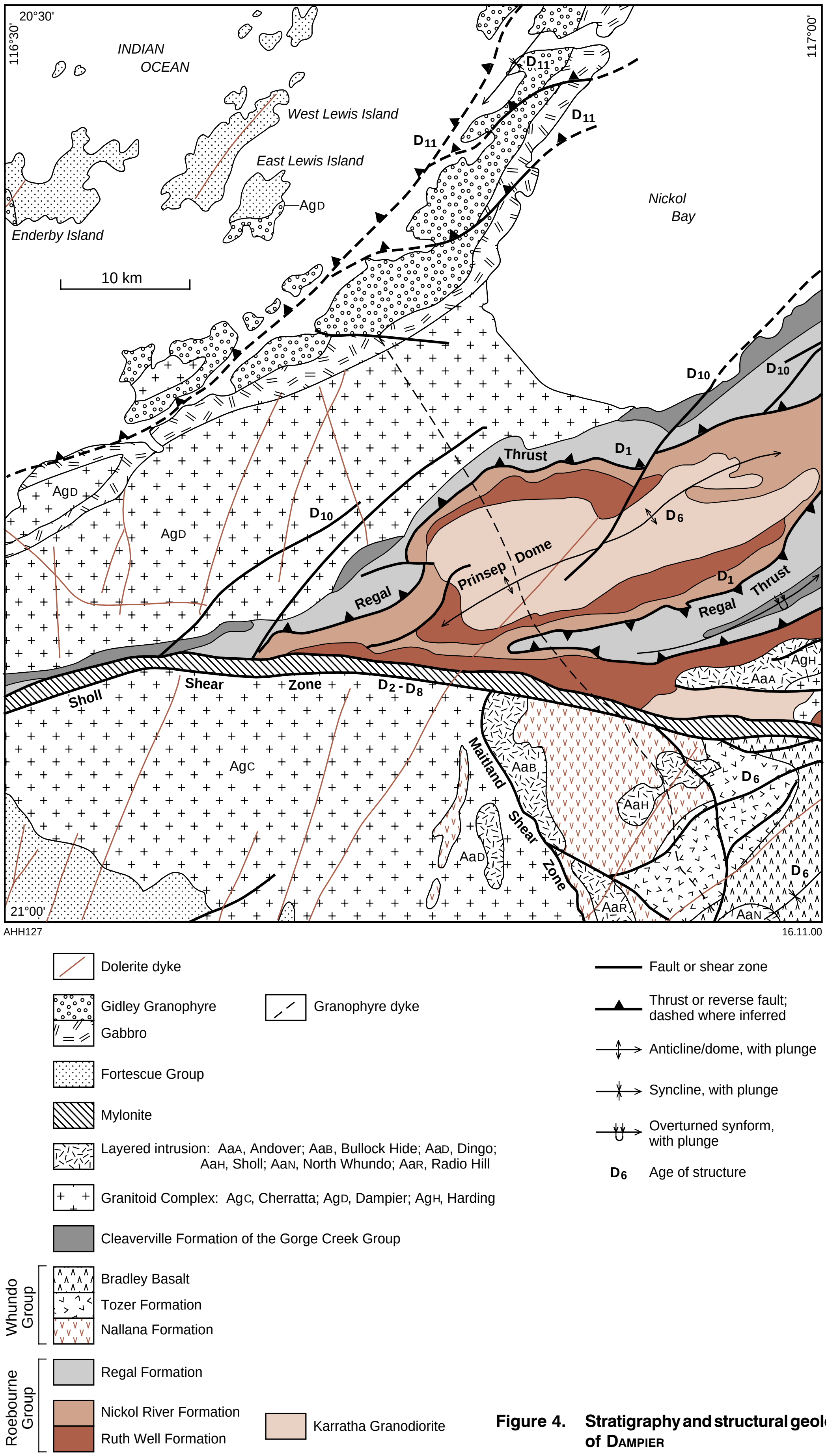

Figure 4. Stratigraphy and structural geology of Dampier

Table 1. Summary of the geological history of DAMPIER

Age (Ma)	*Geological event*
3500–3390	Formation of sialic crust (rocks not preserved?)
3310–3290	Intrusion of granitoids and possible felsic volcanism (rocks not preserved?)
3270–3250	Deposition of Roebourne Group in a area now preserved north of the Sholl Shear Zone; intrusion of Karratha Granodiorite
3160–3130	D_1: thrusting and recumbent folding; thermotectonic event with tonalite intrusion southeast of DAMPIER
3125–3115	Deposition of the Whundo Group in a basin now preserved south of the Sholl Shear Zone
3115–3090	Intrusion of granitoids along the northwestern margin of the Central Pilbara Tectonic Zone
3070–3050	Intrusion of tonalite southeast of DAMPIER
3050–3020	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 the Cleaverville Formation; erosion
3010–2990	Deposition of the lower part of the Whim Creek Group east of DAMPIER; extensive intrusion of granitoids in the West Pilbara Granite–Greenstone Terrane
2990–2960	D_4: local thrusting and folding of the Whim Creek Group east of DAMPIER
2950–2930	D_6 (D_5 absent on DAMPIER): transpressional, northeasterly trending tight to open folding, and commencement of dextral movement along the Sholl Shear Zone; 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 of the West Pilbara Granite–Greenstone Terrane; deposition of the Mount Roe Basalt and (outside DAMPIER) Hardey Formation; intrusion of dolerite dykes
2730–2715	Deposition of Fortescue Group volcanics and sedimentary rocks in the Dampier Archipelago; intrusion of the Gidley Granophyre and granophyric dykes
<2725	D_{11}: faulting and open folding of the Gidley Granophyre
755	Intrusion of northeasterly trending dolerite dykes
545–65	Palaeozoic and Mesozoic erosion
55–present	Uplift and dissection of plateau surface

At about 3015–3010 Ma, strike-slip movement along the northwestern margin of the Central Pilbara Tectonic Zone was accompanied by transpressional folding of the Whundo Group and the Cleaverville Formation, felsic magmatism, and deep erosion. Between 3015 and 2990 Ma mafic–felsic volcanism along the northwestern margin of the Pilbara Tectonic Zone formed the lower part of the Whim Creek Group. About 20 km east of DAMPIER, on ROEBOURNE, a major angular unconformity at the base of the Whim Creek Group defines the northern boundary of the Mallina Basin. Volcanic rocks of the Whim Creek Group are not preserved on DAMPIER, but there are contemporaneously emplaced granitoid intrusions that make up the bulk of the Dampier and Cherratta Granitoid Complexes.

The next important event on DAMPIER was large-scale tight to open D_6 folding about northeasterly trending axes. By analogy with similar structures on SHERLOCK and MOUNT WOHLER, these 2950–2940 Ma folds were probably transpressional and related to dextral movement along east–west and northeast–southwest shear zones. The D_6 folds are the most obvious large-scale fold structures visible on DAMPIER, and deform all Archaean stratigraphic units except the c. 2925 Ma mafic–ultramafic layered intrusions and the Fortescue Group. Strike-slip movement (D_7) at about 2940 Ma reactivated the Maitland Shear Zone, initially a D_2 structure, and produced minor shear zones within the Cherratta Granitoid Complex.

The mafic–ultramafic layered intrusions of the west Pilbara (Hoatson et al., 1992) were emplaced at, or slightly before, 2925 Ma, and occupy a northeasterly trending zone close to the northwestern limit of the Whundo Group. This distribution suggests tectonic control along the northwestern margin of the Central Pilbara Tectonic Zone. Small granitoid plutons and dykes intruded the layered intrusions at 2925 Ma. Dextral strike-slip displacement of the layered intrusions along the Sholl Shear Zone took place at about 2920 Ma, and a thermotectonic disturbance of this age is evident from U–Pb zircon geochronology.

Table 2. Revised stratigraphy of the Roebourne Group

Formation	*Thickness (m)*	*Lithology and relationships*
Regal Formation	~2 000	Basal peridotitic komatiite overlain by pillow basalt and local chert units. Intruded by microgranite and felsic porphyry dated at 3018 ± 2 Ma
.... Tectonized contact		
Nickol River Formation	100–500	Banded chert, iron formation, ferruginous clastic sedimentary rocks, quartzite, felsic volcanics, volcanogenic sedimentary rocks, and local conglomerate. Schist with a maximum depositional age of the precursor sedimentary rock of 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 dated at 3270 ± 2 Ma

SOURCE: after Hickman (1997)

The final deformation event prior to deposition of the Fortescue Group involved a regional north-northwest to south-southeast compression, and the establishment of a conjugate fault system (D_9).

Deposition of the c. 2770 Ma Mount Roe Basalt of the Fortescue Group was controlled by a northeasterly striking rift system. Normal movement on the faults was contemporaneous with extrusion of flood basalts and later deposition of clastic sedimentary rocks and local felsic volcanism (Hardey Formation) at about 2760 Ma. Clastic deposition ceased around 2750 Ma and was followed by local erosion, and extrusion of extensive lava flows that range in composition from basaltic andesite to andesite and dacite. The basalt–andesite succession of the Dampier Archipelago was deposited during this period, probably between 2730 and 2715 Ma. Volcanism was interrupted at 2725 Ma by the intrusion of a major composite body,

Table 3. Stratigraphy of greenstones south of the Sholl Shear Zone, Roebourne–Whundo area

Tectono-stratigraphic unit	*Group/Formation*	*Thickness (m)*	*Lithology and relationships*
MALLINA BASIN	Kialrah Rhyolite	1 000	Feldspar-phyric, commonly flow-banded rhyolite dated at 2972 ± 2 Ma
	WHIM CREEK GROUP		
	Louden Volcanics	~300	Komatiitic basalt and pillow tholeiite
	Cistern Formation	~100	Felsic tuff and volcanogenic sedimentary rocks. Volcanogenic sedimentary rock dated at c. 3010 Ma
	Warambie Basalt	300–500	Vesicular, pyroclastic, and amygdaloidal basalt, with hyaloclastite and local pillow basalt. Basal polymictic conglomerate and sandstone
.... High-angle unconformity			
WEST PILBARA GRANITE–GREENSTONE TERRANE	Cleaverville Formation	~1 500	BIF, chert, fine-grained clastic sedimentary rocks, and dacite–rhyolite ?sills. Clastic metasedimentary rocks dated at c. 3020 Ma
	.... Possible low-angle unconformity		
	WHUNDO GROUP		
	Woodbrook Formation	~1 000	Rhyolite tuff and agglomerate, minor basalt, and thinly bedded BIF. Felsic tuff dated at 3117 ± 3 Ma
	Bradley Basalt	3 000–4 000	Pillow basalt, massive basalt, minor units of felsic tuff, and chert. Felsic tuff dated at 3115 ± 5 Ma
	Tozer Formation	500–2 500	Calc-alkaline volcanics, including felsic pyroclastic units. Rhyolite dated at c. 3120 Ma
	Nallana Formation	~2 000	Dominantly basalt, but includes minor ultramafic and felsic units. Felsic tuff dated at 3125 ± 4 Ma. Base of formation truncated by Maitland Shear Zone

SOURCE: after Hickman (1997)

the Gidley Granophyre, along the unconformity that separates the Dampier Granitoid Complex from the volcanic succession of the Dampier Archipelago.

Late events in the history of the area included D_{11} faulting and folding of the Gidley Granophyre by northwest–southeast compression, and the Neoproterozoic intrusion of northeasterly trending dolerite dykes.

Geological and geochronological data from DAMPIER, SHERLOCK (Smithies, 1997), MOUNT WOHLER (Smithies, 1998c), ROEBOURNE (Hickman, 2000), and PINDERI HILLS (Kojan and Hickman, 2000), indicate that the West Pilbara Granite–Greenstone Terrane comprises three tectono-stratigraphic domains and four granitoid complexes (Fig. 3). The boundaries between greenstone domains are tectonic, whereas the boundaries between greenstones and granitoid complexes are mainly intrusive.

Archaean rocks

On DAMPIER, the geological map presents a lithological subdivision of all Pilbara Supergroup rocks, except for the components of named layered mafic–ultramafic intrusions. At the time of mapping DAMPIER, a reliable stratigraphic interpretation had not been developed, and therefore stratigraphic subdivision was delayed pending completion of the west Pilbara regional mapping program. Subsequent mapping on adjacent 1:100 000 sheets has led to a stratigraphic interpretation (Hickman, 1997), summarized in Figure 4 and Tables 2 and 3.

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

Pilbara Supergroup (not stratigraphically subdivided on the map)

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

Almost all the ultramafic rocks, other than those within layered mafic–ultramafic intrusions, are confined to the area north of the Sholl Shear Zone and concentrated in the lower part of the Roebourne greenstones unit (see **Simplified geology**). Mapping in other areas of the west Pilbara has since established that this stratigraphic level is occupied by the c. 3270 Ma Ruth Well and Nickol River Formations of the Roebourne Group (Hickman, 1997). Despite widespread alteration (e.g. serpentinization, carbonation, and silicification), the common preservation of spinifex texture, combined with other volcanic features, suggests that most of these rocks had a volcanic rather than intrusive origin.

Undivided ultramafic rocks (*Au*) are mostly present close to the intrusive margin of the Karratha Granodiorite. They typically consist of schist that has been contact metamorphosed and then subsequently altered by variable serpentinization, carbonation, and silicification.

Intercalated ultramafic and mafic rocks and thin chert units (*Aub*) form a distinctive assemblage about 4 km south of Karratha. The cherts, which are less than 2 m thick, are interpreted as metamorphosed interflow sediments separating tholeiitic and ultramafic lava flows. Individual mafic and ultramafic units are generally 10–20 m thick, and comprise alternating flow packages. However, shearing along the margin of the Karratha Granodiorite has undoubtedly attenuated the succession, and the original thicknesses of these packages must have been considerably greater.

Metamorphosed komatiite with olivine spinifex texture (*Auk*) is present 1.5 km north of Mount Regal (AMG 735995) and 4.5 km south of Mount Regal (AMG 725939). Other exposures, too small to map at 1:100 000 scale, are present within serpentinite 2 km south of Karratha (Fig. 5, AMG 826050). This locality provides excellent examples of vertical profiles through 1–2 m-thick lava flows.

Serpentinite (*Aus*), representing metamorphosed peridotite, is the most common ultramafic rock type on DAMPIER. A volcanic origin for these rocks is indicated by a number of features: local spinifex texture; common thinly interbedded chert units; and an absence of any visible intrusive relationships with adjacent volcanic and sedimentary rocks. However, some of the thicker and more massive serpentinites (e.g. 3 km southeast from White Quartz Hill, at AMG 976018) may be metamorphosed sills.

Talc–chlorite schist (*Aut*) exposed near Mount Prinsep (AMG 815937), and also 4 km northeast of Karratha Homestead (AMG 680933) and 3 km southeast of Mount Regal (AMG 761960), is interpreted as sheared metamorphosed ultramafic lava. Metamorphosed lava ranging from peridotite to high-Mg basalt (*Auv*) outcrops east of No 6 Well (AMG 990950). The unit includes ultramafic tuff which in thin section contains flattened lapilli, 1–5 mm in diameter, that are composed of chlorite, tremolite, talc, and opaque minerals.

Metamorphosed pyroxenite (*Aux*) forms a large outcrop 2.5 km south of Nickol River Hill (AMG 955860). The shape of the outcrop suggests that the unit is part of a plug, which could be related to the Sholl Intrusion that lies about 3 km to the west. In thin section, the rock is a fine- to medium-grained metapyroxenite with an allotriomorphic granular texture. Pyroxene crystals are pseudomorphed by actinolite, chlorite, epidote, and minor carbonate. The prismatic cleavage of the pyroxene is well preserved, but is slightly curved, indicating deformation. Interstitial clusters of tabular epidote pseudomorphs, probably after plagioclase, are present throughout. Abundant leucoxene pseudomorphs after ilmenite are disseminated throughout the pyroxenite, and goethite boxworks have replaced pyrite.

Figure 5. Platy spinifex texture in peridotite flows within the Nickol River Formation south of Karratha (AMG 826050)

Mafic volcanic rocks (*Ab, Aba, Abgp, Abo, Abp, Abs, Abx*)

Mafic volcanic rocks are the most common components of the greenstone successions on DAMPIER. Geochemical sampling traverses undertaken north and south of the Sholl Shear Zone as part of a joint GSWA–Bureau of Mineral Resources (BMR) Pilbara-wide regional volcanic geochemistry project (Glikson et al., 1986) revealed that most of the mafic rocks are tholeiitic. Geochronology on intercalated felsic and sedimentary rocks (Nelson, 1996, 1997, 1998) has established an age range of c. 3270 – 3250 Ma for the mafic volcanic rocks.

Undivided basaltic rock (*Ab*) is widespread on DAMPIER, and consists mainly of either massive or pillowed basalt that has been metamorphosed to greenschist facies. Pillows are common over a large area east of Mount Sholl (AMG 980840) and in the Cleaverville area (AMG 990125). Varying degrees of strain are indicated by local flattening or shearing of pillow structures. Vesicles in the pillows are filled with quartz, carbonate minerals, or chlorite. Interstitial material between the pillows is composed of cryptocrystalline chloritic rock, palagonite, chert, or altered tuff. Flow tops within the basaltic units are generally difficult to recognize, except where there are interflow sediments or altered flow-top breccias. Alteration in the upper sections of flows has mainly involved silicification and epidotization.

The *Ab* unit locally includes komatiitic basalt. In the southeastern part of DAMPIER, the lower section of the Bradley Basalt (Fig. 4) contains flows of variolitic basalt, spinifex-textured basalt, and amygdaloidal komatiitic basalt (AMG 985827). Spinifex textures include pyroxene needles and olivine plates. In thin section, the komatiitic basalt consists of randomly oriented straight, curved, and splayed crystal-plate pseudomorphs. These plates comprise clear epidote granules and chlorite, whereas the interstices are filled with brown cloudy chlorite and minor epidote containing submicroscopic ?leucoxene. Although most of the polygonal domains between the larger crystal plates are filled with smaller crystal plates, many appear to have contained significant quantities of glass that has devitrified to form a patchy mosaic of small subdomains with radiating optical extinction. The rock contains several subspherical amygdales of sutured mosaic quartz, lined with colloform carbonate and chlorite.

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

Strongly foliated amphibolite-facies metabasalt (*Aba*) constitutes large sections of the upper part of the Roebourne Group north of the Sholl Shear Zone, but is also present within the shear zone. Deformed pillow structures, such as those exposed on the northern slopes of the ridge immediately south of Karratha (AMG 838063) and southwest of Karratha (AMG 817048), testify to an extrusive origin for large parts of the *Aba* unit although elsewhere thin sheets of metadolerite are also included. Massive units consist of a medium-grained randomly oriented assemblage of secondary amphibole and altered plagioclase. Hornblende or actinolite may ophitically enclose relics of primary pyroxene. Minor components include chlorite, quartz, calcite, sphene, phlogopite, rutile, and opaques. Garnet and scapolite occur in mylonitized amphibolite, for example near Nickol River (AMG 904940). Amphibolite schist consists mainly of felted to granoblastic actinolite or hornblende, with subordinate plagioclase, chlorite and epidote, and minor quartz, opaques, and carbonate minerals.

Foliated and sheared amphibolite-facies metabasalt, with sheared veins and sheets of microgranite and pegmatite (*Abgp*), is restricted to the upper part of the Roebourne Group, east of Mount Prinsep (AMG 840945), and to outcrops along the southeastern margin of the Karratha Granodiorite. East of Mount Prinsep, the unit formed in a zone of intense shearing and granitic intrusion, flanked to the southeast by narrow belts of mylonite. On ROEBOURNE (Hickman, in prep.), a foliated sill of felsic 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 the *Abgp* unit, although shearing (which affects both the amphibolite and the granitic components) occurred later. The mixed unit of metabasalt and granitic sheets that outcrops along the margin of the Karratha Granodiorite is assumed to have formed at c. 3270 Ma, when this granitoid intruded the lower part of the greenstone succession.

Metamorphosed variolitic-textured basalt (*Abo*) outcrops 2 km northeast of Mount Prinsep (AMG 805952), and is associated with bedded black chert. The rock may be a high-Mg basalt, but no geochemistry has been undertaken.

Metamorphosed plagioclase-phyric basalt (*Abp*) outcrops 800 m southwest of Radio Hill Mine (AMG 855793). This unusual and highly distinctive basalt contains numerous small euhedral plagioclase phenocrysts. In thin section, saussuritized phenocrysts of plagioclase up to 5 mm across make up about 30% of the rock. The matrix is a fine-grained assemblage of actinolite, epidote, and quartz.

Mafic schist (*Abs*) outcrops in the Sholl Shear Zone near Nickol River Hill (AMG 957890), adjacent to a shear zone 2 km northeast of No 6 Well (AMG 987958), and along a unit of strongly deformed mafic tuff 3 km northeast of Radio Hill Mine (AMG 875811). The schist occurrences that are related to shear zones have the same mineralogy as amphibolite schist within *Aba* units, whereas the deformed tuff has a greenschist assemblage of actinolite, chlorite, and minor quartz.

Fragmental basaltic rock (*Abx*) outcrops 2 km south of Mount Regal (AMG 742970). Field evidence suggests that the rock is a fault breccia between the Regal Thrust, to the northwest, and BIF and clastic metasedimentary rocks of the Nickol River Formation to the southeast. In thin section, the rock is a layered, carbonate-altered metamorphic rock. Patches of carbonate, actinolite, hornblende, and quartz are interspersed with layers of fine-grained mosaic quartz. The mafic precursor (basalt from field evidence) was brecciated prior to amphibolite-facies metamorphism.

Mafic intrusive rocks (*Ao, Aod*)

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

Gabbro and minor dolerite, with local units of norite and anorthosite (*Ao*), generally form sills within the greenstones; however, large dykes outcrop northeast of Mount Prinsep (AMG 830958) and east of Tozer Well (AMG 985791). The gabbro is typically medium or coarse grained and has a primary assemblage of pyroxene and plagioclase that has been variably altered to actinolite–tremolite, chlorite, serpentine, quartz, epidote, sericite, carbonate, clinozoisite, and opaques. Despite saussuritization and carbonation, an original hypidiomorphic texture is generally well preserved.

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

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

Felsic volcanic rocks are a minor component of the greenstones on DAMPIER, and are most common within a calc-alkaline succession (part of the c. 3125 – 3115 Ma Whundo Group, defined by Hickman, 1997) east of Mount Sholl. To the north of the Sholl Shear Zone, felsic volcanic rocks outcrop as thin units within the lower part of the Roebourne Group.

Undivided metamorphosed felsic volcanic rocks (*Af*) outcrop east of Mount Sholl (AMG 927840), close to the southern margin of the Karratha Granodiorite, at Mornong Well (AMG 712941), 2 km north of Nickol River Hill (AMG 955902), 5 km south-southeast of Cleaverville Creek (AMG 999090) and in two outcrops approximately 1 km southeast of Mount Regal. Thin felsic units within metabasalt (*Aba*) are present 3 km east of Pattersons Hut Well (AMG 956980). The rock varies in composition from dacite to rhyolite and appears to be mainly metamorphosed lava, but some units may be fine-grained intrusive rock. Visible pyroclastic textures are absent, but common phenocrysts are locally present, for example, at the locality south-southeast of Cleaverville Creek. Parts of *Af* units have been deformed to produce quartz–sericite schist, which is commonly silicified.

Dacite to andesite lava, with local pyroclastic units (*Afd*), is restricted to the area around Tozers Well (AMG 949801), and outcrops 3 km southeast of Nickol River Hill (AMG 975869). In both areas the rocks are silicified and weathered, and so primary composition is difficult to determine in the field.

Well-exposed metamorphosed rhyolite (*Afr*) outcrops 2 km southeast of Gaffs Well (AMG 917782) and is incorrectly labelled '*AFR*' on the map. Other outcrops are present 2 km southeast of Mount Sholl (AMG 926832) and 5 km south of Cleaverville Creek (AMG 982093). Rock samples from all three localities have been dated (see **Geochronology**). The rhyolite at Gaffs Well forms the top of a small hill, and is fine grained to glassy. In thin section its texture is porphyritic, glomerocrystic, and spherulitic. Phenocrysts are composed of sodic plagioclase, epidote, quartz, or chlorite (replacing ferromagnesian minerals). The aphanitic groundmass consists of ovoid intergrowths of radiating feldspar and quartz, feldspar microlites, anhedral interstitial quartz and chlorite, subhedral granular epidote, sericite, titanite, and accessory minerals. The unit near Mount Sholl is a rhyolite lava with sparse feldspar and quartz phenocrysts, overlain by felsic tuff and volcanogenic metasediment. Its mineralogy is similar to the Gaffs Well rock, except that some phenocrysts are composed of biotite, and minor carbonate is present in the groundmass.

Felsic schist (*Afs*) of rhyolite to andesite composition forms stratigraphic units in the lower part of the greenstone succession, close to the southeastern margin of the Karratha Granodiorite. The rock is strongly foliated and extensively silicified, and probably includes metamorphosed felsic lava, tuff, and volcanogenic sedimentary rock.

Metamorphosed rhyolite and dacite tuff (*Aft*) forms large outcrops about 2.5 km south-southeast of Gaffs Well (AMG 925795). The well-preserved coarse pyroclastic texture and wedge-shaped nature of the unit indicate a locally developed explosive felsic volcanic centre — a rare occurrence in the greenstones of the west Pilbara.

Metamorphosed volcaniclastic rocks of rhyolite and dacite composition (*Afv*), interbedded with local volcano-genic sedimentary rocks, form thin stratigraphic units in the greenstone succession southeast of Mount Sholl (AMG 923829). Secondary silicification has given the finer grained beds a cherty appearance. Graded bedding and small-scale cross-bedding confirm that the succession in this area youngs towards the southeast.

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

Metamorphosed clastic sedimentary rocks on DAMPIER are almost entirely confined to the lower part of the Roebourne greenstones (see **Simplified geology**). This lower part of the succession rims the Karratha Granodiorite and forms part of the Regal Belt further to the west. Since the DAMPIER map was completed, a regional stratigraphic reinterpretion of the west Pilbara (Hickman, 1997) has assigned this sedimentary component to the Nickol River Formation. Nelson (1997, 1998) dated this formation at 3270–3250 Ma, which indicates that it is coeval with intrusion of the underlying Karratha Granodiorite (see **Geochronology**).

Undivided metamorphosed sedimentary rocks (*As*) outcrop at the Earl of Gormley gold mine (AMG 988055) and 1 km further to the east (AMG 997057). At both localities the rocks are arenites, which have been deformed and weathered. In southeastern DAMPIER, a thin unit of cherty tuffaceous metasediment (*As*) outcrops within a thick basalt succession. Small-scale cross bedding and graded bedding indicates current action. Microscopic examination reveals compacted shard-like shapes. Superimposed on the fine felsic groundmass are large diffuse 0.2 to 1 mm diameter prehnite spherulites, and scattered carbonate porphyroblasts.

Metaconglomerate (*Asc*), which outcrops 2 km north of Lower Nickol mining centre (AMG 958074), consists of angular to subrounded pebbles and boulders (up to 15 cm in diameter) of chert and fuchsitic schist in a poorly sorted sandstone matrix. The conglomerate is separated from BIF to the north by a fault that is interpreted to be part of a major thrust zone surrounding the Karratha Granodiorite (see **Structure**).

Metamorphosed ferruginous clastic sedimentary rocks (*Asi*) outcrop north and south of Mount Regal, and 3 km south of Karratha (AMG 864046). This unit is dominantly pelitic, but includes beds of siltstone and chert. The shale protolith is assumed to have been sulfidic. Ferruginous chert and BIF south of Karratha may have formed, at least in part, by near-surface silicification of this unit.

Quartzite (*Asq*) overlies metamorphosed felsic volcanic rocks close to the southeastern margin of the Karratha Granodiorite, and also outcrops 3 km southeast of Mount Regal (AMG 755963). Its lithological associations suggest a volcanogenic origin, probably through decomposition of felsic volcanics to produce quartz sands prior to lithification.

Schistose metasandstone and metasiltstone (*Ass*) form a linear outcrop northeast of Mount Prinsep (AMG 800942). The unit is mainly composed of quartz–sericite schist, phyllite, ferruginous chert, and boudinaged quartz veins.

Metamorphosed sandstone with minor conglomerate and siltstone (*Ast*) forms extensive outcrops north and northeast of the Lower Nickol mining centre and 3 km south of Mount Sholl (AMG 904818). The rocks north of Lower Nickol include cherty silicified breccia, banded grey and white clastic chert, and some mylonitic zones. Graded bedding is locally preserved in both sandstone and chert.

Quartz–sericite schist and chert (*Alm*) forms a distinctive unit 3 km south of Karratha (AMG 827042). Green chert and grey- and white-banded chert are separ-ated by the schist, which is of uncertain origin, being a sheared unit of either sedimentary or felsic volcanic origin.

Chert (*Ac, Acb, Acc, Acf, Acg, Aci, Acj, Acw*)

Chert is widespread in greenstones north of the Sholl Shear Zone, particularly in the lower part of the succession around the margins of the Karratha Granodiorite and in the Regal Belt. Most chert units are colour banded at 1–10 mm intervals, with major bedding planes at 10 cm to 1 m intervals. Most of the units are probably silicified fine-grained clastic sediments or tuff, but some chert has tectonic origins and may be massive, non-banded, fragmental, or mylonitic.

Most undivided chert (*Ac*) units are either non-banded or consist of several different interbedded chert types. Brecciation and late quartz veining is common, and many of these internally complex cherts are probably silicified shear zones. An extensive undivided chert (*Ac*) unit is present within the amphibolite-facies metabasalt (*Aba*) southwest of Mount Regal, where it is locally accompanied by layers of schistose carbonate-altered metabasalt that are approximately 2 m thick (AMG 708966). In the lower part of the Regal Belt succession, around Normie Well (AMG 651933), undivided chert (*Ac*) is composed of grey, green, yellow, grey and white, red and white, ferruginous chert. Undivided chert (*Ac*) southeast of the Karratha Granodiorite is dominantly grey or mixed with pale-yellow and pale-brown layers and lenses. Mylonitic lamination is isoclinally folded in some outcrops (see **Structure**). Southeast of Karratha, undivided chert (*Ac*) includes cream pyritic silicic rock with cross-cutting veins of black quartz (AMG 931068). This chert is either a silicified felsic volcanic rock, or a silicified fine-grained clastic sedimentary rock. Units of undivided chert (*Ac*), commonly no more than 1–5 m thick, are mapped within basaltic successions of the greenstone belts, and typically represent silicified interflow sediments or tuff beds. One such unit, 5 km east of Tozers Well (AMG 998805), is veined by gossanous quartz that contains approximately 1.2% combined Cu and Zn (GSWA 114339).

Black chert (*Acb*) is interpreted as silicified carbonaceous shale. Good outcrops of this unit are present 3 km northeast of Lower Nickol mining centre (AMG 995085), 2 km northeast of Mount Prinsep (AMG 798950), and 2 km south of Mount Regal (AMG 753976). Most of the chert is banded by weakly defined alternating black and dark-grey layers, but some units are homogeneous and have quartz veinlets. Similar Archaean black chert in the east Pilbara (near Marble Bar) contains microfossils (Schopf, 1993), but the black chert on DAMPIER appears to be more metamorphosed and therefore not conducive to microfossil preservation.

Grey and brown chert (*Acc*), mainly replacing sheared clastic sedimentary rocks, outcrops 1 km and 2 km north of Lower Nickol mining centre (AMG 988079 and AMG 990072). The rock, which is brecciated and mylonitic, probably forms part of a shear zone.

Ferruginous chert, interlayered with metamorphosed BIF and fine-grained clastic sedimentary rocks (*Acf*), is widespread in the greenstone succession north of the Sholl Shear Zone, and is also present in the Cleaverville area (AMG 997144). The main outcrops are located between Mount Prinsep and Mount Marie, south of Karratha, and in the Regal Belt. South of the Sholl Shear Zone, 3 km south of Nickol River Hill at AMG 954863, this association outcrops as a thin unit. The protoliths are interpreted as iron-rich shale and siltstone, minor carbonate rocks, and BIF.

Green chert (*Acg*) outcrops south of Mount Regal (AMG 753976), 2 km southeast of Mornong Well (AMG 690931), 3 km south of Gwen Creek (AMG 910055), and 1.5 km southwest of Nickol Well (AMG 988025). The rock is generally banded with alternating dark- and pale-green layering, but may also have pale-grey or white layers. The distinctive colour of the rock is attributed to finely disseminated chromian muscovite (fuchsite). Moreover, green chert commonly outcrops close to chromium-rich ultramafic rocks. In places (e.g. south of Mount Regal), the rock has been quarried for the production of ornamental and semi-precious stone.

Banded iron-formation with minor ferruginous chert (*Aci*) outcrops mainly between Cleaverville Beach (AMG 999158) and Karratha, but it is also exposed at Miaree Pool (AMG 595935). Iron minerals, predominantly magnetite, hematite, and goethite, make up about 50% of the rock and are interlayered with quartz at 1–10 mm intervals. The rock is typically almost black, and forms units up to 50 m thick in which BIF is interbedded with red jasper, shale, or mudstone. At depth, the shale and mudstone are black or dark grey, but surface exposures are commonly pale grey, brown, or cream to off-white due to bleaching.

Jaspilite (*Acj*) is a variety of iron formation containing alternating layers of magnetite and red jasper. The only outcrop of *Acj* distinguished on the map occurs 3 km south of Gwen Creek (AMG 922055), although minor jaspilite is also present within BIF (*Aci*).

Grey-white banded chert (*Acw*), locally associated with beds of quartzite too thin to map separately at 1:100 000 scale, outcrops south of Mount Regal and in the Ruth Well area (AMG 846938). Most of the chert units are probably silicified fine-grained clastic sedimentary rocks or tuff, but some may have originally been primary silica deposits. Alternating white and grey layers, typically 1–10 mm thick, are mostly sharply defined but some colour grading is locally present. This may represent graded bedding in the fine-grained clastic protoliths; consistent way-up evidence is rarely visible.

Granitoid rocks

DAMPIER contains parts of two granitoid complexes (Cherratta and Dampier Granitoid Complexes) and one large pluton (Karratha Granodiorite). Additionally, there are various smaller granitoid outcrops that have been mapped lithologically and without assignment to larger bodies. The granitoids have intrusive contacts with adjacent greenstones, and have locally detached and enveloped sections of the greenstone succession. Many of the granite–greenstone contacts are faulted and sheared. Available geochemical data indicate a wide range of granitoid compositions, ranging from tonalite–trondhjemite–granodiorite (TTG) to monzogranite and syenogranite. TTG magmatism was episodic at c. 3260 Ma, 3150–3100 Ma, and c. 2990 Ma, whereas monzogranite and syenogranite intruded the area between 2990 and 2925 Ma.

Unassigned granitoids and felsic intrusive rocks (*Ag, Agp, Agm, Agx, Agg, Apf*)

On DAMPIER, undivided granitoid rock (*Ag*) is shown on Enderby and West Lewis Islands, and small exposures are mapped within, or adjacent to, the Sholl Shear Zone. The granitoids of Enderby and West Lewis Islands, mapped from airphoto interpretation, probably belong to the Dampier Granitoid Complex. Undivided granitoid (*Ag*) mapped 2 km east-southeast from Cockatoo Bore (AMG 763910) was also interpreted from air photos, and could be either a granitoid of the Cherratta Granitoid Complex or a mylonite related to the Sholl Shear Zone. The granitoid outcrops within, or adjacent to, the Sholl Shear Zone (AMG 869905) are mylonitized, and could be derived either from the Cherratta Granitoid Complex or the Karratha Granodiorite (see below).

Porphyritic granite to tonalite (*Agp*) forms small lenticular intrusive sheets and veins within amphibolite, 3–5 km east-northeast of Ruth Well (e.g. at AMG 875948 and AMG 900955). Porphyroclasts of microcline, set in a sheared and recrystallized fine-grained quartzofeldspathic matrix, are deformed phenocrysts. This fine-grained granitoid is the same as the granitoid within the mixed unit of sheared metabasalt, microgranite, and pegmatite (*Abgp*), but forms outcrops large enough to map out separately at 1:100 000 scale. Its association with *Abgp* suggests that its age is also c. 3018 Ma.

Foliated monzogranite and granodiorite (*Agm*) immediately north of the Sholl Shear Zone and east and west of Nickol River is now thought to include parts of the c. 3270 – 3260 Ma Karratha Granodiorite (see below). However, the intrusive relationships between fine- to medium-grained biotite monzogranite and c. 3014 Ma quartz–feldspar porphyry (*Apf*) indicate that younger granitoids, probably related to c. 2970 Ma monzogranite of the Harding Granitoid Complex on ROEBOURNE (Hickman, in prep.), must also be present. A sample of mylonitized granitoid (JS25) from the Sholl Shear Zone at Nickol River (AMG 948893) was dated at 3024 ± 4 Ma and included a range of zircon $^{207}Pb/^{206}Pb$ ages from 2959 to 3044 Ma (Smith et al., 1998). If this mylonitized granitoid was derived from rocks related to the adjacent monzogranite and granodiorite (*Agm*), then this unit may also include c. 3015 Ma granitoids. North of the Sholl Shear Zone, irregular stocks and sheets of the monzogranite and granodiorite (*Agm*) outcrop in greenstones now assigned to the Roebourne Group (Hickman, 1997). The rocks are typically equigranular, medium grained, and tectonically foliated. Compositional banding is visible in many outcrops and minor shear zones are locally present.

Mixed granitoid–greenstone assemblages (*Agx*) outcrop south and west of Mornong Well (AMG 715938 and AMG 672938), at Bullock Hide Well (AMG 787878), and 3 km north of Bullock Hide Well (AMG 787915). The assemblages comprise approximately equal proportions of greenstone material and granitoids, and formed at granite–greenstone contacts, either by magmatic injection and stoping or by tectonic interleaving. In either situation, subsequent shearing has resulted in interlayered granitoids and greenstones, generally at 0.1 to 1 m intervals. Partial assimilation of amphibolite by the granitoids has resulted in the latter being relatively rich in amphibole and chlorite.

Granodiorite, commonly containing hornblende or biotite (*Agg*), is exposed 2 km west of Mornong Well (AMG 690936) and 5 km east-southeast of Ruth Well (AMG 900918). The granodiorite at Mornong Well is a coarse-grained assemblage of quartz, plagioclase, and hornblende, which contains scattered xenoliths of amphibolite. It has intruded the Sholl Shear Zone, but a weak gneissic foliation indicates emplacement between the earliest and latest strike-slip movements. For this reason, it is assumed to be of similar age to the mylonite (*Amm*) in the shear zone. The Ruth Well granitoid is a hornblende granodiorite or diorite of uncertain age.

Quartz–feldspar porphyry (*Apf*) forms minor intrusions in the area north of the Sholl Shear Zone and east of Ruth Well. It clearly intrudes the greenstones of the Roebourne Group (Hickman, 1997), and is intruded by late monzogranite of the monzogranite and granodiorite (*Agm*) unit in this area. Contacts between *Apf* and the Andover Intrusion (*AaAo, AaAob, and AaAl*) are obscured by scree; however, the porphyry may be the older unit because it is tectonically foliated whereas the rocks of the Andover Intrusion are massive. A sample (GSWA 118979) of the quartz–feldspar porphyry was dated at 3014 ± 2 Ma, with evidence of a disturbance event at 2917 ± 14 Ma (Nelson, 1997). Microscopic examination indicates that the porphyry comprises plagioclase, quartz, and K-feldspar, with minor chlorite, and rare epidote, carbonate, sericite, and zircon. Quartz and plagioclase are highly strained, and lamellar twin planes in plagioclase are curved and broken. The porphyry may be a high-level intrusion related to granodiorite of the monzogranite and granodiorite unit (*Agm*) in this area.

Karratha Granodiorite (*Agka*)

The Karratha Granodiorite (*Agka*) is the oldest identified granitoid unit of the West Pilbara Granite–Greenstone Terrane. U–Pb zircon geochronology (Nelson, 1998; Smith et al., 1998) has established that its components crystallized at 3270–3260 Ma, and Sm–Nd isotopic analyses have given Nd T_{DM} model ages of 3480–3430 Ma (Sun and Hickman, 1998). The c. 200 Ma difference between the emplacement age and the Nd T_{DM} model ages indicates that magma generation involved older crust or enriched lithospheric mantle. A sample (JS17) dated by Smith et al. (1998) contained near-concordant zircon cores with $^{207}Pb/^{206}Pb$ ages up to 3311 Ma, thereby supporting the involvement of older crust in magma generation.

The Karratha Granodiorite intruded and locally enveloped the greenstones of the Roebourne Group (Hickman, 1997) within the Karratha domain (see **Tectono-stratigraphic domains**). U–Pb ages of these greenstones (e.g. GSWA 136819, Nelson, 1998) indicate that they are approximately the same age as the granodiorite. Therefore, felsic volcanics in the greenstones may be extrusive rocks of the same felsic magmatic event. The main body of the Karratha Granodiorite occupies the core of the Prinsep Dome (Fig. 3), and extends across a poorly exposed 250 km^2 area. Subsequent to the mapping of DAMPIER, geochronology by Smith et al. (1998) indicates that the intrusion also outcrops on the southern limb of the Roebourne Synform, immediately north of the Sholl Shear Zone (Fig. 3). On DAMPIER, these parts of the Karratha Granodiorite are labelled *Agm*.

Microscopic examination shows that the Karratha Granodiorite ranges from allotriomorphic granular tonalite to granodiorite. The main constituents are anhedral to subhedral sutured plagioclase, interstitial quartz, and minor K-feldspar, hornblende (variably replaced by actinolite), biotite (commonly replaced by chlorite), epidote, and sericite. Minor minerals include sphene, apatite, leucoxene, opaques, and zircon.

Cherratta Granitoid Complex (*AgC, AgCp, AgCn, AgCg, AgCm, AgCmh*)

The Cherratta Granitoid Complex (*AgC*) is bounded to the north by the Sholl Shear Zone, whereas to the southwest it is unconformably overlain by the Fortescue Group. To the east, the Maitland Shear Zone separates it from the greenstones of the Sholl Belt (see **Simplified geology;** Fig. 3), although small stocks of monzogranite and syenogranite assigned to the complex locally intrude the greenstones. Poor exposure on DAMPIER, and limited geochronological data, prevent a detailed description of the granitoid complex. Where it is better exposed on PINDERI HILLS, it appears that the oldest granitoid components of the complex (3150–3060 Ma) are restricted to the area east of the Munni Munni Intrusion (Kojan and Hickman, in prep.). However, small inliers of the Cherratta Granitoid Complex in the valley of the Fortescue River (PINDERI HILLS) expose 3236 Ma granitoids (Nelson, 1998).

On DAMPIER, the internal structure of the complex can be interpreted using a combination of aeromagnetic data and observations at isolated outcrops. East of the Maitland River, tectonic foliations have a northerly to northeasterly strike and dip steeply eastwards. In the northeast of the Cherratta Granitoid Complex, the Sholl Shear Zone abruptly truncates this structural fabric. West of the Maitland River, aeromagnetic lineaments indicate east-northeasterly striking lithological zones, possibly including concealed large greenstone enclaves. Smaller greenstone enclaves are exposed close to the eastern boundary of the complex north of Toorare Pool (AMG 787823) and south-southwest of Radio Hill mine on PINDERI HILLS.

Porphyritic granite (*AgCp*) is exceptionally well exposed around Karratha Homestead (AMG 657904) and for about 5 km to the southeast along the Maitland River. Granodiorite forms a substantial component of the unit at this locality. The rock is medium grained, foliated to weakly gneissic, and contains megacrysts of microcline up to 10 cm long and 6 cm wide. Plagioclase and quartz are the dominant constituents, and hornblende is present in most exposures. Deformation has caused fragmentation and partial rounding of feldspar crystals, and produced lenticular quartz aggregates. The porphyritic granitoid contains xenoliths and layers of grey gneissic granitoid, and is locally intruded by veins of seriate biotite granite. A sample (GSWA 118974) of porphyritic hornblende granodiorite collected near Karratha Homestead was dated at 2994 ± 2 Ma (Nelson, 1997).

Banded grey granite–tonalite gneiss (*AgCn*), with xenoliths of amphibolite-facies mafic gneiss and sheets of leucocratic gneiss, outcrops in the southwestern part of DAMPIER. Here, the unit underlies the Fortescue Group unconformity, and outcrops intermittently along the Maitland River between Karratha Homestead and the area around Toorare Pool. Other outcrops occur south and southeast of Cockatoo Bore (AMG 745905 and AMG 762882). Along the Maitland River, the gneiss is intruded by porphyritic granite (*AgCp*) and by hornblende–biotite monzogranite (*AgCmh*). Layers of amphibolite gneiss alternate with leucocratic gneiss (Fig. 6) in excellent river-bed exposures 2 km east-southeast of Toorare Pool (AMG 784788). The amphibolite consists of bright-green hornblende, sericite, quartz, epidote, opaque iron minerals (probably magnetite because the rock is very magnetic), and minor sphene. Leucocratic layers are composed of a strongly laminated assemblage of sericitized plagioclase, quartz, hornblende, chlorite, and minor microcline. The rocks have been strongly sheared, metamorphosed to amphibolite facies, and show weak retrogression.

About 2 km west of Toorare Pool, a sample of the gneiss (GSWA 136826) contains zircon populations dated at 2995 ± 11 Ma and 2944 ± 5 Ma (Nelson, 1997). This was interpreted to indicate two generations of granitoid in the gneiss. The sample also returned a Nd T_{DM} age of 3246 Ma (Sun, S-S., 1997, writt. comm.). S-S. Sun also undertook Sm–Nd work on samples of banded gneiss (*AgCn*) from localities near Gregory Well (GSWA 136834, AMG 678876) and Marcia Bore (GSWA 136833, AMG 514821). Respective Nd T_{DM} ages of 3139 Ma and 3149 Ma were obtained. Sun and Hickman (1998) noted that these results were similar to Nd T_{DM} ages obtained from the 3125–3115 Ma Whundo Group of the Sholl Belt, and much younger than the 3430–3480 Ma Nd T_{DM} ages obtained from the Karratha Granodiorite and greenstones of the Roebourne Group north of the Sholl Shear Zone.

Seriate granite (*AgCg*) forms small exposures east of Cherratta Pool (AMG 738811) and 3 km southwest of Possum Bore (AMG 666782). The rock is quartz rich, contains no visible biotite or hornblende, and is either weakly foliated or non-foliated. This last feature suggests that it is one of the younger components of the Cherratta Granitoid Complex.

Foliated granite to granodiorite (*AgCm*), locally sparsely porphyritic and weakly banded, outcrops in the eastern part of the complex and in the vicinity of Jean Well (AMG 720870 and AMG 760870). Hornblende- and

Figure 6. Sheared amphibolite xenolith within gneiss of the Cherratta Granitoid Complex, Maitland River (AMG 784788)

biotite-rich monzogranite (*AgCmh*) outcrops around Toorare Pool (e.g. AMG 770790) and northwest of Cockatoo Bore (AMG 737918). It typically forms massive hilly outcrops, and is foliated and locally weakly banded. In the field, it is distinguished from other granitoids of the complex by its abnormally high hornblende (variably replaced by actinolite) content, and by magnetism due to disseminated magnetite. The hornblende and actinolite crystals are orientated in the plane of the foliation. The rock is generally medium- to coarse-grained monzogranite, but local granodiorite is also present. In thin section it consists of plagioclase, microcline, quartz, hornblende–actinolite, chloritized biotite, sphene, apatite, epidote, and opaques. Some hornblende crystals have relict cores of pyroxene, but this alteration may have been late magmatic. The rock has not been dated, but field relations suggest its age may be similar to that of the porphyritic granite (*AgCp*).

Dampier Granitoid Complex (*AgD, AgDp, AgDm*)

The Dampier Granitoid Complex (*AgD*) is the most northwesterly granitoid complex of the Pilbara Craton. It extends for 100 km southwestward from outcrops on the Burrup Peninsula to Eramurra Pool on northern FORTESCUE. On the Burrup Peninsula, the complex is intruded by the c. 2725 Ma Gidley Granophyre, and in the Dampier Archipelago toward the northwest it is unconformably overlain by the c. 2770 – 2680 Ma Fortescue Group. In the southwest, on PRESTON and FORTESCUE, the complex is also unconformably overlain by the Fortescue Group, but on its southeastern side it intrudes greenstones of the Cleaverville domain. On DAMPIER, less than 1% of the complex is exposed, thereby making conclusions about its overall composition difficult; however, aeromagnetic data suggest that the few outcrops may be representative of most of the complex. On this assumption, the complex comprises porphyritic granite to granodiorite (*AgDp*) and a mixed assemblage of even-grained granite to granodiorite that contains banded gneissic granitoids, syenogranite, and pegmatite (*AgDm*). The composition of the complex is thus similar to that of the Cherratta Granitoid Complex (*AgC*), but limited geochronology (two samples) indicates that the age of the Dampier Granitoid Complex may be less variable than that of the 3240–2940 Ma Cherratta Granitoid Complex, and mostly about 2990 Ma (Nelson, 1998, 1999). Because post-3015 Ma strike-slip movement on the Sholl Shear Zone was less than 40 km (see **Structure**), it may be inferred that large parts of the two granitoid complexes were formed at the same time (c. 2990 Ma), and in the same part of the West Pilbara Granite–Greenstone Terrane. In the western part of DAMPIER, only the Sholl Shear Zone and a narrow belt of greenstones in the Cleaverville domain separate the two granitoid complexes.

Porphyritic granite to granodiorite (*AgDp*) is exposed along the eastern shoreline of the Burrup Peninsula and on several islands of the Dampier Archipelago. Microcline megacrysts up to 5 cm long are set in a medium- to coarse-grained groundmass of plagioclase, microcline, and quartz. The rock is locally non-foliated, but commonly shows a flow alignment of the microcline phenocrysts. All outcrops are within 100 m of basal gabbroic units (*AyGo* or *AyGox*) of the Gidley Granophyre, and therefore evidence of remelting is common. In thin section, tridymite (a high temperature polymorph of silica) and feldspar form a granophyric matrix to saussuritized plagioclase and quartz. On East Lewis Island (AMG 658208), porphyritic monzogranite exhibits layers of alternating phenocryst-rich and phenocryst-poor phases, and a well-developed, parallel flow alignment of the microcline crystals.

Foliated and commonly banded granite to granodiorite (*AgDm*), with veins and sheets of syenogranite, aplite, and pegmatite, is exposed along the margins of the salt evaporation ponds south of Dampier. The oldest components are dark-grey gneiss and amphibolite xenoliths, but the dominant constituent is a later-formed, medium- to coarse-grained monzogranite composed of K-feldspar, quartz, and abundant plagioclase. Biotite is pseudomorphed by chlorite. A sample (GSWA 136844) collected from an abandoned quarry 7 km southwest of Karratha Airport (AMG 708046) was dated at 2997 ± 3 Ma (Nelson, 1998). Analyses on the cores of several zircons gave $^{207}Pb/^{206}Pb$ ages ranging between 3106 and 3255 Ma; the latter age being similar to the age of the Karratha Granodiorite and the lower part of the Roebourne Group (3270–3260 Ma, Hickman, 1997). It is therefore possible that either the Karratha Granodiorite or the lower part of the Roebourne Group, or both, contributed material to the complex. At another locality (AMG 660010), 13 km southwest of Karratha Airport, foliated and banded hornblende granodiorite or tonalite contains sheets of biotite monzogranite similar to the 2997 Ma rock type.

Layered mafic–ultramafic intrusions

The six layered mafic–ultramafic intrusions on DAMPIER are compositionally similar, and occur within a northerly to northeasterly trending zone that extends eastward onto ROEBOURNE and southward onto PINDERI HILLS. Intrusive relations to dated granitoids and greenstones, and one age determination (Arndt et al., 1991) on the Munni Munni Intrusion (PINDERI HILLS), indicate that most, if not all, the intrusions were emplaced at about 2925 Ma. However, the age of the Andover Intrusion, most of which outcrops on ROEBOURNE, is uncertain. If this intrusion also belongs to the c. 2925 Ma suite, then the northeasterly trending belt of intrusions occurs on both sides of the Sholl Shear Zone. Late dextral movement on the shear zone has displaced the Andover Intrusion by about 30 km relative to the other intrusions on DAMPIER (see **Structure**). Hoatson et al. (1992) described the geology, geochemistry, and mineralization of the layered mafic–ultramafic intrusions.

The intrusions are discordant to the greenstones and to the granitoids they intrude, and they are generally lopoliths or funnel-shaped bodies (Hoatson et al., 1992). Most comprise a lower section of ultramafic layers overlain by a layered unit of gabbro, leucogabbro, norite, and rare anorthosite and granophyre. The largest intrusions are several kilometres thick (e.g. the Munni Munni Intrusion on PINDERI HILLS is about 5500 m thick) and outcrop over 100 to 150 km^2. The intrusions have been actively explored by mineral exploration companies (Ruddock, 1999). On DAMPIER, the Radio Hill Intrusion is mined for nickel and copper at the Radio Hill mine. Also on DAMPIER, the Sholl Intrusion contains nickel–copper deposits that have yet to be commercially exploited, although trial mining and extracting nickel and copper using a bioleach method commenced at the Sholl B1 deposit in late 1999. On PINDERI HILLS, about 15 km south of Radio Hill, large, low-grade platinum group elements–nickel–copper deposits have been discovered in the Munni Munni Intrusion (Williams et al., 1990).

The major lithological components of the layered intrusions are common to most of the individual bodies, and therefore can best be described collectively.

Gabbro and minor dolerite and microgabbro (*AaAo, AaBo, AaDo, AaHo, AaNo, AaRo*)

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

Gabbro and dolerite or microgabbro containing angular blocks of basalt (*AaAob, AaBob, AaDob, AaHob*)

Metamorphosed gabbro and microgabbro or dolerite, containing angular blocks of basalt (*AaAob, AaBob, AaDob, AaHob*) is present close to some of the margins of the intrusions. The rock probably formed by fragmentation of basaltic wallrocks followed by injection of gabbro into the resulting breccia. The observation that only basalt forms clasts within the breccia indicates formation more or less in situ. Extensive areas of the injection breccia outcrop north of Bullock Hide Well (AMG 790900) and south of No 6 Well (AMG 970940), possibly close to subhorizontal intrusion margins.

Metadolerite (*AaAd, AaNd, AaRd*)

Metadolerite (*AaAd, AaNd, AaRd*) is a very minor component of the layered intrusions, and forms either marginal zones or sills and dykes in adjacent greenstones. The rock differs from the coarser grained metagabbro by commonly being porphyritic, and containing euhedral plagioclase or pyroxene phenocrysts within a fine-grained pyroxene–plagioclase groundmass.

Metamorphosed leucogabbro (*AaAl, AaBl*)

Metamorphosed leucogabbro (*AaAl, AaBl*) units differ from units mapped as metagabbro by containing more plagioclase, and consequently being paler coloured when broken or observed in clean outcrops. Like all the metagabbro units, it forms bouldery hills and cannot be distinguished by photointerpretation. Microscopic examination shows that the metamorphosed leucogabbro is composed of saussuritized plagioclase, tremolite, clinopyroxene, chlorite, traces of brown hornblende, and variable amounts of calcite. Leucogabbro forms a significant proportion of the Andover Intrusion, and on PINDERI HILLS it is also an important constituent of the Munni Munni Intrusion. These are the two largest layered intrusions of the area, and may have undergone more differentiation than the smaller bodies, such as the Sholl and Radio Hill Intrusions.

Undivided ultramafic rock (*AaAu, AaBu, AaRu*)

Undivided ultramafic rock (*AaAu, AaBu, AaRu*) includes carbonate–chlorite rock, talc–carbonate rock, amphibole–chorite(–talc) schist, and serpentine schist. Prior to hydrothermal alteration and shearing, the primary lithologies of pyroxenite, peridotite, or dunite, are assumed to have formed layers within the intrusions. Because they were much less competent than the thick gabbroic parts of the intrusions, these ultramafic rocks were preferentially deformed during tectonism, and are now commonly present along shear zones.

Serpentinite (*AaBus, AaDus, AaHus*)

Serpentinite (*AaBus, AaDus, AaHus*), replacing peridotite, is relatively massive and forms dark-coloured hills and ridges similar to those composed of metagabbro. The rock is readily mappable within the Bullock Hide (AMG 820840, AMG 819870, AMG 795893) and Dingo (AMG 790828) Intrusions, but in the Andover Intrusion on DAMPIER it is difficult to separate from extrusive peridotite (*Aus)* of the Ruth Well Formation (Hickman, 1997). Thus, unassigned serpentinite (*Aus*) east and west of Nickol River (AMG 980914 to AMG 910922) may belong to the Andover Intrusion. Serpentinization of the peridotite layers has almost completely replaced primary olivine, but opaque minerals commonly define the boundaries of pseudomorphs. Relict olivine and clinopyroxene are locally preserved in serpentinite of the Andover Intrusion on ROEBOURNE (Hickman, in prep.). Minor constituents of serpentinite are talc, hornbende (after pyroxene), tremolite, chlorite, and biotite.

Talc–chlorite schist (*AaHut*)

Talc–chlorite schist (*AaHut*) outcrops 3 km north of Mount Sholl (AMG 901880), where it is interpreted as a sheared pyroxenite and peridotite within the lower part of the Sholl Intrusion.

Metapyroxenite (*AaAx, AaDx, AaHx*)

Metapyroxenite (*AaAx, AaDx, AaHx*) is a minor component of layered intrusions on DAMPIER. The largest of these units is present along the northwestern basal margin of the Sholl Intrusion (AMG 880855 and AMG 900873), and in the Andover Intrusion close to the eastern margin of the map sheet (AMG 985935). Unlike metagabbro and massive serpentinite, metapyroxenite generally forms low, weathered outcrops. The rock is fine to medium grained, with an allotriomorphic granular texture, and is mainly composed of secondary amphibole (actinolite or tremolite) and minor chlorite, talc, and epidote. Relict pyroxene is very rarely preserved. Opaque minerals form disseminated anhedral grains and discontinuous layers along grain boundaries and cleavage traces.

Other metamorphic rocks

Mylonite (*Amm*)

Mylonite (*Amm*), representing intensely sheared granitoids and greenstones, outcrops along the Sholl Shear Zone, which is locally up to 1 km wide. Rock pavements in the Nickol River (AMG 948896) provide excellent exposures (Fig. 7) of the northern section of this major shear zone. Here, the mylonite is dominantly silicic and represents extremely sheared granitoids, but there are also layers of amphibolite. Other good exposures are present 3 km northeast of Karratha Homestead (AMG 680932). At this locality the mylonite comprises 0.5 – 2.0 mm-wide laminae of very fine-grained siliceous material containing small clasts of quartz, plagioclase, microcline, and crushed garnet. The morphology of rare feldspar porphyroclasts in some of the less intensely deformed laminae indicates a sinistral shear sense. Mylonite, too thin to map at 1:100 000 scale, outcrops along strike-slip faults and thrusts (see **Structure**). Within greenstones, the mylonite can be mafic in composition. One such mylonite occurs 3 km south of Bardies Tank (AMG 904940) where the rock is a finely laminated assemblage of hornblende, quartz, feldspar, and biotite, with porphyroblasts of garnet up to 3 mm across.

Structure

The structural geology of pre-Fortescue Group rocks on DAMPIER is best described in relation to the area's regional tectonic setting within the northern part of the Pilbara Craton. Recent geological remapping of the west Pilbara has led to a new tectonic interpretation of the granite–greenstones of the north Pilbara (see **Regional geological setting**). Description of the structure of the area requires reference to the stratigraphy of this part of the West Pilbara Granite–Greenstone Terrane, but for reasons given previously (see **Regional geological setting**) this stratigraphy is not shown on the DAMPIER map. The greenstone stratigraphy of DAMPIER is shown on Figure 4, and summarized in Tables 2 and 3. Additional information is provided by Hickman (1997) and Hickman et al. (in prep.a). The 1:250 000 scale DAMPIER AND BARROW ISLAND map (Hickman and Strong, in prep.) presents a stratigraphic interpretation of the area.

Figure 7. Mylonite of the Sholl Shear Zone exposed in the bed of the Nickol River (AMG 948896). Pale layers are relatively siliceous, and represent mylonitized granitoid; darker layers include silicified mafic rock

Tectono-stratigraphic domains on DAMPIER

Krapez and Eisenlohr (1998) recognized two tectono-stratigraphic domains on DAMPIER (their Domains 5 and 6) separated by the Sholl Shear Zone. Each domain was subdivided into various tectono-stratigraphic units such as granitoid complexes and basins. The interpretation by Krapez and Eisenlohr (1998) was based on previous mapping and a number of local studies such as those of Kiyokawa (1993) in the Cleaverville area (ROEBOURNE) and Smith et al. (1998) on the Sholl Shear Zone. Information from the present mapping program, and accompanying geochronology (Nelson, 1996, 1997, 1998), indicates that the model presented by Krapez and Eisenlohr (1998) cannot be sustained (Hickman et al., in prep.a,b).

Figure 4 presents a tectono-stratigraphic interpretation of DAMPIER, based on the recent mapping and geochronology. The regional setting of DAMPIER is shown in Figure 3. Mapping of DAMPIER resulted in the first recognition of the Regal Thrust, an early (D_1) layer-parallel shear zone that separates the Nickol River Formation from the Regal Formation over an area 70 km (ENE–WSW) by 25 km (NNW–SSE). On DAMPIER, this thrust separates the Karratha and Cleaverville domains (Fig. 3) and is folded by the Prinsep Dome. On ROEBOURNE, the Regal Thrust is folded by the Roebourne Synform (Figs 3 and 4). The mid-oceanic-ridge basalt (MORB)-like geochemistry of the Regal Formation (Sun and Hickman, 1999) suggests that the Regal Thrust may be a plane of obduction of oceanic crust across the Karratha domain. The Karratha domain is a c. 3270 – 3250 Ma granite–greenstone assemblage that represents either a northwestern extension of the East Pilbara Granite–Greenstone Terrane or part of a separate granite–greenstone terrain tectonically juxtaposed with older components of the East Pilbara Granite–Greenstone Terrane.

The Cleaverville domain overlies the Regal Thrust, and is bounded to the south by the Sholl Shear Zone. Stratigraphic components are the Regal Formation and the c. 3020 – 3015 Ma Cleaverville Formation (Fig. 4). The age of the Regal Formation has not been directly established, but is assumed to be similar to that of the Ruth Well and Nickol River Formations. Its contact with the c. 3020 Ma Cleaverville Formation is probably an unconformity, and sandstone or fine-grained clastic sedimentary rocks outcrop at the base of the Cleaverville Formation. Contacts between the c. 2990 Ma Dampier Granitoid Complex and the Regal Formation are not exposed, but granite veins in the Regal Formation indicate an intrusive relationship.

Near Cleaverville, the Cleaverville domain is structurally more complex, with repetition of the Regal and Cleaverville Formations due to faulting and tight to isoclinal folding. Ohta et al. (1996) interpreted the Cleaverville area as part of an accretionary complex related to subduction of oceanic crust. However, this interpretation conflicts with evidence that the Cleaverville Formation is a shallow-water deposit (Sugitani et al., 1998). Additionally, the Cleaverville Formation is distributed over a wide area of the West Pilbara Granite–Greenstone Terrane (Hickman, 1997), and has recently been identified 200 km to the east, on the western margin of the East Pilbara Granite–Greenstone Terrane (Smithies and Farrell, 2000). At least part of the faulting within the Cleaverville domain post-dates the Fortescue Group, and is probably related to a northeasterly trending belt of reverse faults (D_{11}) that deforms the c. 2725 Ma Gidley Granophyre.

To the south of the Sholl Shear Zone, the Maitland Shear Zone (Hickman, 1997) separates the Cherratta Granitoid Complex from the Sholl domain (Fig. 3). The major layered mafic–ultramafic intrusions of the west Pilbara cross the Maitland Shear Zone without visible deformation, indicating that the zone predates 2925 Ma. In addition, it is truncated by the Sholl Shear Zone. The Sholl domain mainly comprises the 3125–3115 Ma Whundo Group, but the Cleaverville Formation is also a component on ROEBOURNE.

Deformation events

D_1 (3160–3130 Ma)

The earliest recognizable tectonic structures on DAMPIER and ROEBOURNE are low-angle thrusts and recumbent folds, which limited evidence from minor structures suggests were produced by southerly directed thrusting. The largest fault is the Regal Thrust (see above; Fig. 4), but large-scale thrusts are also present within the Regal Formation on DAMPIER (AMG 735980 and AMG 935945). Large-scale isoclinal folds in the Nickol River Formation southeast of Mount Regal (AMG 745970) were recumbent and southwesterly facing prior to tilting by the D_6 Prinsep Dome. Intrafolial isoclines are relatively common within the Nickol River Formation of the Mount Regal area (AMG 751968, AMG 749977; Hickman et al., 2000), and are probably minor structures related to the recumbent folds. A bedding-parallel tectonic foliation (S_1), preserved in metasedimentary rocks of the Nickol River Formation (Fig. 8) and in metabasalt of the Regal Formation, is parallel to the D_1 thrusts, and probably the same age, but was reactivated by parallel shearing during later tectonic events.

The Regal Thrust is exposed 13 km southeast of Karratha (AMG 920968) on the southern limb of the Prinsep Dome. Here, a finely laminated silicic mylonite has been isoclinally folded. Part of the outcrop (Fig. 9) shows that the isoclinal folds have been progressively refolded by later tight to isoclinal folds. Plunges of the early isoclines are generally low (up to 30°) and towards the east or west, and the prevailing dip of the mylonite is 60–80° south. This indicates thrusting from either the north or the south.

D_1 structures have not been recognized in the Whundo Group, suggesting that they formed prior to 3125 Ma. A thermotectonic event at 3160–3150 Ma is indicated by zircon geochronology (Smith et al., 1998) and K–Ar

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Figure 8. Laminated chert–carbonate rock in the upper part of the Nickol River Formation (AMG 749977), with a well-developed, bedding-parallel S_1 foliation

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Figure 9. A refolded D_1 isoclinal fold in the mylonite developed along the Regal Thrust (AMG 920968)

geochronology (Kiyokawa, 1993), and is here interpreted as coinciding with D_1. Granitoids of this age have been identified southeast of DAMPIER (Nelson, 1999) and close to the southeastern margin of the Central Pilbara Tectonic Zone (Nelson, 2000), confirming a tectono-magmatic event at this time.

The Sholl Shear Zone may have commenced with sinistral strike-slip movement as early as 3160 Ma (see below), but most movement took place after deposition of the Whundo Group (3125–3115 Ma), and probably culminated between 3050 and 3015 Ma.

D_2 (mainly c. 3050 – 3020 Ma)

Measurable strike-slip movement on the Sholl Shear Zone is dextral and approximately 30–40 km. However, the dextral movement is a late-stage feature of this major crustal structure, and was preceded by far greater sinistral movement (see below). Sun and Hickman (1998) suggested that the c. 3270 – 3250 Ma Roebourne Group might be equivalent to the c. 3260 – 3235 Ma Sulphur Springs Group of the East Pilbara Granite–Greenstone Terrane. Greenstones of the Mount Goldsworthy – Ord Range area have not yet been mapped at 1:100 000 scale, but they may also include the Sulphur Springs Group — this would imply a 250 km sinistral dislocation of the east Pilbara succession from the Ord Range to the Roebourne area.

Sinistral strike-slip movement on the Sholl Shear Zone is consistent with north–south compression similar to that responsible for the D_1 structures. Direct evidence for sinistral movement is provided by porphyroclasts within fine-scale mylonitic lamination (AMG 680932, AMG 773925, and AMG 868904). These shear-sense indicators consistently imply sinistral movement along the foliation planes of the mylonite. Evidence for major early movement is also provided by the stratigraphic mismatch across the fault (see **Tectono-stratigraphic domains**), which cannot be explained by the measurable 30–40 km of dextral displacement (D_8) that took place after deposition of the Whim Creek Group.

The mylonite belt of the Sholl Shear Zone is generally about 1 km wide along its exposed length of 200 km. Magnetic data indicate that the total onshore length of the fault probably exceeds 350 km (Fig. 1). In the northeast (northeastern SHERLOCK, YULE, and THOUIN), only post-3010 Ma rocks are preserved, so the original extent of the sinistral fault in that area is uncertain.

Shearing along the Sholl Shear Zone was partly contemporaneous with c. 3015 Ma felsic intrusions within, and close to, the zone. Examples of such felsic rocks include quartz–feldspar porphyry (*Afp*), and 3023 ± 9 Ma dacite 1 km north of the shear zone at Nickol River (Nelson, 1997). Smith et al. (1998) reported a zircon age of 3024 ± 4 Ma for the mylonite, which was interpreted as the age of a granitoid precursor and the maximum age of movement; however, the shear zone may have been intruded by granitoids during its development. The minimum age for sinistral movement is constrained by the fact that 3010 Ma formations of the Whim Creek Group are not affected by the Sholl Shear Zone. Metamorphic grades immediately north of the shear zone range from upper greenschist to amphibolite facies, whereas grades to the south are greenschist facies. However, the timing of the implied northside-up movement, whether D_2 or D_8, is uncertain.

Several large splay faults are associated with the Sholl Shear Zone. On DAMPIER, these include a mylonite zone south of Nickol River Hill (AMG 963878), and possibly some of the easterly striking mylonite zones in the greenstones north of the Sholl Shear Zone on the eastern part of DAMPIER. The Maitland Shear Zone (see **Simplified geology**; Fig. 4) probably originated as a sinistral D_2 fault, and was reactivated at about 2940 Ma (D_7). On PINDERI HILLS, foliated greenstones immediately northeast of this shear zone are intruded by non-foliated granitoids, one of which was dated by Smith et al. (1998) at 3013 ± 4 Ma.

D_3 (3015–3010 Ma)

Tight to isoclinal east-northeasterly trending folds in the Cleaverville Formation between Karratha and Cleaverville are attributed to the D_3 event, and predate intrusive rhyolite that outcrops 5 km south of Cleaverville Creek (AMG 982093). A sample of this rhyolite (GSWA 118981) has a U–Pb zircon age of c. 3000 Ma (Nelson, D. R., 1997, pers. comm.). The same type of folding deforms the Cleaverville Formation between Miaree Pool and Mount Regal, but the age of these structures has not been directly determined. In the metabasalt of the Regal Formation, S_3 is locally synchronous with intrusive sheets of 3015 Ma quartz–feldspar porphyry (*Afp*) and porphyritic microgranite (*Agp*). At Mount Ada (ROEBOURNE), easterly trending upright tight to isoclinal D_3 folds in the Cleaverville Formation contain a sill of 3014 Ma granophyre (Nelson, 1997). These fold structures are unconformably overlain by the c. 3010 Ma Warambie Basalt.

The depositional age of the Cleaverville Formation is 3020–3015 Ma. South of the Sholl Shear Zone, at Mount Ada (ROEBOURNE), BIF and chert are lithologically indistinguishable from rocks of the Cleaverville Formation north of the Sholl Shear Zone, and have the same depositional age (Hickman, 1997). This indicates that if total sinistral movement along the shear zone was as great as 250 km, then most of the movement probably took place prior to 3020 Ma. Future mapping and geochronology in the Ord Ranges, east of Port Hedland, is expected to resolve the extent of sinistral displacement along the Sholl Shear Zone.

D_4 (c. 2990 – 2960 Ma)

The D_4 event involved local thrusting and folding of the Whim Creek Group on ROEBOURNE. D_4 thrusts in the Warambie Basalt east of Mount Ada (ROEBOURNE, Hickman, in prep.) predate 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–west trending folds on MOUNT WOHLER and SATIRIST (local D_1 folds of Smithies, 1998b; Smithies and Farrell, 2000) may belong to the same event. These correlations suggest that D_4 occurred between 2990 and 2960 Ma.

D_5 (pre-2950 Ma)

Northerly trending folds recognized within the Central Pilbara Tectonic Zone (D_2 folds on MOUNT WOHLER, Smithies, 1998b) and SATIRIST (D_2 folds, Smithies and Farrell, 2000), appear to have no equivalents on DAMPIER, but if present in the west Pilbara Granite–Greenstone Terrane would be assigned to a D_5 event.

D_6 (c. 2950 – 2940 Ma)

The D_6 event formed major northeasterly trending tight to open folds such as the Prinsep Dome, Roebourne Synform, and Bradley Syncline (Fig. 3). Both the Bradley Syncline and the Roebourne Synform extend eastwards onto ROEBOURNE (Hickman, in prep.). These structures are correlated with major 'D_3' folds on MOUNT WOHLER and SHERLOCK (Smithies, 1998a), and are equivalent to Phase 4 structures described by Krapez and Eisenlohr (1998). However, geochronology on MOUNT WOHLER (Smithies, 1998b) established 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 of the West Pilbara Granite–Greenstone Terrane and Central Pilbara Tectonic Zone. The folds are probably a result of transpression within a post-2950 Ma east–west belt of dextral strike-slip movement.

Minor D_6 structures include a steeply dipping, east-northeasterly striking axial-plane foliation (S_6) in the Prinsep Dome and in an anticline east of Mount Sholl. Minor D_6 folds (Fig. 10) deform S_1 southeast of Mount Regal (AMG 749977) and 1 km southwest of Nickol Well (AMG 990027). The Mount Regal folds plunge southwestward, and the Nickol Well folds plunge to the northeast.

D_7 (c. 2940 Ma)

On DAMPIER, the north-northwesterly striking 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. North of Bullock Hide Well all these structures are truncated by the Sholl Shear Zone. Shear zones are present also within the Cherratta Granitoid Complex. About 2 km east-southeast of Toorare Pool (AMG 784788), in the bed of the Maitland River, exposures of gneiss (*Agcn*) have a strong shear foliation (S_6) that dips 30° eastwards. About 2 km west of Toorare Pool, the same gneiss contains late zircon populations dated at 2944 ± 5 Ma and 2925 ± 2 Ma (Nelson, 1997).

D_8 (c. 2920 Ma)

The latest movement on the Sholl Shear Zone was dextral (D_8), which on SHERLOCK displaced the Whim Creek Group and the Caines Well Granitoid Complex by 30–40 km. On ROEBOURNE, it displaced slivers of the Cleaverville Formation at least 20 km from Mount

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Figure 10. D_6 open folds that have deformed S_1 in chert–carbonate rock of the Nickol River Formation (AMG 749977)

Ada to De Witt Hill (Hickman, in prep.), and on DAMPIER it displaced the c. 2925 Ma Andover Intrusion about 30 km. In this connection, it should be noted that the Andover Intrusion (mainly on ROEBOURNE) might originally have been linked to the Bullock Hide Intrusion. On ROEBOURNE, the Black Hill Shear Zone is a major dextral strike-slip fault that is subsidiary to the Sholl Shear Zone. The Black Hill Shear Zone displaces the Andover Intrusion by 10 km (Hickman, in prep.), and extends onto eastern DAMPIER (AMG 990915). 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 that could have coincided with D_8.

Minor D_8 structures in the Sholl Shear Zone include dextral drag folding and isoclinal folding (Fig. 11) of S_2 mylonite lamination, and associated small-scale faulting and brecciation.

D_9 (<2920 Ma)

The Sholl Shear Zone and earlier structures are deformed by a D_9 conjugate system of north-northeasterly striking sinistral faults and west-northwesterly striking dextral faults. Examples of these structures are present in the vicinity of Ruth Well (AMG 846939). The precise age of D_9 faults is unknown, but predates the 2770 Ma Mount Roe Basalt of the Fortescue Group.

Metamorphism

Greenstones of the Roebourne Group north of the Sholl Shear Zone have been metamorphosed to amphibolite facies, whereas south of the shear zone the Whundo Group contains rocks at lower greenschist facies. This difference is attributed to a component of reverse movement on the northerly inclined Sholl Shear Zone. An exception is present in the Cleaverville domain between Karratha and Cleaverville. Here, downward movement on steep faults on the northwestern side of the Prinsep Dome has preserved greenschist facies sections of the Regal Formation.

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

Fortescue Group

The Fortescue Group is the oldest of three groups that belong to the late Archaean to Palaeoproterozoic Hamersley Basin. These groups belong to the Mount Bruce Supergroup, a succession of volcanic and sedimentary rocks up to 10 km thick, which outcrops over 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–

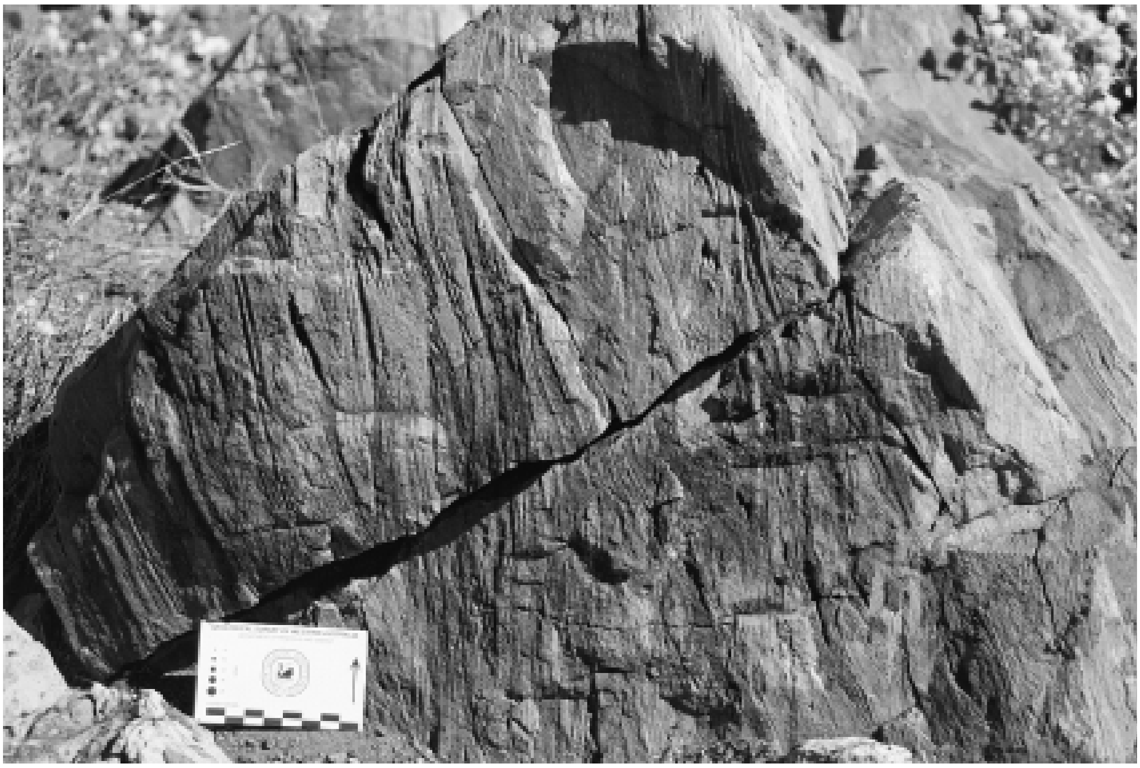

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Figure 11. Isoclinal folding of mylonite foliation in the Sholl Shear Zone at Nickol River (AMG 948896)

greenstone terranes. The age of the dominantly volcanic Fortescue Group is c. 2770 – 2680 Ma (Arndt et al., 1991; Nelson et al., 1992; Wingate, 1999). All rocks in the Fortescue Group are weakly metamorphosed to prehnite–pumpellyite facies (Smith et al., 1982). Blake (1993) and Thorne and Trendall (in prep.) discuss the regional stratigraphy and tectonic evolution of the Fortescue Group.

In the southeastern part of DAMPIER, the basal formation of the Fortescue Group is the Mount Roe Basalt (*AFr*), which unconformably overlies the Cherratta Granitoid Complex (Fig. 12). In the Dampier Archipelago, unassigned basalt and andesite (*AFa*) of the Fortescue Group unconformably overlie the Dampier Granitoid Complex (Figs 13 and 14), and are intruded by the c. 2725 Ma Gidley Granophyre. These volcanics probably belong to the Kylena Formation (see below), but no distinguishing stratigraphic markers are present.

Mount Roe Basalt (*AFr, AFrs*)

In the southwestern part of DAMPIER, the Mount Roe Basalt (*AFr*) comprises a 200 m-thick succession that includes massive, columnar-jointed, vesicular, and glomero-porphyritic flows of basalt and basaltic andesite. The basal unconformity of this formation with underlying granitoids of the Cherratta Granitoid Complex is exceptionally well exposed at Mount Leopold (Fig. 12, AMG 599792), where it outcrops about 50 m above the base of a 100–150 m high, north-facing escarpment. The unconformity is an irregular erosional surface with visible relief up to 50 m. Subaerial lava flows of the Mount Roe Basalt were erupted onto a late-Archaean granitoid landscape of low hills that was cut by deeply incised gulleys. These palaeodrainages and other low-lying areas contained clastic sediments that are now preserved as lenticular units of conglomerate, sandstone, and shale (*AFrs*). Minimal leaching of the granitoids immediately beneath the unconformity indicates rapid erosion. About 1 km east of Mount Leopold (AMG 607792), a palaeoridge of banded granitoid gneiss (*AgCn*) rises about 30 m into the Mount Roe Basalt succession. At the foot of the western slope of this almost vertical unconformity there is a coarse conglomerate containing subrounded granitoid boulders up to 0.5 m in diameter. Above the conglomerate there is a 2 m-thick shale overlain by a 10 m-thick unit of feldspathic sandstone, which is in turn overlain by a vesicular basalt. The clastic sedimentary rocks and the lower part of the vesicular basalt, which are both almost horizontal, have a sharp eastwards contact with the unconformity — a probable cliff face of granitoid gneiss. The lateral variability of the basal clastic succession is well exposed 600 m northeast of Mount Leopold (AMG 603797). Here, a conglomerate overlies basal sandstone, and a rubbly scoriaceous basalt flow is present within the basal sedimentary rocks.

The Mount Roe Basalt and the overlying Hardey Formation (not preserved on DAMPIER) were deposited in an environment of continental rifting (Blake, 1993). The evidence for rapid erosion and local topographic relief, immediately prior to deposition of the Mount Roe Basalt on DAMPIER, is consistent with local uplift related to rifting.

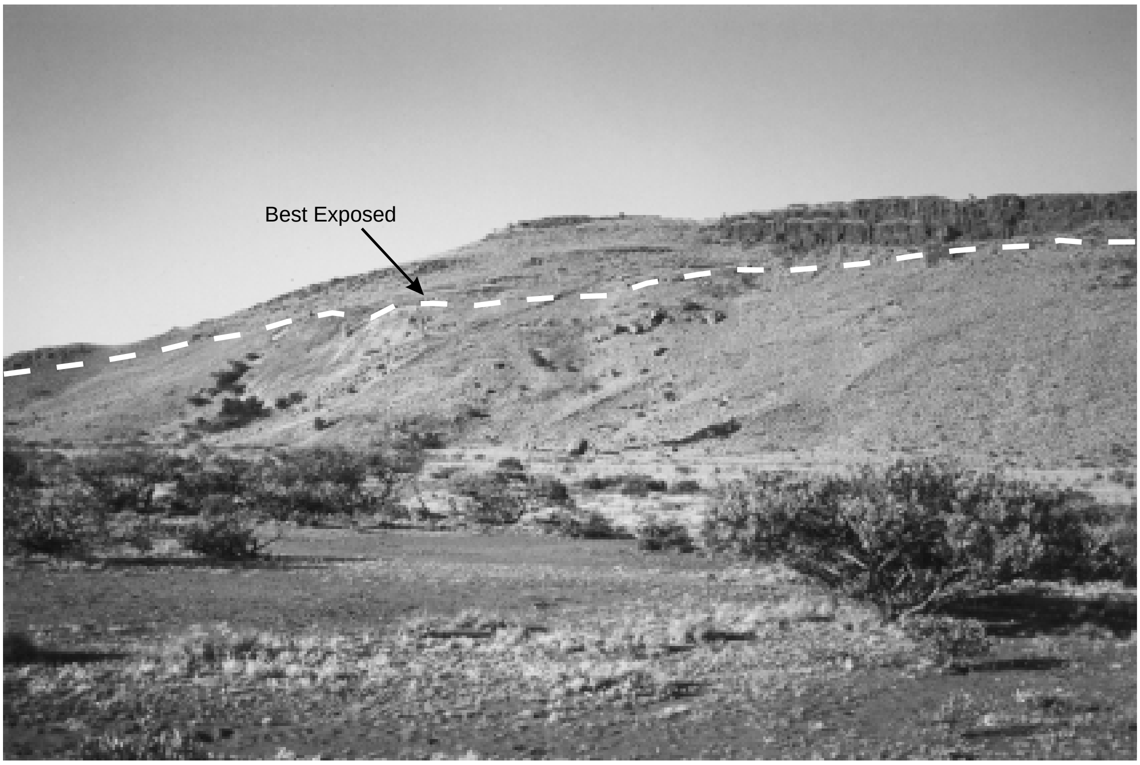

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Figure 12. View westwards of the basal unconformity of the Fortescue Group near Mount Leopold (AMG 615783). Sandstone and basalt of the Mount Roe Basalt (upper part of cliff) overlie granitoid rocks of the Cherratta Granitoid Complex

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Figure 13. Unconformity between the Dampier Granitoid Complex and the Fortescue Group, East Lewis Island (AMG 658208)

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Figure 14. Conglomerate immediately above the basal Fortescue Group unconformity, East Lewis Island (AMG 658208)

Unassigned volcanic and sedimentary rocks (*AFa, AFs*)

A succession of basalt and andesite (*AFa*), with local thin units of sandstone and conglomerate (*AFs*), is present on several islands of the Dampier Archipelago. This dominantly volcanic succession is lithologically similar to some components of the Fortescue Group on the mainland. On East Lewis Island, basaltic andesite of the Fortescue Group unconformably overlies the Dampier Granitoid Complex (Figs 13 and 14) and the Gidley Granophyre (AMG 648200). However, on Enderby Island (AMG 483210), basalt of the succession is intruded by leucocratic veins at the margin of the Gidley Granophyre (Strong et al., in prep.). These apparently conflicting relative ages of the volcanic successions may be explained if the succession includes components that are respectively older and younger than the Gidley Granophyre. Gabbro (*AyGo*) at the base of the Gidley Granophyre was dated at 2725 ± 3 Ma (Wingate, M. T. D., 1997, writt. comm.). Assuming that the age of the Dampier Archipelago volcanic succession is approximately 2725 Ma, geochronological data from the Fortescue Group indicate that the most probable correlation is with the Kylena Formation. Although not directly dated, the Kylena Formation stratigraphically underlies the Maddina Formation, which is dated at 2717 ± 2 Ma (Nelson, 1998).

On Enderby Island, 1–2 m-wide dykes of microgranite intrude the volcanic succession (AMG 522203), but have not been dated. At several localities (e.g. AMG 658208) the volcanic rocks unconformably overlie granitoids of the Dampier Granitoid Complex. The total thickness of the volcanic succession in the Dampier Archipelago is estimated at 200–500 m.

Gidley Granophyre (*AyG, AyGr, AyGo, AyGox, Ayx, Agr*)

De Laeter and Trendall (1971) described the Gidley Granophyre as an intrusion of granophyre and associated gabbro along the basal unconformity of the Fortescue Group. On the Burrup Peninsula and the islands of the Dampier Archipelago, the Gidley Granophyre is a northwesterly dipping composite sill consisting of a lower unit of gabbro (*AyGo*) and quench-textured gabbro (*AyGox*), and an upper unit of granophyre (*AyG*) with local quartz-rich granophyre (*AyGr*). This composite intrusion is at least 2 km thick, and it outcrops over an area of about 100 km^2. Magnetic data indicate that the total areal extent of the Gidley Granophyre (on land and under the Indian Ocean) probably exceeds 300 km^2. The contact between the gabbro and overlying granophyre is intrusive, with veinlets of silicic granophyre intruding the gabbro (Fig. 15, AMG 642103). However, the consistent spatial association between the gabbro and the granophyre, and their common intrusion between the Dampier Granitoid Complex and the Fortescue Group, suggests that they were intruded at about the same time. The basal gabbro (*AyGo*) has been dated at 2725 ± 3 Ma, using U–Th–Pb ion microprobe analyses of baddeleyite (Wingate, M. T. D., 1997, writt. comm.). Several attempts to extract zircon from the granophyre have been unsuccessful, and therefore the precise age of the upper section of the intrusion remains uncertain.

The 2725 Ma baddeleyite age establishes that the Gidley Granophyre is younger than the Mount Roe Basalt and the c. 2760 Ma Hardey Formation (not preserved on DAMPIER), but older than the upper formations of the Fortescue Group. This raises the question of possible extrusive equivalents of the granophyre in the upper Fortescue Group of the west Pilbara. Geochemical data from PINDERI HILLS (Kojan and Hickman, 1998) suggest that volcanic rocks related to the Gidley Granophyre may be present in either the Maddina Formation or the upper Kylena Formation. A rhyolite unit in the Maddina Formation was dated at 2717 ± 2 Ma (Nelson, 1998).

The Gidley Granophyre has intruded, and partially melted, granitoids of the Dampier Granitoid Complex. Xenoliths of remelted granitoid (*Agr*), ranging in size from a few centimetres in diameter to 3 km long (AMG 730140), are present in both the gabbro and granophyre sections of the intrusion, and indicate extensive fragmentation and massive veining of the granitoid complex. In thin section, the remelted granitoid consists of saussuritized plagioclase, quartz, and abundant interstitial remelted feldspar and tridymite.

That the Gidley Granophyre is locally a transgressive sill is illustrated by the fact that the unconformity between the Dampier Granitoid Complex and the Fortescue Group was not intruded in all areas. Excellent exposures of this unconformity are preserved on East Lewis Island (Fig. 13, AMG 658208), and interpretation of aerial photography indicates granitoids are present directly beneath the Fortescue Group on West Lewis Island and Enderby Island.

At the base of the Gidley Granophyre, contact metamorphism and local partial melting of the Dampier Granitoid Complex caused fracturing in the basal gabbro and back-injection of leucocratic veins (AMG 670108, AMG 805211, AMG 795192). At the top of the Gidley Granophyre, basalt and andesite (*AFa*) of the Dampier Archipelago are locally intruded by marginal leucocratic veins (AMG 483210) and dykes of granophyric microgranite (AMG 522203).

The gabbroic section of the Gidley Granophyre is composed dominantly of medium- to coarse-grained gabbro (*AyGo*). De Laeter and Trendall (1971) also described noritic gabbro consisting of hypersthene, augite, and labradorite, with micrographic albite–quartz intergrowth. On the eastern side of the Burrup Peninsula, between Hearson Cove (AMG 790189) and Sloping Point (AMG 860302), and 3 km south of Dampier (AMG 700122), the lower section of the gabbro contains layers of spectacular quench-textured acicular pyroxene (*AyGox*). Pyroxene crystals up to 15 cm long are concentrated in vertical branching structures up to 2 m in height. In thin section, fresh augite is present within a

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Figure 15. Gidley Granophyre, 6 km west-southwest of Dampier (AMG642103), showing gabbro, the early phase of the intrusion, cut by veins of granophyre

coarse matrix of saussuritized plagioclase, chloritized pseudomorphs after clinopyroxene, and interstitial patches of granophyric tridymite and feldspar. These granophyric areas were probably derived from remelted granitoid inclusions. Sheets of melt material locally form sills and dykes in the layered zone, and rare xenoliths of gabbro are present in the marginal zone of the adjacent granitoids of the Dampier Granitoid Complex, suggesting extensive granitoid remelting.

Fine- to medium-grained granophyre (*AyG*) comprises most of the Gidley Granophyre composite sill, and is massive, homogeneous (apart from partly remelted granitoid inclusions), and well jointed. Where layering is visible on 1:25 000-scale colour aerial photographs, or defined by slight colour and grain size variations in outcrop, this layering is orthogonal to the dominantly near-vertical joint system. Outcrops of the rock are typically reddish brown to black, but freshly broken surfaces range from dark reddish green to dark blue-grey or purple-grey. In thin section, the rock consists of finely intergrown quartz and alkali feldspar.

Quartz-rich granophyre (*AyGr*) outcrops at the eastern end of East Intercourse Island (AMG 680163). The unit is 10 m thick at this locality, and is underlain by granophyre that contains blocks of vein quartz (or recrystallized quartz-rich granophyre) and remelted granitoid. This rock is very similar to the granophyric xenolith-rich dykes (*Ayx*) on the mainland. In thin section, the quartz-rich granophyre is a mosaic of strained quartz with minor interstitial K-feldspar and plagioclase. Rare concentrations of interstitial chlorite are also present. The quartz-rich granophyre is a marginal phase of the main granophyre, and may have been fragmented, metamorphosed, and partly assimilated by later granophyre. Similarly, the north-northwesterly trending, granophyric, xenolith-rich dykes (*Ayx*) on the mainland are probably feeder dykes for the Gidley Granophyre. These dykes intruded along a narrow zone from 13 Mile Well (AMG 769049) to North Whundo (AMG 930789). They cut both the Sholl Shear Zone and the Sholl Intrusion, but no contacts with the Fortescue Group are preserved. One kilometre west of Pat Bore (AMG 812975), one such dyke (Fig. 16) is cut by a northeasterly trending dolerite dyke (*d*). The xenolith-rich dykes (*Ayx*) contain angular to subrounded fragments of vein quartz, quartzite, and granitoids up to 1 m in length. These xenoliths commonly comprise 25–50% by volume of the dykes, and are set in a fine-grained grey matrix. In thin section this matrix is granophyric.

Structure of the Fortescue Group

The Fortescue Group and the Gidley Granophyre contain structures that formed during or after development of the Hamersley Basin. Two episodes of deformation are recognized (D_{10} and D_{11}).

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Figure 16. Xenolith-rich granophyre dyke (*Ayx*) near Pat Bore (AMG 812975)

Deformation events

D_{10} (c. 2770 – 2750 Ma)

Blake (1993) recognized a period of west-northwesterly – east-southeasterly crustal extension during deposition of the Mount Roe Basalt and the overlying Hardey Formation. The resulting structures were northeasterly trending normal faults and mafic dykes. Extrusion of flood basalts was followed by the development of extensional intracratonic sedimentary basins. Identification of D_{10} faults on DAMPIER is difficult because there are relatively few outcrops of the lower part of the Fortescue Group. However, mapping on adjacent sheets (PRESTON, ROEBOURNE, and PINDERI HILLS) suggests that northeasterly trending faults did influence deposition of the Mount Roe Basalt and the Hardey Formation. The western part of the Sholl Shear Zone on DAMPIER was probably reactivated and linked to the Lulu Fault (see **Simplified geology**), with downthrow to the southeast. This faulting would explain why exposures of the lower part of the Fortescue Group are mostly restricted to the southeastern part of the postulated D_{10} fault zone. On ROEBOURNE, the northeastern continuation of this zone is associated with locally developed boulder conglomerate and sandstone in the Mount Roe Basalt (Hickman, in prep.)

D_{11} (post-2725 Ma)

The Gidley Granophyre is deformed by northwesterly dipping reverse faults (see map and **Diagrammatic section**). Faults with a similar trend deform the Fortescue Group on the adjacent PRESTON and ROEBOURNE map sheets, and may be related to northerly striking thrusts on PRESTON (Hickman and Strong, 1998). These thrusts deform the Hamersley Group and are interpreted to be Proterozoic in age. Northeasterly trending open folds that deform the layering of the Gidley Granophyre are probably the same age as the D_{11} reverse faults. Much larger open folds, also with a northeastward trend, deform the Fortescue and Hamersley Groups in the west Pilbara. However, it is uncertain which of these folds, if any, are related to D_{11}. Some folds may have originated as synclinal sag structures within the D_{10} depositional basins.

Archaean or Proterozoic rocks

Unassigned dykes, veins, and gossans

Dolerite dykes (*d*)

Dolerite dykes (*d*) intrude almost all Archaean units on DAMPIER, and most are probably Proterozoic in age. The dominant dyke suite trends northeastward, and is correlated with a northerly to northeasterly trending dyke swarm along the western margin of the Pilbara Craton. Other dolerite dykes on DAMPIER strike approximately north-northwest or east–west, and are of unknown age.

Granite and pegmatite veins (*g*, *p*)

Granite (*g*) and pegmatite (*p*) veins intrude amphibolite-facies metabasalt (*Aba*) close to the margins of the Karratha Granodiorite and the Dampier Granitoid Complex. Many of the veins are probably related to the adjacent Archaean granitoids, but some may have formed during later felsic magmatic events (e.g. Gidley Granophyre).

Quartz veins and gossan (*q*, *go*)

Quartz veins (*q*) and gossan (*go*) of unknown age outcrop in many parts of DAMPIER. Quartz veins typically intrude faults, and are up to 20 m thick, but lenticular along strike. The largest quartz veins (*q*) are present along northeasterly striking fractures in the Karratha Granodiorite (AMG 855997), and appear to occupy faults that have deformed the Fortescue Group to the northeast on ROEBOURNE. Gossan (*go*), representing oxidized sulfidic units, is present along faults or sulfidic stratigraphic horizons; for example, 3 km southwest of Orpheus (AMG 965860) and 3 km southwest of Mount Regal (AMG 727950). These gossans and quartz veins may coincide with economic mineralization, and therefore many were sampled for geochemical analysis (see **Economic geology**).

Geochronology

Table 4 summarizes U–Pb zircon geochronology from DAMPIER and adjacent parts of ROEBOURNE. The dates listed in Table 4 are interpreted crystallization ages for igneous rocks and depositional ages for sedimentary units. The results indicate that the West Pilbara Granite–Greenstone Terrane on DAMPIER was formed during four main periods that included volcanism, granitoid intrusion, and sedimentation. The first period, 3270–3250 Ma, involved deposition of the Roebourne Group and intrusion of the Karratha Granodiorite and related granitoids. The second period, between approximately 3130 and 3110 Ma, involved deposition of the Whundo Group and intrusion of related granitoids. The third period, between 3024 and 3014 Ma, involved felsic magmatism and deposition of the Cleaverville Formation. The final phase of granitoid intrusion, during which most of the Dampier and Cherratta Granitoid Complexes were formed, took place between 2997 and 2944 Ma. Geochronology on ROEBOURNE, SHERLOCK, and PINDERI HILLS (Nelson, 1997, 1998, 1999, 2000) has confirmed these periods of activity, but has added constraints on the deposition of the Whim Creek Group between 3015 and 2945 Ma, and dated the layered mafic–ultramafic intrusions and related granitoids at about 2925 Ma.

Pb–Pb model ages on xenocrystic zircon grains and Sm–Nd geochronology (Table 5) provide evidence that c. 3500 – 3400 Ma age rocks were involved in magma generation for some of the west Pilbara granitoids and volcanics. Table 5 also shows that 3461–3287 Ma source rocks contributed detritus to the 3020 Ma Cleaverville Formation. A large part of the East Pilbara Granite–Greenstone Terrane is composed of 3500–3400 Ma rocks,

Table 4. Precise U–Pb zircon geochronology (SHRIMP*, unless otherwise indicated) from the West Pilbara Granite–Greenstone Terrane on DAMPIER and immediately adjacent parts of ROEBOURNE

Age (Ma)	*Lithology/formation*	*Location (AMG)*	*Sample*	*Reference*
3270 ± 2	tonalite, Karratha Granodiorite	771961	142433	Nelson (1998)
3269 ± 2	schist, Nickol River Formation	010057	136819	Nelson (1998)
3267 ± 4	granodiorite, Karratha Granodiorite	855020	N4438	Smith (1997)
3265 ± 4	granodiorite	974910	JS43	Smith et al. (1998)
3261 ± 4	granodiorite, Karratha Granodiorite	847967	JS17	Smith et al. (1998)
3258 ± 12	granodiorite	872906	N3214	Smith (1997)
3251 ± 6	rhyolite, Nickol River Formation	749977	118975	Nelson (1997)
3128 ± 6	rhyolite, Tozer Formation	929789	N4325	Smith (1997)
3125 ± 4	dacite tuff, Nallana Formation	915850	114350	Nelson (1996)
3122 ± 7	rhyolite, Tozer Formation	917782	114358	Nelson (1997)
3121 ± 2	rhyolite dyke	836984	N4413	Smith (1997)
3118 ± 3	rhyolite, Tozer Formation	925832	114356	Nelson (1996)
3115 ± 5	felsic tuff, Bradley Basalt	015863	114305	Nelson (1997)
3114 ± 5	granite	835985	JS20	Smith et al. (1998)
3112 ± 6[a]	felsic tuff, Tozer Formation	973859	W197	Horwitz and Pidgeon (1993)
3024 ± 4	mylonite, Sholl Shear Zone	948893	JS25	Smith et al. (1998)
3023 ± 9	dacite, north of Sholl Shear Zone	955902	118976	Nelson (1997)
3022 ± 12	sandstone, Cleaverville Formation	021143	127330	Nelson (1998)
3018 ± 2	felsic porphyry sill in Regal Formation	020115	127327	Nelson (1998)
3014 ± 2	quartz–feldspar porphyry	969930	118979	Nelson (1997)
2997 ± 3	granite, Dampier Granitoid Complex	708046	136844	Nelson (1998)
2995 ± 11	tonalite, Cherratta Granitoid Complex	755801	136826	Nelson (1997)
2994 ± 2	granodiorite, Cherratta Granitoid Complex	654903	118974	Nelson (1997)
2944 ± 5	late phase in tonalite	755801	136826	Nelson (1997)
2725 ± 3[b]	gabbro, Gidley Granophyre	790190	–	Wingate, M. T. D., 1998, pers. comm.

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

suggesting that between 3270 and 3020 Ma this terrane may have extended into the west Pilbara.

Cainozoic rocks

Cainozoic rocks cover about 60% of DAMPIER and mainly overlie the granitoid units. Three main categories of Cainozoic units are present:

- probable Eocene to early Pleistocene clastic and chemical deposits that have been eroded by the present drainage system (*Czag, Czak, Czrf,* and *Czrk*);
- recent river, creek, outwash fan, scree slope, eluvial, and eolian deposits (*Qaa, Qal, Qac, Qao, Qab, Qas, Qwb, Qc, Qrg,* and *Qs*);
- recent coastal deposits, which include beach, lagoon, and dune deposits (*Qhmm, Qhms, Qhmu,* and *Qpmb*).

Residual calcrete (*Czrk*) overlies amphibolite (*Aba*) southwest of Toorare Pool (AMG 757795) and forms large silicified outcrops 6 km southwest of Karratha Airport (AMG 730050). The underlying bedrock in the latter area is granitic, but Cainozoic colluvium derived from amphibolite to the south may immediately underlie the calcrete. Alluvial calcrete (*Czak*) is distributed along drainages, for example, 2 km west of Radio Hill Mine (AMG 840787) and 1.5 km north of Miaree Pool (AMG 590950). At the locality near Miaree Pool, the calcrete outcrops in the bed of the Maitland River and includes cemented river gravel. High-level alluvial gravel deposits (*Czag*) were mapped at Jean Well (AMG 744874) and 4 km northwest of Miaree Pool (AMG 553955). The unit is extremely widespread in the alluvial valley of the Maitland River, but is concealed beneath younger regolith. Sections through older deposits of the river system are commonly exposed in the steep banks. Gravel beds up to 5 m thick are also present.

Ferricrete (*Czrf*) is preserved on mesas at Twin Table Hills (AMG 855896) and in a large low mound 3 km northwest of Bullock Hide Well (AMG 770900). The rock at Twin Table Hills is a pisolitic ironstone similar to the Eocene Robe Pisolite in the western part of the Pilbara Craton.

Fine- to medium-grained eolian sand (*Qs*) overlies colluvial and sheetwash deposits on the southeastern side of the Burrup Peninsula and near Karratha Airport. The sand is red to yellow due to iron staining of quartz grains and contains few or no shell fragments (unlike sand of the coastal dunes). Eluvial sand over granitoid rocks (*Qrg*) is a quartzofeldspathic residual deposit derived from underlying granitoid bedrock or nearby outcrops, for example, south of Toorare Pool (AMG 775782) and north of Prinsep Well (AMG 775965). Colluvium (*Qc*) is a widespread unit on DAMPIER, and is present as scree slopes and fans of coarse pebbly sand that fringe adjacent hills. The composition of colluvial units depends on the lithology of these hills. Sheetwash sand, silt, and clay, with a gilgai surface (*Qwb*), forms distal outwash fans, typically between colluvial and alluvial units. Whereas colluvial fans commonly exhibit a well-defined radial drainage system of small gullies that originate from adjacent hills, the lower slopes (typically 0–5°) of the sheetwash fans do not have well-developed discrete drainage lines. Clay and silt within the sheetwash deposits commonly occupy claypans or areas that are temporary shallow lakes after periods of flooding.

Quaternary alluvial units occupy large areas of DAMPIER. Alluvial sand and gravel (*Qaa*) is confined to river and creek channels and to minor drainage channels on floodplains. Along the lower reaches of the Maitland River, the main channel is flanked by sand and gravel levees (*Qal*). Beyond the levees are floodplain deposits of alluvial sand, silt, and clay (*Qao*), a deposit type that is also widespread farther inland between most of the main drainage lines. These floodplain deposits commonly contain numerous small claypans (*Qac*) where floodwaters have temporarily ponded before evaporating, or where local heavy rain has resulted in small playa systems. Where floodplain deposits include a substantial amount of clastic material derived from mafic or ultramafic sources, brown soil and expansive clay (*Qab*) are present. In wet weather, such areas are generally impassible by vehicle, and in dry weather the surface of the ground is broken by expansion crevices and depressions known as 'crabholes'. Coastal deposits of mixed alluvial and eolian origin (*Qas*) form irregular low dunes and sandbanks within, and along, the inner margins of lagoons. These deposits are most extensively developed where deltas enter lagoons and alluvial deposits have been eroded, probably by a combination of wind and wave action, and then redeposited along the coast.

Quaternary deposits of marine origin are present in the coastal belt of lagoons, mangrove swamps, and sand dunes, and on the islands of the Dampier Archipelago. The oldest deposit is a siliceous limestone that consists of lime-cemented shelly sand, dune sand, and beach conglomerate (*Qpmb*). This limestone, locally referred to as the Bossut Formation (Lindner, in Johnstone, 1961), is commonly exposed as rock platforms, reefs, and offshore bars within the tidal zone, but is also preserved inland where it forms old coastal dunes and strandlines. Unconsolidated shelly sand (*Qhms*) forms coastal dunes and old beach deposits. At Hearson Cove (AMG 785188) on the Burrup Peninsula, and at Cleaverville (AMG 998155), this unit was mined as a source of limesand (Hickman, 1983). The coastlines of the mainland and the islands are locally fringed by stands of mangroves growing in intertidal mud and silt (*Qhmm*). This association also extends along the sides of estuaries and creek channels into lagoons composed of supratidal to intertidal silt and mud (*Qhmu*). The deposits of these lagoons are highly saline, in contrast to the mud and silt of the mangroves that is constantly flushed by tides.

Economic geology

Some of the earliest mineral discoveries in Western Australia were made in the west Pilbara. In 1872, copper and lead were discovered southwest of Roebourne, and in 1877 auriferous quartz veins were discovered west of Roebourne (Maitland, 1909). Between 1911 and 1913, copper was found south of DAMPIER at Whundo and Yannery Hill on PINDERI HILLS, and these deposits were subsequently mined. On DAMPIER, copper mining was limited to small operations at Tom Well (AMG 827031) and Mount Sholl (AMG 880860), and to copper production as a byproduct of nickel mining at Radio Hill. The Radio Hill nickel mine (AMG 861795) produced 86 932 t of nickel concentrate between 1997 and mid-2000. At the time of writing, metallurgical trials were underway to recover nickel from disseminated mineralization in low-grade stockpiles using biological heap leaching.

The largest mining operation on DAMPIER has been that of salt from the solar evaporation of seawater 7 km south of Dampier. Dampier Salt Limited commenced construction of evaporation ponds in 1969, and production of salt commenced in 1972. During 1997–98 salt production was expanded from 2.5 to 4 Mt per annum. Other commodities quarried on DAMPIER have included limesand, construction materials, sand, and gravel for road construction.

The distribution and geology of metallic mineral deposits in the west Pilbara is summarized by Ruddock (1999).

Table 5. Geochronological data supporting the existence of pre-3270 Ma source rocks in the evolution of the West Pilbara Granite–Greenstone Terrane on DAMPIER and immediately adjacent parts of ROEBOURNE

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

Gold

On DAMPIER, gold was discovered at Upper Nickol in 1890, but much of the early production was not recorded. Between 1900 and 1962, production of 12.13 kg of gold was recorded from mines at Lower Nickol, but prospectors operating in the area during 1995 and 1996 stated that historical production had been far greater, possibly exceeding 100 kg. Only 0.34 kg of alluvial and dollied gold was recorded at Lower Nickol prior to 1962, which in view of the extensive alluvial workings in the area must certainly understate actual production. Likewise, gold production at Upper Nickol also appears to be understated by official production figures (0.357 kg in 1913) because the extent of underground mining is inconsistent with such low production.

All primary gold deposits on DAMPIER are epigenetic and structurally controlled. North of the Sholl Shear Zone, all known deposits are close to the Regal Thrust and are generally hosted by sheared ultramafic or mafic rocks. To the south of the Sholl Shear Zone, gold deposits are confined to fault zones within the Whundo Group.

Primary gold mineralization at Lower Nickol is mainly in narrow lodes that consist of quartz veinlets in sheared ultramafic schist. Inspection of the old workings over an east–west strike length of approximately 4 km, revealed that all the mineralized zones strike east-northeast, and dip south-southeast at 70–85°. The ultramafic schist is a silicified and carbonate-altered actinolite–chlorite–quartz rock with variable amounts of talc and carbonate minerals. Only at the eastern end of the line of workings, near the Lydia mine, is gold mineralization developed in schistose metasedimentary rocks. At the Lydia mine, a 15–20 cm-wide quartz vein dips 80° towards 155° through arenaceous schist. According to production records, the chief mines at Lower Nickol are Tozers (AMG 970059) and Kings (AMG 970051). The Lower Nickol gold deposits occur beneath the Regal Thrust, and on the southern side of a later east-northeasterly striking shear zone that extends northeast to Dixon Island (ROEBOURNE). This late faulting probably took place between the D_6 and D_8 events (see **Structure**). Most recent prospecting at Lower Nickol has concentrated on alluvial deposits. Additional information on the workings is available in Finucane et al. (1939).

The principal gold mine at Upper Nickol was Radleys Find (AMG 889884), but shafts and test pits extend over a strike length of about 1 km. At Radleys Find, mining has followed a 0.5 m-wide quartz vein that dips 70° towards 020° within chloritized and carbonate-altered mafic schist of the Whundo Group. The workings, now collapsed, appear to have been at least 15–20 m deep. The line of workings follows a curved splay fault related to the Sholl Shear Zone, which is present 1 km to the north. Southeast from Radleys Find, this fault appears to dextrally displace the northeastern end of the Sholl Intrusion, suggesting that it is a D_8 structure.

About 3 km south-southwest of Radleys Find, there are old eluvial workings and a shallow pit known as Four Ounce. The collapsed shaft at Four Ounce (AMG 873856) has exposed a quartz vein dipping 80° towards 160° through silicified metabasalt. Approximately half way between Radleys Find and Four Ounce, on the side of Roebourne–Cherratta Road (AMG 881875), a small pit has exposed a 1 m-wide quartz vein striking 100° through chloritized metabasalt.

The Orpheus fault system (D_6–D_8) is approximately 20 km long, extending from Radio Hill (AMG 860798) east-northeastwards to Orpheus (AMG 915836) and the Sholl Shear Zone. Displacement along the fault is difficult to measure because the fault is generally parallel to the strike of the Whundo Group. Gold mineralization is present east of Mount Sholl (AMG 931848) where local prospectors state that over 60 kg of alluvial gold was obtained; old alluvial workings are also present 1 km south of Mount Sholl (AMG 915836). Minor gold mineralization is associated with Cu–Zn mineralization at Orpheus (AMG 996873) and 1 km west-southwest of Orpheus.

Gold mining in the Six Mile Well area (AMG 970947 to AMG 011961, ROEBOURNE) has focused on an east-northeasterly striking belt of faulting and shearing immediately beneath the Regal Thrust. The faulting continues northeastwards to the Carlow Castle mine (AMG 070988) on ROEBOURNE. About 1 km west of Six Mile Well, recent mining has exposed auriferous quartz veins, up to 0.5 m wide and dipping 50° towards 290°, in carbonate-altered and silicified metabasalt. A sample (GSWA 116968) from one of these veins contained 7.02 g/t gold. Workings about 4 km to the east-northeast (extending onto ROEBOURNE) are in talc–carbonate schist intruded by felsic dykes. Here, gold mineralization is in lodes that consist of ultramafic schist with gossanous quartz veinlets. A sample (GSWA 116996) from one of these lodes contained 60 g/t gold.

Gold prospecting has also been carried out 2 km west-southwest of Bardies Tank (AMG 883957), where costeans have been cut into a porphyritic granitoid that intrudes metabasalt.

Base metals (copper, lead, and zinc)

On DAMPIER, the most prospective area for copper–lead–zinc mineralization is along the Orpheus fault system within the Whundo Group. At Orpheus (AMG 996873), Dragon Resources discovered copper–zinc(–silver–gold) mineralization in 1995 (Ruddock, 1999). Additional old workings along the Orpheus fault system are shown on the map, and on ROEBOURNE (Hickman, in prep.) mapping has revealed that the mineralization extends for at least 2.5 km east-northeast from Orpheus to the Bradley Well area. Gossan samples (GSWA 127361 and 127362) collected from Orpheus contained up to 6.8% Cu, 1.04% Zn, 45 ppm Ag, and 0.45 g/t Au. The poorly outcropping Bradley Well gossanous zone was identified during GSWA mapping on ROEBOURNE. No evidence of previous exploration was observed. 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. About 1.5 km west-southwest of Orpheus, a gossanous quartz sample (GSWA 114307) from old shallow workings contained 3.15% Cu and 1.2 g/t Au. About 5 km west-southwest of Orpheus (AMG 949851), another sample of gossan (GSWA 114329) from the Orpheus fault system contained 0.14% Cu and 0.22% Zn, and had been tested by old prospecting pits. Copper–zinc mineralization along the Orpheus fault system is present as 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 copper–zinc mineralization may have been tectonically mobilized from concealed volcanic massive sulfide (VMS) deposits in the Whundo Group. Whundo Group VMS deposits have not been identified on DAMPIER, but are present south of DAMPIER at Whundo and Yannery Hill on PINDERI HILLS (Collins and Marshall, 1999). Although most of the known copper–zinc mineralization is in narrow shear zones, and is irregularly distributed along strike, the Orpheus fault system probably merits further investigation for its mineral potential.

Other known copper occurrences on DAMPIER appear to be isolated small deposits associated with lenticular quartz veins, and appear to have limited economic potential. These deposits are described in Marston (1979) and Ruddock (1999).

Nickel and copper in layered intrusions

Westfield Minerals discovered nickel–copper mineralization at Radio Hill in 1972, but it was not until 1983 that the present nickel–copper deposit at Radio Hill (AMG 861795) was discovered by AGIP and SAMIM. Mining during the late 1990s produced over 43 000 t of nickel concentrate. Measured and indicated resources are estimated to be 0.976 Mt at 2.58% Ni, 1.28% Cu, and 0.11% Co (Ruddock, 1999). Massive lenses and stringer networks of pentlandite, pyrrhotite, and chalcopyrite mineralization occur in gabbro, close to the contact with an ultramafic layer of the c. 2925 Ma Radio Hill Intrusion. Previous descriptions of the Radio Hill mineralization are provided by De Angelis et al. (1987), and Hoatson et al. (1992).

During 1970, Whim Creek Consolidated discovered nickel–copper mineralization in the Mount Sholl Intrusion (deposits A1, B1, and B2). Total resources are currently estimated to be 4.8 Mt at about 0.7% Ni and 0.88% Cu (from data in Ruddock, 1999), with Sholl B2 (incorrectly labelled B1 on DAMPIER) containing most of these resources. The mineralization consists of aggregates of pentlandite, pyrrhotite, and chalcopyrite within a thin gabbroic marginal layer along the northwestern margin of the intrusion. This gabbroic layer underlies a thicker ultramafic layer of peridotite and pyroxenite that forms the main basal section of the Mount Sholl Intrusion. Mathison and Marshall (1981) and Marston (1984) provided additional information on the Mount Sholl deposits.

Minor copper mineralization is present in metabasalt at the contact with gabbro of the North Whundo Intrusion, and is assumed to be related to the intrusion (Ruddock, 1999).

Nickel and copper in komatiite

The Ruth Well nickel–copper deposits were discovered by Whim Creek Consolidated in 1971, and have been described by Tomich (1974) and Marston (1984). Mineralization comprises violaritized pentlandite, pyrrhotite, gersdorffite, niccolite, chalcopyrite, and magnetite within serpentinized extrusive peridotite of the Ruth Well Formation. This association suggests that the deposits are of a similar type to the extrusive Kambalda nickel deposits of the eastern Yilgarn Craton. However, Ruddock (1999) noted that the mineralization may be within a tectonic slice of the Andover Intrusion that has been faulted into the Ruth Well Formation on the northern side of the Sholl Shear Zone. One diamond drillhole intersected 8.38 m of mineralization averaging about 3.52% Ni and 0.78% Cu (Marston, 1984). Although high grade, the deposits are relatively small, probably containing resources of no more than 70 000 t at about 3% Ni (Marston, 1984).

Platinum group elements

Platinum group elements (PGE) and minor gold are associated with nickel–copper sulfide deposits in the layered mafic–ultramafic intrusions of the west Pilbara (Hoatson et al., 1992). On DAMPIER, this type of mineralization has been identified in the Mount Sholl, Radio Hill, and Dingo Intrusions. Additional information is provided by Ruddock (1999).

Iron ore

Although DAMPIER contains outcrops of BIF of the Cleaverville Formation, no economic concentrations of iron ore have been identified. Small deposits of pisolitic iron ore at Twin Table Hills (AMG 855896) are probably uneconomic.

Semi-precious stone

Bright-green chert has been excavated 3 km north of Edna Well (AMG 753977) for use as an ornamental stone. The chert is close to an ultramafic unit within the Ruth Well Formation, and its green colour is due to a chromium impurity.

Limesand and limestone

A review of limestone and limesand resources of Western Australia (Abeysinghe, 1998) includes a summary of deposits in the Dampier Archipelago. Kojan (1994) noted that most of the resources are north of DAMPIER, and largely within nature and conservation reserves. About 379 000 t of limesand was quarried at Hearson Cove (AMG 786187) for use in the Dampier iron-ore pelletizing plant, but since 1980 this area has been closed and rehabilitated. Calcium carbonate content of the deposit was approximately 80%, with the main impurity being silica. Between 1974 and 1992 about 173 000 t of limesand was mined at Cleaverville (Kojan, 1994). Similar deposits are present at numerous places along the coast within dunes of shelly sand (*Qhms*).

Most limestone resources occur in the Dampier Archipelago islands, north of DAMPIER. However, outcrops of Bossut Formation (*Qpmb*) limestone on DAMPIER also contain potentially mineable, if much smaller, deposits. Baxter (1972) reported that $CaCO_3$ content of the limestone ranged up to 87.5%. Because most of the limesand and limestone deposits are along the coast, environmental considerations place serious constraints on their potential for mining.

Sand

Dominantly eolian sand has been obtained from sand and gravel pits east of Karratha (AMG 900070) and from sand pits on the southern side of the Burrup Peninsula, south of Dampier (AMG 745138), mostly for house foundations and fill.

Road building and construction materials

Road building and construction materials include river gravels, mostly obtained from localities along the Maitland River, and colluvium and weathered rock, which are typically available close to wherever gravel roads require maintenance or construction projects exist. The Gidley Granophyre has been quarried for industrial developments on the Burrup Peninsula, and has been investigated for use as ‘armour stone’ (Brice and Abeysinghe, 1998).

Salt

Salt mining from the solar evaporation of seawater, 7 km south of Dampier, commenced in 1972. Dampier Salt Limited’s operations are currently capable of producing salt at about 4 Mt per annum.

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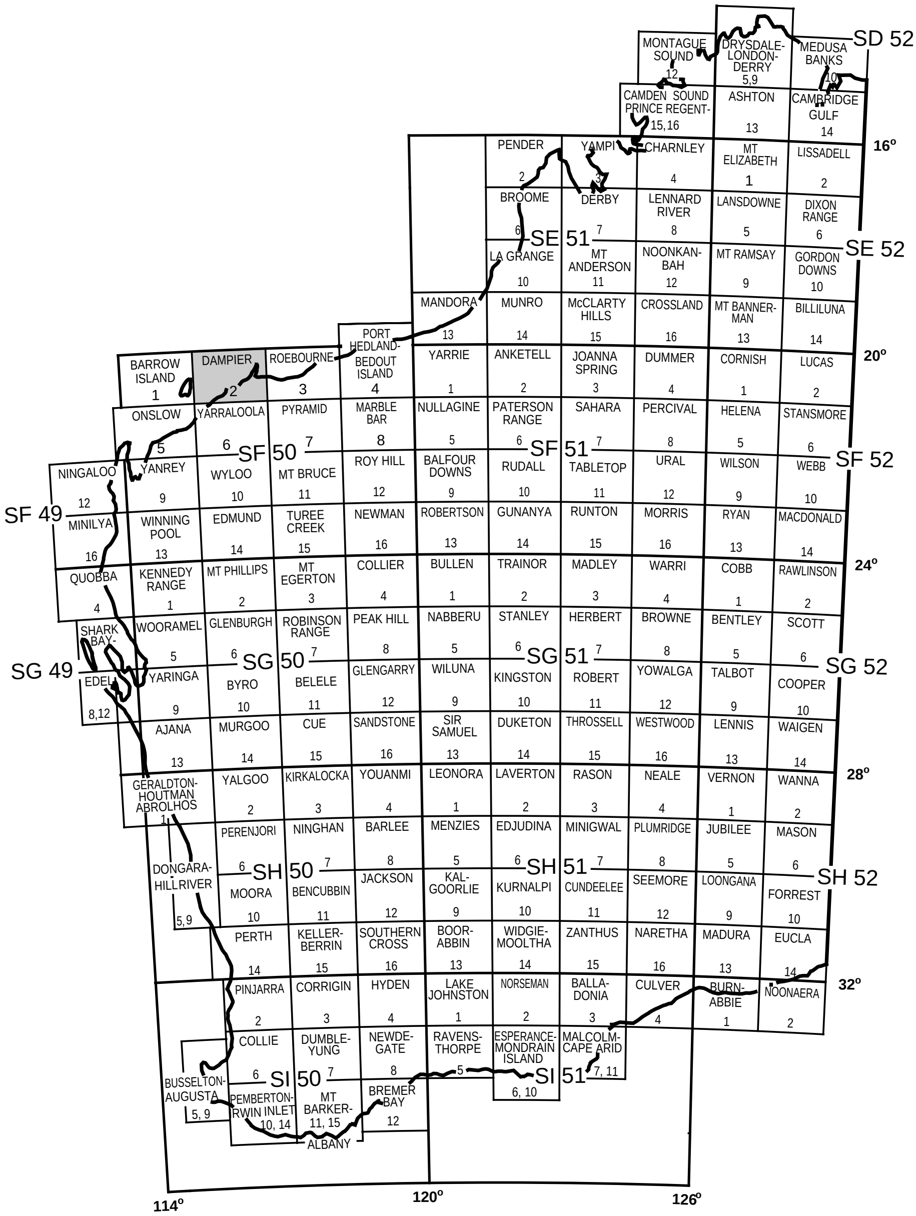
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RAVENS-THORPE
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ESPERANCE-MONDRAIN ISLAND
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BUSSELTON-AUGUSTA
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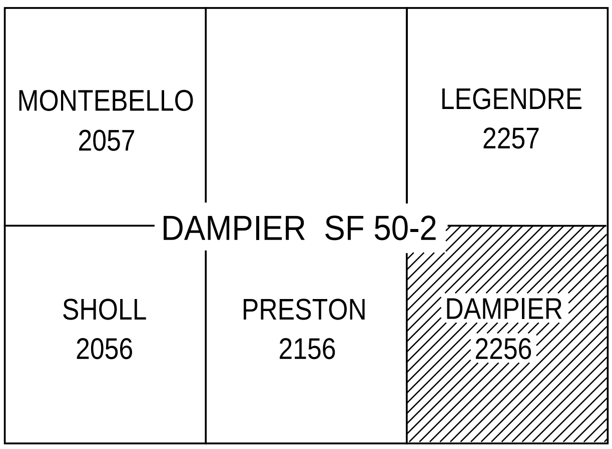
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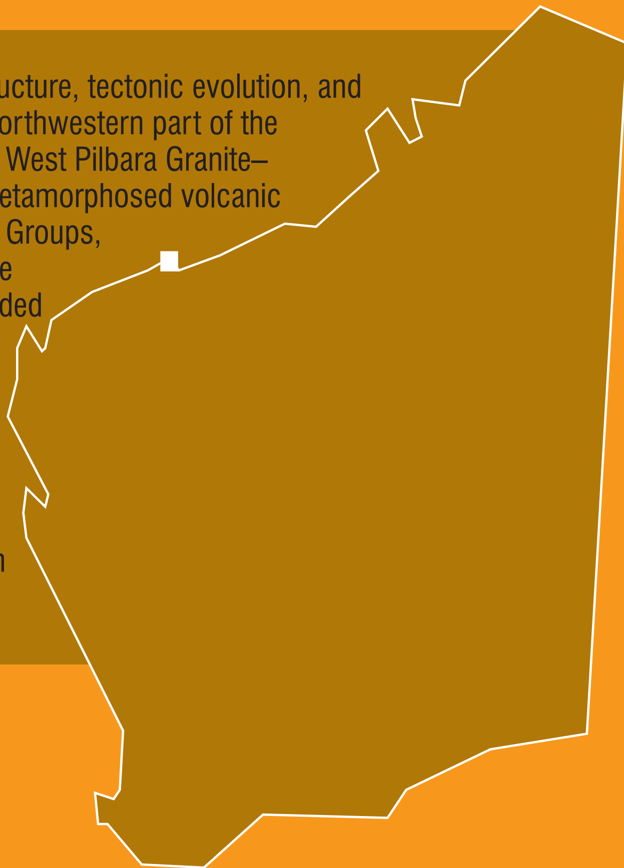
These Explanatory Notes describe the stratigraphy, structure, tectonic evolution, and mineralization of the DAMPIER 1:100 000 sheet in the northwestern part of the Archaean Pilbara Craton. The area includes part of the West Pilbara Granite–Greenstone Terrane (3270–2900 Ma), consisting of metamorphosed volcanic and sedimentary rocks of the Roebourne and Whundo Groups, the Cleaverville Formation, and intrusive granitoids. The stratigraphic succession was folded, faulted, and intruded by granitoids over a period of 350 million years, and then deeply eroded and unconformably overlain by basaltic volcanic rocks of the Fortescue Group (2770–2680 Ma). The largest fault on DAMPIER, the Sholl Shear Zone, is a major crustal fracture with a strike-slip displacement of up to 250 km. Gold, nickel, copper, and salt have been mined from the area, which also has potential for platinum group elements.



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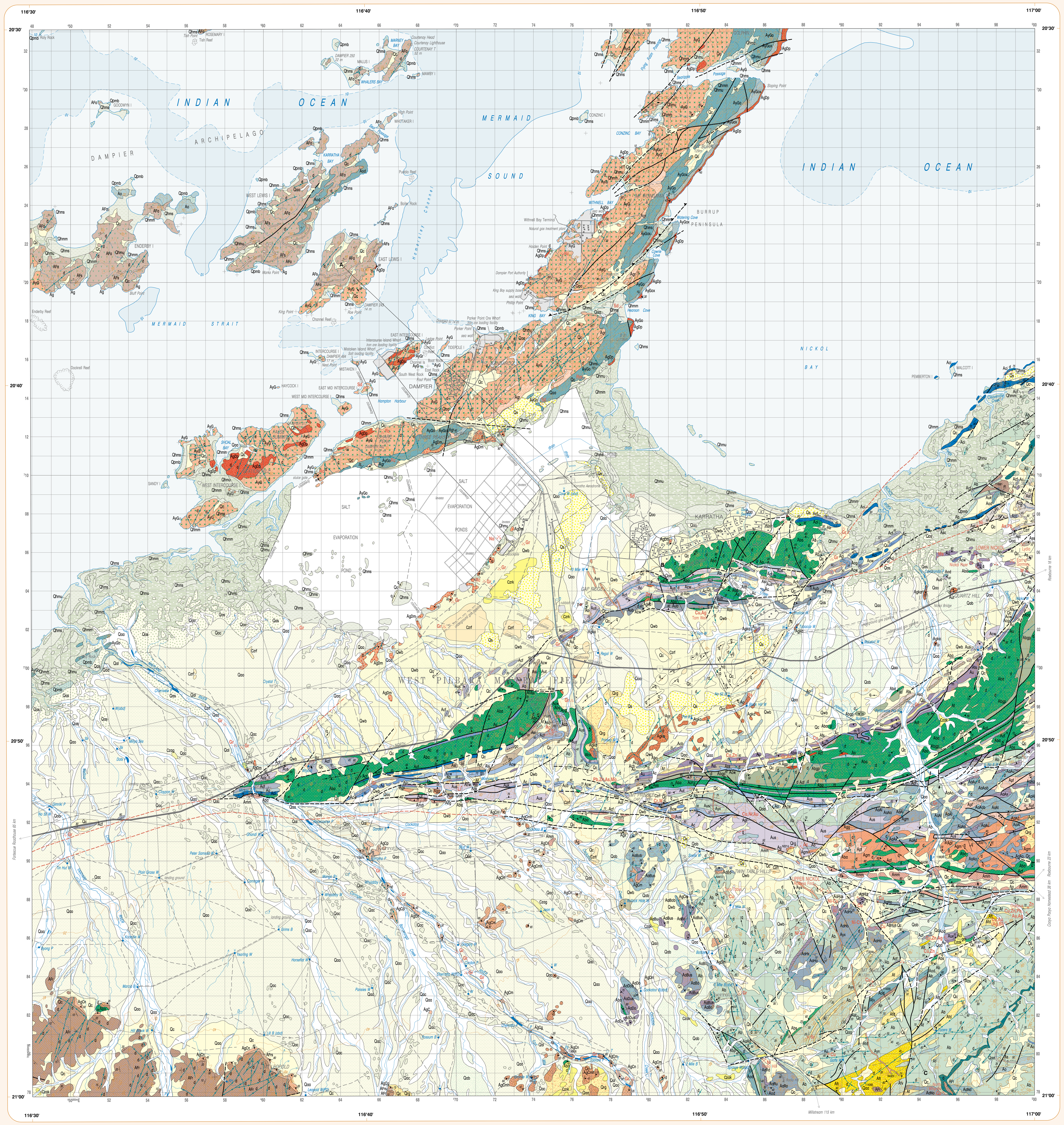
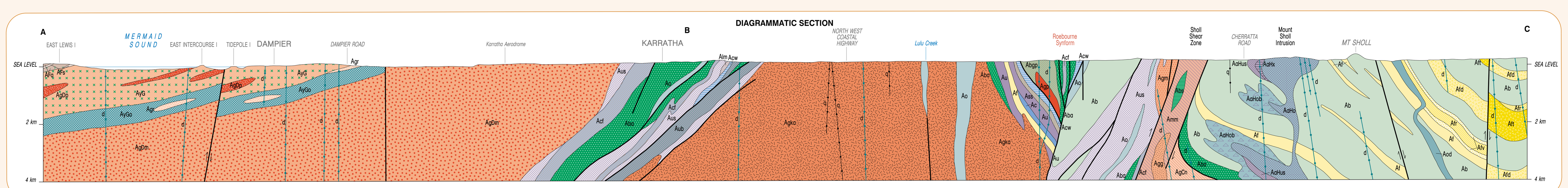
DAMPIER

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 2256



DIAGRAMMATIC SECTION



CAINOZOIC

QUATERNARY

- Qhmm Marine mud and silt; intertidal with mangroves
- Qhms Shelly sand in coastal dunes and old beach deposits; contains *Anadara granosa*
- Qhmu Silt and mud in supratidal to intertidal flats and lagoons
- Qpmb Coastal limestone—lime-cemented shelly sand, dune sand, and beach conglomerate
- Qaa Alluvium—sand and gravel in rivers and creeks; clay, silt, and sand in channels on floodplains
- Qal Alluvial sand and gravel in levees and sandbanks associated with deltas
- Qac Claypan deposits on floodplains
- Qao Alluvial sand, silt, and clay in floodplains
- Qab Alluvial sand, silt, and clay in floodplains, with gilgai surface in areas of expansive clay
- Qas Coastal sand deposits of mixed alluvial and eolian origin
- Qwb Sheetwash sand, silt, and clay in distal outwash fans, with gilgai surface in areas of expansive clay
- Qc Colluvium — sand, silt and gravel in outwash fans and scree
- Qrg Eluvial sand over granitoid rocks
- Qs Eolian sand — red-yellow wind blown sand; local sand ridges
- Czag Alluvium—high-level gravel deposits, unrelated to recent drainage
- Czak Calcrete—massive, nodular and cavernous limestone; variably silicified; alluvial origin
- Czrf Ferricrete—includes ferruginous duricrust and pisolitic ironstone on lateritic surface
- Czrk Calcrete—massive, nodular, and cavernous limestone, variably silicified; residual origin

- d Dolerite dyke
- g Granite vein
- p Pegmatite
- q Quartz vein
- go Gossan

HAMERSLEY BASIN

c. 2760 Ma — Mount Bruce Supergroup — Fortescue Group

- AFa Unassigned basalt and andesite (Dampier Archipelago)
- AFs Unassigned sandstone and conglomerate (Dampier Archipelago)
- AFr **MOUNT ROE BASALT:** massive, vesicular, and glomeroporphyritic basalt
- AFrs Sandstone and conglomerate; minor shale
- AyG **GIDLEY GRANOPHYRE:** fine- to medium-grained granophyre, commonly porphyritic
- AyGr Altered quartz-rich granophyre
- AyGo Gabbro
- AyGox Gabbro containing quench-textured acicular pyroxene crystals
- Ayx Granophyric, xenolith-rich dyke; generally andesitic
- Agr Partly remelted granitoid; occurs in GIDLEY GRANOPHYRE and AyGo

- Agg Granodiorite, commonly with biotite or hornblende, poorly foliated

c. 3000–2900 Ma

- Amm Mylonite and mylonitic gneiss; derived by extreme shearing of granitoid, gneiss, and a wide range of supracrustal rock types; chiefly in Sholl Shear Zone

ARCHAEAN — PILBARA CRATON

Pilbara Supergroup — Layered mafic intrusions c. 2925 Ma

Andover Intrusion
- AaAo Gabbro and minor dolerite or microgabbro; local norite and anorthosite; metamorphosed
- AaAob Gabbro and dolerite or microgabbro containing angular blocks of basalt; metamorphosed
- AaAl Leucogabbro; metamorphosed
- AaAd Dolerite or microgabbro; metamorphosed
- AaAu Ultramafic rock, undivided
- AaAx Pyroxenite; commonly schistose; metamorphosed

Bullock Hide Intrusion
- AaBo Gabbro and minor dolerite or microgabbro; local norite and anorthosite; metamorphosed
- AaBob Gabbro and dolerite or microgabbro containing angular blocks of basalt; metamorphosed
- AaBl Leucogabbro; metamorphosed
- AaBu Ultramafic rock, undivided
- AaBus Serpentinite; replacing peridotite

Dingo Intrusion
- AaDo Gabbro and minor dolerite or microgabbro; local norite and anorthosite; metamorphosed
- AaDob Gabbro and dolerite or microgabbro containing angular blocks of basalt; metamorphosed
- AaDx Pyroxenite; commonly schistose; metamorphosed
- AaDus Serpentinite; replacing peridotite

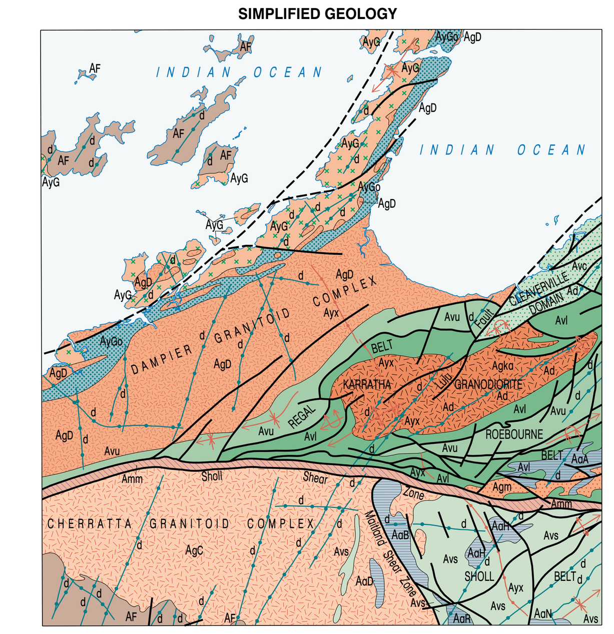
Mount Sholl Intrusion
- AaHo Gabbro and minor dolerite or microgabbro; local norite and anorthosite; metamorphosed
- AaHob Gabbro and dolerite or microgabbro containing angular blocks of basalt; metamorphosed (Section only)
- AaHx Pyroxenite; commonly schistose; metamorphosed
- AaHut Talc-chlorite schist
- AaHus Serpentinite; replacing peridotite

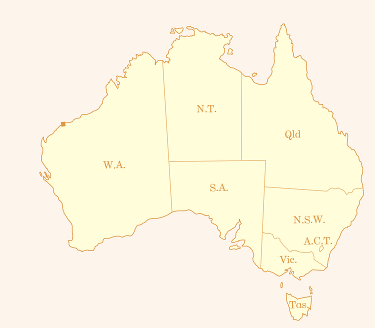
North Whundo Intrusion
- AaNo Gabbro and minor dolerite or microgabbro; local norite and anorthosite; metamorphosed
- AaNd Metadolerite

Radio Hill Intrusion
- AaRo Gabbro and minor dolerite or microgabbro; local norite and anorthosite; metamorphosed
- AaRd Metadolerite
- AaRu Ultramafic rock, undivided

- AgC **CHERRATTA GRANITOID COMPLEX:** granite to tonalite, locally porphyritic and generally foliated; gneissic granitoid contains xenoliths of amphibolite-facies mafic gneiss (Simplified Geology only)
- AgCp Porphyritic granite; metamorphosed
- AgCn Banded grey granite-tonalite gneiss with xenoliths of amphibolite-facies mafic gneiss, and sheets of leucocratic gneiss
- AgCg Granite, partly seriate and moderately foliated
- AgCm Granite to granodiorite, foliated
- AgCmh Hornblende- and biotite-rich granite, foliated

SIMPLIFIED GEOLOGY





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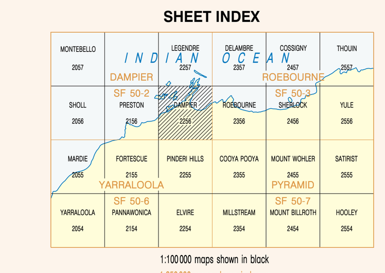

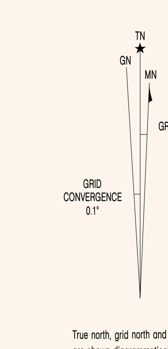

SCALE 1:100 000

TRANSVERSE MERCATOR PROJECTION

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

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