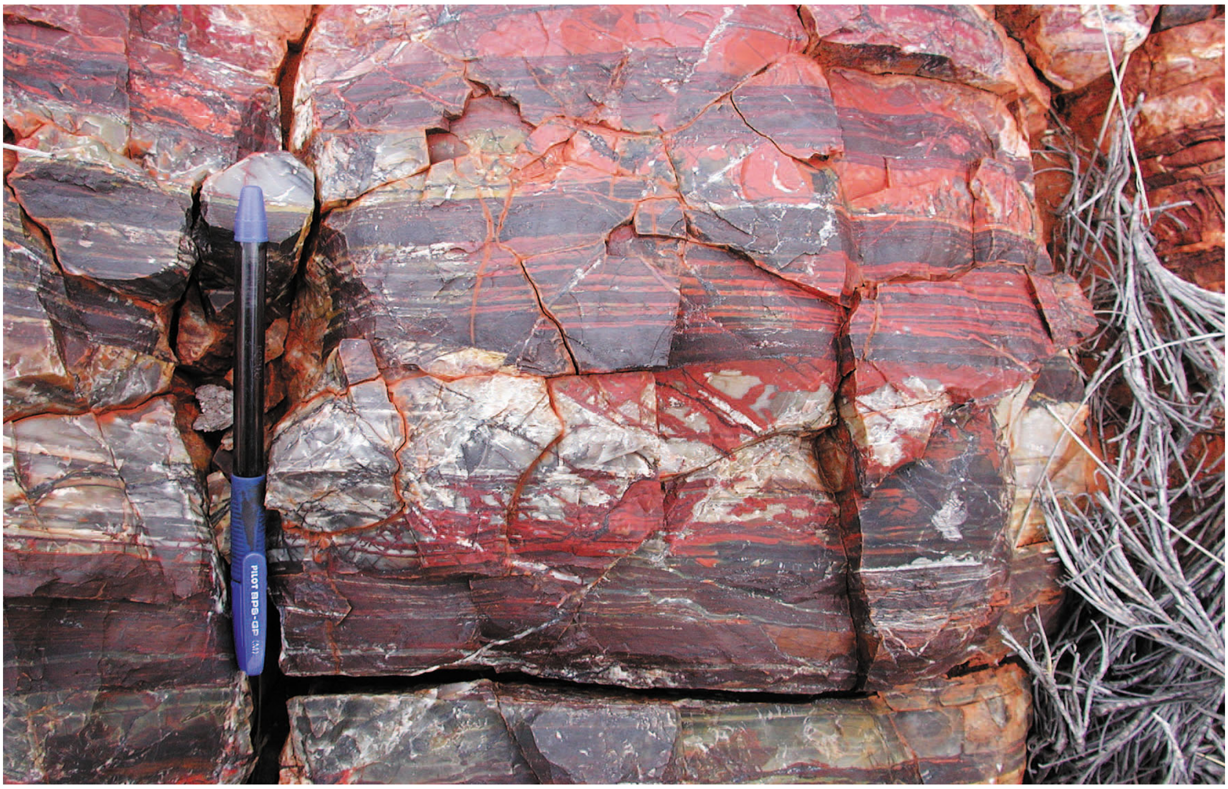
EXPLANATORY NOTES

Department of
Industry and Resources

GEOLOGY OF THE DE GREY AND PARDOO 1:100 000 SHEETS

by R. H. Smithies

1:100 000 GEOLOGICAL SERIES



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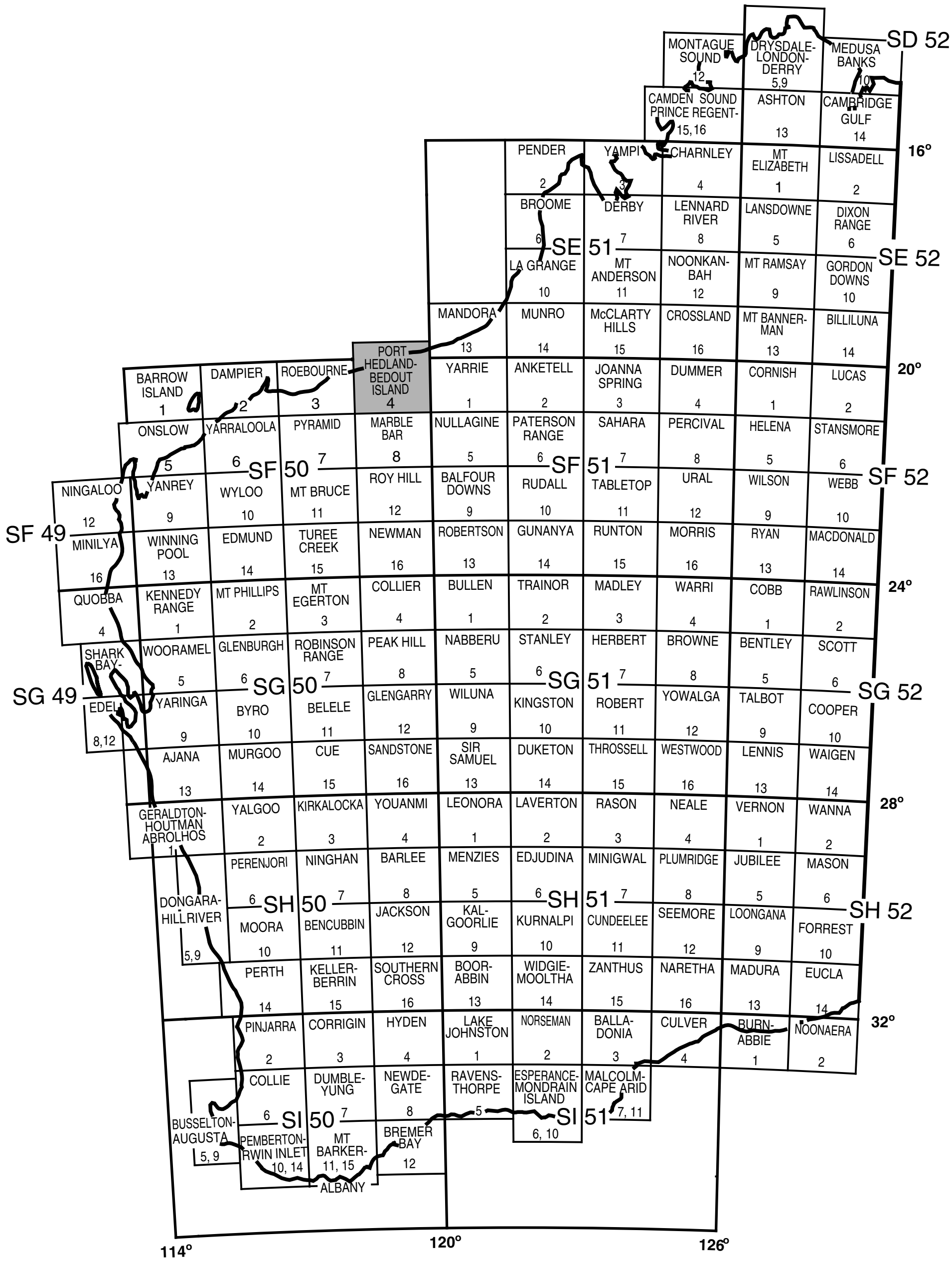

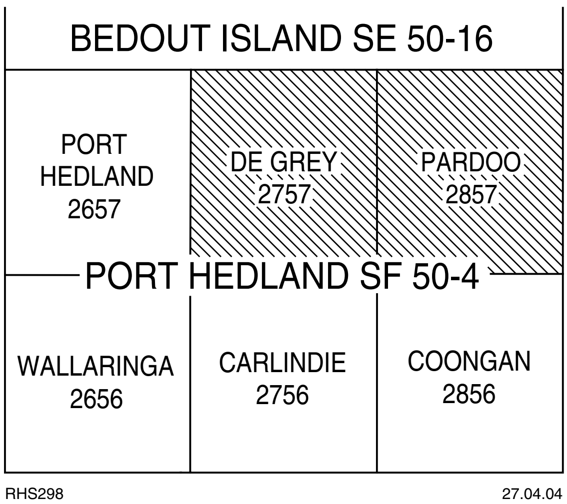

RHS298 27.04.04

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF THE DE GREY AND PARDOO 1:100 000 SHEETS

EDITION 1, MAP VERSION 2

by
R. H. Smithies

Perth 2004

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Cover photograph:
Incipient iron staining primarily along fractures within a chert/ironstone unit of the Nimingarra Iron Formation (*AGncc*): DE GREY (MGA 725659E 7751581N). Length of pen = 13 cm

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Geology of the De Grey and Pardoo 1:100 000 sheets

by

R. H. Smithies

Abstract

The De Grey and Pardoo 1:100 000 geological sheets lie in the far north of the exposed Pilbara Craton, where Archaean rocks are onlapped by rocks of the Jurassic–Cretaceous Callawa Formation that occupy the Lambert Shelf of the Northern Carnarvon Basin (Westralian Superbasin). The sheets straddle the boundary between the Archaean East Pilbara Granite–Greenstone Terrane (EPGGT) and the Central Pilbara Tectonic Zone (CPTZ). In this region the boundary is marked by the Tabba Tabba Shear Zone and the Pardoo Fault. Exposed Archaean rocks occupy less than 20% of the combined sheet areas. Greenstone sequences outcrop in three areas — the Ord Range greenstone belt, the Goldsworthy greenstone belt, and the western part of the Shay Gap greenstone belt. Archaean granites form components of three granitoid complexes: Pippingarra, Carlindi, and Muccan. The Ord Range greenstone belt is confined to the CPTZ but shares close similarities with the Goldsworthy greenstone belt in the EPGGT. Both are dominated by chert, ironstone, and banded iron-formation of the Nimingarra Iron Formation (Gorge Creek Group), unconformably overlain by thick accumulations of sedimentary and volcanic rocks of the Paradise Plains Formation (De Grey Group). The latter formation shows an upward transition from clastic and basaltic volcanic and volcaniclastic rocks of dominantly debris-flow origin to coarse-grained and conglomeratic rocks of fluvial origin. Underlying the Nimingarra Iron Formation in the Goldsworthy greenstone belt, the recognition of thinly preserved outcrop of the c. 3460–3430 Ma Panorama Formation and Strelley Pool Chert significantly extends the known distribution of this stromatolitic horizon. Mount Goldsworthy, on Pardoo, was the site of significant iron-ore mining from 1965 to 1982. Smaller deposits of iron ore have been identified within the Nimingarra Iron Formation in the Ord Range greenstone belt. Tiger eye, an unusual semiprecious stone, is sourced from the Ord Range.

KEYWORDS: Archaean, Pilbara Craton, regional geology, iron ore, Goldsworthy, Nimingarra Iron Formation, Gorge Creek Group, De Grey Group, Strelley Pool Chert, tiger eye.

Introduction

The De Grey and Pardoo* 1:100 000 geological sheets (SF 50-4, 2757 and 2857) cover most of the northeastern part of the Port Hedland – Bedout Island 1:250 000 map sheet along the exposed northern margin of the East Pilbara Granite–Greenstone Terrane (EPGGT; Hickman, 2001) of the Archaean Pilbara Craton (Fig. 1). De Grey lies immediately west of Pardoo and together these are bounded by latitudes 20°00'S and 20°30'S, and longitudes 119°00'E and 120°00'E, and lie in the East Pilbara Mineral Field. Exposure throughout these two sheets is primarily limited to a few regions where strike ranges rise abruptly out of the typically flat Quaternary floodplain, and minor areas of low-lying granite hills. The scarcity of outcrop, and the close similarity in lithological range and geological history, make it convenient to describe the geology of both sheet areas in a single set of notes.

The northern portions of De Grey and Pardoo incorporate the southern preserved margin of the Mesozoic Lambert Shelf, part of the Northern Carnarvon Basin of the Westralian Superbasin (Hocking et al., 1994). According to Williams (2000), regional magnetic, gravity, and stratigraphic data indicate that the Lambert Shelf is only a thin onlapping succession within this region. The majority of the exposed rocks on De Grey and Pardoo, as well as the basement to the Lambert Shelf, are components of the Palaeoarchaean to Mesoarchaean (c. 3500–2930 Ma) East Pilbara Granite–Greenstone Terrane (EPGGT) and Central Pilbara Tectonic Zone (CPTZ) of the Archaean Pilbara Craton. Cainozoic

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

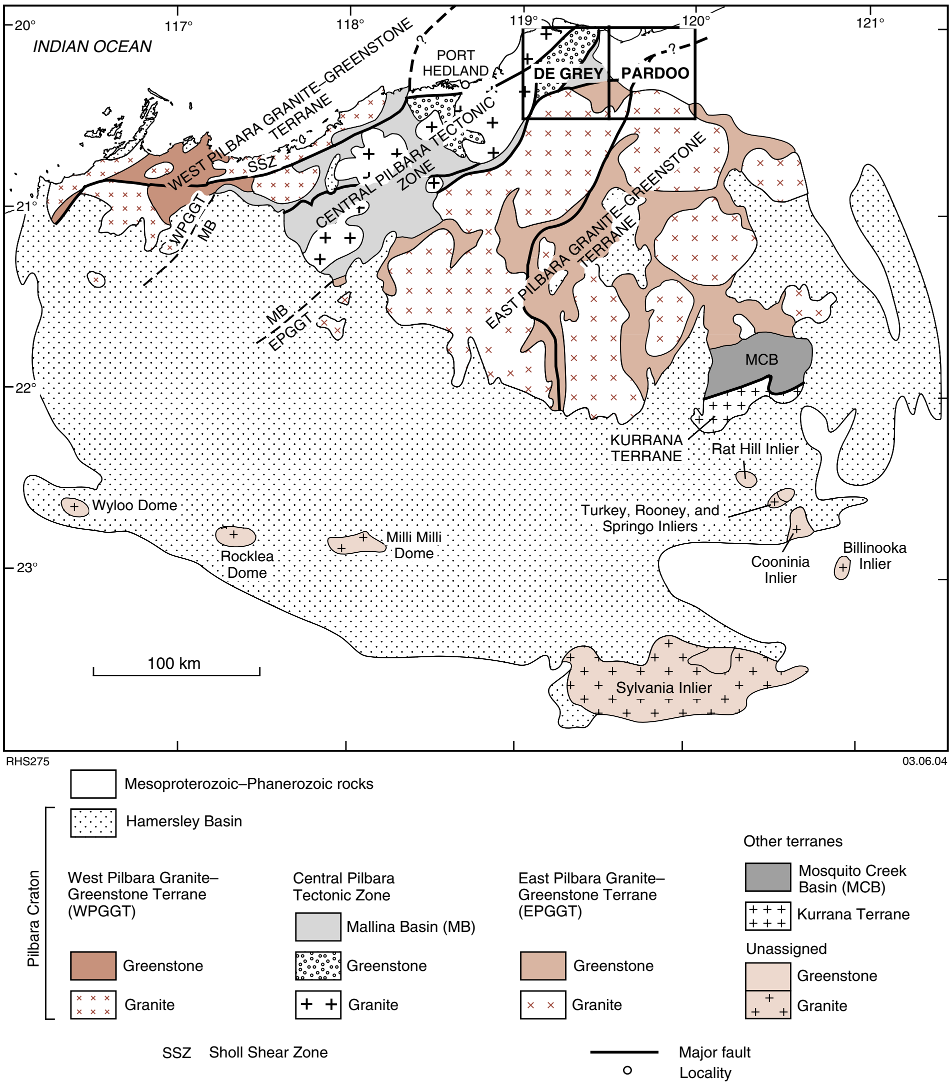


Figure 1. Regional geological setting of De Grey and Pardoo

deposits form a regolith cover that occupies 80% of each sheet area. Regional mapping was carried out in 2001, using both 1:25 000 scale colour and 1:50 000 scale black-and-white aerial photographs, and incorporated interpretations of available regional airborne magnetic datasets.

Access and land use

The area of the two map sheets is to the east of Port Hedland (Fig. 1). The sealed Great Northern Highway transects both De Grey and Pardoo in an east to northeasterly direction, connecting the major coastal towns of Port Hedland and Broome. The Pardoo Roadhouse is situated in the northeastern part of Pardoo (Fig. 2) where the highway is crossed by the unsealed Cape Keraudren Road. An unsealed service road is located alongside the Port Hedland – Yarrie railway line, which transects both sheets in an east-southeasterly direction, crossing the Great Northern Highway on the western margin of De Grey. Both the railway line and the parallel service road now bypass the abandoned Goldsworthy iron ore mine and associated townsite, which lie near the western margin of Pardoo. Other areas of De Grey and Pardoo can be reached along pastoral station access roads and along intermittently maintained pastoral tracks.

De Grey Homestead is the only currently inhabited settlement on De Grey. On Pardoo, Pardoo Roadhouse and Pardoo Homestead are the only inhabited settlements. Cattle grazing is the main agricultural activity on De Grey and Pardoo and since the closure of the Goldsworthy iron ore mine in 1982, there have been no active mines.

Climate and vegetation

The area has an arid to semi-arid climate. The average annual rainfall is about 250 mm, with most of this related to tropical cyclones and thunderstorms occurring in the summer months from December to March. Rainfall during the remainder of the year is light and erratic. Mean summer maximum temperatures are about 42°C and minimum temperatures are as high as 26°C, whereas in winter the mean maximum and minimum temperatures are around 28°C and 12°C respectively.

Several species of spinifex grass (*Triodia*) are present throughout DE GREY and PARDOO, and on sandy plains are accompanied by scattered shrubs, mainly of *Acacia* species. In coastal regions scattered *Eucalyptus zygophylla* and desert walnut (*Owenia reticulata*) are also found. Tidal zones are fringed by low, shrubby mangrove of *Avicennia marina* and *Rhizophora mucronata* (Beard, 1975). Mesas and buttes scattered throughout the northern half of both sheets are sparsely vegetated by *Eucalyptus* and *Acacia* species with *Eucalyptus, Grevillea, Hakea,* and *Acacia* species found on the marginal slopes and tree steppes surrounding the mesas and buttes. The hills that form the Ord Range (DE GREY) and the Goldsworthy Range (DE GREY and PARDOO), are covered with a sparse tree steppe of snappy gum (*Eucalyptus brevifolia*) and shrubby *Acacia* species. River gums (*Eucalyptus camaldulensis*) have a scattered distribution along creeks and rivers.

Physiography

In the central part of DE GREY, the Strelley and Shaw Rivers converge with the De Grey River – Ridley River system, forming a north to northwesterly flowing drainage network that meets the Indian Ocean on the northwestern corner of the sheet (Fig. 2). The De Grey River also truncates the southwestern corner of PARDOO, but the only other major drainage system on that sheet is Pardoo Creek, which flows north along the western edge of the sheet area.

A belt of marine and estuarine sediments forms supratidal to intertidal mud flats with local mangrove swamps along the coast. This belt may be up to 10 km wide and is flanked by shelly sand and silt deposits that locally form dunes reaching to 20 m above high-tide level.

An alluvial–colluvial plain, locally including a coastal belt with a component of eolian sand deposits, covers most of DE GREY, whereas most of PARDOO and the central eastern portion of DE GREY are dominated by eolian sand deposits of the Great Sandy Desert. These eolian deposits form a gently undulating sandplain carrying a few widely spaced east-northeasterly trending longitudinal and chain dunes. The sandplain surrounds scattered mesas and buttes of Mesozoic sandstone and ferruginous residual deposits, which rise to a maximum of about 20 m above the plain. The southern and southeastern part of PARDOO is dominated by sandplain surrounding low-lying granite hills and tors.

The elevated surface that forms the Ord Ranges (DE GREY) and the Goldsworthy Ranges (DE GREY and PARDOO) is divided between dissected plateaus and more deeply eroded strike-controlled ridges. The dissected plateau surface rises to about 120 m above sea level and is part of the peneplain that Campana et al. (1964) called the Hamersley Surface.

Previous investigations and regional geological setting

The earliest significant geological interest in the region surrounding DE GREY and PARDOO was in the late 1940s and was directed towards the oil potential in the southeastern part of what is now referred to as the Lambert Shelf, a part of the Northern Carnarvon Basin of the Westralian Superbasin (Hocking et al., 1994). Previous geological investigations in the 1930s had recognized the iron ore potential of the Mount Goldsworthy area (Finucane and Telford, 1939). However, a Commonwealth Government embargo on the export of iron ore prevented further work until 1960 (Ferguson and Ruddock, 2001). In 1963 Mount Goldsworthy Mining Associates announced reserves of 65 Mt of hematite and hematite–goethite ore containing 54–65% Fe (Hickman, 1983). This mineralization is hosted in metasedimentary rocks of the East Pilbara Granite–Greenstone Terrane on the western margin of PARDOO, and similar (although hitherto subeconomic) deposits have been identified throughout the Ord and Goldsworthy Ranges (Finucane and Telford, 1939; Low, 1961; Noldart and Wyatt, 1962; Hickman, 1983). Noldart and Wyatt (1962) and Hickman (1983) detailed the early geological investigations in the region, while Low (1965) and Hickman and Gibson (1982) provided the first detailed accounts on the geology of the PORT HEDLAND 1:250 000 map sheet, on which DE GREY and PARDOO lie.

The Archaean Pilbara Craton contains some of the oldest exposed crustal elements of Australia. It is divided into two components (Fig. 1) — a basement of granite–greenstone terrain that formed between c. 3600 and c. 2800 Ma (Hickman, 1983; Barley, 1997) and the unconformably overlying volcano-sedimentary sequences (Mount Bruce Supergroup) of the c. 2775 to 2400 Ma Hamersley Basin (Arndt et al., 1991; Thorne and Trendall, 2001). The granite–greenstone terrain is exposed mainly in the north and northeast of the craton where erosion has removed all but local remnants of the Mount Bruce Supergroup. No rocks of the Mount Bruce Supergroup are exposed on DE GREY or PARDOO.

Hickman (1983) provided a comprehensive interpretation of the geological evolution of the granite–greenstone terrains of the Pilbara Craton, and included what was thought to represent a regionally applicable supercrustal stratigraphy: the Pilbara Supergroup. Recently, there has been substantial revision of the stratigraphy of the greenstone successions (Buick et al., 1995; Van Kranendonk, 1998; Van Kranendonk and Morant, 1998; Van Kranendonk et al., 2002). The recognition of separate lithotectonic elements with distinct lithostratigraphy and history has led to a subdivision into the East and West Pilbara Granite–Greenstone Terranes, the northeasterly trending Central Pilbara Tectonic Zone, the Mosquito Creek Basin and the Kurrana Terrane (Fig. 1; Hickman, 2001). A detailed description of this subdivision and of the geological setting and history of the region is presented by Van Kranendonk et al. (2002).

DE GREY and PARDOO straddle the boundary between the East Pilbara Granite–Greenstone Terrane (EPGGT)

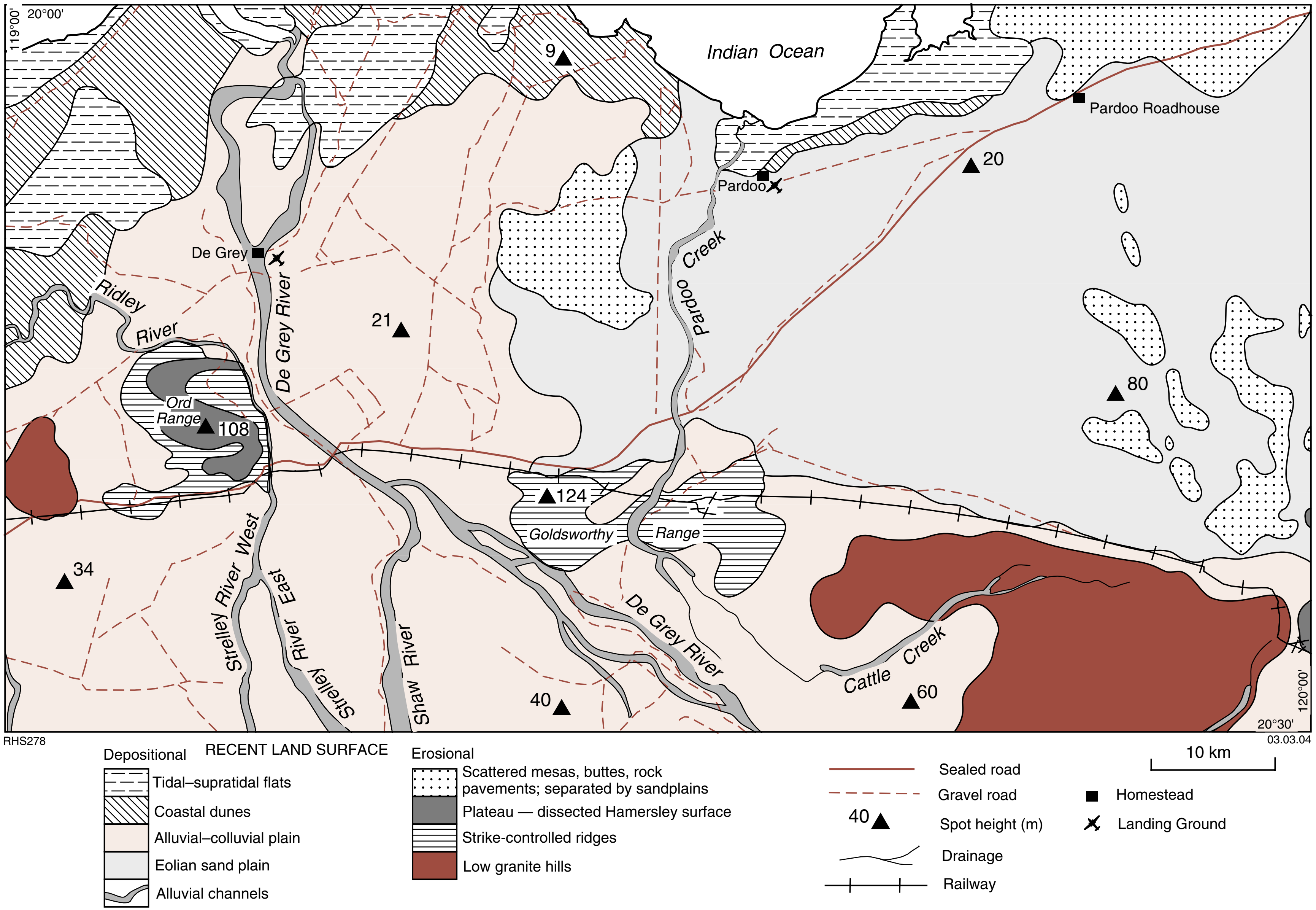


Figure 2. Physiographic features of De Grey and Pardoo

and the Central Pilbara Tectonic Zone (CPTZ) — marked in this region by the Tabba Tabba Shear Zone and the Pardoo Fault (Fig. 3). The geological evolution of the area is summarized in Table 1. Regionally, the EPGGT consists of large ovoid granitoid–gneiss complexes partially surrounded by belts of tightly folded and near-vertically dipping volcanic and sedimentary rocks that are typically metamorphosed to greenschist facies. The various named granitoid complexes and greenstone belts are shown in Figure 3. Regionally, the oldest dated greenstone sequence forms the c. 3515–3498 Ma Coonterunah Group (Buick et al., 1995; Van Kranendonk, 1998; Nelson, 2002). Protoliths to the greenstone successions accumulated until c. 2940 Ma, although the majority were deposited before c. 3240 Ma. Felsic magmatism was also active periodically between c. 3600 Ma and c. 2830 Ma. The majority of granitoids in the eastern part of the EPGGT were intruded before c. 3240 Ma. In contrast, granitoids dated at between c. 2945 Ma and 2930 Ma form a volumetrically significant and locally dominant component of granitoid complexes in the western part of the terrane, and almost certainly dominate the unexposed geology on the southwestern parts of DE GREY.

The main component of the CPTZ is the c. 2970–2945 Ma Mallina Basin (Smithies et al., 2001). To the southwest, the boundary between the EPGGT and the CPTZ is the basal contact between the Mallina Basin, which is typically a fault or a faulted unconformity. The basement to the basin includes chert, assigned to the Cleaverville Formation of the Gorge Creek Group, that has been dated at c. 3015 Ma (Smithies et al., 1999). On WALLARINGA to the southwest, the Tabba Tabba Shear Zone separates the CPTZ, including the Mallina Basin, from the EPGGT. Rocks of the Mallina Basin do not outcrop on DE GREY or PARDOO. In this northern region the boundary between the CPTZ and the EPGGT is essentially based on interpretation of aeromagnetic data, and is suggested to coincide with the east-northeasterly trending Pardoo Fault. Here, the inferred boundary separates only zones that suffered greater and lesser degrees of deformation during the development of the Mallina Basin. Lithological correlations in rocks older than the basin are locally preserved.

Archaean rocks

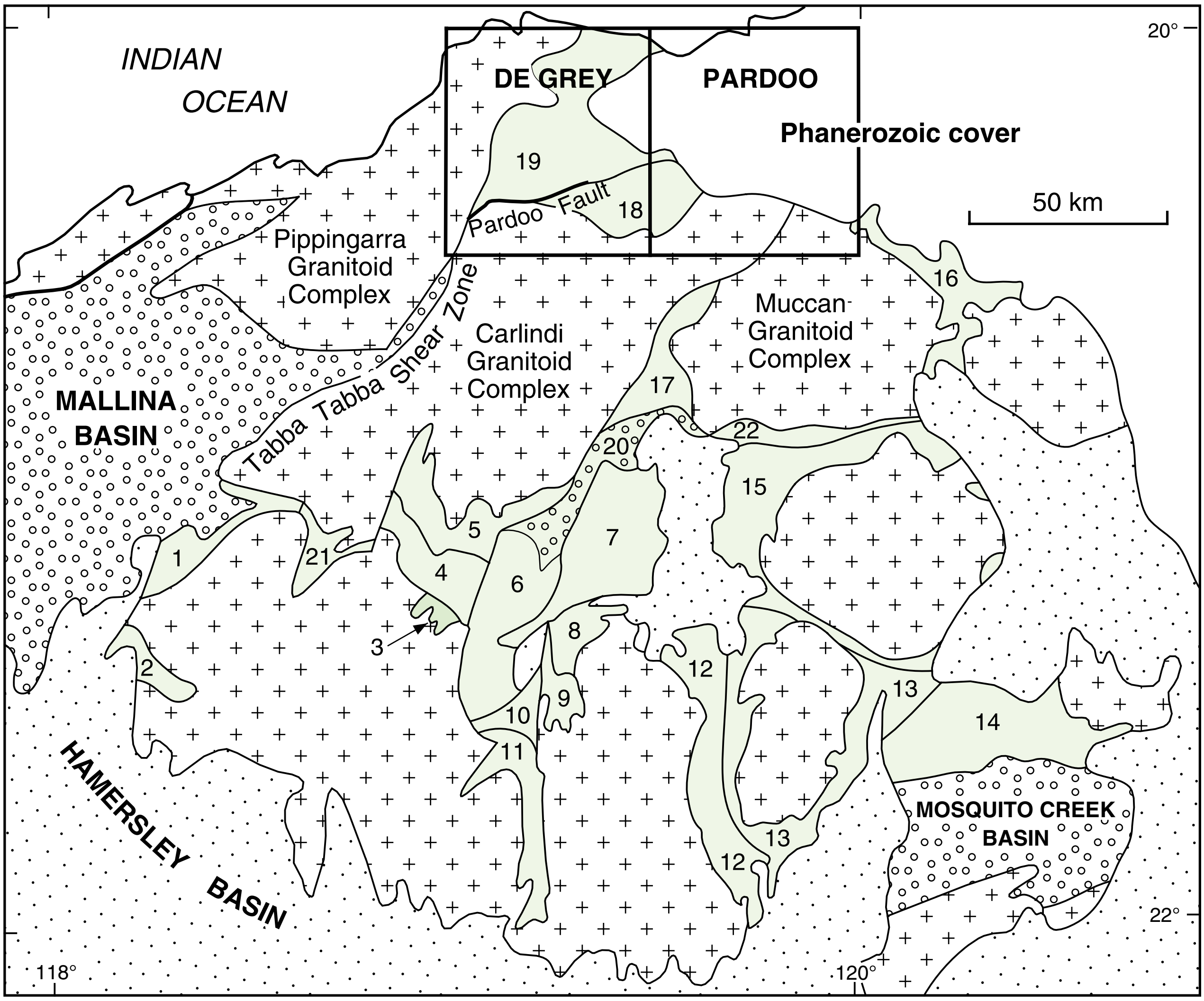
The geology of DE GREY and PARDOO is summarized in Figure 4 and geochronological data relevant to these sheets and to surrounding areas are presented in Table 2. The Archaean geology is divided between greenstone sequences, or greenstone belts, and granitoid complexes. Greenstone sequences on DE GREY belong to both the Ord Range greenstone belt and the Goldsworthy greenstone belt (Fig. 3). Archaean supracrustal rocks on PARDOO belong to the Goldsworthy greenstone belt, except for those occurring in the western extremity of the Shay Gap greenstone belt that lies on the eastern margin of the sheet area. Granites are divided between the Pippingarra, Carlindi, and Muccan Granitoid Complexes (Fig. 4).

The Goldsworthy greenstone belt essentially covers the lithostratigraphically diverse supracrustal sequences exposed in and around the east-northeasterly trending Goldsworthy Syncline (Fig. 4). The stratigraphically lowest package of rocks is dominated by metabasalt and is assigned to the 3490–3312 Ma Warrawoona Group. Here, the package includes a thin (typically < 200 m true thickness) but distinctive unit of sandstone, possibly at least partly of volcaniclastic origin, that overlies chert horizons. The chert includes thinly laminated layers which may have originally been stromatolitic carbonate laminites. This sedimentary unit closely resembles a distinctive succession elsewhere assigned to the 3458–3426 Ma Panorama Formation and the conformably overlying Strelley Pool Chert (Van Kranendonk et al., 2002).

Metasedimentary rocks of the Gorge Creek Group directly overlie the Warrawoona Group in the Goldsworthy Syncline, and low angle truncation of the older stratigraphy (e.g. on DE GREY: MGA 751100E 7745600N) shows the contact to be unconformable. The age range for the Gorge Creek Group is constrained only by the ages of the lithostratigraphic units above and below: between the minimum age of 3235 Ma for the Sulphur Springs Group (Van Kranendonk et al., 2002) and the minimum age of c. 3010 Ma for the overlying Whim Creek Group (Hickman and Smithies, 2001). In the Goldsworthy Syncline, the Gorge Creek Group includes the fine- to coarse-grained clastic metasedimentary rocks of the Corboy Formation and the overlying Nimingarra Iron Formation, dominated by fine-grained clastic and chemical metasedimentary rocks, including banded iron-formation (BIF) that is locally supergene enriched.

The De Grey Group stratigraphically overlies the Gorge Creek Group. In the Goldsworthy greenstone belt, an erosional contact locally cuts out much of the stratigraphy of the latter group (e.g. DE GREY: MGA 752800E 7748500N). Here, the De Grey Group comprises a highly variable succession dominated by medium- to coarse-grained metasedimentary rocks of fluvial origin, but also includes minor metamorphosed rocks of volcanic and volcaniclastic origin. This combined package is grouped into the Paradise Plains Formation that forms the exposed core of the Goldsworthy Syncline (Fig. 4).

Throughout the entire Pilbara Craton, the De Grey Group includes a number of clastic metasedimentary packages deposited in isolated but more or less contemporaneous basins (Fig. 3), at a stage when the major lithotectonic components of the craton were in their present relative position. The best depositional age constraints for rocks of this group are those for the Mallina Formation and Constantine Sandstone of the Mallina Basin (CPTZ), which were deposited between c. 2970 and 2945 Ma (Smithies et al., 2001). The Bookingarra Group describes the northwestern, fault-bounded part of the Mallina Basin, dominated by felsic to mafic volcanic and volcaniclastic rocks, and has the same depositional age range as the Mallina Formation and Constantine Sandstone (Smithies et al., 2001; Van Kranendonk et al., 2002). To the north of the Goldsworthy Syncline on DE GREY, poorly exposed felsic volcanic rock is in faulted contact (along the Pardoo Fault) with rocks of the Goldsworthy greenstone belt. Based on airborne regional magnetic data, similar felsic rocks are inferred to form a



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Fortescue Group
De Grey Group
Granitoid rocks
Greenstone
Geological boundary

Greenstone belts and complexes

1. Pilbara Well greenstone belt
2. Cheearra greenstone belt
3. Abydos greenstone belt
4. Pincunah greenstone belt
5. East Strelley greenstone belt
6. Soanesville greenstone belt
7. Panorama greenstone belt
8. North Shaw greenstone belt
9. Emerald Mine greenstone complex
10. Tambina greenstone complex
11. Western Shaw greenstone belt
12. Coongan greenstone belt
13. Kelly greenstone belt
14. Yilgalong greenstone belt
15. Marble Bar greenstone belt
16. Shay Gap greenstone belt
17. Warralong greenstone belt
18. Goldsworthy greenstone belt
19. Ord Range greenstone belt
20. Lalla Rookh Synclinorium
21. Wodgina greenstone belt
22. Dooleena Gap greenstone belt

Figure 3. Generalized geological map of the EPGGT (modified from Van Kranendonk et al., 2002)

major component to this part of the CPTZ (Fig. 4). The felsic volcanic rock on DE GREY has been dated at 2948 ± 3 Ma (Nelson, 2002), placing it within the depositional age range of the De Grey and Bookingarra Groups further to the southwest.

The Ord Range greenstone belt is generally well exposed in the Ord Ranges, on the western side of DE GREY (Figs 2 and 4). Here, fine-grained clastic and chemical metasedimentary rocks of the Gorge Creek Group dominate the outcrop, and are assigned to the Nimingarra Iron Formation. The structure of the Ord Range greenstone belt is slightly more ambiguous than that of the Goldsworthy greenstone belt, mainly because no definitive sedimentary 'younging' or 'way-up' indicators could be identified. Thus, the Ord

Table 1. Summary of the geological history of De Grey and Pardoo

Age (Ma)	*East Pilbara Granite–Greenstone Terrane*
3510–3425	Deposition of basalt, felsic volcanic and volcaniclastic rocks and chert of the Warrawoona Group, including the Panorama Formation and Strelley Pool Chert
c. 3420	Intrusion of tonalitic component of the Muccan Granitoid Complex
c. 3315	Intrusion of biotite monzogranite of the Muccan Granitoid Complex
?	Deformation of tonalitic component of the Muccan Granitoid Complex; northerly trending foliation. Early development of the Tabba Tabba Shear Zone
3252–3244	Intrusion of the Wolline Monzogranite of the Muccan Granitoid Complex
<3235 – >3010	Deposition of clastic and chemical sedimentary rocks of the Gorge Creek Group: Corboy Formation, Nimingarra Iron Formation, and Cleaverville Formation
?	Deformation: early folding recognized in the Ord Range
?2950	Deformation: major east-southeast trending folds in the Ord Range. First recognizable phase of folding in the Goldsworthy greenstone belt
<2970 – >2945	Deposition of sedimentary rocks, and basaltic to felsic volcanic and volcaniclastic rocks of the De Grey and ?Bookingarra Groups: Paradise Plains Formation
?	Deformation: major east-northeast trending folds in the Goldsworthy greenstone belt
2955–2940	Major sinistral movement along the Tabba Tabba Shear Zone and along the northerly trending zone, on Pardoo, occupied by tonalite of the Muccan Granitoid Complex, with intrusion of mafic and ultramafic dykes into extensional zones
2955–2850	Intrusion of granites of the northern parts of the Pippingarra and Carlindi Granitoid Complexes
c. 2930–2775	Erosion
c. 2775–2630	Deposition of volcanic and sedimentary rocks of the Fortescue Group
<2630	Complete erosion of the Fortescue Group
c. 100	Deposition of Mesozoic sedimentary rocks (Wallal Sandstone, Jarlemai Siltstone, and Callawa Formation)

Range greenstone belt has been mapped as a series of easterly trending faulted synforms and antiforms. Metamorphosed basalt and ultramafic schist occur locally and appear to be older than rocks of the De Grey Group, but it is not clear that they pre-date the Gorge Creek Group.

Exposed rocks of the De Grey Group are confined to the eastern edge of the Ord Ranges and form only a minor component of the Ord Range greenstone belt. They show a clear, high-angle unconformity that truncates the major folds within the rocks of the Gorge Creek Group. The lithological range and generalized stratigraphy of the De Grey Group in the Ord Range greenstone belt is similar to that in the Goldsworthy greenstone belt, and so these rocks have also been placed into the Paradise Plains Formation. On the southeastern corner of the Ord Range (De Grey: MGA 729500E 7750200N) clastic and mafic volcaniclastic rocks, of subaqueous origin, show a well-marked transition to stratigraphically overlying coarse-grained rocks of fluvial origin.

Only the western extremity of the Shay Gap greenstone belt lies on Pardoo, forming an inferred and exposed area of less than about 2 km^2. Here, fine-grained clastic and chemical metasediments of the Gorge Creek Group are exposed, and these are assigned to the Nimingarra Iron Formation.

Granite that crops out on the western side of De Grey has been correlated with the Chillerina Granodiorite, which forms part of the Pippingarra Granitoid Complex to the southwest, on Wallaringa. A vast area of unexposed granite to the north of this outcrop is likewise interpreted to belong to the Pippingarra Granitoid Complex. The southern contact of this granitoid complex with the Carlindi Granitoid Complex is the east-northeasterly to north-northeasterly trending Tabba Tabba Shear Zone.

Rocks of the Carlindi Granitoid Complex are inferred to have intruded metabasalts of the Warrawoona Group to the south of the Goldsworthy Syncline (Fig. 4), but this contact is not exposed. Only a single small outcrop of the granitoid complex remains on De Grey (MGA 725300E

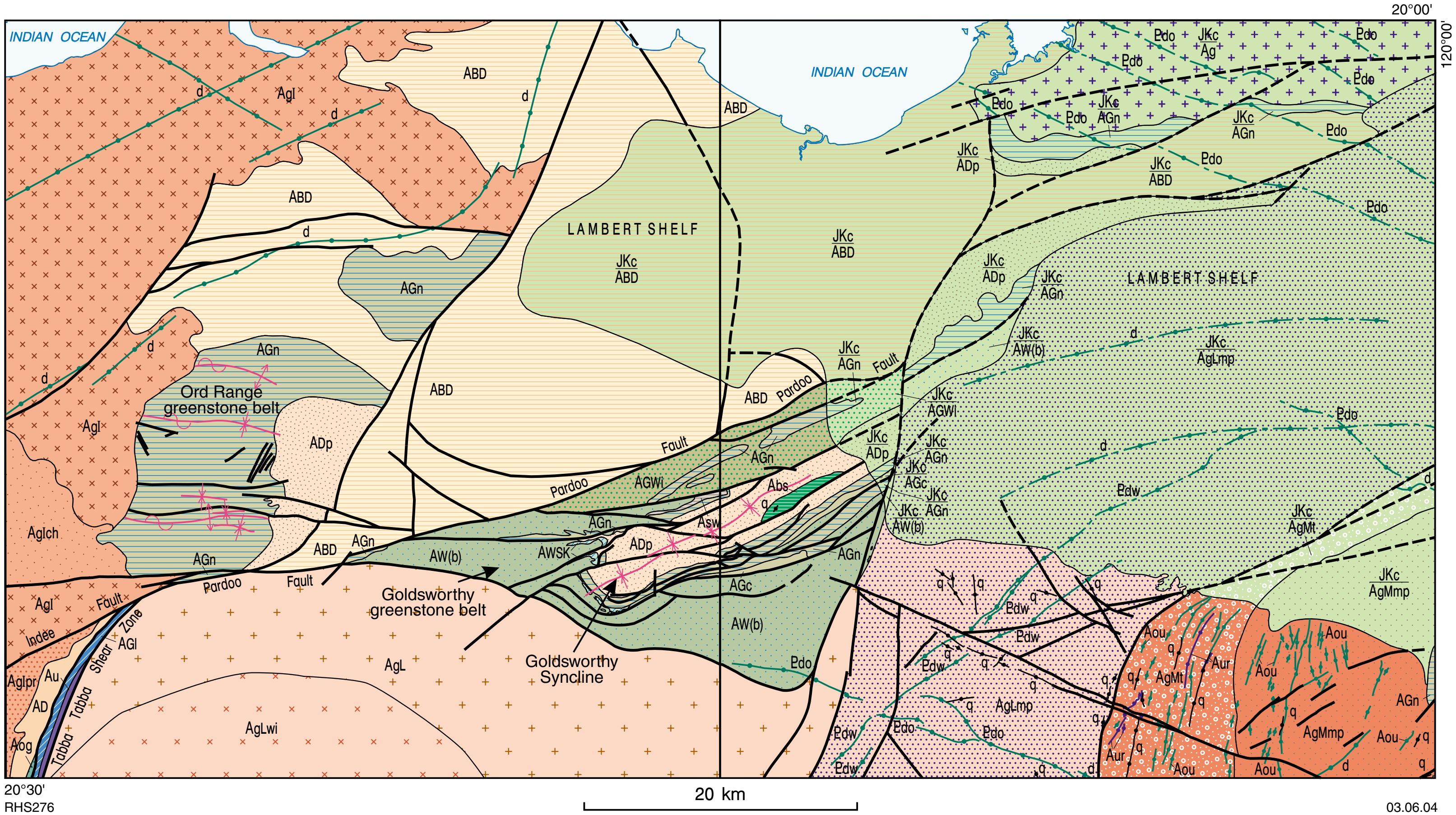
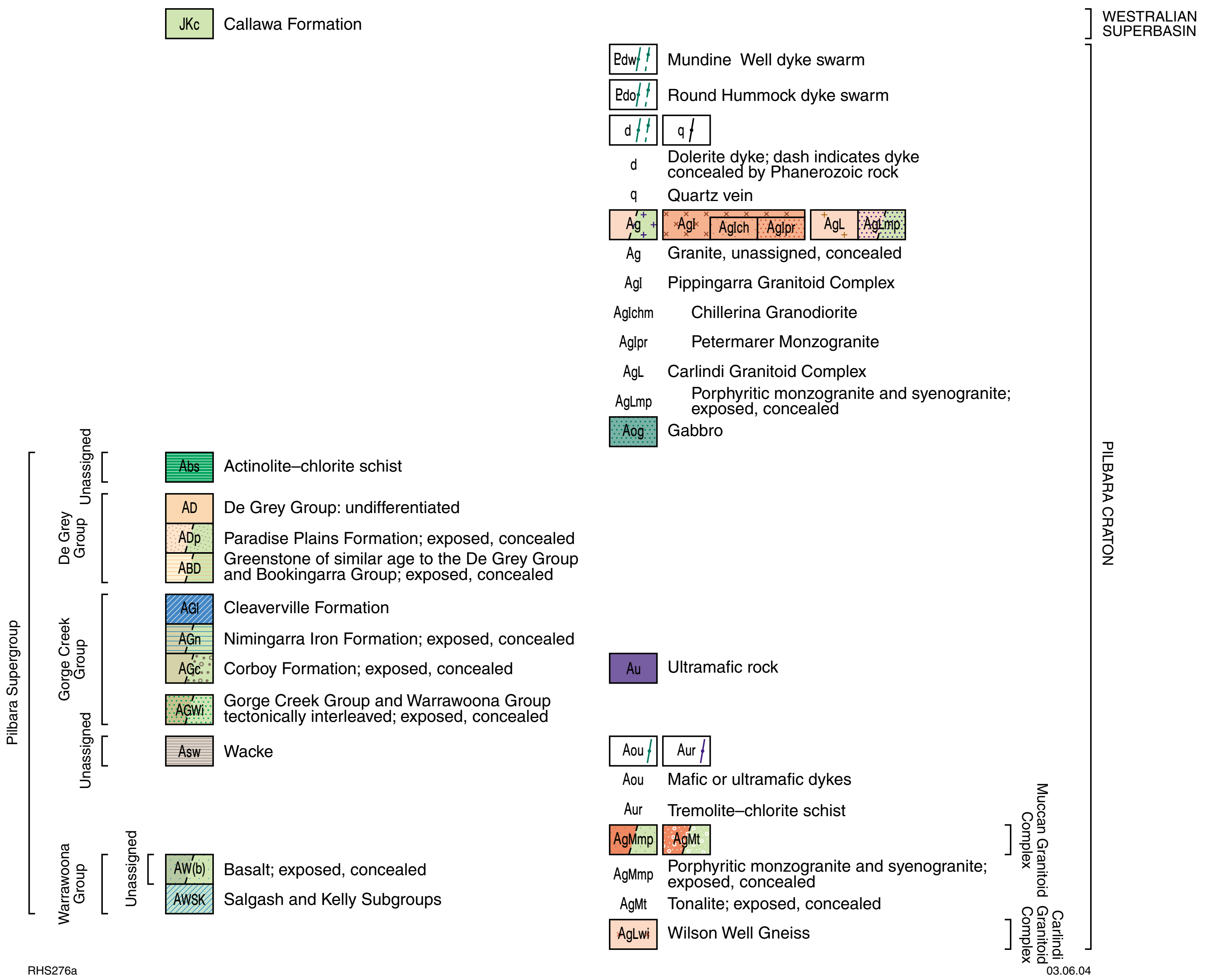


Figure 4. Interpreted bedrock geology of De Grey and Pardoo (simplified from Smithies, 2001a,b)


JKc Callawa Formation
WESTRALIAN SUPERBASIN
Ᵽdw Mundine Well dyke swarm
Ᵽdo Round Hummock dyke swarm
d
q
d Dolerite dyke; dash indicates dyke concealed by Phanerozoic rock
q Quartz vein
Ag
Agl
Aglch
Aglpr
AgL
AgLmp
Ag Granite, unassigned, concealed
Agl Pippingarra Granitoid Complex
Aglchm Chillerina Granodiorite
Aglpr Petermarer Monzogranite
AgL Carlindi Granitoid Complex
AgLmp Porphyritic monzogranite and syenogranite; exposed, concealed
Aog Gabbro
PILBARA CRATON
Pilbara Supergroup
Unassigned
Abs Actinolite–chlorite schist
De Grey Group
AD De Grey Group: undifferentiated
ADp Paradise Plains Formation; exposed, concealed
ABD Greenstone of similar age to the De Grey Group and Bookingarra Group; exposed, concealed
Gorge Creek Group
AGl Cleaverville Formation
AGn Nimingarra Iron Formation; exposed, concealed
AGc Corboy Formation; exposed, concealed
AGWi Gorge Creek Group and Warrawoona Group tectonically interleaved; exposed, concealed
Au Ultramafic rock
Unassigned
Asw Wacke
Aou
Aur
Aou Mafic or ultramafic dykes
Aur Tremolite–chlorite schist
AgMmp
AgMt
Muccan Granitoid Complex
Warrawoona Group
Unassigned
AW(b) Basalt; exposed, concealed
AWSK Salgash and Kelly Subgroups
AgMmp Porphyritic monzogranite and syenogranite; exposed, concealed
AgMt Tonalite; exposed, concealed
AgLwi Wilson Well Gneiss
Carlindi Granitoid Complex
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7745100N), but the complex is more extensively exposed in the southwestern corner of PARDOO and to the southwest, on CARLINDIE and on WALLARINGA. The eastern margin of the Carlindi Granitoid Complex is inferred to be in faulted contact with the Muccan Granitoid Complex (Fig. 4).

Rocks of the Muccan Granitoid Complex dominate outcrop in the southeastern part of PARDOO. A porphyritic and seriate granite from this area has recently been dated at 3315 ± 3 Ma (GSWA 178022: Nelson, in prep.). In the central to eastern part of PARDOO, the Muccan Granitoid Complex also includes a north-northeasterly trending zone of tonalitic rocks with a strong north-northeasterly trending foliation. The monzogranite has clearly intruded the tonalite, which locally forms abundant xenoliths within the monzogranite, but a significant proportion of the north-northeasterly directed deformation post-dates both granite types, since lithologically mixed zones are themselves deformed. The tonalite has been dated at 3420 ± 3 Ma (Nelson, in prep.).

Mafic to ultramafic dykes intruded the Muccan Granitoid Complex on PARDOO. On the western side of PARDOO these dykes have a northeasterly trend and on the eastern side of the sheet the dykes form a northerly trending swarm. Within the central region, these dykes are strongly deformed, and their trend follows that of the deformed tonalite host.

Warrawoona Group

The 3490–3319 Ma Warrawoona Group has been subdivided, from base to top, into the Talga Talga, Salgash, and Kelly Subgroups (Hickman, 1983; Van Kranendonk et al., 2002). To the south of DE GREY and PARDOO, these subgroups are typically dominated by metabasaltic rocks but locally include voluminous felsic volcanic and volcaniclastic rocks, the most notable being the Duffer Formation in the Talga Talga Subgroup and the Panorama Formation in the Salgash Subgroup. On PARDOO the Warrawoona Group consists entirely of metabasalt that cannot be assigned to any particular subgroup. On DE GREY, however, a sequence of metasedimentary rocks in the Goldsworthy Syncline is interpreted to belong to the Panorama Formation and Strelley Pool Chert (Salgash Subgroup). Here, they separate two metabasaltic units. The stratigraphically higher metabasaltic unit has been assigned to the Euro Basalt (Kelly Subgroup), but the lower metabasaltic unit remains unassigned.

Panorama Formation and Strelley Pool Chert (*AWpy*)

Within the EPGGT, to the south of DE GREY and PARDOO, the Strelley Pool Chert and the conformably underlying felsic volcanic and volcaniclastic rocks of the Panorama Formation typically form distinct mappable units. However, the combined thickness of the tectonically related Panorama Formation and Strelley Pool Chert (Van Kranendonk et al., 2002) is locally such that they are grouped into a composite mapping unit (*AWpy*). This is also the case at the western and southwestern end of the Goldsworthy Syncline on DE GREY. Here, a composite unit, typically less than 200 m thick, comprises felsic volcanic and sedimentary rocks overlain by chert and silicified siliciclastic and carbonate rocks.

On DE GREY, the composite Panorama Formation – Strelley Pool Chert mapping unit (*AWpy*) consists of sandstone and quartz-rich sandstone, overlain by finely laminated chert. The sandstone is typically well sorted and moderately- to well-bedded at a 10 to 50 cm scale, and individual beds locally grade upwards to siltstone. The chert is typically a finely laminated grey and white rock forming a layer up to about 3 m thick. Similar units elsewhere in the EPGGT have been interpreted as silicified stromatolitic carbonate laminites (Hoffman et al., 1999). The felsic volcanic or volcaniclastic component of the composite unit is rare on DE GREY and could be confidently identified at only a single site (MGA 750090E 7748660N). Here, a fine- to medium-grained volcanolithic sandstone, comprising about 40% lithic fragments and 15–20% angular quartz clasts in a quartz-rich matrix, was sampled for geochronology (sample GSWA 169026: Nelson, in prep.). The sandstone gave a maximum depositional age of 3458 ± 9 Ma (Table 2).

Euro Basalt (*AWe*)

On the western edge of the Goldsworthy Syncline on DE GREY, metamorphosed basalt and mafic schist locally form a layer up to about 300 m thick between the composite Panorama Formation and Strelley Pool Chert unit (*AWpy*) and rocks of the Gorge Creek Group. Because of their stratigraphic position, these mafic rocks have been assigned to the Euro Basalt of the Kelly Subgroup (*AWe*). They are locally variolitic and vesicular, with metre-scale pillow structures that confirm a northeasterly facing direction.

Table 2. Precise U–Pb zircon geochronology (SHRIMP) relevant to units mapped on DE GREY and PARDOO

Age (Ma)	*Lithology*	*Formation/Group/Complex*	*Sample*	*Reference*
>3458 ± 9	Sandstone	Panorama Formation – Strelley Pool Chert	169026	Nelson (in prep.)
3420 ± 3	Tonalite	Muccan Granitoid Complex	178023	Nelson (in prep.)
3315 ± 3	Biotite monzogranite	Muccan Granitoid Complex	178022	Nelson (in prep.)
3252 ± 3	Wolline Monzogranite	Muccan Granitoid Complex	143805	Nelson (1998)
3244 ± 3	Wolline Monzogranite	Muccan Granitoid Complex	143810	Nelson (1998)
2954 ± 4	Granodiorite	Pippingarra Granitoid Complex	142935	Nelson (2001)
2948 ± 3	Felsic volcanic	De Grey/Bookingarra Group	169025	Nelson (in prep.)
2945 ± 2	Chillerina Granodiorite	Pippingarra Granitoid Complex	160744	Nelson (2001)

Unassigned units (*Aw(b)*, *Aw(bs)*, *Aw(bz)*)

Locally variolitic and pillowed metabasalts (*AW(b)*), variably schistose (*AW(bs)*), and silicified (*AW(bz)*), outcrop to the north, west, and south of the Goldsworthy Syncline, on De Grey and Pardoo. An extensive outcrop of metabasalt, locally preserving varioles up to 3 cm in diameter (Fig. 5), is found on Pardoo, between Mount Goldsworthy and Mine Well (Pardoo: around MGA 768000E 7745000N). At some localities (e.g. De Grey: MGA 751000E 7748300N) metabasalt stratigraphically underlies the composite mapping unit of the Panorama Formation and Strelley Pool Chert (*AWpy*). Elsewhere, the metabasalt appears to be older than the Gorge Creek Group, but no definite stratigraphic relationships have been established. Schistose rocks (*AW(bs)*) are tremolite-rich, indicating a magnesian-rich protolith, and typically occur close to faults. In the area between Mount Goldsworthy and Mine Well, C–S fabric preserved in tremolite-rich schist (*AW(bs)*) consistently indicates a sinistral sense of shearing. In the same area, tremolite-rich schist is locally interleaved with 10–30 cm-thick layers of black and white banded cherty rock.

Unassigned greenstone units older than the Gorge Creek Group (*Ab*, *Aosg*, *Aou*, *Au*, *Aur*, *Aut*, *Ac*, *Asw*)

Undivided metamorphosed mafic rock (*Ab*) crops out in the southern part of the Ord Range, on De Grey (e.g. MGA 727500E 7752900N). It is locally intruded by gabbro (*Aog*) and is either in faulted contact with metasedimentary rocks of the Gorge Creek Group, or is separated from those rocks by a layer of ultramafic rock (*Au*), typically talc–serpentine–chlorite–tremolite schist (*Aut*). It is likely that the mafic (*Ab*) and ultramafic rocks (*Au* and *Aut*) are contemporaneous, but the stratigraphic relationships required to confirm this have not been observed. However, the few available data, primarily from sedimentary grain-size grading in rocks of the Gorge Creek Group, suggest that the southern part of the Ord Range is an anticline (mapped as an antiformal syncline). If this is correct, then the mafic (*Ab*) and ultramafic rocks (*Au* and *Aut*) would stratigraphically underlie the Gorge Creek Group and could belong to the Warrawoona Group.

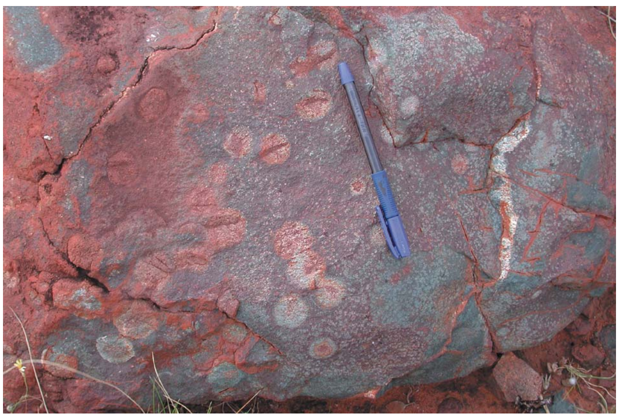

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Figure 5. Variolitic basalt of the Warrawoona Group (*Aw(b)*): Pardoo (MGA 769106E 7746708N). Length of pen = 13 cm

Plagioclase–actinolite–epidote–chlorite schist after gabbro (*Aosg*) is interleaved with, and extensively intruded by, porphyritic and seriate granite (*AgMmp*) in the south-eastern part of Pardoo (e.g. at MGA 801000E 7738200N). The schistose metagabbro locally forms continuous layers up to 2 km long and 500 m wide, but also forms abundant rafts and xenoliths, down to a cm-scale, within the granite. The age of the metagabbro is not clear but it must pre-date the c. 3315 Ma intrusive age of the granite. In the same area, the Muccan Granitoid Complex has been intruded by dykes of mafic to ultramafic rock (*Aou*), including the protolith to tremolite–chlorite schist (*Aur*). The protoliths to these rocks range from pyroxene gabbro to dunite. Original mineralogy, including olivine, is locally preserved, but more typically the rocks are massive to schistose combinations of actinolite, sericite, chlorite, carbonate, and quartz or chlorite, tremolite, talc, serpentine, magnetite, and carbonate.

To the west and northwest of the Goldsworthy Ranges, on De Grey, outcrop of metamorphosed banded chert (*Ac*) is either isolated within the floodplain of the De Grey River (e.g. at MGA 747000E 7750650N), or is tectonically interleaved with metabasaltic rocks of the Warrawoona Group (e.g. at MGA 750000E 7750800N). In neither case can the stratigraphic position of the chert be confidently determined although it probably belongs to the Nimingarra Iron Formation. The chert is banded white and grey, on a millimetre to centimetre scale, and limonite bands are developed locally.

Metamorphosed medium- to coarse-grained, poorly sorted and poorly graded wacke (*Asw*) straddles the boundary between De Grey and Pardoo, approximately 3 km to the south of the Great Northern Highway. This wacke resembles components of both the Corboy Formation (wacke component of *AGcsw*) of the Gorge Creek Group and the Paradise Plains Formation of the De Grey Group, and it lies close to exposures of both.

Gorge Creek Group

Corboy Formation (*AGc*, *AGcss*, *AGcst*, *AGcsw*)

The Corboy Formation (*AGc*) is a sequence of metamorphosed fine- to coarse-grained clastic rocks, including conglomerate, which forms the stratigraphically lowest unit of the Gorge Creek Group. It is exposed on both De Grey and Pardoo along the southern limb of the Goldsworthy Syncline. In areas around Mount Goldsworthy (Pardoo; e.g. at MGA 766000E 7747200N) the formation reaches a combined thickness of about 500 m. Contacts with the underlying rocks of the

Warrawoona Group are usually disconformable, although there is a low-angle unconformity in the southwestern part of the Goldsworthy Syncline (De Grey; at MGA 751200E 7745600N).

Within the Goldsworthy Ranges, the Corboy Formation can be subdivided into three mappable units, although no persistent stratigraphic sequence can be established. The three units include: poorly bedded wacke and lithic arenite (*AGcsw*); sandstone and siltstone with rare pebble-conglomerate interbeds (*AGcss*); and sandstone with pebble conglomerate interbeds (*AGcst*). All of these units include interbeds of laminated black, grey, and white siltstone and chert, which increase in both abundance and thickness towards contacts with the overlying Nimingarra Iron Formation (*AGn*).

Poorly bedded wacke and lithic arenite (*AGcsw*) are typically fine- to medium-grained and consist primarily of subangular grains of quartz and chert. Individual beds are up to 2 m thick and are massive to weakly graded.

Sandstone and siltstone with rare pebble-conglomerate interbeds (*AGcss*) are dominated by thickly bedded, medium- to coarse-grained, poorly-sorted sandstone. The sandstone consists of subrounded grains of quartz and chert, but appears more quartz-rich (up to ~80%) than rocks of the wacke and lithic arenite unit (*AGcsw*). Individual beds are up to 4 m thick and are massive to weakly graded. Pebble beds and matrix-supported conglomerate containing tabular pebble- to cobble-sized intraclasts of laminated siltstone occur locally. Where the sandstone and siltstone unit (*AGcss*) forms the basal component of the Corboy Formation, it locally includes a conglomerate containing subrounded pebbles and cobbles of basalt.

The sandstone with pebble conglomerate interbeds unit (*AGcst*) differs from the sandstone and siltstone unit (*AGcss*) primarily in that it contains a higher proportion of conglomerate that has tabular pebble- to cobble-sized intraclasts of laminated siltstone. The conglomerate interbeds are up to 1.5 m thick and are more laterally persistent than those in the sandstone and siltstone unit (*AGcss*).

Nimingarra Iron Formation (*AGn*, *AGncc*, *AGnccss*, *AGnccw*, *AGnccx*, *AGnssc*, *AGnci*, *AGncic*, *AGncih*, *AGncix*)

Hickman (1983) assigned the main BIF and chert unit of the Gorge Creek Group to the Cleaverville Formation, originally defined from the West Pilbara Granite–Greenstone Terrane. However, correlations between BIF units in all of the EPGGT and the type locality for the Cleaverville Formation have not been proven. Accordingly, Williams (1999) preferred to give the BIFs and cherts of the Gorge Creek Group, in the northeastern part of the EPGGT, a local stratigraphic name, the Nimingarra Iron Formation (*AGn*).

The Nimingarra Iron Formation (*AGn*) consists of BIF, jaspilite (banded hematite and red jasper), banded and ferruginous chert, black (pyritiferous) shale, and mudstone (Williams, 1999). It is the main formation exposed in the Ord Ranges (De Grey) and forms a significant proportion of the Goldsworthy Ranges. No significant lithological or stratigraphic differences in the sequences assigned to the Nimingarra Iron Formation were noted between the Ord and Goldsworthy Ranges, and no persistent stratigraphic sequence of lithologies within the iron formation was noted in either area.

A unit comprising laminated white and grey chert, weakly banded to massive white chert, and dark-grey chert after carbonaceous shale (*AGncc*) forms the main component of the formation in both the Ord and Goldsworthy Ranges (Fig. 6). Banding is defined by variations in shade between white and dark-grey and typically occurs on a 0.5 – 2 cm scale, but bands as thin as 1 mm, and massive units as thick as 2 m (typically of white chert) are also found. Laminations are commonly defined by a combination of colour and grain-size

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Figure 6. Banded white chert from the Nimingarra Iron Formation (*AGncc*): De Grey (MGA 722495E 7754034N). Length of hammer = 30 cm

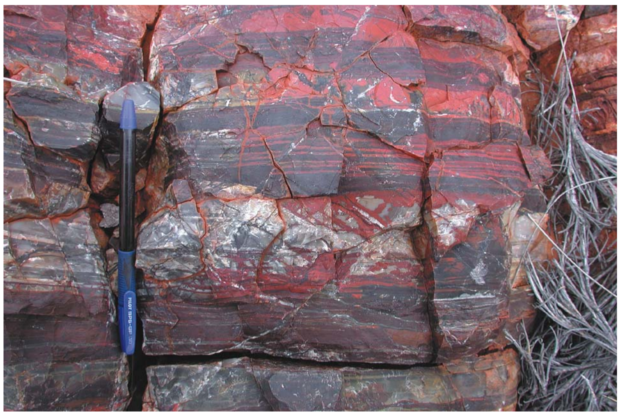

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Figure 7. Incipient iron staining primarily along fractures within a chert/ironstone unit of the Nimingarra Iron Formation (*AGncc*): De Grey (MGA 725659E 7751581N). Length of pen = 13 cm

variations and are on a 1–2 mm scale. Accumulations of iron oxide (hematite, now variably altered to goethite) are not a major component of this chert unit, but locally form distinct layers between 2 mm and 1 cm thick. The amount of iron staining varies from minor and fracture-controlled (Fig. 7) to extensive and pervasive. Some of this staining might result from the alteration of pre-existing iron oxides to goethite, but the majority appears related to a later influx of iron-rich solutions.

Many bands of grey and dark-grey chert (Fig. 8) are variably silicified siltstone, shale, and fine-grained sandstone (Fig. 9). The shade of grey becomes darker with increasing proportions of carbonaceous (graphite) material. Laminations may also be defined by variations between siltstone layers and layers that contain a higher proportion of phyllosilicate minerals (now sericite after clay minerals). The siltstone, shale, and fine-grained sandstone unit is very poorly sorted and, in rare cases (Fig. 9), individual bands preserve grain-size grading. Lenses of conglomerate, locally up to 80 cm thick, consist of tabular pebble- to cobble-sized rip-up clasts of laminated chert supported in a matrix of poorly sorted, fine-grained sandstone (Fig. 10). Although most of these lenses probably resulted from sedimentary deposition, some may also be a result of tectonic slumping.

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Figure 8. Banded and laminated grey chert of the Nimingarra Iron Formation (*AGncc*). These are variably silicified siltstones, shale, and fine-grained sandstone; see Fig. 9: De Grey (MGA 725592E 7755675N). Length of hammer shown = 27 cm

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Figure 9. Close-up view of banded and laminated grey chert (Nimingarra Iron Formation: *AGncc*) shown in Fig. 8: De Grey (MGA 725592E 7755675N). Thickness of fine-grained sandstone bed is approximately 1 cm

Many dark-grey chert bands are also a result of hydrothermal deposition and alteration. These layers of very fine-grained silica are up to 50 cm thick and are conformable with the sedimentary bedding for distances greater than outcrop scale. Hydrothermal brecciation is observed close to many of the fracture systems that fed these silica deposits. There appears to be no clear relationship between hydrothermal silicification and iron enrichment.

In the Ord Range greenstone belt, the chert unit (*AGncc*) has been further subdivided based on the presence of abundant fine-grained siltstone and sandstone (*AGnccss*), abundant massive to weakly banded white chert (*AGnccw*), or chert conglomerate and sedimentary chert breccia (*AGnccx*). Approximately 1 km to the south of the Ord Ridley iron prospect (at MGA 723500E 7753400N), poorly sorted fine-grained sandstone and siltstone forms a discrete mappable unit.

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Figure 10. Sedimentary breccia unit in the Nimingarra Iron Formation (*AGncc*): De Grey (MGA 722495E 7754034N)

The other major component of the Nimingarra Iron Formation in the Ord Range and Goldsworthy greenstone belts is a unit consisting of BIF, jaspilite, banded and ferruginous chert, and black carbonaceous shale (*AGnci*). Supergene enrichment of the BIF has produced a number of significant iron deposits (e.g. Mount Goldsworthy, Ord Ridley). Local variations of this unit are particularly rich in ferruginous chert, jaspilite, and ironstone (*AGncic*), ferruginous shale (*AGncih*), or are brecciated (*AGncix*). This BIF-rich unit (*AGnci*) locally includes all of the lithologies found in the chert unit (*AGncc*) but most of these lithologies show extensive limonite alteration and are interbedded with abundant BIF, ironstone, and jaspilite.

BIF is typically hematite-rich. Bands comprise up to 98% Fe-oxide, with minor silica, and are interleaved with either finely laminated and variably limonitised and graphite-rich chert, or with jasper (Fig. 11). Ironstone appears to be extensively ferruginised shale, but locally includes interbeds of limonite-rich banded chert and jaspilite up to 30 cm thick, as well as discontinuous seams of hematite. The latter are the result of fracture-controlled iron-rich solutions. A notable outcrop of the shale- and fine-grained sandstone-rich component of the BIF unit (*AGncih*) is exposed in the Ord Range (e.g. at De Grey: MGA 727000E 7757500N).

Cleaverville Formation (*AGl*)

Chert and BIF also forms a single small outcrop on the southwestern edge of De Grey (MGA 710800E 7732000N), south of where the Tabba Tabba Shear Zone is buried beneath Quaternary sheetwash deposits. The northwesterly trending Tabba Tabba Shear Zone is better exposed on Wallaringa and in the northwestern corner of Carlindi, where the zone contains chert and BIF that Smithies et al. (2002) assigned to the Cleaverville Formation. Subsurface continuity between the small exposure on De Grey and rocks assigned to the Nimingarra Iron Formation, in the Ord Range, is not supported by aeromagnetic data.

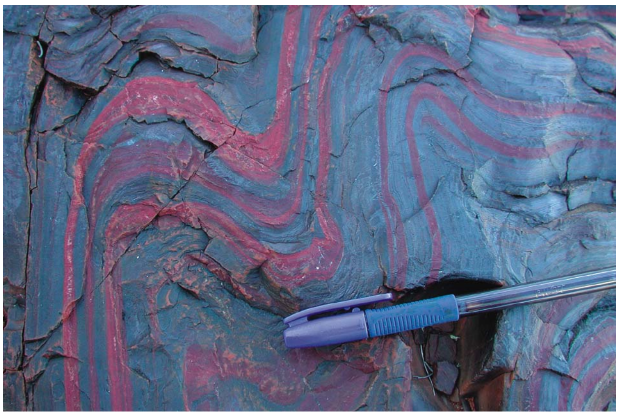

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Figure 11. Banded iron-formation (jaspilite) of the Nimingarra Iron Formation (*AGnci*): De Grey (MGA 722365E 7756573N). Bands of red jasper, in hematite. Length of pen shown = 8 cm

De Grey Group

Paradise Plains Formation (*ADpspp*, *ADpspc*, *ADpspr*, *ADpstr*, *ADpspq*, *ADpsxc*, *ADpscp*, *ADpsgb*, *ADpb*, *ADpvsb*, *ADpl*, *ADpld*, *ADplx*, *ADpss*, *ADpssb*)

The Paradise Plains Formation comprises a sequence of metamorphosed fine- to coarse-grained and conglomeratic clastic rocks and rare interbeds of mafic volcanic and volcaniclastic rocks. It outcrops on both De Grey and Pardoo, forming the southeastern corner of the Ord Range and the central part of the Goldsworthy Syncline in the Goldsworthy Range. In the Ord Range, the basal contact is generally a disconformity on cherts and BIFs of the Gorge Creek Group, but in the western part of the Goldsworthy Syncline (De Grey: MGA 752700E 7748700N), the Paradise Plains Formation lies directly on rocks of the Warrawoona Group. In contrast to the typically disconformable basal relationship in the Goldsworthy Range, the basal contact of the Paradise Plains Formation in the Ord Range is an angular unconformity, the bedding plane of basal debris-flow deposits truncating at right-angles the steeply dipping bedding trend of the Gorge Creek Group.

The stratigraphy of the Paradise Plains Formation is well preserved in the Goldsworthy Range. In the Ord Range, the stratigraphy is poorly preserved but shows the same generalized sequence. The basal units are typically of medium- to coarse-grained, poorly sorted sandstone and lesser siltstone and include mafic volcanic detritus, some of which is juvenile. These rocks have formed from dominantly high-energy subaqueous deposits, including debris flows. In both the Goldsworthy and Ord Range, these rocks are overlain by basaltic flow units and rocks formed from mafic volcaniclastic debris-flow deposits. In the Goldsworthy Range, the basalts were incorrectly shown as komatiitic basalt and the sequence was called the Salt Well Member (Smithies, 2001). Subsequent petrographic studies show this basalt to be a strongly plagioclase-phyric rock. The basalt and associated volcaniclastic pile does not differ between the Ord and Goldsworthy Range and so the rocks at both localities (i.e. *ADpb, ADpvsb* on De Grey; *ADpl, ADpld, ADplx* on Pardoo) can all be included within the Salt Well Member. The upper part of the Paradise Plains Formation is dominated by coarse-grained sandstone and conglomerate. The stratigraphically lowest unit of this upper sequence (*ADpsgb*), is found in both the Ord and Goldsworthy Ranges, but is the only unit of the upper sequence to be exposed in the Ord Range. The unit includes thin interbeds of mafic volcaniclastic rock, indicating a transition from volcanic and volcaniclastic deposition to clastic deposition.

Overall, the Paradise Plains Formation records an early period of subaqueous clastic, mainly debris-flow, deposition with increasing input from mafic volcanism, mainly as volcaniclastic deposits but locally including vesicular and pillowed subaqueous flow units. Subaqueous clastic deposition continued as volcanic and volcaniclastic deposition waned and eventually ceased. A transition, from subaqueous debris-flow deposits to deposits characteristic of subaerial, fluvial environments, ultimately resulted in the formation of the medium- to coarse-grained, trough cross-bedded sandstones and polymictic conglomerates that characterize the upper levels of the formation. These conglomerates show a regular persistent stratigraphic variation in clast population, reflecting a secular change of hinterland.

Lower clastic and volcaniclastic units (ADpssb, ADpss)

Medium- to coarse-grained, poorly sorted sandstone and lesser siltstone (*ADpss*), locally interbedded with mafic tuffaceous rocks (*ADpssb*), are preserved on the south-eastern side of the Ord Ranges (e.g. at MGA 728900E 7752000N) and in the southwestern part of the Goldsworthy Syncline (e.g. at MGA 754200E 7744700N), on DE GREY. The sandstone and siltstone are very immature, containing angular to subangular grains, fragments and clasts of quartz, chert, and basalt in a chlorite-, sericite-, and carbonate-rich matrix that typically forms more that 30% of the rock. The proportion of chert and basalt fragments or clasts is approximately equal. Chert clasts and fragments are probably derived from the underlying Nimingarra Iron Formation, and show a range of textural and compositional types consistent with that interpretation. In the sandstone, rock fragments typically range up to pebble size, but blocks up to 4 m in size are also found. Grains, clasts, and fragments typically show little or no size sorting, but rare grain-size grading to laminated siltstone top beds is locally observed. The rocks are interpreted to have formed from subaqueous debris-flow deposits, with local preservation of silt-rich layers formed from suspended material that settled after each debris flow.

Finer grained top beds may also preserve pea-sized inclusions comprising numerous concentric shells of silt accreted around a fine-grained rock or mineral fragment. The inclusions are interpreted to be accretionary lapilli and suggest volcanism contemporaneous with clastic (debris-flow) deposition. Tuffaceous beds comprising abundant accretionary lapilli occur locally. The petrography of basalt clasts and fragments in the sandstone is consistent with derivation from the Salt Well Member (see below), and combined with the presence of accretionary lapilli, suggests that sedimentation overlapped the early stages of basaltic magmatism.

Salt Well Member and associated rocks (ADpl, ADpld, ADplx, ADpb, ADpvsb)

Vesicular, plagioclase-rich basalt, typically with a trachytic texture (*ADpl*), locally including dolerite intrusions (*ADpld*) and volcaniclastic debris-flow deposits and breccias (*ADplx*), occupy the western part of the Goldsworthy Syncline (e.g. at MGA 754200E 7749000N) and constitute the Salt Well Member. In the Ord Range, basalt (*ADpb*) and volcaniclastic sandstone derived from debris-flow deposits (*ADpvsb*) are found at the same stratigraphic level as the Salt Well Member, and are here correlated with that member.

The basalts in the Ord and Goldsworthy Ranges (*ADpl* and *ADpb*) are petrographically very similar. They contain up to 40% tabular to acicular plagioclase euhedra that, in many cases, are flow aligned and this gives the rock a trachytic texture. The plagioclase euhedra are up to 4 mm long, but in dolerite intrusions (*ADpld*), they are up to 8 mm in length. They are normally zoned and, rarely, skeletal. Euhedral pyroxene phenocrysts are up to 1.5 mm in length, locally form up to about 10% of the mode, and have been completely altered to actinolite or, most commonly, chlorite, carbonate, and silica. The fine-grained groundmass is plagioclase-rich and is extensively altered to chlorite, sericite, carbonate, and epidote, with minor leucoxene. Interstitial quartz occurs in some samples but may not be a primary mineral. Where they occur, vesicles are up to 1 cm in diameter, commonly contorted or flattened, and are now filled by combinations of quartz, epidote, calcite, and chlorite. The dolerites (*ADpld*) lack a trachytic texture, but are mineralogically identical to the basalts.

Sedimentary basaltic breccia (*ADplx*) is known only in the Goldsworthy Syncline (DE GREY: at MGA 754500E 7749300N) where it forms a clast-supported accumulation of angular basaltic and volcaniclastic fragments that are up to 4 cm in size (Fig. 12). This rock has been extensively replaced by carbonate and is locally ferruginized. The breccia unit is massive and poorly sorted over a thickness of many metres, but the upper parts of the unit show grain-size grading to a volcaniclastic siltstone. The basalt fragments are petrographically recognizable as belonging to the Salt Well Member (*ADpl*), and coherent basalt flows are found along strike.

A unit of volcaniclastic sandstone and siltstone derived from basalt (*ADpvsb*) is best exposed immediately to the east of the Ord Range (DE GREY; e.g. at MGA 729100E 7753800N). The unit is typically well bedded (Fig. 13). Individual beds may include a 0.5 – 2 m-thick layer of massive, poorly sorted rock comprising coarse sand-sized particles of basalt, and rare to locally common basalt

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Figure 12. Highly carbonate-altered mafic volcaniclastic breccia, Paradise Plains Formation (*ADplx*), comprising a clast-supported accumulation of angular basaltic and volcaniclastic fragments: DE GREY (MGA 754300E 7749200N)

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Figure 13. Well-bedded mafic volcaniclastic sandstone, Paradise Plains Formation (*ADpvsb*): De Grey (MGA 728941E 7753828N). Pen is 13 cm in length

fragments up to 50 cm in size (Fig. 14). This sandstone layer may be capped by a 10–30 cm-thick layer that grades upwards to laminated siltstone. The basalt component of the sandstone layer is derived from the Salt Well Member. Matrix forms up to 40% of the rock and consists of fine-grained basalt particles or basaltic minerals (mostly plagioclase) that have been extensively altered to chlorite, carbonate, sericite, and epidote.

Upper clastic (including debris-flow) units (ADpsxc, ADpscp, ADpsgb)

Polymictic conglomerate (*ADpscp*), locally including mafic volcaniclastic rock and debris-flow deposits (*ADpsgb*), outcrops in both the Ord and Goldsworthy Range (e.g. at Ord Range, MGA 729500E 7750300N). These rocks contain subrounded to subangular pebble- to boulder-sized clasts derived from a range of basement lithologies including basalt (probably of the Warrawoona Group), chert, and granite. The clasts are supported in a quartz-rich sandy matrix. Lenses of poorly sorted mafic volcaniclastic sandstone and siltstone (?tuff) occur locally, as do interbeds of poorly sorted, quartz-rich sandstone.

Fine- to coarse-grained, poorly sorted chert breccia (*ADpsxc*) outcrops only in the Goldsworthy Range. It comprises a highly chaotic polymictic mix of angular chert, siltstone, and ironstone fragments, and rounded basalt clasts, up to 1 cm in size, supported by a fine-grained quartz matrix.

Upper clastic (fluvial) units (ADpspp, ADpspc, ADpspr, ADpstr, ADpspq)

These units outcrop widely in the core of the Goldsworthy Syncline, but are rare in the Ord Range, where they are restricted to a single outcrop of sandstone and pebbly sandstone (*ADpspc;* at MGA 729600E 7749800N). They comprise a range of fluvial deposits: coarse-grained, poorly sorted subarkosic sandstone and pebbly sandstone, which is typically trough cross-bedded and locally shows well developed graded bedding; clast- to matrix-supported polymictic pebble- to cobble-conglomerate; and matrix-supported quartz-pebble conglomerate. These deposits combined in various proportions to produce distinct mapping units. These mapping units include: coarse-grained, poorly sorted sandstone (*ADpstr*); coarse-grained, poorly sorted pebbly sandstone containing pebbles of black chert and quartz (*ADpspp*); coarse-grained, poorly sorted pebbly sandstone, locally with clast-supported black-chert and quartz-pebble conglomerate (*ADpspc*); interbedded sandstone and clast-supported black-chert and quartz-pebble conglomerate (*ADpspr*); and coarse-grained, poorly sorted sandstone, locally interbedded with quartz-pebble conglomerate (*ADpspq*). The latter unit is distinctive amongst the conglomerate units in that it alone was monomictic, containing quartz pebbles but no black chert clasts.

Rocks of similar age to the De Grey and Bookingarra Groups (*ABD*, *ABD(f)*, *ABD(fs)*, *ABD(fy)*)

On the eastern edge of De Grey, in the area between Coolan Well and Knaptons Well, there are several scattered northeasterly trending outcrops of felsic volcanic rock (*ABD(f)*), including schistose (*ABD(fs)*) and vesicular (*ABD(fy)*) varieties. The felsic rock has been dated (GSWA sample 169025) by Nelson (2001) at 2948 ± 3 Ma. This date is in the depositional age range of both the De Grey and Bookingarra Groups, as established from studies of the Mallina and Whim Creek Basins in the Central Pilbara Tectonic Zone (Smithies et al., 1999, 2001; Huston et al., 2000). These felsic volcanic rocks do not form part of the Goldsworthy greenstone belt, and are separated from it by the east-northeasterly trending Pardoo Fault. Based on airborne regional magnetic data and limited drillhole data (Leech, 1979), stratigraphically undivided greenstones equivalent in age to the De Grey and Bookingarra Groups (*ABD*) are interpreted to form a major component of the unexposed basement to the north of the Pardoo Fault (Fig. 4).

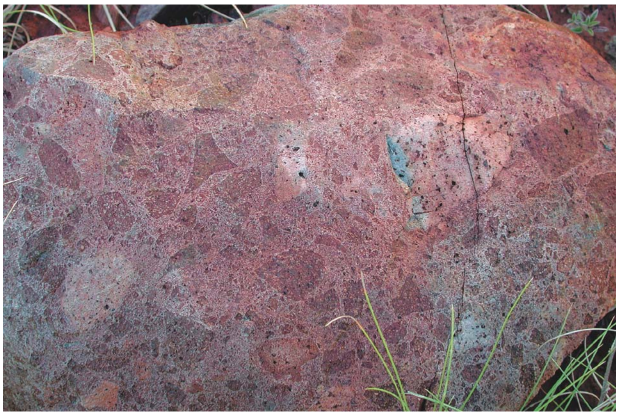

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Figure 14. Mafic volcaniclastic breccia, Paradise Plains Formation (*ADpvsb*): De Grey (MGA 729161E 7753855N). Outcrop shown is approximately 30 cm high

The least-deformed felsic volcanic rocks locally display flow-banding, and margins to individual units can show both flow-brecciation and hyaloclastite. Spherulites are common and may constitute up to 70% of the rock. The abundance of spherulites indicates an originally glass-rich rock. In many cases, much of the rock is now extensively altered to sericite, but grains (?phenocrysts) of quartz and feldspar are locally recognizable. Much of the feldspar component is probably alkali-feldspar (?sanidine — based on rare simple twins), suggesting a rhyolitic protolith.

Unassigned greenstone units younger than the De Grey Group (*Abs*, *Aog*, *Afp*)

Minor outcrops of supracrustal rocks of the Pilbara Supergroup known or inferred to be younger that the De Grey Group are found on both De Grey and Pardoo.

Deeply weathered actinolite–chlorite schist after mafic rock (*Abs*) forms scattered outcrop in the core of the Goldsworthy Syncline on Pardoo (e.g. at MGA 766500E 7751500N). Metagabbro (*Aog*) outcrops in the Ord Ranges (De Grey; at MGA 725000E 7752500N), where it is interpreted to define a late intrusion into deformed rocks of the Nimingarra Iron Formation. It is a medium-grained pyroxene gabbro, showing weak to moderate replacement of original mineralogy (including both clinopyroxene and orthopyroxene) to actinolite, chlorite, sericite, carbonate, and quartz. The metagabbro is locally in faulted contact with a small outcrop of strongly weathered, metamorphosed, plagioclase porphyry (*Afp*). The porphyry contains plagioclase phenocrysts up to 1 cm in size, occurs only at this locality, and is interpreted to be similar in age to the metagabbro.

Felsic intrusions

Muccan Granitoid Complex (*AgMmp*, *AgMpx*, *AgMmpl*, *AgMt*, *AgMtx*)

Outcrop of the Muccan Granitoid Complex lies entirely on the southeastern part of Pardoo and essentially comprises porphyritic to seriate monzogranites and syenogranites (*AgMmp*), and an older phase of tonalite (*AgMt*). A sample of monzogranite (GSWA 178022) taken from near Granite Well (MGA 799700E 7738870N), in the eastern part of Pardoo, has an age of 3315 ± 3 Ma (Nelson, in prep.). The tonalite found on Pardoo (GSWA 178023; MGA 797995E 7738470N) has been dated at 3420 ± 3 Ma (Nelson, in prep.).

The tonalite locally contains abundant greenstone xenoliths (*AgMtx*), particularly close to the faulted western contact between the Muccan and Carlindi Granitoid Complexes (e.g. at MGA 791000E 7741000N and MGA 794000E 7743000N). Adjacent to the northerly trending eastern margin of the tonalite, the monzogranitic and syenogranitic rocks have incorporated abundant rafts and inclusions of tonalite (Fig. 15), which have become strongly attenuated and partially disaggregated, giving the outcrop a prominent schlieric texture (*AgMmpl*).

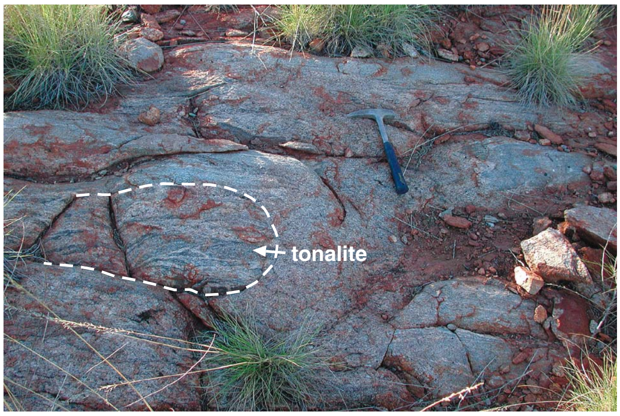

Figure 15. Rafts of foliated tonalite (*AgMt*) in monzogranite: Pardoo (MGA 798887E 7738826N)

The monzogranitic to syenogranitic rock (*AgMmp*) is weakly foliated to massive. It is typically a medium- to coarse-grained, K-feldspar porphyritic to megacrystic rock containing up to 7% biotite as the only mafic mineral. K-feldspar megacrysts reach 3 cm in length and enclose earlier-crystallized plagioclase and biotite. Biotite, locally aggregated into clots up to 5 mm in diameter, is partially to totally altered to a combination of chlorite and muscovite.

In the tonalite (*AgMt*), segregation into mafic-rich bands and quartz–plagioclase-rich bands defines a moderately to well-developed foliation. Hornblende is the dominant mafic phase, with minor magnetite and biotite, but this assemblage is partially to totally chloritised. No alkali-feldspar is observed in thin section.

Carlindi Granitoid Complex (*AgL*, *AgLmp*, *AgLmpx*, *AgLmpf*, *AgLt*)

Based on airborne regional magnetic data, the contact between the Muccan and Carlindi Granitoid Complexes is a major north-northeasterly trending fault or shear zone (Fig. 4). The northern part of the Carlindi Granitoid Complex (*AgL*) is inferred to lie beneath Quaternary sand cover in the southern part of De Grey but is exposed in the southwestern corner of Pardoo and extends to the northeast beneath Quaternary sand cover. On De Grey only one outcrop of the complex has been found, a strongly foliated leucocratic tonalite (*AgLt*). This is southwest of Merrigu Well (at MGA 725300E 7745100N), and it lies close to the interpreted position of the Pardoo Fault. The tonalite is a plagioclase-porphyritic biotite tonalite, that contains rounded to lobate inclusions of hornblende diorite and hornblende tonalite. Plagioclase phenocrysts are up to 1 cm in diameter and have been rounded during deformation of the rock. Groundmass minerals wrap around the phenocrysts and include strongly strained and flattened quartz. Biotite is typically completely altered to chlorite. On Pardoo, outcrop of the

Carlindi Granitoid Complex comprises porphyritic and seriate-textured monzogranite and syenogranite (*AgLmp*) petrographically indistinguishable from that found in the adjacent Muccan Granitoid Complex (*AgMmp*). Locally, this granitic rock contains abundant greenstone xenoliths (*AgLmpx*). Adjacent to the faulted contact between the two granitoid complexes, rocks of the Carlindi Granitoid Complex have been strongly foliated (*AgLmpf*).

Pippingarra Granitoid Complex (*AgI, AgIchm, AgId*)

The Pippingarra Granitoid Complex (*AgI*) forms a large area of outcrop on DE GREY to the west of the Ord Range, and the complex is interpreted to form a major proportion of the Archaean bedrock on the western half of that sheet area. Here, the outcrop is divided between K-feldspar porphyritic monzogranite and lesser granodiorite of the Chillerina Granodiorite (*AgIchm*) and hornblende–biotite diorite and granodiorite (*AgId*). Both rocks also outcrop extensively to the southwest on WALLARINGA, where the Chillerina Granodiorite has been dated at c. 2945 Ma, and the age of the hornblende–biotite diorite and granodiorite (*AgId*) has been constrained between c. 2955 and 2945 Ma (Smithies et al., 2002).

Dolerite dykes (*d, Pdo, Pdw*)

Because of extensive Cainozoic cover over DE GREY and PARDOO, outcrops of dolerite dykes (*d*) are extremely sparse. These clearly post-date the granite–greenstone terranes and are represented by a few northeasterly trending, weakly metamorphosed dykes that have intruded the Muccan Granitoid Complex on the southwestern half of PARDOO. Aeromagnetic data, however, define two sets of late dolerite dykes, one trending from northeast to east-northeast, the other trending to the northwest. The former dykes are probably part of the Mundine Well dyke swarm (*Pdw*) (Hickman, 1983) that has been dated by Wingate (1999) at 755 ± 3 Ma. They crosscut the northwest trending dykes, which can be assigned to the Round Hummock dyke swarm (*Pdo*; Van Kranendonk, M. J., 2004, written comm.).

Metamorphism and structure

In general, the rocks of the EPGGT, on DE GREY and PARDOO, show little evidence of having re-equilibrated at grades higher than middle greenschist facies. One exception to this is the presence of greenstone xenoliths within hornblende tonalites (*AgMt*) of the Muccan Granitoid Complex on PARDOO, where mafic rocks have re-equilibrated at amphibole facies to produce hornblende–plagioclase amphibolite.

The earliest recognizable structures are found in the Ord Range, where the prominent easterly trending folding of the Nimingarra Iron Formation has affected an earlier fabric. This is most clearly seen in terms of the marked rotation of early fold hinges around the later easterly trending folds (e.g. at MGA 723700E 7759100N; 723800E 7753500N; 724200E 7749900N); and in what appear to be interference folds on the southern limb of the main synformal anticline (e.g. around MGA 726500E 7755200N). The major folds are tight to isoclinal, with a steep axial plane, and typically plunge at a moderate to shallow angle to the east-southeast. Because the rocks of the Nimingarra Iron Formation typically provide few indications of sedimentary way-up direction, these folds have been mapped as a series of synforms and antiforms (incorrectly shown on the map as synformal anticlines and antiformal synclines). The precise age of folding is unknown, but the deformation did not affect the c. 2955 and 2945 Ma granodiorite of the Pippingarra Granitoid Complex.

In the northern part of the Pilbara Craton, the boundary between the CPTZ and the EPGGT is essentially based on an interpretation of aeromagnetic data; from this it appears that the boundary coincides with the east-northeasterly trending Pardoo Fault. Here, the inferred boundary simply separates zones that suffered greater and lesser degrees of deformation during the development of the Mallina Basin. For rocks both older and younger than the basin, lithological correlations across the fault are locally preserved. Lithological successions in the Ord and Goldsworthy Ranges, on either side of the Pardoo Fault, can be correlated, and the similarities between the respective outcrops of the De Grey Group are compelling. Structurally, however, the two areas differ in that the major folds in each do not appear to be related to the same event. In the Ord Ranges, the basal unconformity of the Paradise Plains Formation drapes over rock already folded during the main easterly trending folding event. In contrast, the Paradise Plains Formation in the Goldsworthy Range has been folded, along with the underlying Nimingarra Iron Formation, to form the tight, upright, northeasterly trending Goldsworthy Syncline. In this syncline, rocks of the Nimingarra Iron Formation locally preserve an earlier cleavage, axial planar to smaller scale folds (e.g. DE GREY: MGA 757300E 7746000N). This is not observed in rocks of the Paradise Plains Formation, which is folded around the Goldsworthy Syncline.

The oldest supracrustal rocks on DE GREY and PARDOO are those of the Warrawoona Group, best exposed on PARDOO, to the southeast of the Goldsworthy Range. The earliest preserved structure here is southwesterly trending folding, preserved only as a folded fault (MGA 767600E 7745300N). The age of this folding is not clear, but similarly oriented folds(?) affecting both the basalts and the Nimingarra Iron Formation (at MGA 766300E 7747300N) suggest that it is quite late. A strongly developed northeasterly trending foliation parallels, and presumably relates to, faulting and shearing that post-dates this folding, but it can locally be seen to intersect a more northerly trending foliation that may be axial planar to the early folding event.

Extensive faulting and shearing is a feature of the Archaean geology on DE GREY and PARDOO. Some fault systems, such as the Tabba Tabba Shear Zone, and probably also the Pardoo Fault, include periods of movement that pre-date deposition of the Paradise Plains Formation. They appear to have controlled deposition of the De Grey Group to the west on WALLARINGA (Smithies et al., 2002). The Tabba Tabba Shear Zone is a sinusoidal feature along which sinistral strike slip has provided local areas of extension that have been the focus of deeply sourced mafic magmas between c. 2970 and 2940 Ma (Smithies and Champion, 2002). On a regional scale, the north and northeasterly trending contact between the Carlindi and Muccan Granitoid Complex, as well as the adjacent zone of c. 3420 Ma tonalite (*AgMt*), has the same general sinuous shape and dominantly sinistral displacement as the Tabba Tabba Shear Zone. A strong foliation was imposed on the tonalite prior to intrusion of the c. 3315 Ma monzogranite and syenogranite of the Muccan Granitoid Complex, but a significant proportion of the north-northeasterly directed deformation post-dates these later granites, since lithologically mixed zones are themselves deformed. Mafic and ultramafic magmas were focused into a bend in this zone of tonalite after intrusion of the c. 3315 Ma granitic rocks.

East-northeasterly trending faults in the Goldsworthy Range probably relate to late movement along the Pardoo Fault. This movement post-dates deposition of the Paradise Plains Formation (c. 2970–2950 Ma: Smithies et al., 2001), but there is no indication from aeromagnetic data that the movement has significantly affected all phases of the northern part of the Carlindi Granitoid Complex, some of which are known to be c. 2940 Ma or younger in age (Smithies et al., 2002). It is interesting to note that the Goldsworthy Iron Ore Mine lies at the convergence of a number of these faults. Pillow basalt has been exposed within the mine pit at Goldsworthy (D. Kepert, written communication, 2001; Fig. 16) and almost certainly represents a faulted slice of the Warrawoona Group.

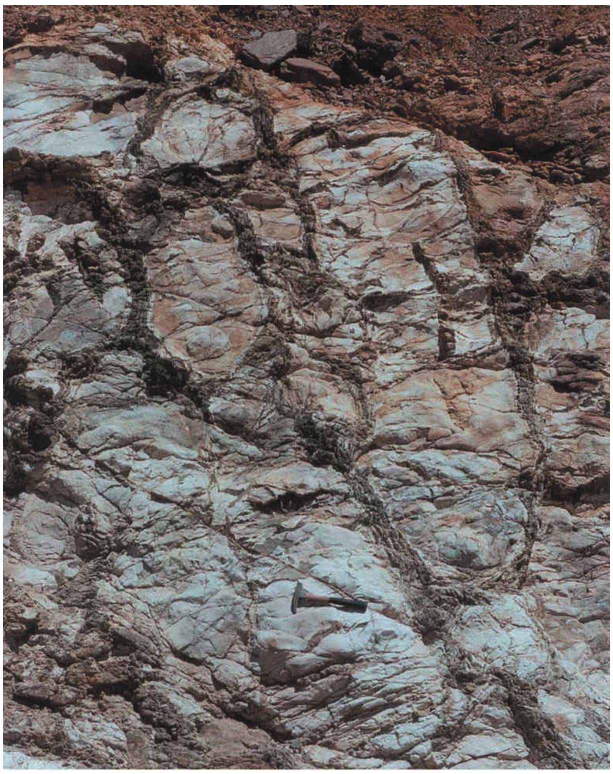

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Figure 16. Pillowed basalt, presumed to be of the Warrawoona Group, in the Goldsworthy Iron Ore mine: Pardoo (courtesy of D. Kepert)

North-northeasterly trending faults truncate the eastern part of both the Ord Range greenstone belt and the Goldsworthy greenstone belt. Movement along the fault that truncates the Goldsworthy greenstone belt is clearly sinistral and displaces the Pardoo Fault by as much as 20 km. A well-developed C–S fabric in basalts of the Warrawoona Group in the area to the southwest of the Goldsworthy Range is consistent with sinistral movement along the north-northeasterly trending fault system in that area.

Mesozoic rocks

Jarlemai Siltstone (*Jr*) and Wallal Sandstone (*Jl*)

Underlying the Callawa Formation, mudstone and minor sandstone of shallow marine origin form the Jarlemai Siltstone (*Jr*) and conformably overlie fine to very coarse grained, continental to marginal marine sandstone and conglomerate of the Wallal Sandstone (*Jl*). Neither the Jarlemai Siltstone nor the Wallal Sandstone outcrop on De Grey or Pardoo, but they are intersected in drillholes in the northern part of the sheets (Leech, 1979).

Callawa Formation (*JKc*)

Sedimentary rocks of the Callawa Formation outcrop throughout both De Grey and Pardoo, and represent remnants of a considerably more continuous, but thin, Mesozoic succession that onlapped the Pilbara Craton (Williams, 2000). This succession formed the southern margin of the Mesozoic Lambert Shelf, part of the Northern Carnarvon Basin of the Westralian Superbasin (Hocking et al., 1994). White (1961) considered the Callawa Formation to be Late Jurassic to Early Cretaceous in age based on plant fossils.

In the northern part of Pardoo and the northeastern part of De Grey, the Callawa Formation typically comprises interbedded ferruginous cobble to boulder polymictic conglomerate and ferruginous siltstones and sandstones. Where the formation directly overlies elevated outcrops of the Pilbara Supergroup, in the Ord and Goldsworthy Ranges, it is typically a medium- to very coarse-grained ferruginous sandstone. The sandstones consist of angular grains, dominantly of quartz but also including lithic fragments (mainly chert), in a partly to totally ferruginized silty matrix. Fossilised plant stems and branches occur locally (e.g. De Grey: at MGA 722300E 7758000N) and have been totally replaced by iron oxides.

Cainozoic rocks

Eocene to early Pleistocene deposits (*Cza*, *Czag*, *Czc*, *Czcf*, *Czcg*, *Czrf*, *Czrm*)

Dissected and consolidated colluvium (*Czc*) forms outwash fans flanking elevated outcrop in the Ord and

Goldsworthy Ranges. These deposits consist of clay- or silica-cemented, poorly stratified silt, sand, and gravel. Immediately west of the Shay Gap greenstone belt (e.g. PARDOO: at MGA 812000E 7738000N) they contain abundant ferruginous silt, sand, and gravel bound by a limonitic cement (*Czcf*). To the northeast and east of exposed areas of the Muccan Granitoid Complex (e.g. PARDOO: at MGA 810000E 7740000N), quartzofeldspathic colluvium (*Czcg*) has been derived from granitoid.

Undivided alluvial sand, silt, and clay, partly dissected by recent drainage (*Cza*), occurs in the southern part of DE GREY, between the Strelley and De Grey Rivers. Alluvial gravel (*Czag*) occurs in a small area to the southeast of the Goldsworthy Range (e.g. PARDOO: at MGA 767000E 7744500N), where it overlies rocks of the EPGGT on an old floodplain related to the De Grey River system.

Ferricrete (*Czrf*), or ferruginous duricrust, including ferruginous and pisolitic ironstone, occurs mainly on PARDOO, where it surrounds and partially overlies outcrop of the Callawa Formation. Minor accumulations are also found to the southwest and west of the Ord Range (e.g. DE GREY: at MGA 717000E 7746700N). Massive, grey to white siliceous caprock overlying altered high-Mg basalt (*Czrm*) of the Warrawoona Group forms low-lying outcrops to the north of the Goldsworthy Range (e.g. DE GREY: at MGA 754300E 77503000N) and locally shows minor green chromium staining.

Quaternary deposits

Alluvial, colluvial, eluvial, and eolian deposits (*Qaa*, *Qal*, *Qac*, *Qao*, *Qaoc*, *Qab*, *Qas*, *Qw*, *Qwg*, *Qc*, *Qs*, *Qrg*)

Present-day drainage channels contain alluvial clay, silt, and sand in channels on floodplains, and sand and gravel in rivers and creeks (*Qaa*). Alluvial clay, silt, and sand form overbank deposits on floodplains (*Qao*) and locally include gilgai (*Qab*). Gilgai is a clay-rich silt or sand deposit characterized by the development of numerous cracks and sinkholes. Alluvial sand and gravel also locally accumulates into levees and sandbanks (*Qal*) surrounding major channels (e.g. DE GREY: at MGA 728200E 7763000N). Large areas of lacustrine deposits (*Qac*) are present in the northeastern part of DE GREY and consist of clay, silt, and evaporite in shallow depressions on alluvial floodplains. On both DE GREY and PARDOO, smaller areas of claypan deposits lie on floodplains dominated by alluvial overbank deposits (*Qaoc*). Coastal sand deposits of mixed alluvial and eolian origin (*Qas*) form irregular low dunes and sandbanks that fringe lagoons.

Colluvium, consisting of sand, silt, and gravel (*Qc*) is locally derived from elevated outcrops and deposited on outwash fans and talus slopes. In more distal regions, sheetwash deposits (*Qw*) of silt, sand, and pebbles, locally overlying and derived from granite (*Qwg*), are deposited on outwash fans. Locally reworked by wind action, the sand deposits have generally been stabilized by extensive grass and shrub cover. Eolian sand (*Qs*) forms sheets and rare, unstable, east-southeasterly trending dunes on the eastern side of DE GREY and throughout the northern half of PARDOO. Quartzofeldspathic eluvial sand with quartz and rock fragments (*Qrg*) overlies, and has been derived from, a large proportion of granites of the Muccan Granitoid Complex.

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

Tidal-flat deposits, with or without mangrove swamp (*Qhmm* and *Qhmu*, respectively), comprise clay, silt, and sand. They tend to be less sandy than supratidal mudflat deposits (*Qhms*), which comprise partially vegetated calcareous clay, silt, and sand deposits on the landward fringe of the intertidal zone (tidal flats) and form elevated relicts within that zone. Lime-cemented dune sand and beach conglomerate including shell fragments (*Qpmb*) outcrop discontinuously at or near the coast.

Economic geology

A detailed description of the mineral occurrences and exploration potential of the EPGGT is provided by Ferguson and Ruddock (2001), from which the following summary is drawn.

Gold

To the southeast of the Goldsworthy Range, on PARDOO, gold has been worked from a series of generally north-easterly trending seams within altered metamorphosed, sulfide-bearing basalt and ultramafic rocks of the Warrawoona Group (Mine Well 1–3: at MGA 767290E 7743310N).

Iron ore

The Mount Goldsworthy mine (PARDOO) is the only iron ore mine on either DE GREY or PARDOO. Here, supergene-enriched iron ore has been extracted from the Nimingarra Iron Formation, on the southern limb of the Goldsworthy Syncline. This type of mineralization develops as a result of alteration and iron-enrichment processes involving supergene metasomatic replacement in BIF (Ferguson and Ruddock, 2001). Similar deposits have also been identified in the Ord Range (DE GREY: at Ridley No 4 and Ord Ridley).

Commencing in 1965, the Mount Goldsworthy mine was the first iron ore producer to export from the Pilbara region, and by 1972 had produced 32.7 Mt of ore. Between 1972 and 1982, when the mine closed, production from Goldsworthy was supplemented with ore from the Shay Gap and Sunrise Hill deposits to the east on COORAGOORA, with a combined production of 65.1 Mt.

Pisolitic iron ore deposits have also been identified on DE GREY, as Cainozoic mesa cappings to the west (at MGA 720000E 7752300N) and southwest (MGA 716500E

7746000N) of the Ord Range, with an estimated 2.3 Mt of ore containing between 52.2 and 59.4% Fe (Hickman and Gibson, 1982).

Nickel and base metals

On PARDOO, nickel and copper mineralization has been identified at the Highway prospect, and zinc mineralization has been discovered at the Supply Well prospect (Weir et al., 1992). At the Highway prospect, an unusual hydrothermal nickel–copper mineralization occurs in veins within rocks assigned to the Nimingarra Iron Formation, beneath 30–50 m of Mesozoic cover. An inferred resource is estimated at 37 Mt at 0.31% Ni and 0.12% Cu. At the Supply Well prospect, drilling intersected a 0.85 m-wide zone of zinc mineralization, containing 16.7% Zn and 0.38% Pb, in sulfidic chert of the Nimingarra Iron Formation.

Manganese

A small deposit of pisolitic and colloform pyrolusite is developed in Cainozoic duricrust over rocks of the Nimingarra Iron Formation, immediately west of the Shay Gap greenstone belt (PARDOO: at MGA 812435E 7737056N). Between 1959 and 1962 a total of 19 661 t of ore was removed at an average grade of 44% Mn, and estimated reserves of similar grade are about 50 000 t (Hickman and Gibson, 1982).

Tiger eye

Tiger eye is a semiprecious golden-brown chatoyant material formed by oxidation and silicification of crocidolite (Heaney and Fisher, 2003). It has been worked from 30–40 m-wide zones within the Nimingarra Iron Formation in the Ord Range (in the Ord Range 1–4 prospects on DE GREY). Jaspilite and haematite are also quarried as semiprecious materials. These deposits are periodically mined.

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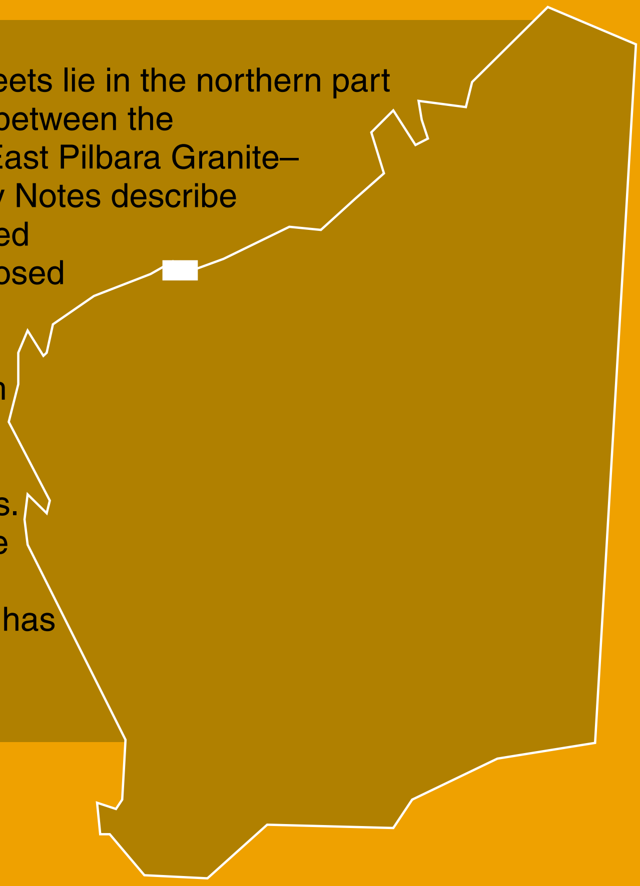
Appendix 1

Gazetteer of localities

Place name	*MGA coordinates*	
	Easting	*Northing*
Coolan Well	755450	7751950
De Grey Homestead	729100	7767600
Granite Well	799100	7740350
Highway prospect	766090	7756160
Knaptons Well	751350	7760250
Merrigu Well	726950	7746400
Mine Well	767250	7742100
Mount Goldsworthy mine	764838	7747456
Ord Range 1–4 prospects	723446	7755371
Ord Ridley prospect	723677	7754292
Pardoo Homestead	769800	7774500
Pardoo Roadhouse	795800	7780000
Ridley No 4 prospect	728340	7759434
Supply Well prospect	779036	7762777

The De Grey and Pardoo 1:100 000 sheets lie in the northern part of the Pilbara Craton, on the boundary between the Central Pilbara Tectonic Zone and the East Pilbara Granite–Greenstone Terrane. These Explanatory Notes describe the Archaean geology of the two exposed greenstone belts, and of the poorly exposed intervening granitoid complexes. The Archaean rocks are onlapped by thin units of Jurassic–Cretaceous age. Much of the area of the map sheets is covered by extensive Cainozoic and Quaternary alluvial and coastal deposits. In the past, the economic geology of the area was dominated by iron ore mining (Mount Goldsworthy), and other mining has included gold and semiprecious stones.



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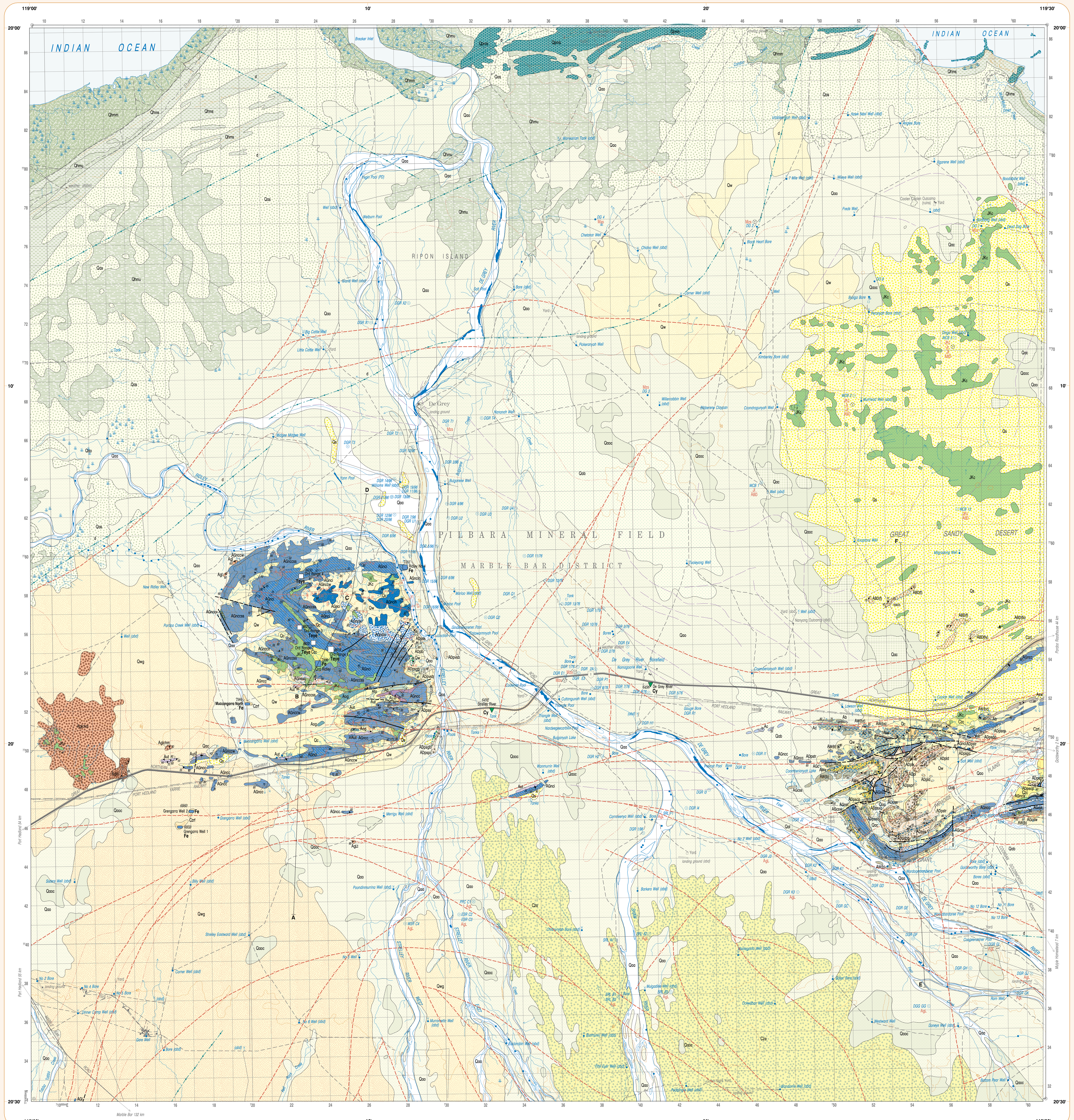
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 2757



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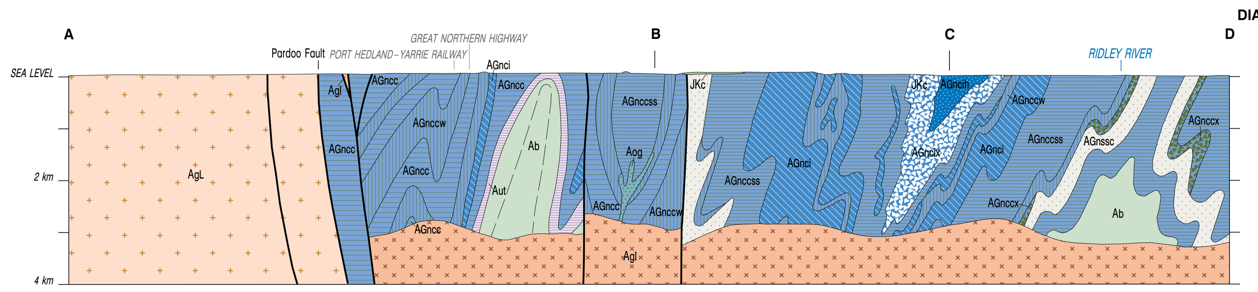

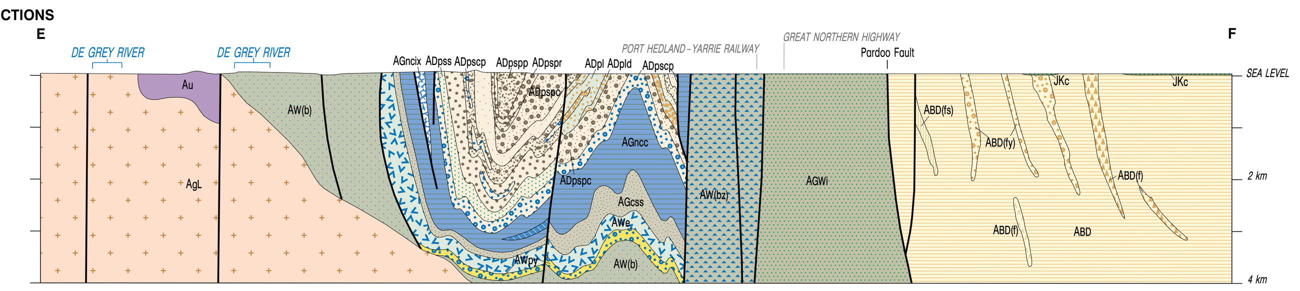

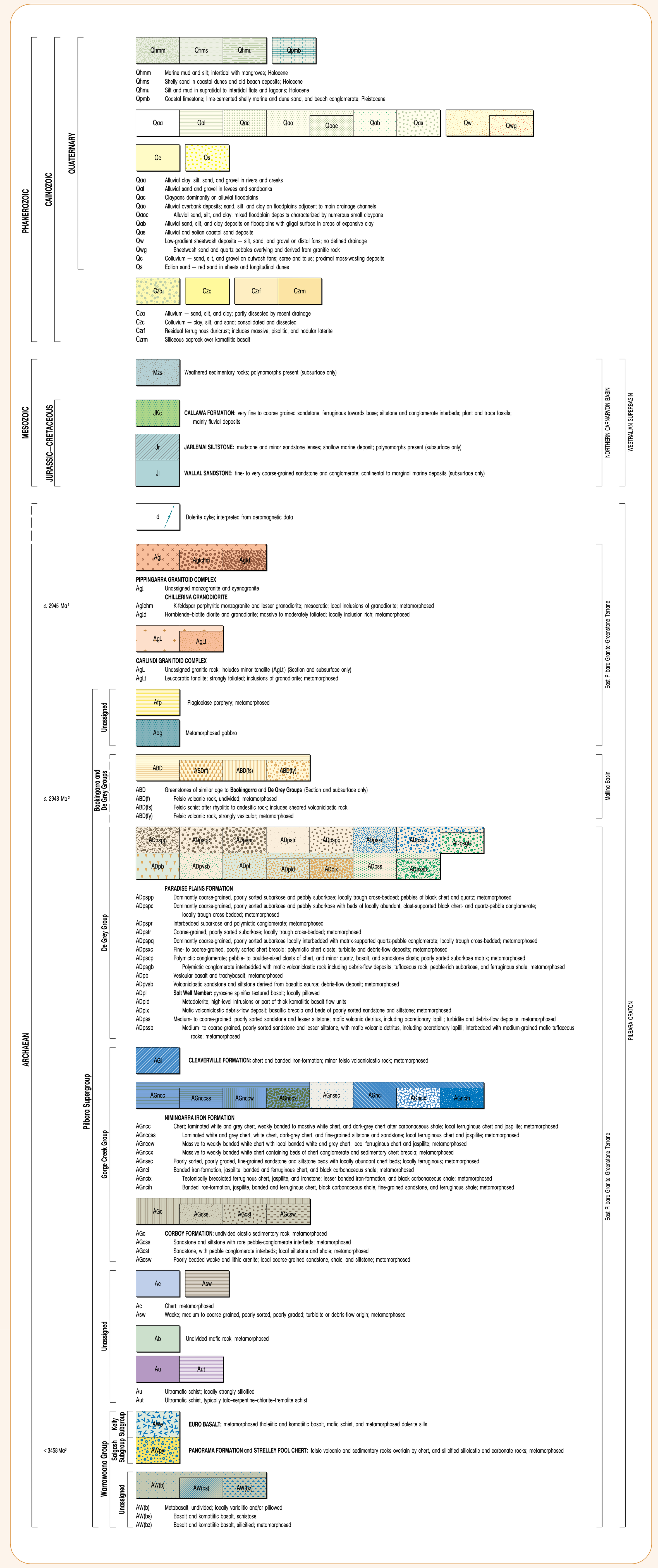

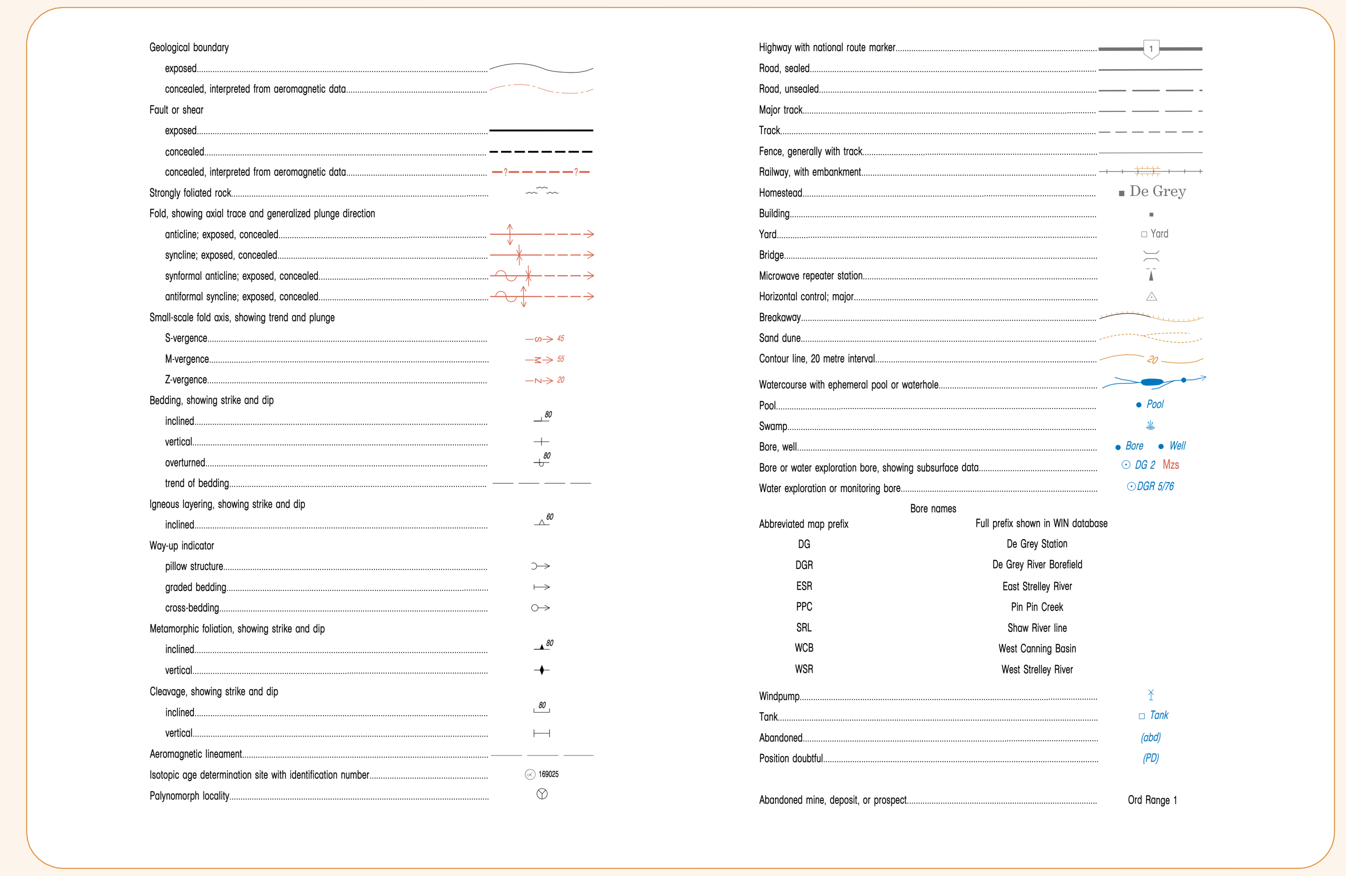

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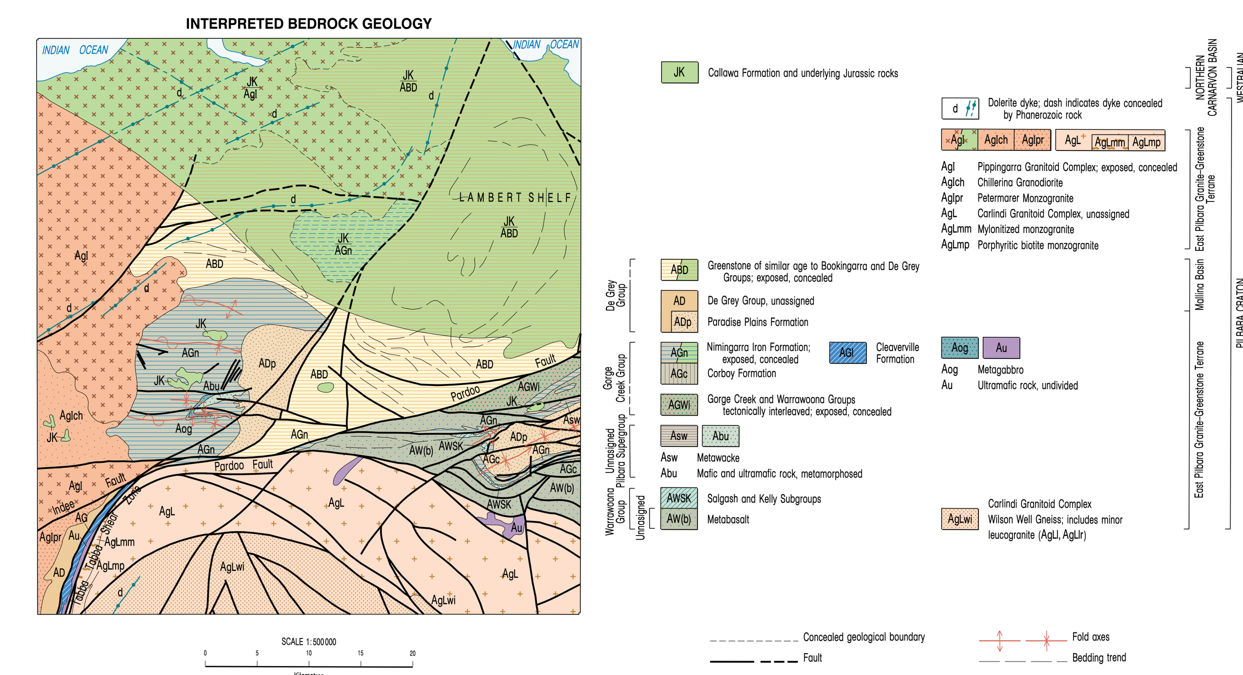

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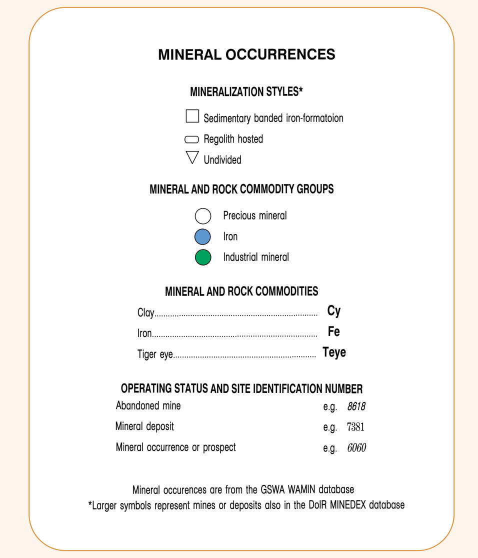

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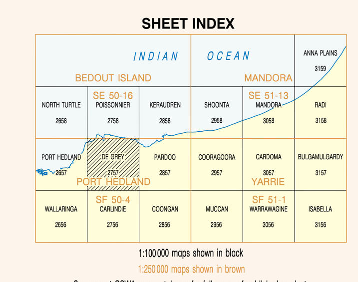

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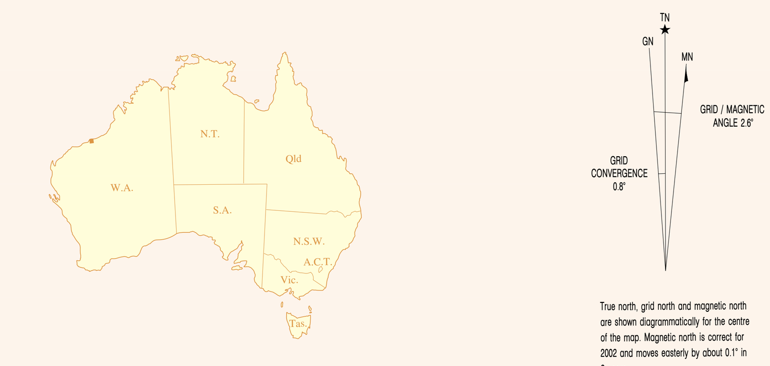

True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 2002 and moves easterly by about 0.1° in 2 years.

Geology by R. H. Smithies 2001, M. J. Van Kranendonk 2003, and A. H. Hickman 2004

Geochronology by:
(1) D. R. Nelson, 2001, GSWA Record 2001/2, p. 123–125.
(2) D. R. Nelson, 2002, GSWA Record 2002/2, p. 171–173.
(3) D. R. Nelson, in prep., GSWA Record 2004/2.

Edited by C. Strong, G. Hall, K. Greenberg, and G. Loan

Cartography by A. Francois and D. Ladbrook

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Geology	GSWA	2001	Dept of Industry and Resources
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Cadastre	TENGRAPH	JUN 2001	Dept of Industry and Resources
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Water bores	Water Information system (WIN)	AUG 2003	Dept of Enviromental Protection

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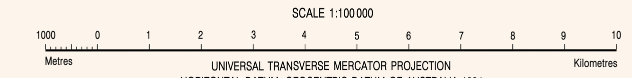

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DE GREY

SHEET 2757 **FIRST EDITION 2004**

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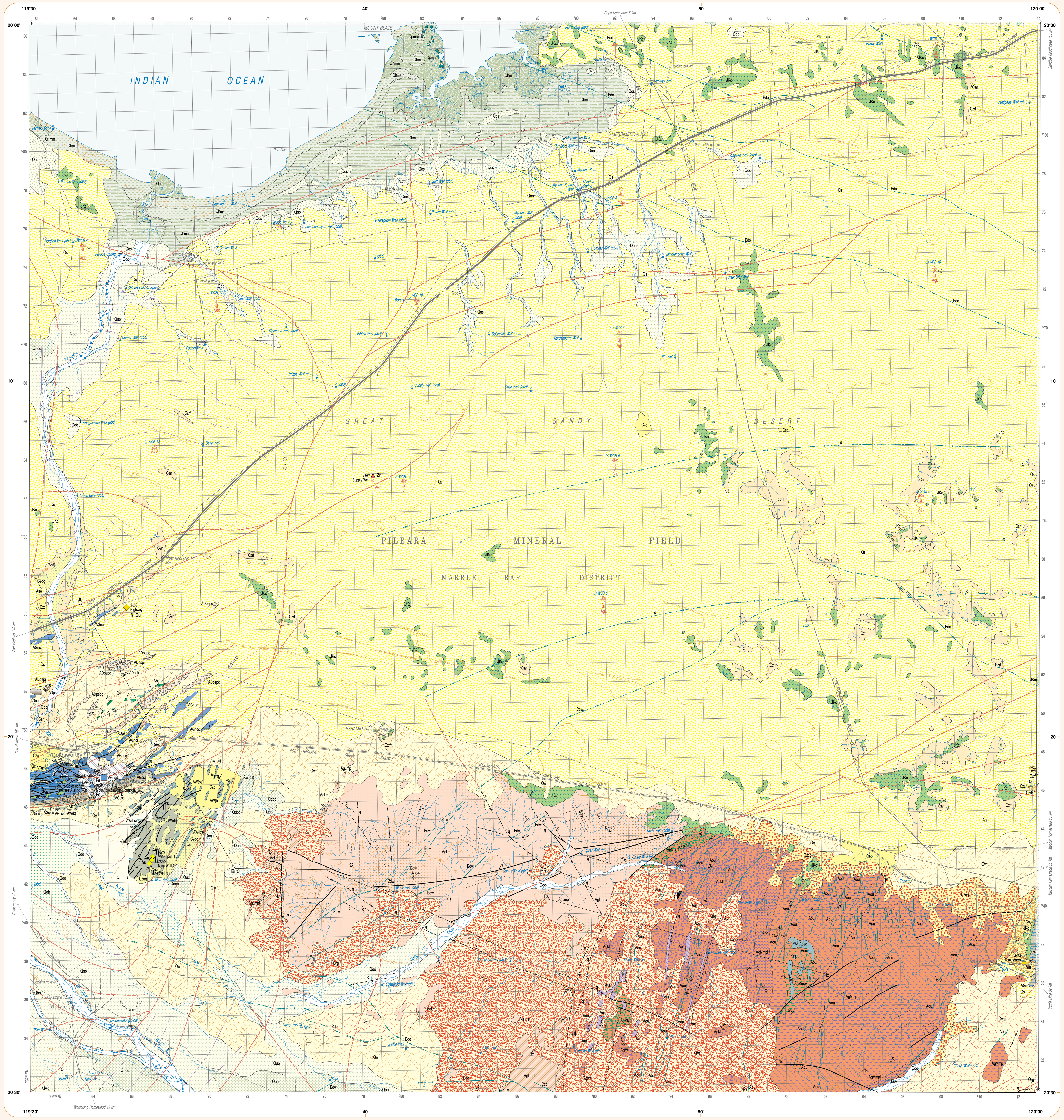
AUSTRALIA 1:100 000 GEOLOGICAL SERIES

PARDOO

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 2857



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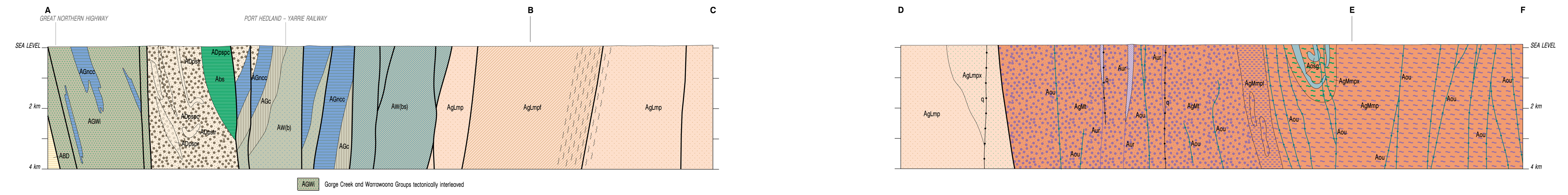


AGWi Gorge Creek and Warrawoona Groups tectonically interleaved

Legend

Code	Description
Qhmm	Marine mud and silt; intertidal with mangroves; Holocene
Qhms	Shelly sand in coastal dunes and old beach deposits; Holocene
Qhmu	Silt and mud in supratidal to intertidal flats and lagoons; Holocene
Qpmb	Coastal limestone; lime-cemented shelly marine and dune sand, and beach conglomerate; Pleistocene
Qaa	Alluvial clay, silt, sand, and gravel in rivers and creeks
Qac	Claypans dominantly on alluvial floodplains
Qao	Alluvial overbank deposits; sand, silt, and clay on floodplains adjacent to, and including, main drainage channels
Qaoc	Alluvial sand, silt, and clay; mixed floodplain deposits characterized by numerous small claypans
Qab	Alluvial sand, silt, and clay deposits on floodplains with gilgai surface in areas of expansive clay
Qas	Alluvial and eolian coastal sand deposits
Qw	Low-gradient sheetwash deposits — silt, sand, and gravel on distal fans; no defined drainage
Qwg	Sheetwash sand and quartz pebbles overlying and derived from granitic rock
Qc	Colluvium — sand, silt, and gravel on outwash fans; scree and talus; proximal mass-wasting deposits
Qs	Eolian sand — red sand in sheets and longitudinal dunes
Qrg	Residual quartzofeldspathic sand with quartz and rock fragments; overlying and derived from granitic rock
Czag	Alluvial gravel; consolidated; unrelated to, and dissected by, present-day drainage
Czc	Colluvium — clay, silt, and sand; consolidated and dissected
Czcf	Colluvail ferruginous deposits; recemented, broken, ferruginous duricrust rubble, ironstone pebbles, clay, silt, and sand; consolidated and dissected
Czcg	Colluvial clay, silt, sand, and gravel derived from granitoid rock; variably consolidated and dissected
Czrf	Residual ferruginous duricrust; includes massive, pisolitic, and nodular laterite
Mzs	Weathered sedimentary rocks; palynomorphs present (subsurface only)
JKc	**CALLAWA FORMATION:** very fine to coarse grained sandstone, ferruginous towards base; siltstone and conglomerate interbeds; plant and trace fossils; mainly fluvial deposits
Jr	**JARLEMAI SILTSTONE:** mudstone and minor sandstone lenses; shallow marine deposit (subsurface only)

PHANEROZOIC — CAINOZOIC — QUATERNARY; MESOZOIC — JURASSIC–CRETACEOUS; NORTHERN CARNARVON BASIN; WESTRALIAN SUPERBASIN; PROTEROZOIC; ARCHAEAN; PILBARA CRATON

Geological boundary
- exposed
- concealed
- concealed, interpreted from aeromagnetic data

Fault or shear
- exposed
- concealed
- concealed, interpreted from aeromagnetic data

Strongly foliated rock

Fold showing axial trace
- syncline; exposed, concealed

Bedding, showing strike and dip
- inclined
- vertical

Igneous layering, showing strike and dip
- inclined

Igneous flow banding, showing strike and dip
- inclined

Metamorphic foliation, showing strike and dip
- inclined
- vertical

Cleavage, showing strike and dip
- inclined
- vertical

Airphoto lineament
- fracture pattern

Aeromagnetic lineament

Palynomorph locality

Highway with national route marker, bridge

Formed road

Major track

Track

Fence, generally with track

Railway with siding, cutting, and embankment — Taplin

Powerline

Homestead — Pardoo

Building

Yard — Yard

Microwave repeater station

Horizontal control; major

Sand dune

Contour line, 20 metre interval — 40

Watercourse with ephemeral pool or waterhole

Soak, spring — Soak, Spring

Swamp

Bore, well — Bore, Well

Bore or water exploration bore, showing subsurface data — WCB 5 Mzs

Bore names

Abbreviated map prefix	Full prefix shown in WIN database
WCB	West Canning Basin

Windpump

Dam, tank — Dam, Tank

Artesian flow

Abandoned — (abd)

Abandoned mine, deposit, or prospect — Mount Goldsworthy

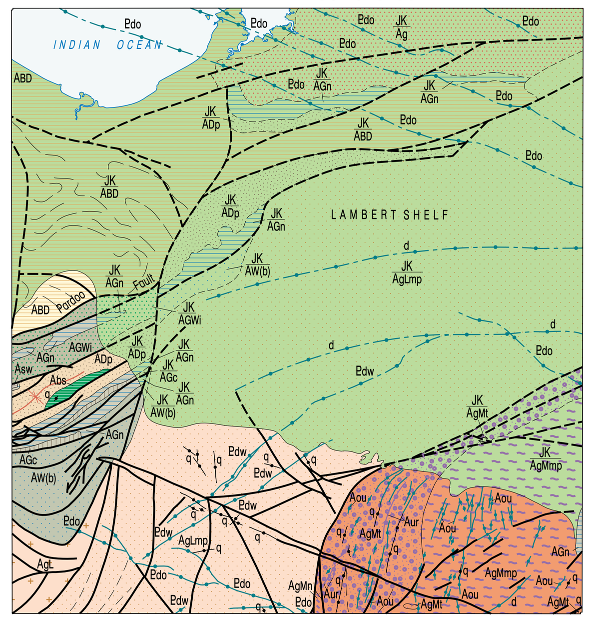
Opencut

Made ground or mining area

Tailings or stockpile

Mineral exploration drillhole showing subsurface data — AGn

INTERPRETED BEDROCK GEOLOGY



SCALE 1:500 000

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Code	Description
JK	Callawa Formation and underlying Jurassic rocks
Pdo	Round Hummock dyke swarm; dash indicates dyke concealed by Phanerozoic rock
Pdw	Mundine Well dyke swarm; dash indicates dyke concealed by Phanerozoic rock
d	Dolerite dyke; dash indicates dyke concealed by Phanerozoic rock
q	Quartz vein
AgL	Carlindi Granitoid Complex, unassigned
AgLmp	Porphyritic biotite monzogranite; exposed, concealed
Ag	Granitic rock, unassigned; concealed
Abs	Actinolite–chlorite schist
ABD	Greenstone of similar age to Bookingarra and De Grey Groups; exposed, concealed
ADp	Paradise Plains Formation; exposed, concealed
AGn	Nimingarra Iron Formation; exposed, concealed
AGc	Corboy Formation; exposed, concealed
AGWi	Gorge Creek and Warrawoona Groups tectonically interleaved; exposed, concealed
Asw	Metawacke
Aou	Mafic or ultramafic dykes
Aur	Tremolite–chlorite schist
	Muccan Granitoid Complex
AgMmp	Foliated porphyritic monzogranite; exposed, concealed
AgMt	Tonalite; exposed, concealed
AgMn	Migmatitic orthogneiss
AW(b)	Metabasalt; exposed, concealed

Unassigned Pilbara Supergroup; De Grey Group; Gorge Creek Group; Unassigned Pilbara Supergroup; Warrawoona Group; Unassigned; NORTHERN CARNARVON BASIN; WESTRALIAN SUPERBASIN; East Pilbara Granite–Greenstone Terrane; Mallina Basin; PILBARA CRATON

Concealed geological boundary

Fault

Fold axis

Bedding trend

Foliation trend

For further details, refer to main reference

MINERAL OCCURRENCES

MINERALIZATION STYLES*

MINERAL AND ROCK COMMODITY GROUPS

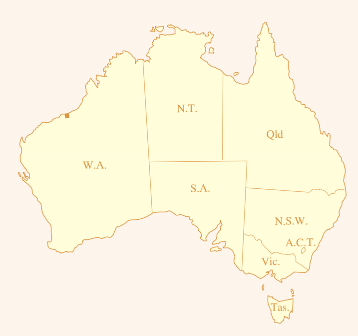
MINERAL AND ROCK COMMODITIES

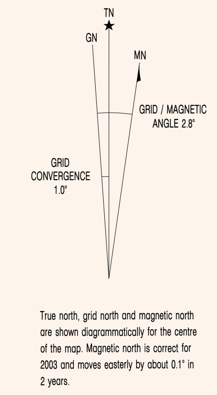
OPERATING STATUS AND SITE IDENTIFICATION NUMBER

Abandoned mine	e.g.	6058
Mineral deposit	e.g.	7456
Mineral occurrence or prospect	e.g.	7460

Mineral occurences are from the GSWA WAMIN database

*Larger symbols represent mines or deposits also in the DoIR MINEDEX database





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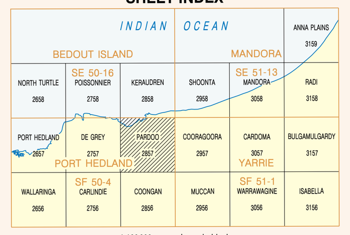

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(2) D. R. Nelson, in prep., GSWA Record.

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

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PARDOO

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Version 2.0 – June 2004