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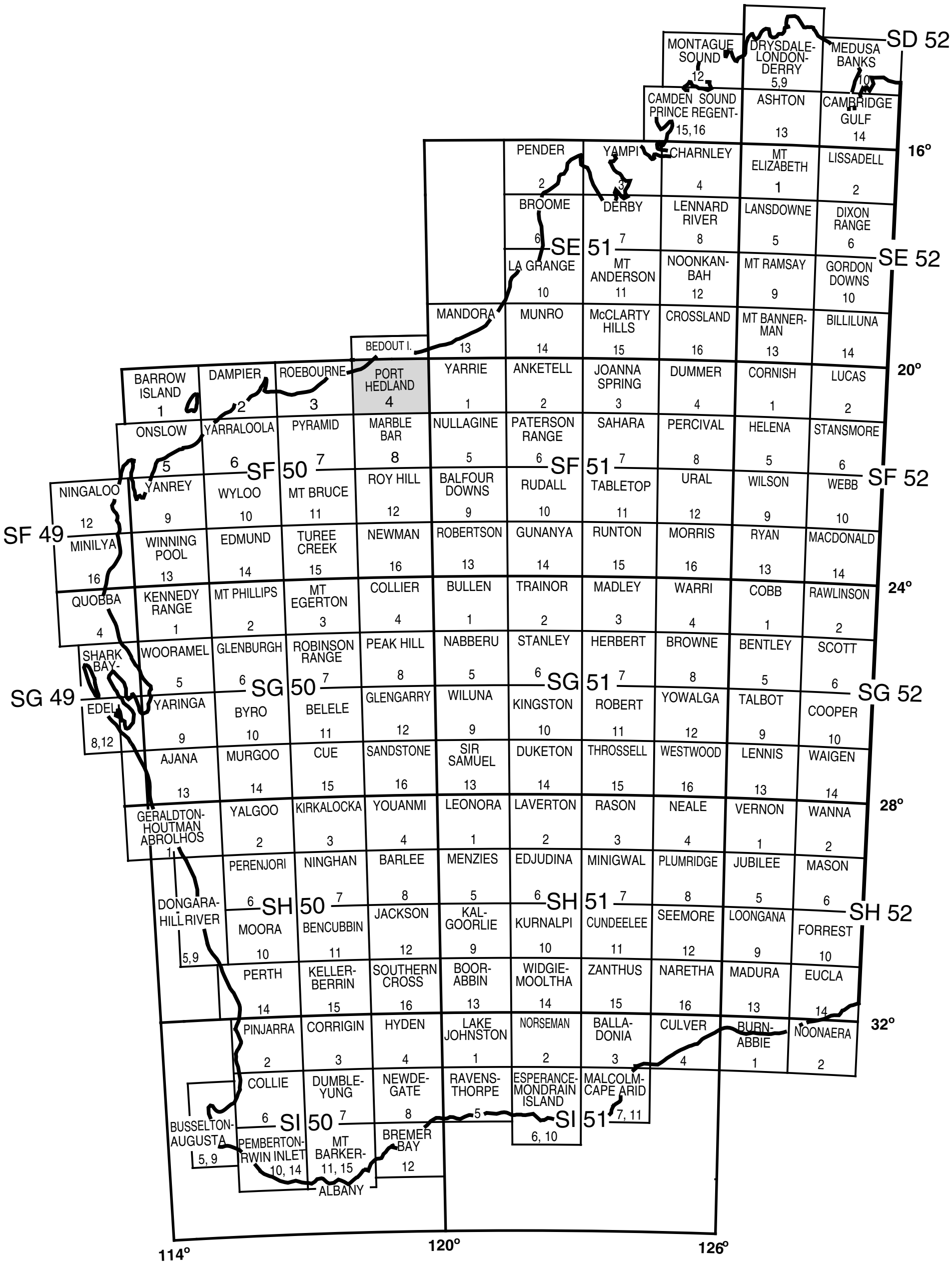
EXPLANATORY NOTES

GEOLOGY OF THE COONGAN 1:100 000 SHEET

by MJ Van Kranendonk

1:100 000 GEOLOGICAL SERIES

Geological Survey of Western Australia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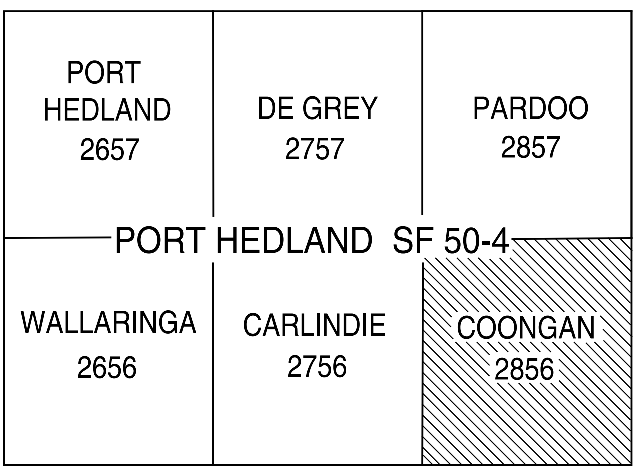
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by
MJ Van Kranendonk

Geological Survey of Western Australia

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Cover photograph:
View from Doolena Peak, looking east along strike of the Talga Range. The Coongan River at Doolena Gap is in the lower right foreground. The dark stripe of rocks from the centre across to the left of view is the c.2772 Ma Black Range Dolerite Dyke. Orange-weathering rocks on the far side of the Coongan River on the right of view are hydrothermally altered pillow basalts of the Mount Ada Basalt. Talga Peak is visible in the semi-distance. Rocks in the foreground are iron-stained quartzites of the Strelley Pool Chert. Flat area behind the Black Range Dyke is underlain by granitic rocks of the Muccan Granitic Complex.

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Geology of the Coongan 1:100 000 sheet

by

MJ Van Kranendonk

Abstract

The COONGAN 1:100 000 sheet covers parts of Paleoarchean to Mesoarchean East Pilbara Terrane of the north part of the Pilbara Craton and the Marble Bar Sub-basin of the Neoarchean–Paleoproterozoic Mount Bruce Supergroup. The East Pilbara Terrane on COONGAN comprises greenstone successions of the Pilbara Supergroup and part of the Carlindi, Muccan, and Mount Edgar granitic complexes. Volcano-sedimentary rocks belonging to two groups and one formation have been recognized, bounded by angular unconformities and a basal intrusive contact with granitic rocks. The Warralong, Doolena Gap, and Marble Bar greenstone belts in the south of COONGAN are composed of the c. 3490–3420 Ma Warrawoona Group, the c. 3400 Ma Strelley Pool Formation, and lower parts of the c. 3350–3315 Ma Kelly Group. A small part of the Panorama greenstone belt is exposed in the far southwestern corner of COONGAN, underlain by rocks of the Kelly Group. A Ni–Cu deposit is hosted by the Warrawoona Group along the eastern margin of the Warralong greenstone belt, and minor chromitite pods are present in the Doolena Gap greenstone belt. Minor Cu deposits are present in this belt, as well as in the Doolena Gap and Marble Bar greenstone belts. Minor Au deposits are present in the northern part of the Warralong greenstone belt and far eastern parts of the Doolena Gap and Marble Bar greenstone belts, with more significant Au mineralisation in the southern part of the Marble Bar greenstone belt, at McPhees Reward. Hydrothermal barite veins were observed in the Marble Bar greenstone belt.

The four greenstone belts on COONGAN are separated by unconformably overlying rocks of the De Grey and Mount Bruce supergroups or by long-lived faults. The De Grey Supergroup on COONGAN consists of the c. 3.01 Ga Gorge Creek Group and the Lalla Rookh Sandstone of the Croydon Group, deposited between 2.97 – 2.94 Ga. The two groups are separated by a regional unconformity and are themselves unconformably overlain by the interbedded volcanic and clastic sedimentary rocks of the Fortescue Group of the Mount Bruce Supergroup, preserved in the Pear Creek Centrocline of the Marble Bar Sub-basin.

The domal Muccan Granitic Complex dominates the COONGAN sheet area, and is well exposed in the eastern part of the map area. This multi-component complex shows intrusive relationships with rocks of the Warrawoona Group exposed in the Doolena Gap and Warralong greenstone belts. Components of the complex range in age from c. 3470 to 2940 Ma and comprise at least five main age groupings at c. 3470, 3420 Ma, 3310 Ma, 3250 Ma, and 2940 Ma. The northernmost part of the Mount Edgar Granitic Complex outcrops in the southeastern part of the sheet area and comprises c. 3310 Ma granitic rocks of the Emu Pool Supersuite. The Carlindi Granitic Complex occupies the northwestern part of the sheet area and includes predominantly late tectonic granites of the Sisters Supersuite, emplaced at c. 2940 Ma. Alluvial Sn, Ta, and Li in the Warralong and Marble Bar greenstone belts were probably derived through erosion of even younger granitic rocks belonging to the post-tectonic Split Rock Supersuite, not exposed on COONGAN.

Nine sets of structures are recognized in the basement granite–greenstone terrane on COONGAN; these are collated into four main deformation events. D_1 deformation involved syn-volcanic doming at c. 3467 Ma and the development of a disconformity between the Duffer and Panorama Formations of the Warrawoona Group. Folded leucosome veins in the Carlindi Granitoid Complex also formed at this time, and greenstones were further tilted (D_2) prior to deposition of the unconformably overlying Strelley Pool Chert of the Warrawoona Group at c. 3426–3350 Ma. D_3 and D_4 deformation events at c. 3325–3300 Ma and c. 3240 Ma involved major episodes of partial convective overturn of upper and middle crust accompanied by emplacement of granitic rocks of the Emu Pool and Cleland supersuites. Greenstones were further tilted during the Prinsep Orogeny at c. 3.07 – 3.05 Ga (D_5), prior to deposition of the De Grey Supergroup. The Gorge Creek Group was accompanied by syn-depositional growth faulting (D_6) and affected by post-depositional tilting (D_7), prior to deposition of the unconformably overlying Croydon Group. All rocks were then affected by the c. 2.94 Ga North Pilbara Orogeny (D_8), which included a major component of sinistral transpression within the Lalla Rookh – Western Shaw structural corridor that transects the northwestern corner of COONGAN. Subsequent tilting of the Croydon Group prior to deposition of the unconformably overlying Mount Bruce Supergroup is attributed to the effects of the c. 2905 Ma Mosquito Creek Orogeny (D_9). Rocks of the Mount Bruce Supergroup on Coongan have been affected by a further nine sets of syn-depositional deformation (D_{FOM1}–D_{FOM9}), including growth faults and tilting of bedding during formation of the Pear Creek Centrocline. These structures only weakly affected older greenstones, but served to amplify the pre-existing granite dome – greenstone syncline geometry of the area.

KEYW0RDS: Archean geology, Pilbara Craton, greenstones, granites, mineralization

Introduction

These Explanatory Notes describe the tectonic units, lithostratigraphic units, events, Cenozoic geology, and mineralization of the COONGAN* 1:100 000 sheet (2856), based on regional mapping carried out between 2000 and 2002, using 1:25 000-scale colour aerial photography together with interpretations of available regional aeromagnetic, geochronologic, and radiometric datasets.

COONGAN covers the southeastern part of the PORT HEDLAND – BEDOUT ISLAND 1:250 000 sheet (SF 50-4; Van Kranendonk and Smithies, 2006) between latitudes 20°30' and 21°00'S and longitudes 119°30' and 120°00'E in the northern part of the East Pilbara Terrane of the Pilbara Craton (Fig. 1; terminology after Van Kranendonk et al., 2006a). COONGAN lies within the East Pilbara Mineral Field and covers an area of Paleoarchean to Mesoarchean (3520–3200 Ma) metavolcanic and metasedimentary rocks of the Pilbara Supergroup, unconformably overlying, low-grade metasedimentary rocks of the 3020–2930 Ma De Grey Supergroup, and granitic rocks belonging to a number of supersuites that were emplaced throughout the evolution of the craton between 3525–2830 Ma. Unconformably overlying these are volcanic and sedimentary rocks of the Neoarchean (2775–2630 Ma) Fortescue Group of the Mount Bruce Supergroup (MacLeod et al., 1963; Trendall, 1990, 1995; Thorne and Trendall, 2001; Fig. 2). Cenozoic deposits cover extensive parts of the central and northern areas of COONGAN.

Geological events that have affected the rocks on COONGAN are summarized in Table 1. Three main periods of geological activity are recognized that relate to each of the Pilbara, De Grey, and Mount Bruce supergroups. Each of these main sets of events includes several discrete pulses of magmatism and/or basin formation that are either accompanied by, and/or followed by, deformation and metamorphism. The following notes are arranged to describe each of the periods according to tectonic unit, lithostratigraphy, and events.

Rock units described in these notes apply to the Geological Survey of Western Australia (GSWA) 1:100 000 digital database, using current lithostratigraphic and rock code practices. Neither the lithostratigraphy nor the rock codes used herein match those used on the published map. To facilitate cross referencing between these notes and the map, both the current code scheme and that used on the map (shown in square brackets) are given in rock unit descriptions.

Access, land use, climate, and vegetation

The main access on COONGAN is provided by the sealed Port Hedland – Marble Bar Road that transects the southern part of the map area (Fig. 3). A well-maintained, graded road extends east from the Port Hedland – Marble Bar Road, across the Talga River, to the Bamboo Creek Mining Centre and Yarrie Station on MUCCAN. Another well-maintained graded road extends north from the Port Hedland – Marble Bar Road along the west bank of the Coongan River, providing access to Warralong and Mulyie Stations, and continues north to the abandoned town of Goldsworthy and the Great Northern Highway. Several intermittently maintained pastoral tracks cross other flat parts of COONGAN, but much of the rugged terrain in the east is only accessible by four-wheel-drive or by foot traverse.

Warralong Station is the only extant settlement on COONGAN and runs cattle, as does Mulyie Station, 5 km north of the map sheet area, on PARDOO. Eginbah, Ettrik, and Nimingarra Homesteads are abandoned. Water, usually potable, is present in the central rivers, and in the rugged greenstone hills in the southwest.

COONGAN has an arid climate with an average annual rainfall of approximately 254 mm and an average annual evaporation of about 3600 mm (Pink, 1992), leaving the region dry during the late winter to early summer months. Rainfall is erratic, with little precipitation during the winter months of May and June, but the area is subject to floods during cyclone and thunderstorm activity between December and March. Average summer temperatures range from daily maxima of about 30–40°C, whereas daily winter temperatures typically vary between minima of around 12°C and maxima of about 30°C (Pink, 1992). The prevailing winds blow from the east and southeast.

Several species of spinifex grass (*Triodia*) grow on the area of COONGAN, with the largest species inhabiting creek beds or their banks. Elsewhere, the size and species of spinifex depends on the availability of near surface water and when the area was last burned. Sandy areas and some valleys contain *Grevillea*, wattles (*Acacia*), soft shrubs (e.g. *Crotalaria*), eucalypts, tea tree (*Melaleuca*), and Sturt Desert Pea. Creeks and rivers contain large eucalypts and grasses, and areas of rock outcrop include small shrubs, grasses, mulga, stunted eucalypts, and fig trees. Mixed outcrop and colluvium have spinifex, small shrubs, grasses and wattles.

Physiography

The physiography of COONGAN is divisible into three broad regions (Fig. 3). The rugged western part of the map is underlain by the Warralong greenstone belt, whereas the southeastern part of the map is underlain by strike-controlled ridges of the Marble Bar and Doolena Gap greenstone belts. The rugged southwestern part of the map is underlain by the northern part of the Marble Bar Sub-basin of the Fortescue Basin. Granitic rocks of the Muccan and Carlindi Granitic Complexes outcrop as more subdued, undulating topography in the southeast and in scattered outcrops across the north and in the Coongan River. The central and northern parts of COONGAN are flat colluvial–alluvial sand plains transected by several large rivers that drain north into the Indian Ocean. These include the Coongan and Talga Rivers that join together in the

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

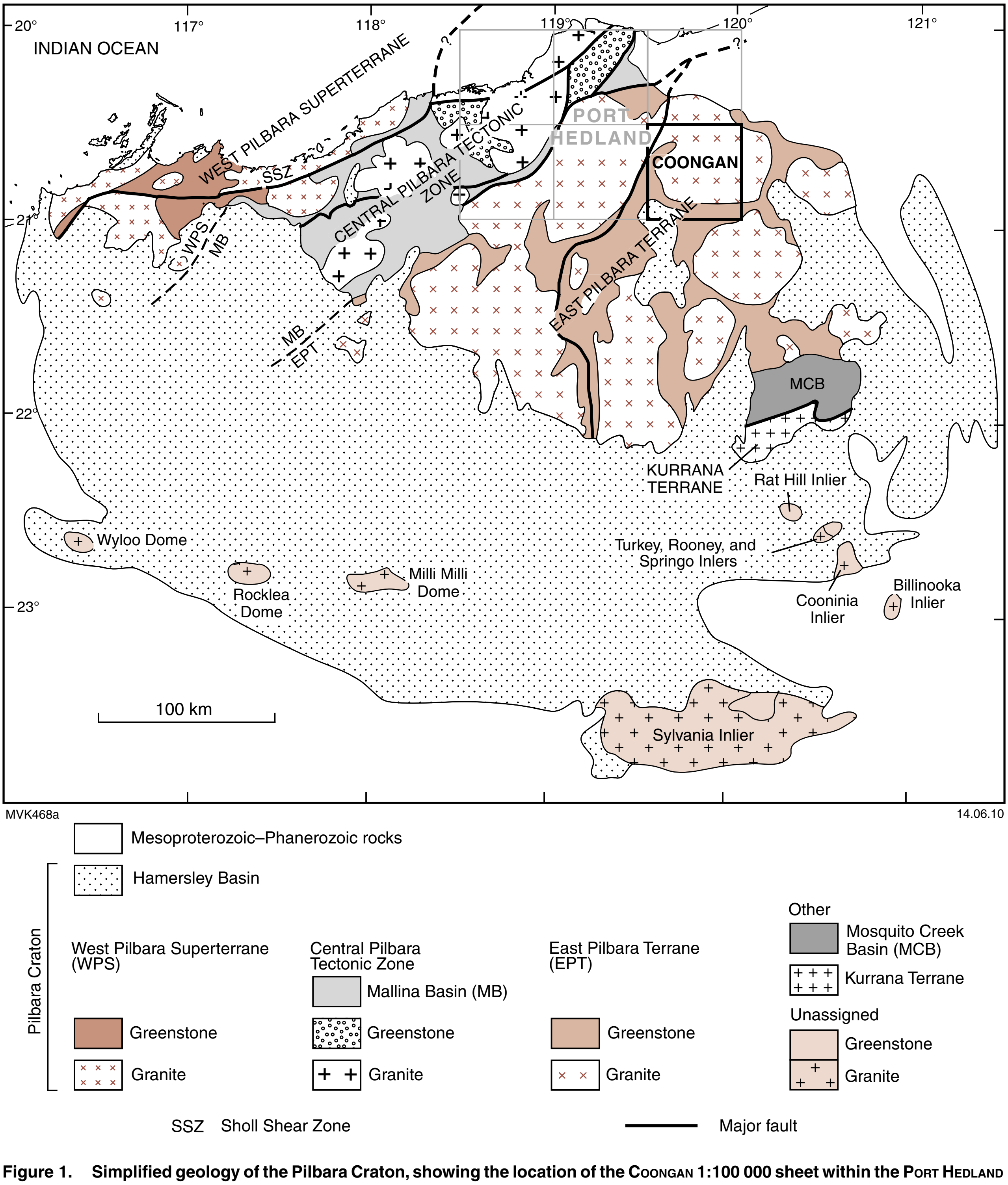


Figure 1. Simplified geology of the Pilbara Craton, showing the location of the Coongan 1:100 000 sheet within the Port Hedland 1:250 000 sheet.

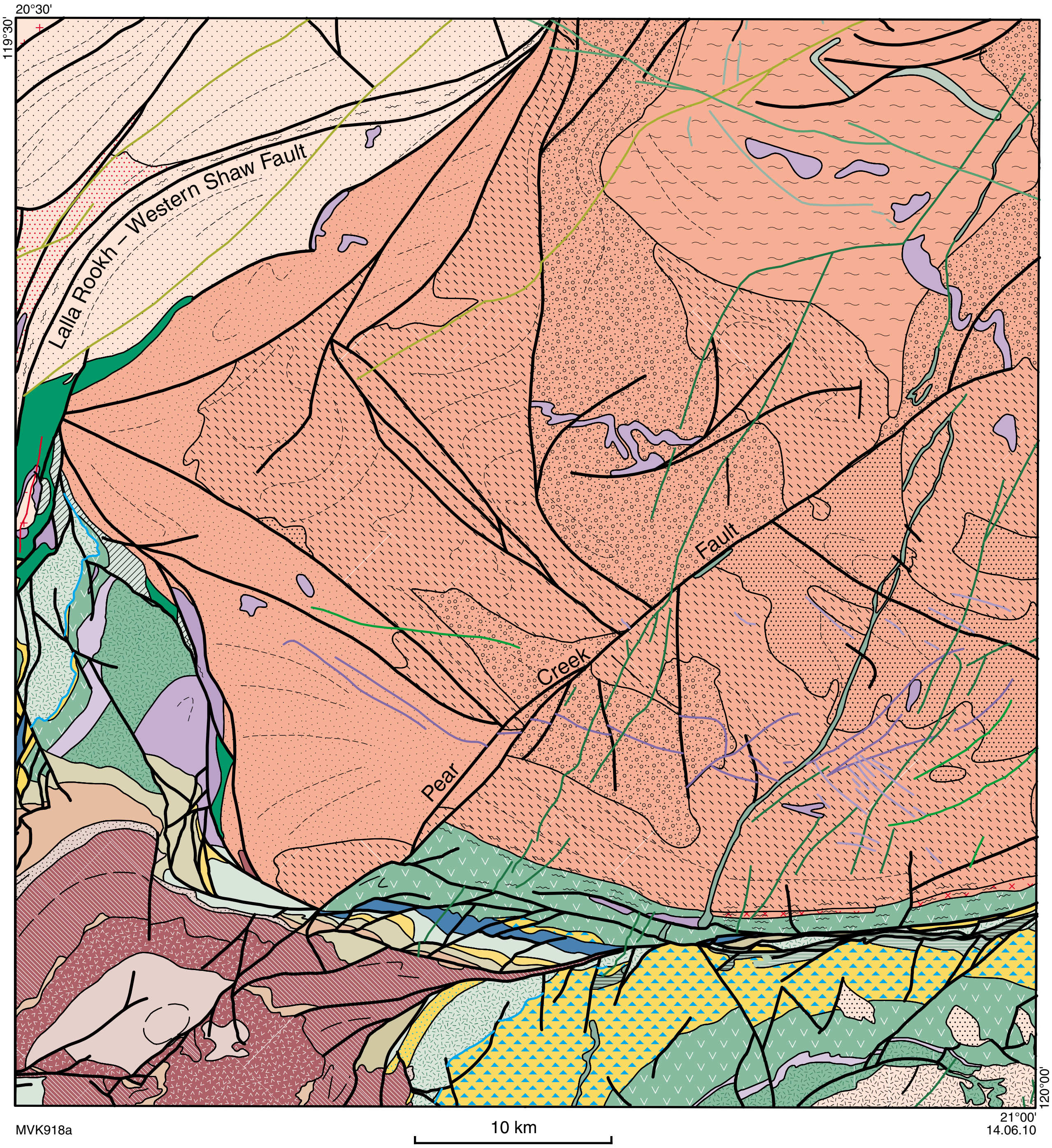


Figure 2. Simplified solid geology interpretation of Coongan, showing major lithostratigraphic units.

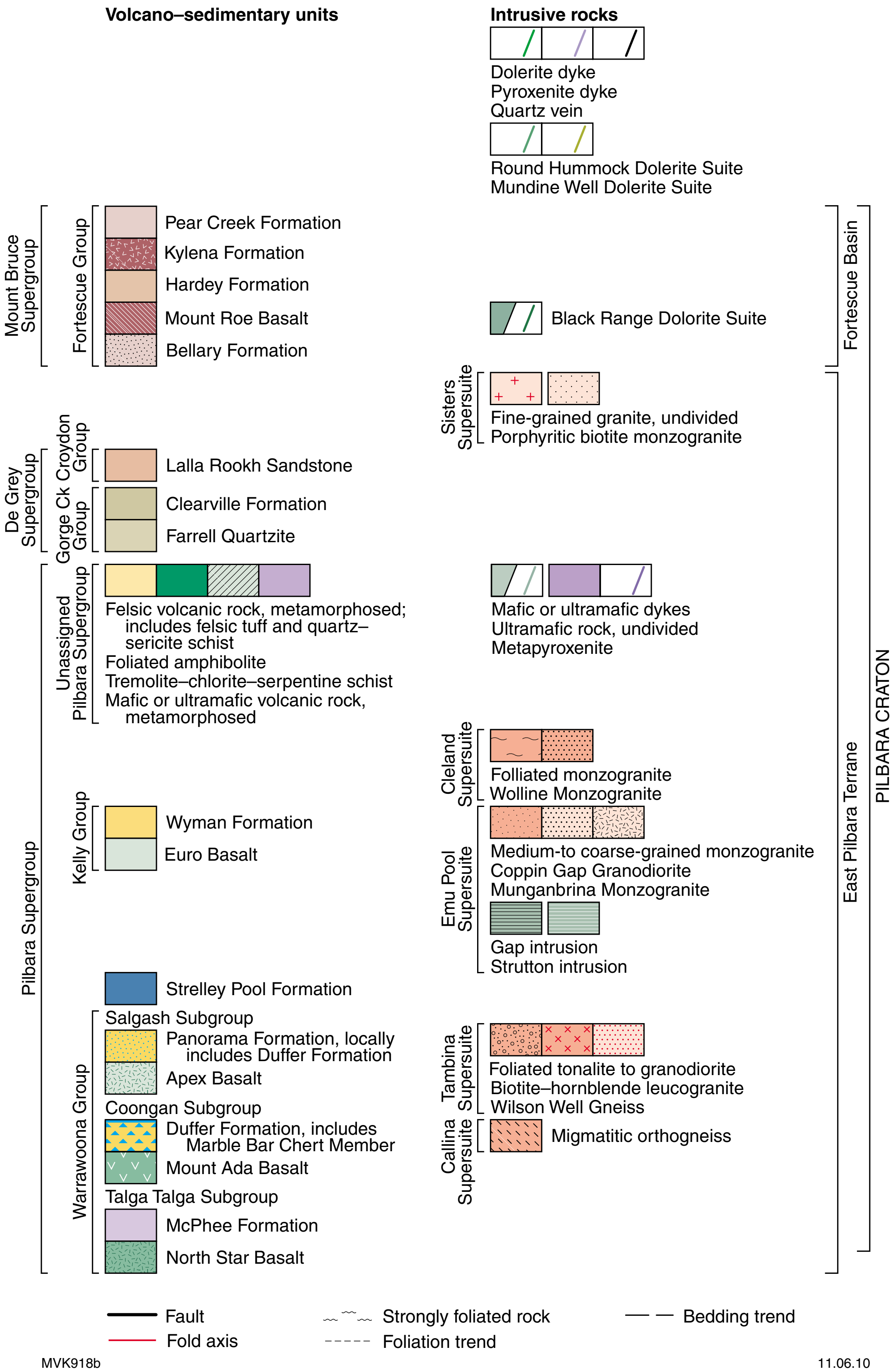

Volcano–sedimentary units
Intrusive rocks
Dolerite dyke
Pyroxenite dyke
Quartz vein
Round Hummock Dolerite Suite
Mundine Well Dolerite Suite
Mount Bruce Supergroup
Fortescue Group
Pear Creek Formation
Kylena Formation
Hardey Formation
Mount Roe Basalt
Bellary Formation
Black Range Dolerite Suite
Fortescue Basin
Sisters Supersuite
Fine-grained granite, undivided
Porphyritic biotite monzogranite
De Grey Supergroup
Croydon Group
Lalla Rookh Sandstone
Gorge Ck Group
Clearville Formation
Farrell Quartzite
Unassigned Pilbara Supergroup
Felsic volcanic rock, metamorphosed; includes felsic tuff and quartz–sericite schist
Foliated amphibolite
Tremolite–chlorite–serpentine schist
Mafic or ultramafic volcanic rock, metamorphosed
Mafic or ultramafic dykes
Ultramafic rock, undivided
Metapyroxenite
Cleland Supersuite
Folliated monzogranite
Wolline Monzogranite
Kelly Group
Wyman Formation
Euro Basalt
Emu Pool Supersuite
Medium-to coarse-grained monzogranite
Coppin Gap Granodiorite
Munganbrina Monzogranite
Gap intrusion
Strutton intrusion
Pilbara Supergroup
East Pilbara Terrane
PILBARA CRATON
Strelley Pool Formation
Warrawoona Group
Salgash Subgroup
Panorama Formation, locally includes Duffer Formation
Apex Basalt
Coongan Subgroup
Duffer Formation, includes Marble Bar Chert Member
Mount Ada Basalt
Talga Talga Subgroup
McPhee Formation
North Star Basalt
Tambina Supersuite
Foliated tonalite to granodiorite
Biotite–hornblende leucogranite
Wilson Well Gneiss
Callina Supersuite
Migmatitic orthogneiss
Fault
Fold axis
Strongly foliated rock
Foliation trend
Bedding trend
MVK918b
11.06.10

Table 1. Summary of the major geological events on Coongan

Age range (Ma)	Geological events
c. 3600	Formation of ancient, at least partly sialic crust, forming proto-continental basement to the Warrawoona Group. This crust is unexposed, and its existence inferred from detrital zircon populations
3490–3460	Deposition of the Talga Talga and Coongan Subgroups of the Warrawoona Group accompanied by extensional growth faulting; intrusion of Callina Supersuite granitic rocks in the Muccan Granitic Complex
c. 3460	D_1 deformation: synvolcanic doming, minor tilting and folding of greenstones; contact-style amphibolite- to greenschist-facies metamorphism of greenstones adjacent to granitic rocks
3460–3430	Deposition of the Salgash Subgroup of the Warrawoona Group and intrusion of Tambina Supersuite granitic rocks in the Muccan and Carlindi Granitic Complexes
3430–3400	D_2 deformation: a component of tilting of greenstones and doming of granitic complexes; local foliations; migmatization and deformation of older granitoids
3400–3350	Uplift and erosion, followed by deposition of the Strelley Pool Formation across a regional unconformity
3350–3315	Deposition of the volcanic component of the Kelly Group; intrusion of mafic–ultramafic sills
3325–3290	Intrusion of Emu Pool Supersuite granitic rocks during major D_3 deformation and metamorphism during partial convective overturn of the middle to upper crust and amphibolite- to greenschist-facies metamorphism
3255–3240	Intrusion of Cleland Supersuite granitic rocks, accompanied by D_4 deformation
c. 3200	Deposition of the Soanesville Group during rifting of the East Pilbara Terrane margins and basin formation within the East Pilbara Terrane; intrusion of ultramafic–mafic rocks and mafic dykes
3070–3050	Prinsep Orogeny (D_5): reactivation of granite-cored domes and tilting of older greenstones and Soanesville Group rocks
3020–2940	Deposition of Gorge Creek and Croydon Group rocks of the De Grey Supergroup during periods of intracratonic extension accompanied by growth faulting (D_6) and episodes of tilting of older greenstones and rocks of the Gorge Creek Group ($D_{7–8}$)
2940–2930	Intrusion of Sisters Supersuite granites into the Carlindi Granitic Complex during shear deformation associated with the North Pilbara Orogeny (D_9); greenschist- to amphibolite-facies metamorphism
<2830, >2772	Uplift and erosion; deposition of the Bellary Formation, Fortescue Group, followed by gentle tilting (D_{FOM1})
c. 2775	Deposition of the Mount Roe Basalt and intrusion of the Black Range Dolerite Suite, followed by folding and faulting (D_{FOM2})
2764–2756	Deposition of the Hardey Formation, followed by gentle folding (D_{FOM3})
c. 2740	Deposition of the Kylena Formation and intrusion of dolerite sills (AFOk-od [AF(d)]), followed by gentle tilting and faulting (D_{FOM5})
<2740	Deposition of units of the Pear Creek Formation, accompanied by pulses of gentle titling and faulting (D_{FOM6}–D_{FOM8})
<2740	Gentle folding and faulting (D_{FOM9})
?	Intrusion of mafic and ultramafic dyke swarms
1803–1703	Intrusion of Bridget Suite porphyry silicic dykes
c. 755	Intrusion of NE-striking Mundine Well Dolerite Suite (ƐMW-od) and NW-striking Round Hummock Dolerite Suite (ƐRH-od)
?	Faulting

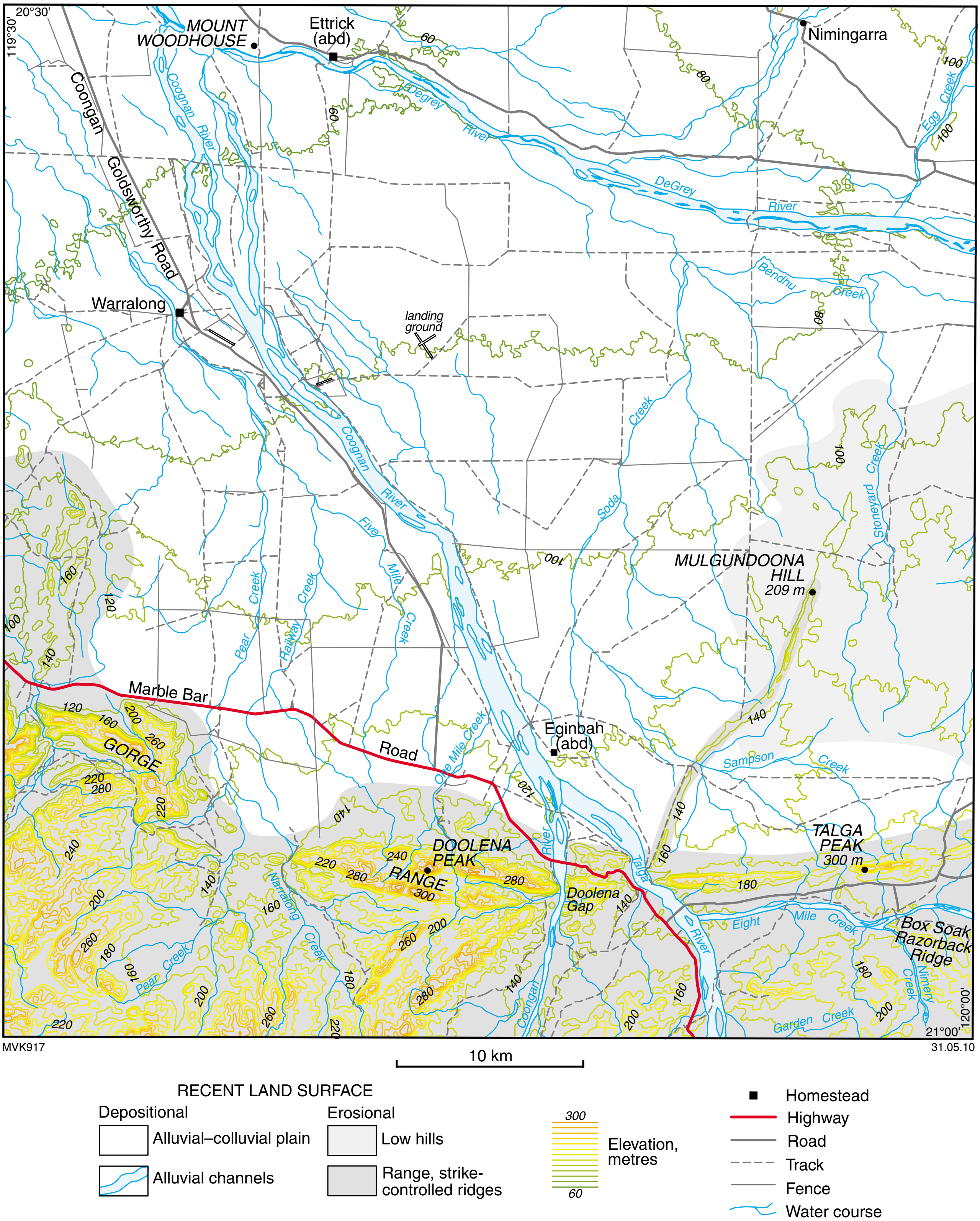


Figure 3. Physiographic features of Coongan.

south and flow into the De Grey River in the north. Pear Creek flows north from south of the Gorge Range across the western part of the map area. The highest point of elevation is Doolena Peak at 335 m above mean sea level (AMSL) in the Gorge Range, which extends across the southern part of COONGAN. Talga Peak, in the eastern part of the range is 297 m AMSL. The lowest point of elevation is 42 m AMSL in the far northwestern corner of COONGAN (MGA 761300E 7730300N).

Previous investigations

Noldart and Wyatt (1962), and Hickman (1983), give details of the early history of exploration, mining, and geological studies in the Pilbara Craton, including the PORT HEDLAND – BEDOUT ISLAND 1:250 000 sheet area on which COONGAN is located.

Hickman and Gibson (1981) mapped the PORT HEDLAND – BEDOUT ISLAND 1:250 000 sheet (second edition) in 1975–1977 during a Geological Survey of Western Australia (GSWA) – Bureau of Mineral Resources (BMR, now Geoscience Australia) mapping program in the east Pilbara. The main area of granite–greenstone rocks in the northern part of the Pilbara Craton was then referred to as the 'Pilbara Block', the geology of which was described by Hickman (1983, 1984). This terminology was later changed so that the area of granite–greenstone rocks in the northern part of the Pilbara Craton was referred to as the 'northern Pilbara granite–greenstone terrane' (Griffin, 1990) and the north Pilbara Terrain (Van Kranendonk et al., 2002), and the craton was defined as including both the basement granite–greenstone rocks and overlying Hamersley Basin (Trendall, 1990). However, the use of Terrain was thought to be confusing, as geological terranes within this area have now been recognized (see below), so that this northern area of basement granite–greenstone rocks is herein referred to as the northern part of the Pilbara Craton, which contains ten tectonic units, the central and largest of which is the East Pilbara Terrane (Van Kranendonk et al., 2002, 2006a, 2007). The Fortescue and Hamersley basins are now separated from the Pilbara Craton in terms of tectonic unit nomenclature within GSWA.

Hickman (1983) grouped the oldest volcano-sedimentary rocks across the 'Pilbara Block' into the 'Archean Pilbara Supergroup' and proposed that the lower part of the supergroup formed a single, layer-cake stratigraphy that was divided into the Warrawoona, Gorge Creek and Whim Creek Groups. The major tectonic structures of the region were interpreted as the result of solid-state diapirism of the Archean granitic complexes (Hickman, 1983, 1984). The lithostratigraphy of the Pilbara Supergroup was modified by Hickman (1990) to separate the 'De Grey Group' (now De Grey Supergroup) from the Gorge Creek Group. A major revision was made by Hickman (1997) to distinguish the greenstone successions of the west Pilbara from those of the east Pilbara, as suggested by previous geochronology (e.g. Horwitz and Pidgeon, 1993). This has been supported by subsequent data (Smith et al., 1998; Sun and Hickman, 1998; Van Kranendonk et al., 2002; Smith, 2003). Recent work has also identified separate stratigraphic components in the east Pilbara, including the Sulphur Springs Group (Buick et al., 1995, 2002; Van Kranendonk and Morant, 1998; Van Kranendonk, 2000). Following further mapping and geochronology, Van Kranendonk et al. (2002) re-defined the Warrawoona Group so that the Duffer Formation was included in the Talga Talga Subgroup, the Apex Basalt, Panorama Formation, and Strelley Pool Formation were ascribed to the Salgash Subgroup, and the Euro Basalt, Wyman Formation, and Charteris Basalt were ascribed to the Kelly Subgroup. More recently, the Warrawoona Group has been subdivided into four subgroups, the oldest of which — the Coonterunah Subgroup — is represented by rocks formerly ascribed to the 'Coonterunah Group' (Van Kranendonk et al., 2006a). Rocks formerly referred to as the 'Kelly Subgroup' have been elevated to group status on the basis of a regional basal unconformity beneath the 'Strelley Pool Chert' (Van Kranendonk et al., 2006a, 2007), recently revised to Strelley Pool Formation (Hickman, 2008).

Granitic rocks of the northern part of the Pilbara Craton form broad, domical complexes consisting of multiple phases that intruded from c. 3500 Ma to 2830 Ma (see data in Van Kranendonk et al., 2002, 2006a). Bickle et al. (1983) described the c. 3467 Ma, calc-alkaline North Shaw Suite in the Shaw Granitic Complex and compared it favourably with Phanerozoic calc-alkaline igneous suites in subduction settings. However, Smithies (2000) showed that the compositions are incompatible with an origin from slab melting in a modern-style steep subduction setting and suggested instead that the early (c. 3490–3430 Ma) tonalite–trondhjemite–granodiorite–granite (TTG) rocks were more likely generated by melting of mafic lower crust. Geochemical evidence that syn- to post-tectonic suites of granitic rocks (c. 3320–2830 Ma) were derived by partial melting of pre-existing sialic crust has been presented by Hickman (1983 and references therein), Bickle et al. (1989), and Collins (1993). Granitic rocks have recently been ascribed to several supersuites and suites based on age and geochemical data, as described in Van Kranendonk et al. (2006a).

A detailed diapiric model of structural evolution has been proposed for the Mount Edgar Granitic Complex of the East Pilbara Terrane (Hickman, 1984; Collins, 1989; Williams and Collins, 1990; Collins et al., 1998; Collins and Van Kranendonk, 1999). This model has been applied to the rest of the East Pilbara Terrane (Van Kranendonk et al., 2002, 2004, 2006a; Hickman and Van Kranendonk, 2004), with diapirism taking place during multiple thermo-tectonic events throughout the history of the terrane to c. 2.7 Ga.

Bickle et al. (1985) challenged the solely diapiric model for the tectonic evolution of the East Pilbara Terrane, and suggested that an early period of Alpine-style thrusting affected the western part of the Shaw Granitic Complex. Zegers et al. (1996, 2001) proposed that this thrusting, which was interpreted to have taken place before c. 3470 Ma, produced an overthickened crust that experienced extensional collapse at c. 3467 Ma, when the domical granitic complexes rose as metamorphic core complexes. Similar core complex models involving early thrusting and later extensional collapse were developed for the Mount Edgar Granitic Complex and structures in adjacent greenstones, but at c. 3300 Ma (van Haaften and White, 1998; Kloppenburg et al., 2001). Blewett (2002) reintroduced a cross-folding model (first proposed by Noldart and Wyatt, 1962) for the formation of the dome-and-syncline structure of the East Pilbara Terrane, but did not explain the contrary evidence in favour of a diapiric origin for these structures.

Tectonic models of horizontal tectonic accretion and core complex formation in the structural development of the East Pilbara Terrane have been challenged by several recent studies based on detailed mapping and geochronology (Van Kranendonk et al., 2001a,b, 2002, 2004, 2007; Hickman and Van Kranendonk, 2004). These authors showed that the type stratigraphic section of the Warrawoona Group in the Marble Bar greenstone belt is a right-way-up, upward-younging, autochthonous succession affected by diapirism of the granitic complexes.

Blake (1993, 2001) applied sequence-stratigraphic principles to the stratigraphy of the Mount Bruce Supergroup that unconformably overlies the East Pilbara Terrane and includes the Fortescue Group, whereas Thorne and Trendall (2001) retained a strictly lithostratigraphic nomenclature in their overview of the Fortescue Group.

Pilbara Craton

The ovoid Pilbara Craton underlies approximately 250 000 km^2 in the northwestern part of Western Australia. It is composed of Archean (3.65 – 2.83 Ga) rocks, including a wide range of variably metamorphosed granitic rocks, and metamorphosed and deformed volcanic, sedimentary, and mafic–ultramafic intrusive rocks (greenstones). These rocks are unconformably overlain by the 2.78 – 2.3 Ga Mount Bruce Supergroup and intruded by swarms of related dolerite dykes, and by younger, Proterozoic dyke swarms.

The Pilbara Craton is divided by Van Kranendonk et al. (2006a, 2007; Fig. 1) into the 3.52 – 3.23 Ga East Pilbara Terrane (EPT), the 3.27 – 3.07 Ga West Pilbara Superterrane (WPS), and the ≥3.18 Ga Kurrana Terrane (KT). The EPT represents the nucleus of the craton, formed through a succession of mantle plumes that erupted a dominantly basaltic volcanic succession, known as the Pilbara Supergroup, onto an older sialic basement, as discussed in more detail below.

The WPS is a collage of the 3.27 – 3.25 Ga Karratha Terrane (Roebourne Group and Cleland Supersuite; possibly a rifted fragment of the EPT), the c. 3.2 Ga Regal Terrane (MORB basalts of the Regal Formation), and the 3.13 – 3.11 Ga Sholl Terrane (Whundo Group intra-oceanic arc and Railway Supersuite) (Hickman, 2004; Smithies et al., 2005a; Van Kranendonk et al., 2006a, 2007). These terranes were accreted during collision with the EPT at 3.07 – 3.05 Ga (Prinsep Orogeny), accompanied by emplacement of granites of the Elizabeth Hill Supersuite (Van Kranendonk et al., 2006a, 2007). Mineralization includes volcanogenic Cu–Zn (Sholl Terrane) and komatiite-hosted Ni deposits (Karratha Terrane) (Ruddock, 1999).

Terrane accretion was followed by deposition of the dominantly sedimentary rocks of the 3.02 – 2.94 Ga De Grey Supergroup in the Gorge Creek, Whim Creek, Mallina, Lalla Rookh, and Mosquito Creek basins. The basal, 3.02 Ga, Gorge Creek Group — including widespread banded iron-formation of the Cleaverville Formation — was deposited during orogenic relaxation. Slab breakoff led to deposition of the 3.01 Ga Whim Creek and 2.97 – 2.94 Ga Croydon Groups in the local Whim Creek Basin and the regionally extensive Mallina Basin. This was accompanied by widespread granitic magmatism that swept across the WPS, Mallina Basin, and western part of the EPT from 2.99 – 2.94 Ga. Mallina Basin magmatism included sanukitoids, boninites, and LREE-enriched gabbros, indicating derivation from a subduction-modified mantle source. Magmatism in the WPS and EPT at this time derived from crustal melting (Maitland River and Sisters Supersuites). Episodes of extensional basin formation alternated with periods of compression, including a final compressional phase at 2.93 Ga (North Pilbara Orogeny) that was followed by transtension and emplacement of layered mafic–ultramafic complexes hosting platinum-group element (PGE) mineralization (Ruddock, 1999).

Accretion of the KT onto the EPT at 2.93 – 2.90 Ga across the Mosquito Creek Basin (Mosquito Creek Orogeny) was accompanied by granitic magmatism (Cutinduna Supersuite) and gold mineralization. This was followed by intrusion of 2.89 – 2.83 Ga post-tectonic granites (Split Rock Supersuite) across the KT and EPT, which host Sn–Ta–Li mineralization.

Reactivation of structures in the EPT during deposition of the Mount Bruce Supergroup resulted in the further economic concentration of gold mineralization (Van Kranendonk, 2003b).

East Pilbara Terrane tectonic units

The 3.52 – 3.23 Ga East Pilbara Terrane (EPT) represents the ancient nucleus of the Pilbara Craton and is characterized by a large-scale dome-and-keel map pattern consisting of approximately 60 km diameter, circular to ovoid granitic domes and intervening greenstone synclinal keels (Van Kranendonk et al., 2002, 2006a, 2007). It is separated from the adjacent West Pilbara Superterrane and Kurrana Terrane by the Mallina and Mosquito Creek Basins, respectively, which are filled by the syn- to late-tectonic sedimentary and volcanic rocks of the 3.02 – 2.94 Ga De Grey Supergroup. The EPT is also intruded by a variety of younger granitic supersuites to 2.83 Ga, and is unconformably overlain by the 2.78 – 2.45 Ga Mount Bruce Supergroup and intruded by a variety of younger dolerite dykes.

The EPT consists of two principal lithological components: greenstones and granites. The 3.52 – 3.23 Ga Pilbara Supergroup is a demonstrably autochthonous succession of dominantly basaltic volcanic rocks, subordinate felsic volcanic and sedimentary rocks, and associated subvolcanic intrusions. The supergroup reaches a maximum cumulative thickness of 26 100 m when measured across the flanks of progressively accumulated synclines, but is ≤12 000 m thick in individual greenstone belts (Hickman, 1983; Van Kranendonk et al., 2002, 2007). The Pilbara Supergroup is composed of three groups and one unassigned formation: the 3.53 – 3.43 Ga, dominantly volcanic Warrawoona Group; the c. 3.42 – 3.35 Ga Strelley Pool Formation; the 3.35 – 3.31 Ga, dominantly volcanic Kelly Group; the 3.27 – 3.24 Ga, volcanic and sedimentary Sulphur Springs Group (Buick et al., 1995, 2002; Van Kranendonk et al., 2002, 2007).

The Pilbara Supergroup is conformably to disconformably overlain by the 3.20 – 3.16 Ga, dominantly sedimentary, Soanesville Group, which was deposited during rifting of the East Pilbara Terrane margins (Van Kranendonk et al., 2010).

The other major lithological component of the EPT is a variety of granitic rocks that were episodically emplaced during deposition of the Pilbara Supergroup. These granitic rocks have been divided into four supersuites: the c. 3.47 Ga Callina, c. 3.43 Ga Tambina, c. 3.31 Ga Emu Pool, and c. 3.25 Ga Cleland supersuites (Van Kranendonk et al., 2006a). The two older, predominantly sodic supersuites were derived from melting of basaltic protoliths (Smithies et al., 2007a) and were emplaced as a sheeted sill complex in the greenstones (Van Kranendonk et al., 2002, 2004, 2007). The two younger, more potassic supersuites were derived from partial melting of the older supersuites (Smithies et al., 2003) and the basement, and were emplaced during episodes of partial convective overturn of the upper and middle crust, resulting in the prominent dome-and-basin map pattern of the EPT (Collins et al., 1998; Van Kranendonk et al., 2004). The granitic rocks are variably metamorphosed.

Predating the Pilbara Supergroup is a largely cryptic sialic basement that is represented by rare inclusions of folded, c. 3.65 Ga trondhjemite gneiss and c. 3.58 Ga metagabbroic anorthosite in younger granitic rocks (McNaughton et al., 1988; Thorpe et al., 1992; Nelson, 1999a). That these rocks most likely formed a basement to the Pilbara Supergroup is indicated by the widespread occurrence of inherited and detrital zircons to 3.8 Ga in younger volcanic and sedimentary rocks (Van Kranendonk et al., 2002, 2007). Evidence of widespread contamination of basaltic rocks is also indicated by geochemical and Nd model age data, the latter suggesting that at least some of the older crust may have been Hadean basalt (Green et al., 2000; Smithies et al., 2007b; Tessalina et al., 2010).

Map data and geochemical analysis of the volcanic rocks indicates derivation of the three volcanic groups of the Pilbara Supergroup from discrete mantle plume events (Van Kranendonk and Pirajno, 2004; Van Kranendonk et al., 2007; Tessalina et al., 2010). These successive melting events caused progressive depletion of the subcontinental mantle lithosphere, which led to formation of a thick, depleted lithospheric keel (Smithies et al., 2005b; Griffin and O'Reilly, 2007). This was followed by rifting of the EPT, intrusion of granitic rocks (Mount Billroth Supersuite), and deposition of the Soanesville Group on a passive margin at 3200–3165 Ma (Van Kranendonk et al., 2007, 2010).

The EPT is dominated by three types of broad, regional structures, only the first of which was formed during development of the terrane (Van Kranendonk et al., 2002). This oldest type is related to the long-lived, but punctuated, formation of the dome-and-keel map pattern, which developed as a result of punctuated episodes of partial convective overturn of the upper and middle crust between 3.47 – 2.74 Ga (Hickman, 1983, 1984; Collins, 1989; Collins et al., 1998; Collins and Van Kranendonk, 1999; Hickman and Van Kranendonk, 2004; Van Kranendonk et al., 2002, 2004). This deformation resulted in the formation of broad domes with central granitic complexes and flanking greenstone belts that are attached to the granitic complexes by intrusive or sheared intrusive contacts. Adjacent domes are separated by ring faults that lie along the axial zone of greenstone synclines and separate adjacent greenstone belts. Locally, adjacent domes are separated by the unconformably overlying Marble Bar Sub-basin of the Fortescue Basin, by rocks of the De Grey Supergroup, and, locally, by the Lalla Rookh – Western Shaw structural corridor.

Three principal sets of younger structures affected the terrane during subsequent events. These include north- to northeast-striking sinistral faults related to west northwest – east southeast regional compressional deformation associated with the c. 2.95 – 2.93 Ga North Pilbara Orogeny (Van Kranendonk et al., 2002, 2006a, 2007). The main structures associated with this deformation include the Tabba Tabba Shear Zone along the northwestern margin of the EPT, and the Lalla Rookh – Western Shaw structural corridor, which is a broad, roughly north–south striking zone of transpressional shear deformation and folding in the western central part of the EPT (Van Kranendonk and Collins, 1998; Zegers et al., 1998; Van Kranendonk, 2008).

The second set of younger regional structures is an east–west striking belt of thrust faults and folds located along the southeastern margin of the EPT. These structures are associated with north–south regional compressional deformation at 2905 Ma during the Mosquito Creek Orogeny (Van Kranendonk et al., 2007).

The third set of younger structures include faults, upright folds, and tilting of volcano-sedimentary units associated with syn-depositional deformation of the unconformably overlying Fortescue Group, as described by Van Kranendonk (2003b).

Major types of mineralization in the EPT include epithermal barite (3.48 Ga), volcanogenic Cu–Zn (3.47 and 3.24 Ga), and shear-zone hosted gold (c. 3.40 Ga, 3.31 Ga, 3.24 Ga, 2.89 Ga, 2.7 Ga) deposits, porphyry Cu–Mo (3.31 Ga), and PGE and Ni in layered ultramafic–mafic intrusions of the c. 3.2 Ga Dalton Suite (Brauhart et al., 1998; Neumayr et al., 1998; Vearncombe et al., 1998; Ferguson and Ruddock, 2001; Huston et al., 2001, 2002, 2007; Baker et al., 2002; Zegers et al., 2002; Thébaud et al., 2006; Van Kranendonk et al., 2010).

Greenstone belts on Coongan*

Greenstone belts on Coongan include the eastern part of the Warralong greenstone belt in the western part of the map area, a small part of the Panorama greenstone belt in the far southwestern part of the map area, and parts of the Doolena Gap and Marble Bar greenstone belts across the southern part of the map area.

Warralong greenstone belt

The Warralong greenstone belt is a synclinal succession of metavolcanic and metasedimentary rocks belonging to the Pilbara Supergroup. This belt is preserved between the Muccan and Carlindi Granitic Complexes to the east and west, respectively, and is unconformably overlain by the De Grey Superbasin to the south.

Panorama greenstone belt

The Panorama greenstone belt is exposed in the North Pole Dome, and consists of a succession of metavolcanic and metasedimentary rocks belonging to the Pilbara Supergroup and Soanesville Group. This belt is unconformably overlain by the De Grey Superbasin to the north and south, and by the Marble Bar Sub-basin of the Fortescue Basin to the east. The belt is in faulted contact with rocks of the De Grey Superbasin to the west.

Doolena Gap greenstone belt

The Doolena Gap greenstone belt represents a steeply tilted to overturned panel of metavolcanic and metasedimentary rocks belonging to the Pilbara Supergroup. This belt is unconformably overlain by the De Grey Superbasin and by the Marble Bar Sub-basin of the Fortescue Basin to the southwest, and is in fault contact with the Marble Bar greenstone belt along the rest of the southern margin. To the north, the belt lies in strongly sheared, intrusive contact with granitic rocks of various ages belonging to the Muccan Granitic Complex.

Marble Bar greenstone belt

The Marble Bar greenstone belt represents a tilted panel of metavolcanic and metasedimentary rocks belonging to the Pilbara Supergroup that wraps around, and faces away from, granitic rocks within the Mount Edgar Granitic Complex. The rocks of this belt are unconformably overlain by the Fortescue Basin to the east and southeast (northeast Pilbara Sub-basin), and west (Marble Bar Sub-basin), and are in fault contact with the Kelly greenstone belt and Doolena Gap greenstone belts to the south and north, respectively. The relationships of the belt with the Mount Edgar Granitic Complex vary from intrusive to strongly sheared intrusive contacts.

* Greenstone belts are litho-tectonic units defined on a craton-wide basis after Van Kranendonk (1998). They do not strictly adhere to terrane nomenclature because they may include stratigraphic units younger than the terrane itself, but individual belts are restricted to distinct terranes and are useful geographic tools.

Granitic Complexes on Coongan†

Granitic complexes on Coongan include part of the Carlindi Granitic Complex in the northwestern part of the map area, the northernmost part of the Mount Edgar Granitic Complex in the southeastern part of the map area, and the Muccan Granitic Complex, which dominates the map area in the northeast.

Carlindi Granitic Complex

The Carlindi Granitic Complex is a large (150 km long by 70 km wide), multicomponent complex of granitic rocks located in the northwestern part of the EPT. It has strongly sheared contacts with the Warralong and Goldsworthy greenstone belts in the north and east, respectively, but intrusive contacts with the East Strelley and Wodgina greenstone belts. The northwestern margin of the complex is the major Tabba Tabba Shear Zone. Component phases within the complex include gneissic tonalites and undeformed porphyritic monzogranites of the 3490–3460 Ma Callina Supersuite, strongly foliated and folded granitic rocks of the 3275–3225 Ma Cleland Supersuite, foliated to weakly strained monzogranites of the 2955–2920 Ma Sisters Supersuite, and undeformed monzogranites and syenogranites of the 2890–2830 Ma Split Rock Supersuite. This complex is broadly domical in form, but elongate in a southwesterly direction due to strong compressional deformation associated with the c. 2930 Ma North Pilbara Orogeny. Tin–tantalum mineralization is associated with intrusive rocks of the Split Rock Supersuite, and mica was mined from pegmatites along the eastern margin of the complex.

Mount Edgar Granitic Complex

The Mount Edgar Granitic Complex is a large (60 km diameter), roughly circular, multicomponent complex of granitic rocks located in the eastern central part of the EPT. It has strongly sheared contacts with the Marble Bar greenstone belt around the southern margin, but intrusive contacts with this belt in the west, north, and northeast. Component phases within the complex include gneissic tonalites of the 3490–3460 Ma Callina and 3450–3420 Ma Tambina Supersuites, strongly foliated and folded granitic rocks (tonalite through monzogranite) of the 3325–3290 Ma Emu Pool and 3275–3225 Ma Cleland Supersuites, and undeformed monzogranite of the 2890–2830 Ma Split Rock Supersuite (Moolyella Monzogranite). Shear deformation along the southern margin of the complex involved granite-side-up displacement relative to flanking greenstones and developed at 3324–3200 Ma. Porphyry copper–molybdenum mineralization is associated with a granodiorite stock at the northern tip of the complex, and there is tin–tantalum mineralization in pegmatites associated with the Moolyella Monzogranite (Hickman, 1983).

† As with greenstone belts, granitic complexes are defined as craton-wide litho-tectonic map elements, following Van Kranendonk (1998), and may include components younger than the terrane proper, as a result of younger, craton-wide events.

Muccan Granitic Complex

The Muccan Granitic Complex is a large (60 km diameter), roughly circular, multicomponent complex of granitic rocks located in the northeastern part of the EPT. It has a strongly sheared, overturned contact with the Doleena Gap greenstone belt around the southern margin, sheared intrusive contacts with the Warralong greenstone belt in the west, and is unconformably overlain by rocks of the De Grey Supergroup in the northeast (Dawes et al., 1995). Component phases within the complex include gneissic tonalites of the 3490–3460 Ma Callina and 3450–3420 Ma Tambina Supersuites, and strongly foliated and folded granitic rocks (tonalite through monzogranite) of the 3325–3290 Ma Emu Pool and 3275–3225 Ma Cleland supersuites.

Structural map elements on Coongan

On Coongan, granitic complexes and greenstone belts are deformed into four broad domes separated by narrow faults or basins, or by part of the Lalla Rookh – Western Shaw structural corridor (Fig. 4). The Muccan Dome is composed of the Muccan Granitic Complex and flanking Doolena Gap and Warralong greenstone belts. The Mount Edgar Dome in the southeast includes the Mount Edgar Granitic Complex and Marble Bar greenstone belt. These two domes are separated by the Talga Peak Fault and Marble Bar Sub-basin of the Fortescue Basin.

The Carlindi Dome in the northwest part of the sheet area is composed only of the Carlindi Granitic Complex on Coongan, although it includes the East Strelley greenstone belt further south and west on Carlindi, North Shaw, and Wodgina, and the Goldsworthy greenstone belt on De Grey in the north. The Carlindi Dome is separated from the Muccan Dome by the Lalla Rookh – Western Shaw structural corridor. A small part of the North Pole Dome is exposed in the far southwestern part of the map sheet, where it consists of the Panorama greenstone belt. This dome is separated from the Mount Edgar and Carlindi Domes by the Marble Bar Sub-basin of the Fortescue Basin.

The Lalla Rookh – Western Shaw structural corridor on Coongan consists of a northeast-striking zone of folded and faulted greenstones of the Warralong greenstone belt and sheared granitic rocks of the Carlindi Granitic Complex (Fig. 4). The northwestern margin of the corridor is a broad zone of strong, sinistral, ductile shear, known as the Lalla Rookh – Western Shaw Fault. The southeastern boundary of the corridor is a series of faults that mark the western margin of a panel of weakly strained, west-facing greenstones of the Warralong greenstone belt. Farther to the northeast, the southeastern boundary of the corridor is interpreted to continue along a train of large greenstone xenoliths that have been identified from images of aeromagnetic data, within younger granitic rocks.

Other major, linear, structural map elements on Coongan include the South Muccan Shear Zone, which is developed across the southern contact of the Muccan Granitic Complex with the Doolena Gap greenstone belt.

Major folds on Coongan include the Deep Well Anticline in the northwestern part of the Warralong greenstone belt, and the Warralong Syncline, which is faulted out along the southeastern boundary of the Lalla Rookh – Western Shaw structural corridor. The Eight Mile Creek Syncline separates the domical Muccan and Mount Edgar Granitic Complexes and has an axis that is strongly sheared within the Talga Peak Fault.

East Pilbara Terrane lithostratigraphic units

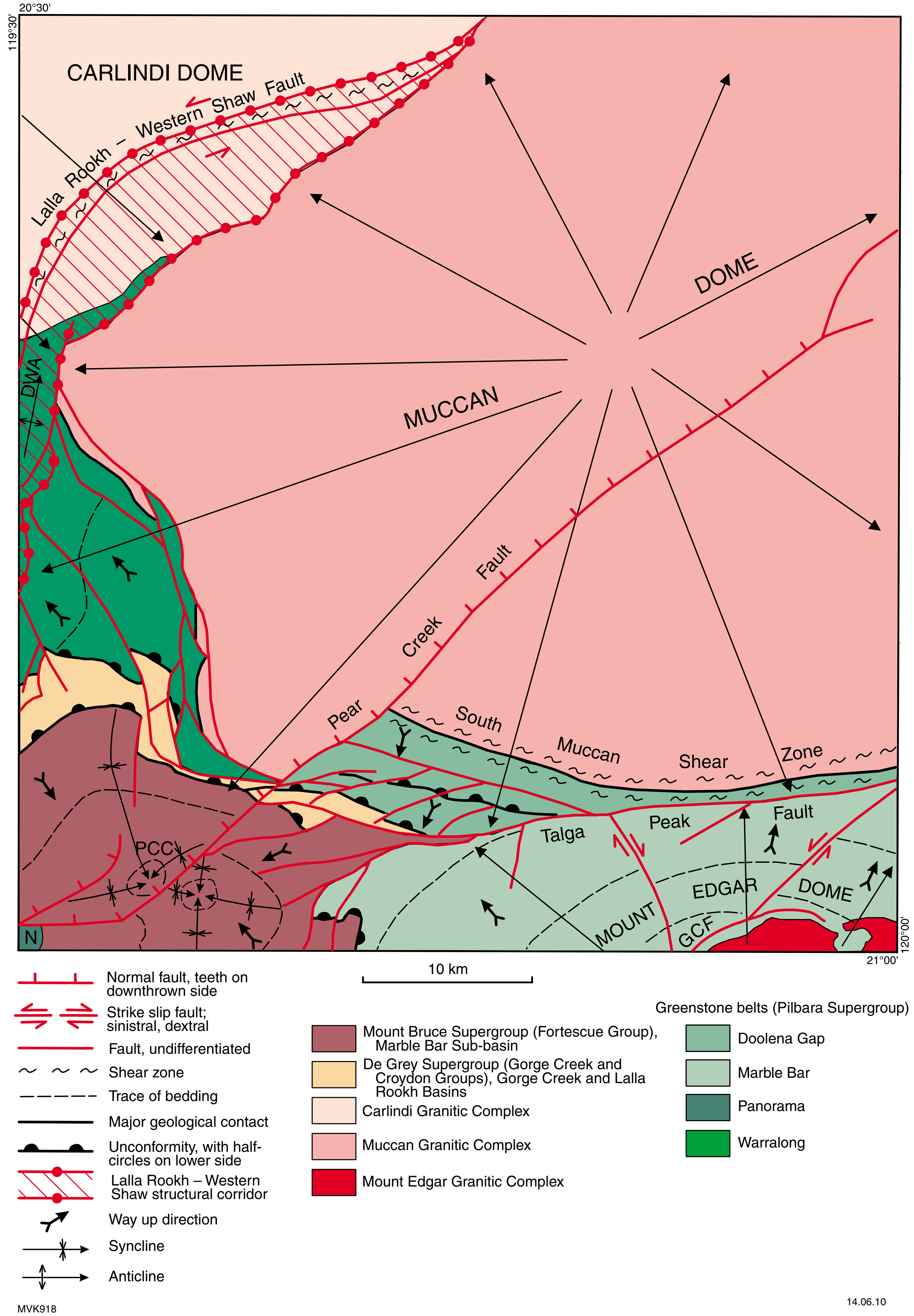
Pilbara Supergroup

The 3.52 – 3.23 Ga Pilbara Supergroup (Hickman, 1983, but since revised herein and in Van Kranendonk et al., 2010) is exposed over an area of 225 by 215 km, or almost 35 000 km^2. The name derives from the Pilbara mining centre, the site of the first major gold discovery in the northwest of Western Australia. Previously, all supracrustal rocks of the northern Pilbara Craton were ascribed to the supergroup (Hickman, 1983), which is herein redefined to consist of a succession of three demonstrably autochthonous groups and one formation: the 3.52 – 3.43 Ga Warrawoona Group, the c. 3.4 Ga Strelley Pool Formation; the 3.35 – 3.31 Ga Kelly Group, and the 3.27 – 3.23 Ga Sulphur Springs Group. The Warrawoona Group, and hence the Pilbara Supergroup, is everywhere intruded at the base by younger granitic rocks, whereas the Kelly and Sulphur Springs groups have unconformable relationships on older rocks. Recognition that the disconformably to unconformably overlying Soanesville Group is a rift-related, passive margin succession (Van Kranendonk et al., 2010) has prompted its removal from the Pilbara Supergroup.

The Warrawoona Group (Hickman, 1977, but since revised) consists predominantly of basaltic volcanic rocks, but felsic volcanic and sedimentary intervals are also present (Hickman, 1983; Van Kranendonk et al., 2007). Thin horizons of sedimentary rocks within the group contain the oldest traces of life on Earth in the form of stromatolites, putative microfossils of controversial biogenicity, and organic carbonaceous material (Lowe, 1980, 1983; Walter et al., 1980; Schopf, 1993; Hofmann et al., 1999; Ueno et al., 2001a,b, 2004, 2006; Brasier et al., 2002, 2005; Allwood et al., 2006; Duck et al., 2007; Marshall, 2007; Schopf et al., 2002, 2007; Van Kranendonk, 2007).

The Strelley Pool Formation (Van Kranendonk et al., 2006a) was deposited across a regional subaerial erosional unconformity (Buick et al., 1995; Van Kranendonk, 2000; Van Kranendonk et al., 2006b, 2007; Hickman, 2008). The formation consists of a basal unit of quartzite and conglomerate, overlain by a variably silicified unit of carbonate and stromatolitic carbonate, and an upper unit of clastic sedimentary rocks.

Figure 4. (Facing page) Simplified solid geology interpretation of Coongan, showing major lithotectonic and structural map elements. DWA = Deep Well Anticline; GCF = Garden Creek Fault; N = North Pole Dome; PCC = Pear Creek Centrocline.


20°30'
119°30'
CARLINDI DOME
Lalla Rookh – Western Shaw Fault
DWA
MUCCAN
DOME
Pear Creek Fault
South Muccan Shear Zone
Talga Peak Fault
PCC
MOUNT EDGAR DOME
GCF
N
120°00'
21°00'
10 km
Normal fault, teeth on downthrown side
Strike slip fault; sinistral, dextral
Fault, undifferentiated
Shear zone
Trace of bedding
Major geological contact
Unconformity, with half-circles on lower side
Lalla Rookh – Western Shaw structural corridor
Way up direction
Syncline
Anticline
Mount Bruce Supergroup (Fortescue Group), Marble Bar Sub-basin
De Grey Supergroup (Gorge Creek and Croydon Groups), Gorge Creek and Lalla Rookh Basins
Carlindi Granitic Complex
Muccan Granitic Complex
Mount Edgar Granitic Complex
Greenstone belts (Pilbara Supergroup)
Doolena Gap
Marble Bar
Panorama
Warralong
MVK918
14.06.10

The Kelly Group (Van Kranendonk et al., 2006a; Hickman and Van Kranendonk, 2008b) was deposited conformably above the Strelley Pool Formation. The group consists of a thick (up to 9000 m) volcanic succession of interbedded basalt, komatiitic basalt, and komatiite (Euro Basalt), and a major unit of high-K rhyolite derived from melting of older felsic crust (Wyman Formation; Jahn et al., 1981; Smithies et al., 2007b).

The Sulphur Springs Group (Van Kranendonk and Morant, 1998) was deposited across a regional unconformity and includes a basal unit of clastic sedimentary rocks that is overlain by a 4 km thick succession of komatiite, komatiitic basalt, basaltic andesite, dacite, and rhyolite, hosting volcanogenic massive sulfide deposits (Brauhart et al., 1998; Vearncombe et al., 1998; Van Kranendonk, 2000). The succession has been interpreted either as a back-arc sequence (Vearncombe et al., 1998; Brahart, 1999), or as an upward-fractionating, plume-derived volcanic sequence that was affected by increasing degrees of crustal contamination (Smithies et al., 2007b; Van Kranendonk et al., 2007).

The Pilbara Supergroup is unconformably overlain by low-grade metasedimentary and metavolcanic rocks of the c. 3200–3165 Ma Soanesville Group, the 3020–2930 Ma De Grey Supergroup, and/or the 2775–2630 Ma Fortescue Group of the Mount Bruce Supergroup. Thickness estimates of the Pilbara Supergroup vary significantly across the EPT due the intrusive or unconformable relationships with overlying and underlying rocks, as well as the presence of major internal unconformities. A maximum lateral accumulated thickness of 26 100 m is estimated for the supergroup across the Panorama and Soanesville greenstone belts, indicating that it must have accumulated in actively developing basins during periods of crustal extension (Van Kranendonk et al., 2004, 2007).

Pilbara Supergroup greenstones have been affected by low-grade seafloor metamorphism and low-pressure, high-temperature contact-style metamorphism (Hickman, 1983) that varies from high-temperature amphibolite- and rare granulite-facies assemblages within, and adjacent to, granitic complexes, to greenschist and prehnite–pumpellyite facies with increasing distance up stratigraphic section and away from granitic rocks (Van Kranendonk et al, 2002; Terabayashi et al., 2003; Van Kranendonk, 2006). Ar–Ar data from around the margins of granitic complexes show that these assemblages developed over the full history of tectonic development of the craton, between c. 3500 and 2775 Ma (Wijbrans and McDougall, 1987; Davids et al., 1997; Zegers et al., 1999).

Deposition of the Pilbara Supergroup was accompanied by the emplacement of suites of synvolcanic granitic and mafic–ultramafic layered intrusions. These include early synvolcanic tonalite–trondhjemite–granodiorite (TTG) rocks of the Callina and Tambina Supersuites that were emplaced contemporaneously with felsic volcanic formations of the Warrawoona Group. Various dominantly monzogranitic rocks of the 3325–3290 Ma Emu Pool Supersuite was emplaced during eruption of the Wyman Formation of the Kelly Group. Granitic rocks ascribed to the Cleland Supersuite were emplaced during eruption of the Sulphur Springs Group.

Several types of mineralization are associated with deposition of the Pilbara Supergroup and emplacement of synvolcanic intrusions. Significant amongst these are volcanogenic-hosted massive sulfide deposits associated with felsic volcanic intervals in both the Warrawoona and Sulphur Springs Groups. Massive hydrothermal barite mineralization is associated with a c. 3480 Ma felsic volcanic caldera in the North Pole Dome (Van Kranendonk, 2006; Van Kranendonk et al., 2008). Epigenetic gold mineralization hosted by Pilbara Supergroup rocks spans a wide range of ages, from 3400–2700 Ma, and a significant porphyry Cu–Mo deposit is c. 3317 Ma in age (Huston et al., 2002, 2007).

Warrawoona Group

The Warrawoona Group (Hickman, 1977, 1983; Van Kranendonk et al., 2006a) is composed of metamorphosed volcanic and sedimentary rocks that were deposited from 3.52 – 3.43 Ga in the EPT, over an area of ~35 000 km^2. The name derives from the Warrawoona mining centre, where Maitland (1905) first used the name 'Warrawoona Beds' to describe a sequence of greenstones. The group represents the oldest, lowermost supracrustal succession of the Pilbara Supergroup, and has recently been redefined to consist of ten formations assigned to four subgroups (Van Kranendonk et al., 2006a): the 3515–3490 Ma Coonterunah Subgroup (Tabletop, Coucal, and Double Bar Formations; not exposed on COONGAN), the 3490–3477 Ma Talga Talga Subgroup (North Star Basalt and Dresser and McPhee formations), the 3477–3463 Ma Coongan Subgroup (Mount Ada Basalt and Duffer Formation), and the 3463–3426 Ma Salgash Subgroup (Apex Basalt and Panorama Formation). Stratigraphic and geochronological data indicate accumulation of the group through several ultramafic–mafic–felsic volcanic cycles of 11–37 million year duration (Hickman and Van Kranendonk, 2004). Deposition of the Talga Talga and Coongan Subgroups was accompanied by local growth faulting, indicating minor degrees of extension.

The base of the group is everywhere an intrusive — or sheared intrusive — contact with synvolcanic or younger granitic rocks. The group is unconformably overlain by low-grade metasedimentary and metavolcanic rocks of the c. 3400 Ma Strelley Pool Formation and 3350–3315 Ma Kelly Group, the 3020–2930 Ma De Grey Supergroup, and the 2775–2630 Ma Fortescue Group of the Mount Bruce Supergroup. Thickness estimates of the group vary significantly across the EPT due to intrusive and/or unconformable relationships with overlying and underlying rocks, as well as of significant lateral facies variations and internal disconformities. A maximum thickness of 15 000 m is estimated for the Warrawoona Group in the Marble Bar greenstone belt, and 11 500 m in the Panorama greenstone belt in the North Pole Dome; in other greenstone belts the group is commonly 5000–8000 m thick.

Geochemical studies on Warrawoona Group volcanic rocks indicate derivation of the dominantly basaltic succession from a long lived mantle plume event. Basaltic rocks show very weakly fractionated N-MORB-like trace-element patterns (Van Kranendonk and Pirajno, 2004) and follow tholeiitic trends that Smithies et al. (2005b) showed could be subdivided into high-Ti and low-Ti types, irrespective of age, which are interbedded and cannot be distinguished in the field. Low-Ti basalts were derived from a slightly more depleted source than the source for the associated high-Ti rocks, with increasing depletion of that source through time (Smithies et al., 2005b). Basaltic rocks show evidence of variable degrees of contamination by older felsic crust (Green et al., 2000; Van Kranendonk et al., 2002, 2007; Smithies et al., 2007b). Felsic volcanic intervals derive either from fractional crystallization of tholeiitic magma chambers with variable degrees of contamination by older felsic crust, or from melting of basalt (Smithies et al., 2007a,b).

Metamorphic grade varies from high-temperature amphibolite- and rare granulite-facies assemblages within, and adjacent to, granitic complexes, to greenschist and locally prehnite–pumpellyite facies with increasing distance up stratigraphic section and away from granitic rocks.

Deposition of the Warrawoona Group was accompanied by the emplacement of suites of syn-volcanic granitic intrusions. These include early syn-volcanic tonalite–trondhjemite–granodiorite (TTG) rocks of the Callina Supersuite (3490–3460 Ma) and TTG and monzogranite intrusions of the 3450–3420 Ma Tambina Supersuite. Both of these supersuites were emplaced contemporaneously with deposition of the main felsic volcanic formations of the Warrawoona Group.

Massive sulfide (Cu–Pb–Zn) deposits are hosted by felsic volcanic rocks of the Duffer Formation of the Warrawoona Group, and stratiform Cu–Zn mineralization is locally present in pelitic schist (metamorphosed black shale) of the Apex Basalt (Salgash Subgroup) (Hickman, 1983; Huston et al., 2007). Polymetallic Au–Cu–Pb–Zn mineralization is present in c. 3450 Ma felsic intrusions at Miralga Creek and Breens (North Pole Dome), and felsic volcanic rocks of the c. 3430 Ma Panorama Formation host Pb–Zn mineralization at Quartz Circle in the McPhee Dome. Massive hydrothermal barite mineralization is associated with the c. 3480 Ma felsic volcanic caldera of the Dresser Formation in the North Pole Dome (Hickman, 1973; Van Kranendonk, 2006; Van Kranendonk et al., 2008).

Talga Talga Subgroup

The Talga Talga Subgroup is the second oldest of four subgroups of the Warrawoona Group, with an age range of 3490–3477 Ma. The name derives from the Talga Talga mining centre, north of Marble Bar, and was first used to refer to the lowest exposed portion of the Warrawoona Group in the Marble Bar greenstone belt. Hickman (1983) defined the subgroup as consisting of the North Star Basalt, McPhee Formation, and Mount Ada Basalt, but this has been revised such that only the lower two formations are included within the subgroup, the Mount Ada Basalt having been assigned to the overlying Coongan Subgroup (Van Kranendonk et al., 2006a). Recent data suggest that the Dresser Formation in the North Pole Dome is 3481 ± 2 Ma (Van Kranendonk et al., 2008) and thus forms a lateral equivalent to the c. 3477 Ma McPhee Formation, thereby warranting its inclusion in the Talga Talga Subgroup. Rocks that are known to belong to the Talga Talga Subgroup have an intrusive lower contact with younger granitic rocks. The lower contact of the Talga Talga Subgroup with the older Coonterunah Subgroup is not exposed (or not recognized) across the EPT.

The type area of the Talga Talga Subgroup is in the Talga Talga Anticline of the Marble Bar greenstone belt, where it is approximately 2100 m thick (Hickman, 1983). Rocks of the subgroup extend to the north and south of this area, and outcrop discontinuously over an area of ~10 000 km^2 in the central part of the EPT. The North Star Basalt comprises up to 2000 m of dominantly tholeiitic, massive and pillowed metabasalt, metakomatiitic basalt, serpentinized peridotite, and thin units of layered sedimentary chert, including siliceous iron-formation. Numerous sills of dolerite and gabbro are also present in the formation. The McPhee Formation is up to 750 m thick and includes felsic volcaniclastic rocks, layered sedimentary chert including minor pelite and siliceous iron-formation, and carbonate–chlorite–quartz rock (metamorphosed ultramafic rock) that forms the bulk of the formation. The Dresser Formation is restricted to the Panorama greenstone belt and most likely represents a lateral facies equivalent of the McPhee Formation. The Dresser Formation contains grey and white (and locally jaspilitic) layered metachert, finely laminated sulfides with stromatolitic textures, minor bedded carbonate, coarse polymictic breccia horizons, and sandstone. This formation shows evidence for rapid lateral facies variations across growth faults, and for deposition within a felsic volcanic caldera that included voluminous hydrothermal fluid circulation in a white-smoker type, steam-heated acid-sulfate system under shallow water to subaerial conditions (Nijman et al., 1998; Van Kranendonk and Pirajno, 2004; Van Kranendonk, 2006; Van Kranendonk et al., 2008).

On Coongan, rocks of the Talga Talga Subgroup outcrop in all greenstone belts except the Panorama greenstone belt. In the Warralong greenstone belt, rocks of the subgroup are west-facing and overturned, and unconformably overlain by the Gorge Creek Group to the south. They are south-facing and overturned in the Doolena Gap greenstone belt, and are unconformably overlain by the Strelley Pool Formation. In the Marble Bar greenstone belt, rocks of the Talga Talga Subgroup are right way up, facing north to northwest or northeast, and conformably overlain by the Coongan Subgroup.

North Star Basalt (AWAn-b [AWn], AWAn-bb [AWnb], AWAn-mba [AWnba], AWAn-xmwa-g [AWnbag], AWAn-xmbs-mus [AWnubs], AWAn-mc [AWncc], AWAn-mzc [AWncch])

The North Star Basalt (Hickman, 1977) (AWAn-b [AWn]) constitutes the lowest formation of the Talga Talga Subgroup of the Warrawoona Group. This formation consists of up to 2000 m of dominantly tholeiitic, massive and pillowed metabasalt, metakomatiitic basalt, serpentinized peridotite, and thin horizons of layered sedimentary chert. Numerous sills of dolerite and gabbro intrude the formation. The type area is in the Talga Talga Anticline of the Marble Bar greenstone belt, where it is exposed over an area of approximately 50 km^2, but the formation is also present in several other greenstone belts of the EPT. The lower contact of the formation is intrusive with younger granitic rocks and the upper contact is conformably overlain by the McPhee Formation (Marble Bar and Warralong greenstone belts) and Dresser Formation (Panorama greenstone belt) of the subgroup. Lower parts of the North Star Basalt, adjacent to intrusive granitic rocks, are metamorphosed to lower amphibolite facies, whereas the middle and upper parts are at greenschist facies. The age of the formation is broadly indicated by an $^{40}Ar/^{39}Ar$ cooling age of 3490 ± 15 Ma on hornblende from a retrogressed pyroxenite lens in the lower part of the formation (van Koolwijk et al., 2001). Geochemical data indicate derivation of basaltic rocks from a mantle plume source (Van Kranendonk and Pirajno, 2004; Smithies et al., 2005b) and contamination by older felsic crust (cf. Glikson and Hickman, 1981; Green et al., 2000; Smithies et al, 2005b, 2007a,b).

On COONGAN, rocks assigned to the North Star Basalt outcrop in the eastern part of the Warralong greenstone belt and in the southern part of the Marble Bar greenstone belt. These rocks have been intruded by granitic rocks of the Muccan and Mount Edgar Granitic Complexes, respectively, and are conformably overlain by the McPhee Formation.

A major component of the North Star Basalt in the Marble Bar greenstone belt is low strain, pillowed to massive tholeiitic basalt at greenschist facies (AWAn-bb [AWnb]). This unit is up to 800 m thick and consists of a fine-grained intergrowth of chlorite–epidote–carbonate, with accessory quartz and opaque minerals. Fine- to medium-grained, foliated and lineated amphibolite derived from basalt (AWAn-mba [AWnba]) is exposed in the Marble Bar and Warralong greenstone belts, where it can reach a thickness of 1500 m. This unit consists of a medium-grained assemblage of hornblende–plagioclase–titanite. Enclaves of amphibolite derived from the North Star Basalt, intruded up to 50% by volume by a net of granitic veins (AWAn-xmwa-g [AWnbag]), occur within the Mount Edgar Granitic Complex in the Marble Bar greenstone belt.

Interlayered amphibolite and chlorite–tremolite ultramafic schist (AWAn-xmbs-mus [AWnubs]) is exposed as a thin enclave in the northern part of the Mount Edgar Granitic Complex, approximately 1 km north of Garden Creek (MGA 804400E 7676700N). This represents the only clearly high-Mg metavolcanic rocks in the formation on COONGAN.

A 5–30 m thick unit of layered grey, white, and blue-black metachert (AWAn-mc [AWncc]) forms the top of the North Star Basalt in the Warralong greenstone belt. Layering at centimetre to decimetre scale in the chert is defined by alternating bands of blue-black, grey, and white quartz (derived from recrystallized chert). These rocks contain a fine-grained, recrystallized mosaic of interlocking quartz grains and show a well-developed foliation and lineation defined by streaky textures and elongate quartz grains.

Local veins and sills of blue-black hydrothermal metachert (AWAn-mzc [AWncch]) intrude footwall metabasalts beneath the layered chert horizons (AWAn-mc [AWncc]) and represent former hydrothermal feeder veins that provided pathways for silicifying fluids.

McPhee Formation (AWAh-xu-s [AWh], AWAh-bb [AWhb], AWAh-bk [AWhbk], AWAh-mutk [AWhuc], AWAh-mc [AWhcc])

The McPhee Formation (Hickman, 1977) (AWAh-xu-s [AWh]) constitutes the uppermost formation of the Talga Talga Subgroup of the Warrawoona Group in the map area. The formation on COONGAN consists of typically 100 m, but up to 750 m, of weakly metamorphosed felsic volcaniclastic rocks and layered sedimentary chert, including minor pelite and siliceous iron-formation, which are interlayered with metabasalt plus carbonate–chlorite–quartz rock that forms the bulk of the formation. The type area of the formation is in the Talga Talga Anticline of the Marble Bar greenstone belt, but the formation is also present in the Warralong greenstone belt on COONGAN, and in the North Shaw greenstone belt on MARBLE BAR, SPLIT ROCK, and NORTH SHAW. The lower contact of the formation is apparently conformable on the North Star Basalt and it is conformably overlain by the Mount Ada Basalt of the Coongan Subgroup. The age of the McPhee Formation is given by a U–Pb SHRIMP zircon date of 3477 ± 2 Ma on silicified, felsic, volcaniclastic siltstone from near the base of the formation (Nelson, 2000a). The McPhee Formation is metamorphosed to greenschist facies.

On COONGAN, the McPhee Formation outcrops in the Warralong and Marble Bar greenstone belts, where it consists of mafic and ultramafic volcanic rocks and related intrusions, and thin metacherts, minor shale and felsic schist (AWAh-xu-s [AWh]) (Hickman, 1983). A good section of the McPhee Formation is preserved in the Marble Bar greenstone belt, approximately 2 km east of the Talga River, near the southern boundary of the sheet area, where it is up to 330 m thick (MGA 800000E, 7677500N). Here, it consists of alternating white to grey and blue-black layered chert, and unassigned ultramafic rocks. A more detailed description of the formation from a short distance along strike to the southwest on MARBLE BAR is presented by Hickman (1983, p. 89–90). In the Warralong greenstone belt, the McPhee Formation is interpreted to overlie a thick chert at the top of the North Star Basalt and to be capped by another unit of chert (AWAh-mc [AWhcc]), and the formation reaches a maximum thickness of 750 m.

At the base of the formation in this area is a foliated and lineated unit of massive basalt (AWAh-bb [AWhb]), which consists of a fine-grained interlocking assemblage of chlorite–epidote–actinolite. This unit is overlain by metamorphosed komatiitic basalt with local pyroxene spinifex texture and common pillows (AWAh-bk [AWhbk]), and by a thick unit of black-weathering, medium-grained, carbonate–talc–chlorite–serpentine ultramafic schist (AWAh-mutk [AWhuc]) with variably developed foliations and lineations. This unit is present in the upper part of the formation and is interpreted to represent a heavily altered metakomatiitic rock. Although no primary textures are preserved, chemical analysis has revealed high Ni and Cr contents (Hickman, 1983).

At the top of the formation are interlayered rocks including several thin units (up to 5 m thick) of grey and white layered metachert (AWAh-mc [AWhcc]), layered ferruginous metachert consisting of centimetre thick layers of magnetite-bearing black and white chert, or white and brown layered metachert with limonite after magnetite. Metadolerite is also present, as are chlorite schist, minor grey sandstone (local beds, 30 cm thick), and a thin unit of pale yellow-weathering, layered metasedimentary rock interpreted to be derived from fine-grained, felsic, volcaniclastic sediment.

Coongan Subgroup

The Coongan Subgroup was deposited from 3474–3463 Ma (Van Kranendonk et al., 2006a). The name derives from the Coongan River that flows through the best developed part of the Coongan Subgroup on MARBLE BAR and COONGAN in the Marble Bar greenstone belt. The Coongan Subgroup consists of the Mount Ada Basalt and the overlying, dominantly felsic volcanic rocks of the Duffer Formation (Van Kranendonk et al., 2006a). Rocks of the subgroup conformably overlie the Talga Talga Subgroup, and are paraconformably overlain by the Salgash Subgroup of the Warrawoona Group, or unconformably overlain by younger units.

The type area of the Coongan Subgroup is in the Marble Bar greenstone belt on MARBLE BAR, where it is up to 8200 m thick (see Hickman and Van Kranendonk, 2008a,b). The Mount Ada Basalt comprises up to 2000–2500 m of dominantly pillowed metabasalt, metamorphosed pyroxene spinifex-textured komatiitic basalt, and thin horizons of metasedimentary chert and felsic volcaniclastic rocks. Numerous sills of dolerite and gabbro also intrude the formation. The Duffer Formation is up to 8000 m thick and consists predominantly of dacitic volcaniclastic rocks, although it grades up to rhyolite and also contains pillow basalt and layered sedimentary chert (Marble Bar and Chinaman Pool Chert Members).

Rocks of the Coongan Subgroup outcrop in the Marble Bar, Warralong and Doolena Gap greenstone belts on COONGAN. In the Warralong greenstone belt they are west-facing and overturned, and unconformably overlain by the Gorge Creek Group to the south. They are south-facing and overturned in the Doolena Gap greenstone belt, and are unconformably overlain by the Strelley Pool Formation. In the Marble Bar greenstone belt, rocks of the Coongan Subgroup are right way up, facing north to northwest or north-northeast, and paraconformably overlain by the Salgash Subgroup.

Mount Ada Basalt (AWAm-b [AWm], AWAm-bb [AWmb], AWAm-mba [AWmba], AWAm-mbas [AWmbas], AWAm-xmwa-g [AWmbag], AWAm-mbbz [AWmbz], AWAm-bk [AWmbk], AWAm-mbk [AWmbc], AWAm-mbms [AWmbks], AWAm-mut [AWmut], AWAm-muts [AWmubs], AWAm-muzk [AWmuc], AWAm-bnvt [AWmbt], AWAm-cc [AWmcc], AWAm-ccb [AWmccj], AWAm-fdvt [AWmft])

The Mount Ada Basalt (Hickman, 1977) (AWAm-b [AWm]) of the Coongan Subgroup consists predominantly of low-grade pillowed and massive basalt and pyroxene spinifex-textured komatiitic basalt , minor, thin, chert units, and both felsic and mafic metavolcaniclastic units. The name derives from the Mount Ada mine on MARBLE BAR, and the type area is designated as a traverse extending 3 km northwest from the McPhee Reward mine (on COONGAN) to the base of the Duffer Formation, 5 km east of the Coongan River (Hickman, 1983). The Mount Ada Basalt conformably overlies either the McPhee Formation or the Dresser Formation of the Talga Talga Subgroup in different greenstone belts, and is conformably overlain by, and locally partly interfingers with, felsic volcanic and volcaniclastic rocks of the Duffer Formation. The age of the Mount Ada Basalt is bracketed by the age of the underlying McPhee Formation (SHRIMP U–Pb zircon date of 3477 ± 2 Ma; Nelson, 2000a), by a unit of felsic tuff within Mount Ada pillow basalts on COONGAN, 4 km west of the Talga River approximately one km north of the southern boundary of the sheet area, dated at 3469 ± 3 Ma (Nelson, 1999b; MGA 793350E, 7676040N), and by the age of a felsic volcanic unit from within 50 m of the base of the overlying Duffer Formation on MARBLE BAR, dated at 3468 ± 2 Ma (Nelson, 2000b).

The Mount Ada Basalt is well preserved in the Marble Bar, Warralong, and Doolena Gap greenstone belts on COONGAN, reaching a maximum stratigraphic thickness of 2460 m in the Marble Bar greenstone belt. The formation is characterized by thick sections of pillow basalt and pillowed komatiitic basalt, with thin chert interbeds. Pillow structures are well developed in all greenstone belts, and indicate way up directions; they are right way up in the Marble Bar greenstone belt, but overturned in both the Doolena Gap and Warralong greenstone belts (e.g. 2.5 km north of the Marble Bar Road, 3 km east of Gorge Creek (at MGA 763600E 7697200N), and south of the Marble Bar Road, just west of the Talga River (at MGA 792000E 7683900N)).

Weakly metamorphosed basalt (AWAm-bb [AWmb]) forms the bulk of the Mount Ada Basalt, and contains common pillows and interpillow hyaloclastite. The metamorphic grade of this unit is greenschist facies.

Weakly-deformed, amphibolite-facies metabasalts (AWAm-mba [AWmba]) consist of a fine-grained, interlocking texture of amphibole and plagioclase. These rocks are developed adjacent to, and as enclaves within, the Mount Edgar Granitic Complex in the far southeast of the sheet area, where they have been affected by contact metamorphism during intrusion of c. 3300 Ma granitic rocks.

Amphibolite-facies metabasaltic rocks (partially and locally retrogressed to greenschist facies) of the formation adjacent to the Muccan Granitic Complex have been deformed into strongly foliated mafic schists (AWAm-mbas [AWmbas]), consisting of aligned prisms of medium-grained hornblende in a fine- to medium-grained matrix of plagioclase, quartz, epidote, chlorite, and titanite.

Adjacent to the contact with granitic rocks, foliated and lineated amphibolites are interlayered with approximately equal amounts of intrusive, c. 3300 Ma granitic rocks (AWAm-xmwa-g [AWmbag]), representing a transposed intrusive vein network that was responsible for the contact metamorphism of the greenstones.

Silicic alteration has locally affected metabasalts of the Mount Ada Basalt (AWAm-mbbz [AWmbz]) in the Doolena Gap greenstone belt, just east of the Coongan River, approximately 1 km south of the Marble Bar Road (MGA 7905000E 7683500N). Despite alteration of the rocks to a pale beige-weathering, quartz–sericite–leucoxene-bearing assemblage, preservation of pillow structures and other primary features indicates that this alteration developed in the absence of penetrative deformation. The alteration style is typical of low-temperature phyllic hydrothermal alteration generally associated with the development of hydrothermal chert feeder-vein systems to bedded cherts in the Pilbara Supergroup (see Van Kranendonk and Pirajno, 2004).

Weakly metamorphosed komatiitic basalt (AWAm-bk [AWmbk]) with common pillows is well exposed in the Doolena Gap greenstone belt. It is characterized by an orange-weathering appearance that contrasts with the brown-weathering appearance of the (tholeiitic) metabasalts. Fine-grained microspinifex texture is locally well developed within pillows, and hyaloclastite breccia fills pillow interstices. The metamorphic grade is greenschist facies.

Metabasalts in the Doolena Gap greenstone belt are affected by strong carbonate alteration (AWAm-mbk [AWmbc]), for example about 1 km east of the Coongan River on the Marble Bar Road (MGA 791000E 7684600N). Where heavily altered, the rocks weather very dark brown to black, and the pillow structures in this area are typically poorly preserved, in part due to the alteration, and in part to the strong deformation associated with overturning of the stratigraphy in this belt.

Tremolite–chlorite–serpentine and chlorite–carbonate schists derived from komatiitic basaltic protoliths (AWAm-mbms [AWmbks]) weather to a distinctively more orange colour than the dark green- to brown-weathering amphibolites, and are typically more strongly foliated due to the presence of chlorite, serpentine and minor talc. These rocks are exposed in the far eastern part of the Doolena Gap greenstone belt.

Talc–carbonate (magnesite)–chlorite–serpentine schists (AWAm-mut [AWmut]) in the far northern part of the Doolena Gap greenstone belt, west of the Talga River, weather to a light brown colour and are interpreted to represent metamorphosed komatiite flows or the basal cumulate parts of thicker komatiitic basalt flows or intrusions. Strongly schistose equivalents (AWAm-muts [AWmubs]) are widespread in the eastern part of the Doolena Gap greenstone belt, where they consist of strongly foliated, light orange-weathering carbonate–chlorite–talc schists, commonly interlayered with mafic schists at a scale of metres.

A thin (<50 m) unit of black-weathering, talc–carbonate–chlorite rock (AWAm-muzk [AWmuc]), exposed at the base of the Mount Ada Basalt in the Marble Bar greenstone belt about 2 km west of the Marble Road near the southern boundary of the sheet area (MGA 795000E 7675950N), is interpreted to be a strongly carbonate-altered komatiite flow, or possibly cumulate rock (no primary textures are preserved). Similar rocks cropping out part way through the formation (e.g. about 2 km east of the Talga River and 2.5 km south of Eight Mile Creek; MGA 800000E 7679500N) are also interpreted as altered komatiite flows.

Marking the top of the Mount Ada Basalt in the Marble Bar greenstone belt is a unit of predominantly mafic volcaniclastic rock, with lesser felsic volcaniclastic sandstone and interbedded milky grey cherts (AWAm-bnvt [AWmbt]. Examples of this unit are exposed at MGA 791500E 7676600N, 5.5 km west of the Talga River and 2 km north of the southern edge of the map sheet boundary. At the base of this unit is pillow breccia, overlain by fine-grained, light-green to dark-green tuffaceous siltstone, with well developed, millimetre-scale bedding. These rocks are interbedded with very thin horizons of grey chert and silica-rich banded iron-formation and pass up into lithic tuff. Thin dolerite sills intrude this package of rocks and are metamorphosed. This unit grades up into the conformably overlying Duffer Formation.

Chert horizons throughout the Mount Ada Basalt typically consist of grey, white, and blue-black layered cherts (AWAm-cc [AWmcc]), affected by low-grade metamorphism. One of the thickest of these forms the Box Soak Razorback Ridge in the far southeast of the map area (MGA 80900E 7680500N), and contains gold mineralization. Another chert horizon, located 1 km east of the Coongan River and 1 km south of the Marble Bar Road (MGA 791340E 7683660N), is a silicified, fine-grained, grey, felsic tuffaceous sedimentary rock veined by white chert, which contains wavy laminates and domical stromatolites up to 20 cm diameter and 5 cm amplitude (Fig. 5). Felsic agglomerate immediately above these rocks is interpreted to mark the onset of felsic volcanism associated with the Duffer Formation. The stromatolitic laminations are defined by thin beds of black carbonaceous material, some of which has been broken off and incorporated as clasts in immediately overlying clastic beds. Prismatic ghosts of evaporite crystals are common. Some of the stromatolitic domes grow on top of long, vertically oriented clasts of felsic volcanic material, with a similar texture to that common in flat-pebble conglomerates of stromatolitic carbonate units.

Another stromatolitic horizon outcrops nearby (MGA 790440E 7683757N), and also contains up to 2 m thick of underlying, silicified felsic volcaniclastic material, including beds up to 10 cm thick, with felsic glass shards up to 1 cm long (Fig. 6). The stromatolites in this horizon are texturally distinct from those described above, however, consisting of a wrinkly laminated rock that weathers to a dark-red colour. Stromatolites outcrop over 75 m of strike length in a layer approximately 60–100 cm thick. Individual stromatolites range from 1 cm in diameter to 100 by 60 cm, but have low amplitudes (Fig. 7a–c). In detail, the wavy laminae are seen to consist of millimetre thick beds of ferruginous material in a silica matrix (Fig. 7d). These stromatolites are similar to some of those described from the Dresser Formation on NORTH SHAW (Van Kranendonk, 2000, 2006).

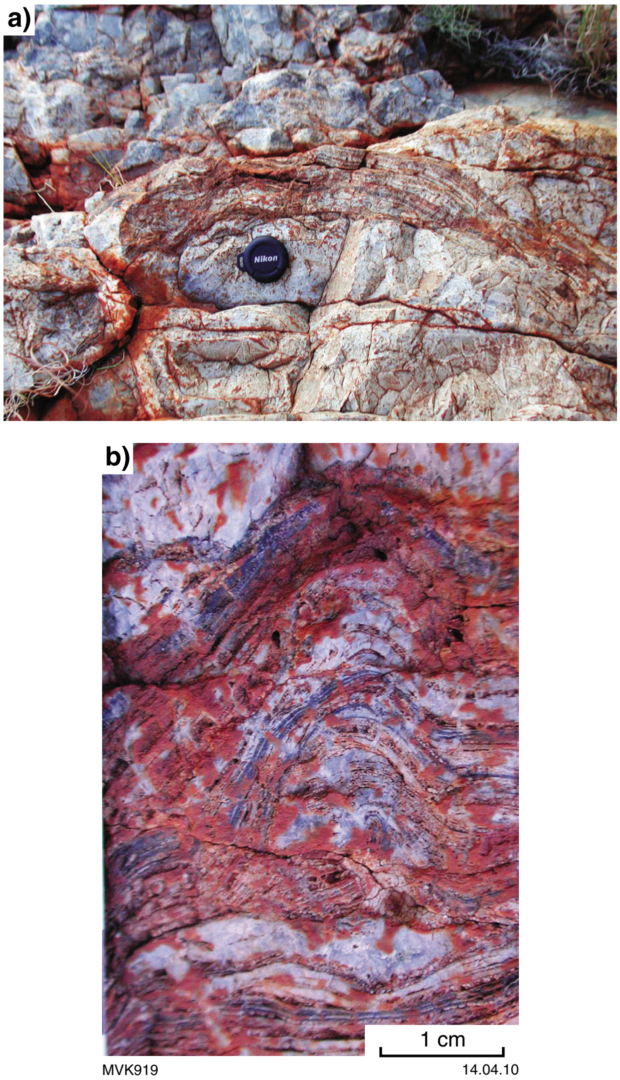


Figure 5. Domical stromatolites in outcrop, defined by millimetre-thick layers of black carbonaceous material in silicified felsic ash from a thin chert unit in the Mount Ada Basalt in the Doolena Gap greenstone belt (MGA 791340E 7683660N): a) cross-sectional view of broad, domical stromatolite (lens cap is 2.3 cm diameter); b) cross-sectional view of a columnar stromatolite.

Ferruginous chert, consisting of jasper, white, and blue-black layered chert (AWAm-ccb [AWmccj]), is interbedded with pillow basalts in the Marble Bar greenstone belt, about 4 km west of the Talga River along the southern edge of the map sheet area (MGA 794000E 7675950N). These metacherts are similar to the Marble Bar Chert Member of the Duffer Formation. Such cherts are more common along strike to the south and in the Coongan greenstone belt on Marble Bar. Two closely adjacent chert units in hydrothermally altered metabasalts of the Doolena Gap greenstone belt contain stromatolites.

A thin unit of albite-porphyritic felsic accretionary lapilli tuff (AWAm-fdvt [AWmft]) is present part way through the Mount Ada Basalt in the Marble Bar greenstone belt, 4 km west of the Talga River and just north of the southern edge of the map sheet area (MGA 7933500E 7676000N). This tuff has been dated at 3469 ± 3 Ma (Nelson, 1999b) and indicates that the Mount Ada Basalt was at least partly coeval with the Duffer Formation, which has returned dates of 3474–3463 Ma.

Duffer Formation (AWAd-f [AWd], AWAd-fdx [AWdfx], AWAd-fnt [AWdft], AWAd-fd [AWdfd], AWAd-gmap [AWdfdp], AWAd-skv [AWdsvc], AWAd-stv [AWdsv], AWAd-stq [AWdstq], AWAd-ca [AWdsh], AWAd-bbo [AWdb], AWAd-zi [AWdqgo]: AWAa-od [AWdd] (*described under Apex Basalt*))

The Duffer Formation (Lipple, 1975) (AWAd-f [AWd]) is the uppermost of two formations that comprise the Coongan Subgroup of the Warrawoona Group. The type area is designated as the creek that flows from west to east (along latitude approximately MGA 7669000N) into the Coongan River, 14 km north of the town of Marble Bar on Marble Bar (Hickman, 1983). The formation is well exposed in the Marble Bar, Doolena Gap, and Warralong greenstone belts on Coongan. The Duffer Formation consists predominantly of weakly metamorphosed dacitic to rhyolitic felsic volcaniclastic rocks, but also includes felsic volcanic flows, interbedded pillow basalt, and layered red and white metachert horizons, most spectacularly developed as the Marble Bar Chert Member at the top of the formation. Feldspar-porphyritic subvolcanic intrusions are common and voluminous beneath thick eruptive parts of the formation. Deposition of the formation was accompanied by local growth faulting.

Dolerite dykes (AWAa-od [Awdd]) that were formerly assigned to, but in fact cut through, the Duffer Formation in the Marble Bar greenstone belt are now assigned to the Apex Basalt.

On Coongan, the Duffer Formation is up to 4750 m thick in the Marble Bar greenstone belt, but varies to a minimum

Figure 6. Outcrop view of felsic volcanic sandstone with angular fragments of silicified, fine-grained material (altered ?basalt) in a fine-grained grey matrix. Note intrusive bands of grey hydrothermal silica at base. Height of view is approximately 15 cm (MGA 790440E 7683757N).

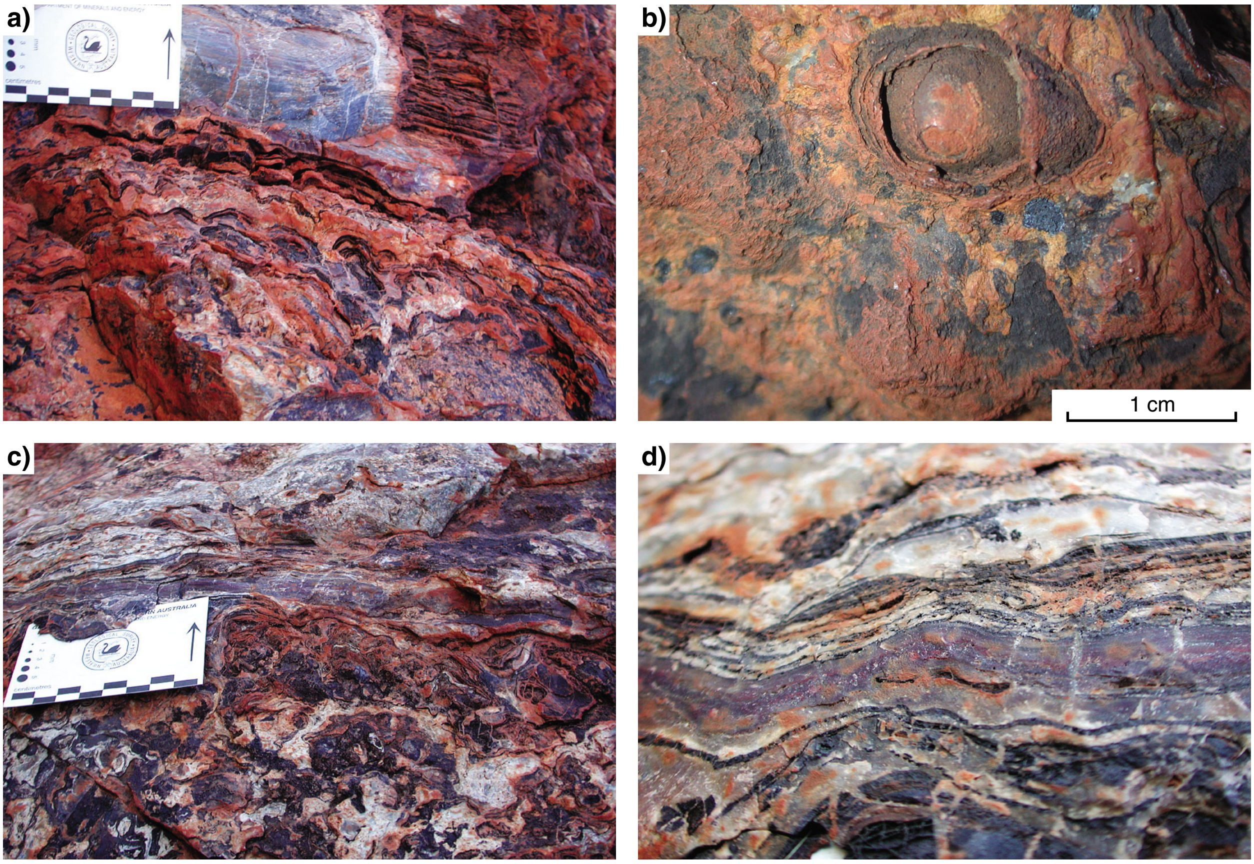


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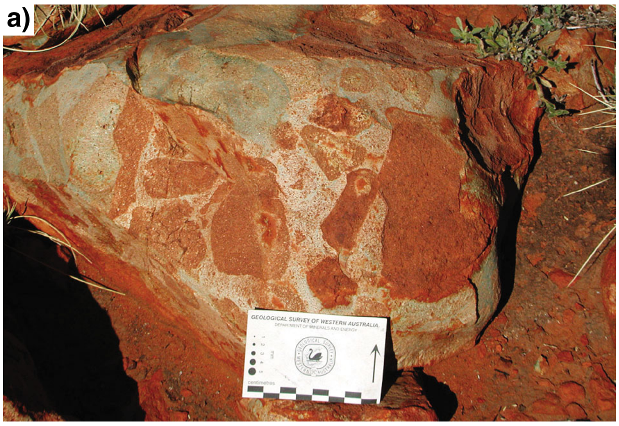
Figure 7. Probable stromatolites from a thin chert unit from the Mount Ada Basalt in the Doolena Gap greenstone belt: a) cross-sectional outcrop view of finely-laminated material with small, well-developed domes; b) view looking down onto a bedding plane of a small, circular domical or columnar stromatolite; c) oblique cross-sectional outcrop view of wrinkly laminated material; d) detailed outcrop view of wrinkly laminated material. Width of view in d) is 5 cm (All images from MGA 790440E 7683757N).

thickness of 50 m in the Warralong greenstone belt, about 2 km east of Gorge Creek and 7 km north of the Marble Bar Road (MGA 762800E 7700500N). The formation reaches a maximum thickness of approximately 530 m in the central part of the Doolena Gap greenstone belt, but has an erosional contact along strike to the west against the unconformably overlying Strelley Pool Formation, at about 4.5 km south of the Marble Bar Road and 5 km west of the Coongan River (MGA 785000E 7685000N). The Duffer Formation is sheared out along strike to the east, within the axial zone of an isoclinal, highly asymmetrical, overturned syncline between the Mount Edgar and Muccan domes.

The thickest part of the Duffer Formation in the Marble Bar greenstone belt is composed of coarse, dacitic, volcaniclastic breccia (AWAd-fdx [AWdfx]), with angular to rounded fragments of quartz-phyric dacite to rhyolite in a finer grained, felsic volcanic matrix, which probably represents a coarse agglomerate or proximal debris flow (Fig. 8). Fragments vary in size from less than 1 cm to 10 cm, and are locally coarser grained. Bedding is typically not visible in this unit, except locally in the lower part of the formation, at about 1.5 km south of the Talga River crossing on the Marble Bar Road (MGA 795400E 7680000N). At this locality, graded sequences of crystal tuffs and crystal-lithic tuffs pass up into coarse volcanic breccia and agglomerate.

Along strike to the west, at about 2 km southwest of the Talga River crossing off the Marble Bar Road (MGA 795000E 7679500N), the base of the Duffer Formation is marked by thinly bedded, fine-grained, felsic volcaniclastic rocks (AWAd-fnt [AWdft]), consisting of upward-coarsening sequences of tuffaceous siltstones, lithic tuff, and crystal-lithic tuffs with quartz phenocrysts and numerous rock fragments derived from the underlying lithology. Interbedded with these rocks are thin units of unusual, coarsely plagioclase-phyric (5–10 mm long) and highly vesicular rocks, possibly representing very shallow level andesitic flows or sills. A similar lithology also forms the top of the formation in the Marble Bar greenstone belt, about 4 km west of the Coongan River (MGA 785000E 7679500N), where it is characterized by fine-grained, dacitic to rhyolitic volcaniclastic rocks with well-developed bedding at centimetre to millimetre scale (Fig. 9a).

Massive, fine-grained dacite–andesite (AWAd-fd [AWdfd]) forms sills at the base of the Duffer Formation and in a)



b)

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Figure 8. a) Outcrop view of a weathered surface of coarse volcanic breccia from the thickest part of the Duffer Formation in the Marble Bar greenstone belt (AWAd-fns [AWdfx]; MGA 799690E 7680405N). Note the slightly rounded nature of the fragments; b) outcrop view of a fresh surface of coarse volcanic breccia from the thickest part of the Duffer Formation in the Marble Bar greenstone belt (AWAd-fns [AWdfx]; MGA 804740E 7681555N). Note the larger volume of matrix in this example relative to that in a).

underlying rocks of the Mount Ada Basalt in the Marble Bar greenstone belt. These rocks are homogeneous in texture and typically have a fine- to medium-grained matrix of fine-grained interlocking quartz and feldspar.

Massive quartz- and feldspar-phyric dacite–andesite (AWAd-gmap [AWdfdp]) forms coarse-grained sills at the base of the Duffer Formation. These contain centimetre-size plagioclase feldspar phenocrysts (Fig. 9b). A sample of this unit on Coongan returned a SHRIMP U–Pb zircon date of 3463 ± 2 Ma (sample ANU89-332 in McNaughton et al., 1993; MGA 796350E 7680450N).

Near the top of the formation in the Marble Bar greenstone belt, about 4 km west of the Coongan River (MGA 785000E 7678500N), a unit of massive porphyritic dacite (AWAd-gmap [AWdfdp]) is bounded by growth faults and forms a sheet at the contact between the lower, massive volcanic breccia unit and overlying felsic tuffs. This sheet is medium grained, with quartz and feldspar phenocrysts up to 5 mm. It contains angular inclusions of jaspilitic chert (Fig. 9c), indicating that the processes that formed the Marble Bar Chert Member were already in operation at an earlier stage in Duffer Formation history. This is part of the rationale for placing the Marble Bar Chert Member within the Duffer Formation from its former position as a separate formation (Van Kranendonk et al., 2006a).

The base of the Duffer Formation in the southeastern part of the sheet area, east of the Talga River (MGA 799500E 7680200N), is marked by a less than 200 m thick unit of dark-red to black weathering shale and finely layered red and black banded iron-formation that probably represents ferruginized and partly silicified shale (AWAd-ca [AWdsh]).

The Duffer Formation in the Warralong greenstone belt predominantly consists of fine-grained, carbonate-cemented, felsic volcaniclastic sandstone and siltstone. (AWAd-skv [AWdsvc]) deposited as a series of 2–70 cm thick beds with well-developed internally fining-upwards textures. The unit as a whole gradually fines upwards from basal beds with 20–40 cm thick sandy bases and 10–30 cm thick, fine-grained, welded mudstone ash tops (Fig. 10a), to 2 cm-thick beds with sandy bases and ultra-fine-grained tops resembling porcelinite (Fig. 10b). These rocks pass upwards into the layered red, white, and black cherts of the Marble Bar Chert Member.

The Duffer Formation also includes up to 450 m thick of massive to weakly bedded sandstone and siltstone (AWAd-stv [AWdsv]), with poorly defined beds (approximately 3–5 m thick) that have 30 cm thick tops defined by finer-grained rocks. Some rhyodacite flows to 5 m thick were observed. The main lithology of this unit is a quartz and feldspar crystal-rich volcaniclastic rock, with lithic (chert) fragments up to 2 cm. Quartz crystals are commonly euhedral bipyramids, although some show evidence of resorption and others are fragments. Altered feldspar crystals and lithic fragments account for up to 25% of the rock, which also contains altered biotite phenocrysts. The rock matrix is largely microcrystalline to cryptocrystalline quartz and minor sericite that is presumably after glassy particles. The unit is cut by numerous blue-black to grey hydrothermal chert veins, up to 60 cm wide. A U–Pb SHRIMP zircon date from a sample of bedded, crystal-lithic, felsic tuff on Carlindie returned an age for the main population of zircons of 3477 ± 5 Ma (Nelson, 2002a), which is interpreted as the maximum depositional age of the rock.

Overlying the interbedded sandstones and siltstones is a unit, up to 200 m thick, of white, quartz-rich sandstone and quartz-arenite (AWAd-stq [AWdstq]). Quartz-rich sandstones at the base of this unit are interbedded with a 2-m thick bed of coarse conglomerate that has well-rounded pebbles and cobbles of quartzite, up to 20 cm in diameter, in a felsic, sandy matrix. Bedding in the sandstones is conspicuous and typically 30 cm to 1 m

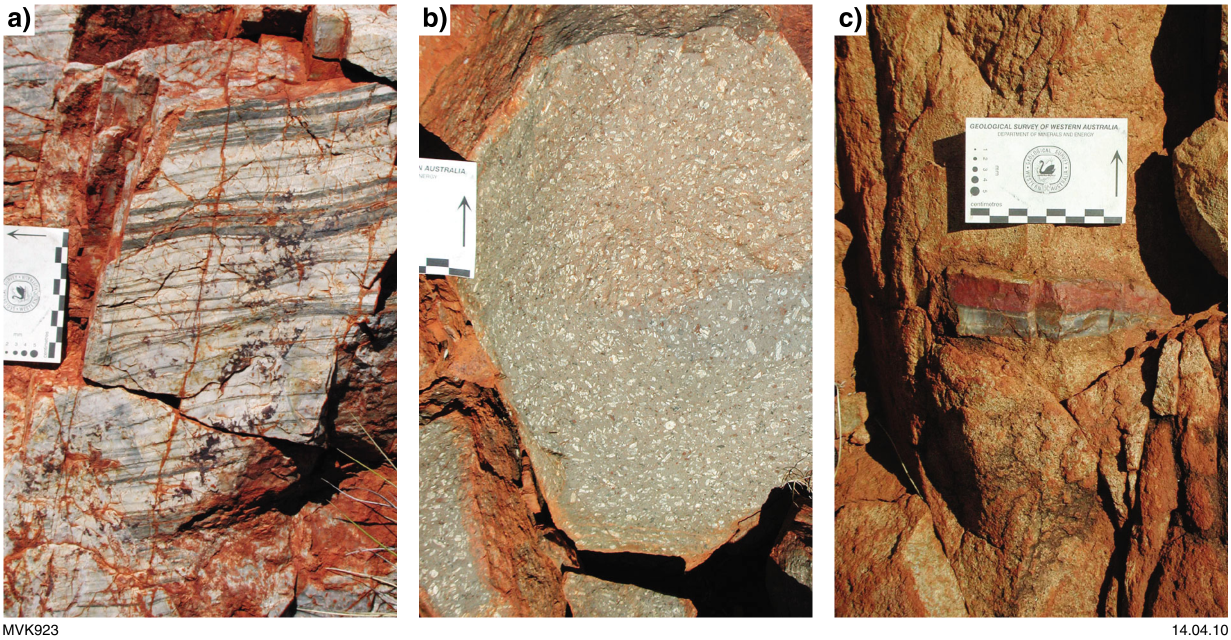

Figure 9. a) Outcrop view looking down on surface of steeply-dipping, fine-grained, thinly bedded felsic volcaniclastic tuff of the Duffer Formation (AWAd-fnt [AWdft]; MGA 799690E 7683800N); b) outcrop view of a fresh surface of plagioclase-phyric dacite–andesite of the Duffer Formation (AWAd-fdp [AWdfdp]; MGA 800440E 7681655N); c) outcrop view of a fragment of jaspilitic chert in massive dacite of the Duffer Formation in the Marble Bar greenstone belt (AWAd-fdp [AWdfdp]; MGA 783790E 7678340N).

thick. The sandstones contain granules of black chert and are cut by blue-black hydrothermal chert veins.

Pillowed, mafic volcanic rocks of basaltic, or possibly andesitic, composition (AWAd-bbo [AWdb]) are interbedded with massive to fragmental dacitic rocks in the northern part of the Marble Bar greenstone belt, about 7 km east of the Talga River, just north of Eight Mile Creek (MGA 804000E 7682700N). The pillows are very well preserved and metamorphosed at greenschist facies.

Veins of dark red-brown weathering, gossanous material with boxwork textures indicative of weathered out sulfides (AWAd-zi [AWdqgo]; Fig. 10c) extend for several hundreds of metres long, but less than 1–2 m wide, through the lower parts of the Duffer Formation in a few places, roughly orthogonal to bedding. Larger veins are present approximately 4 km west of the Coongan River, just north of the southern edge of the map sheet area (e.g. MGA 784000E 7677800N and 784300E 7676500N). The gossanous veins are filled by network of thin, white to grey silica veinlets and show marginal silicification of their host rocks. Higher up in the Duffer Formation in the Marble Bar greenstone belt, these veins consist of a network of grey to white quartz veins, including some 1–2 m thick veins that are subparallel to bedding and show textural evidence of open-space (epithermal) infilling (Fig. 10d).

Marble Bar Chert Member (AWAdm-ccb [AWt, AWtm], AWAd-zc [AWtcch])

Layered grey, white, and red chert assigned to the Marble Bar Chert Member (AWAdm-ccb [AWtm]) was originally designated part of the Towers Formation (Hickman, 1977), but has been re-assigned to the Duffer Formation (Van Kranendonk et al., 2006a). The Marble Bar Chert Member is up to 150 m thick in the Marble Bar greenstone belt and forms a 20 m-thick cap to the Duffer Formation in the Warralong greenstone belt. The unit consists of millimetre- to centimetre-thick layers of different coloured cherts, with local wavy textures forming small domes. Fine-grained, clastic sedimentary rock is locally present in the chert. Thickness variations of this member across faults in the Marble Bar greenstone belt suggest deposition during growth faulting, a relationship that is well preserved farther south on Marble Bar.

The Marble Bar Chert Member is also present on the eastern limb of the Warralong Syncline in the Warralong greenstone belt, just east of Gorge Creek, about 1 km north of the Marble Bar Road (MGA 760600E 7699000N), as a 1–5 m thick unit of bright red and white layered metachert that conformably overlies bedded, felsic, volcaniclastic sandstone and siltstone. On the western limb of the Warralong Syncline about 3 km north of the Marble Bar Road and just east of the western edge of the map sheet area (MGA 760720E 7699800N), the Marble Bar Chert Member is split up by intrusive veins of coarsely crystalline hydrothermal barite. Here, the chert is erosionally overlain by felsic volcaniclastic sandstone that contains clasts of the Marble Bar Chert Member and quartz crystals in a felsic volcanic matrix (?rhyolite), and which is interpreted to be part of the Panorama Formation (AWAp-fnck [AWpsv]).

The Marble Bar Chert Member in the more highly metamorphosed and more strongly deformed northern part of the Warralong greenstone belt, about 9 km north

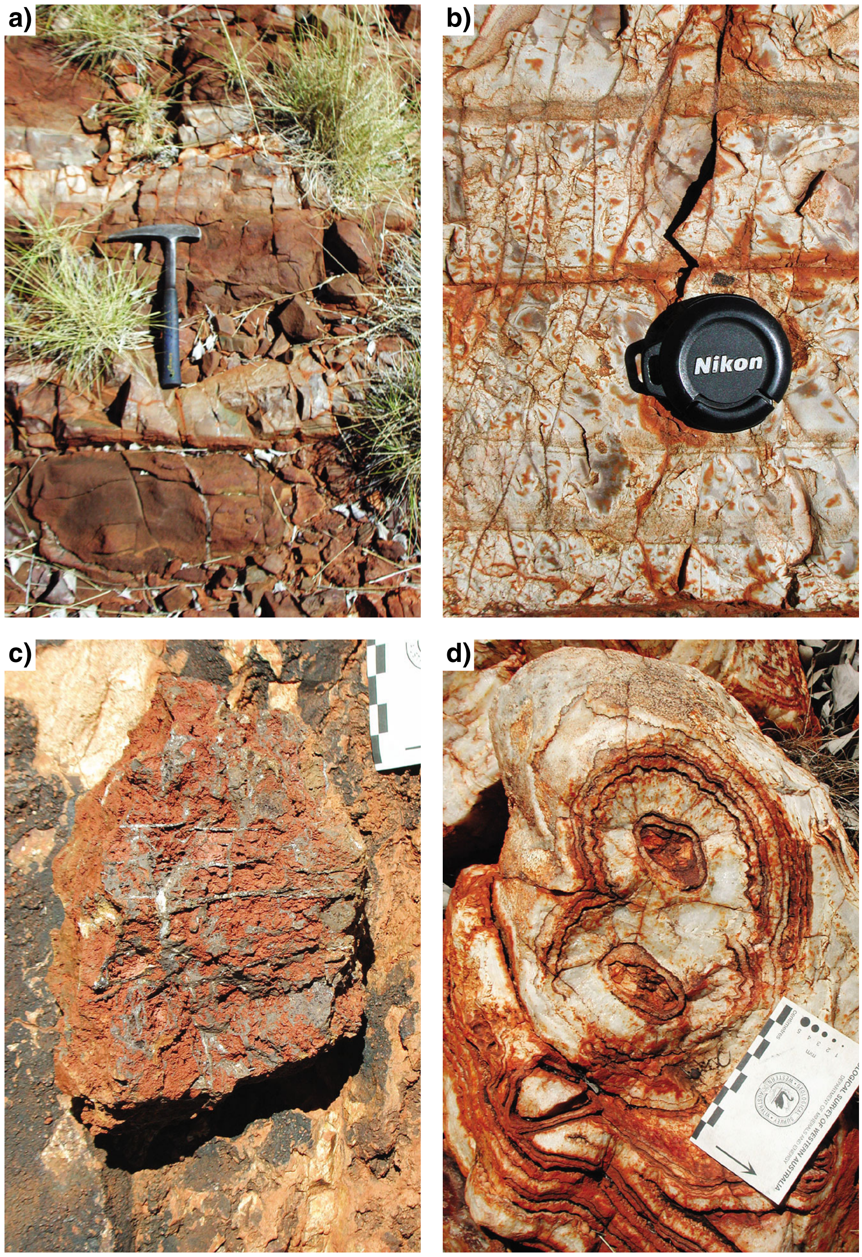

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Figure 10. Fining up sequences of a) carbonate altered, and b) silicified, fine-grained, felsic volcaniclastic rocks of the Duffer Formation (way-up direction in a) and b) is to left side of photograph) in the Warralong greenstone belt (AWAd-skv [AWdsvc]; MGA 762040E 7695600N); c) sample of ferruginous gossan from the Duffer Formation (AWAd-zi [AWdqgo]), showing fine network of grey silica veins in weathered sulfides (MGA 784040E 7677860N); d) outcrop view of a cross-section through white epithermal vein quartz in the Duffer Formation, showing well-developed chalcedonic layering defining vertical pipes that are interpreted to represent stalactites in a horizontal vein fill (MGA 783490E 7678400N).

of the Marble Bar Road (from MGA 764000E 7603700N northwards), is represented by a thick unit of centimetre-thick layers of white and dark-brown chert, which weathers to a more uniform yellow colour . In these rocks, the jasper of the fresher chert has been altered to limonite in the dark brown layers as a result of surficial weathering and/or high-grade shear deformation.

Bedded chert of the Marble Bar Chert Member is locally partly cut, and underlain, by hydrothermal veins of weakly metamorphosed blue-black chert (AWAd-zc [AWtcch]) that taper downwards into the footwall felsic volcanic rocks. These are interpreted as fossil hydrothermal fluid pathways during, or just after, sediment accumulation, as documented by Van Kranendonk (2006).

Callina Supersuite (ACL -mgtn [AgMn])

The Callina Supersuite is the name applied to 3490–3460 Ma, dominantly sodic metagranitic rocks in the EPT (Van Kranendonk et al., 2006a). The name is derived from Callina Bore on NORTH SHAW, which lies in the type area underlain by the North Shaw Suite (Bickle et al., 1983). Components of this supersuite outcrop in the Yule, Carlindi, Shaw, Mount Edgar, and Muccan Granitic complexes, and vary in composition from hornblende diorite, through leucocratic biotite tonalite and mafic granodiorite (the dominant lithology), to monzogranite and local alkali granite (Homeward Bound Granite; a subvolcanic intrusion to the Duffer Formation on MARBLE BAR). These rocks are locally well preserved (e.g. North Shaw Suite in the northern part of the Shaw Granitic Complex; Van Kranendonk, 2000), but are typically highly migmatized throughout much of the EPT.

Callina Supersuite tonalite–trondhjemite–granodiorite (TTG) rocks are typical of Paleoarchean TTG that, when compared with modern-style, subduction zone-related adakite, have low Mg number, and Cr and Ni concentrations that provide no evidence for evolution in a subduction zone environment (Smithies, 2000). Despite contemporaneity, the TTG of the Callina Supersuite and the felsic volcanic rocks of the Duffer Formation have different trace element and Nd-isotopic compositions and were derived from different sources (Smithies et al., 2007a, 2007b). Whereas the Duffer Formation was probably a result of fractionation of a crustally (TTG) contaminated tholeiitic parent magma, Nd-isotopic and Pb–Pb data from the North Shaw Suite indicate that at least some of the Callina Supersuite TTG were derived through melting of basaltic crust and earlier TTG rocks, some of which were older than 3.7 Ga (Bickle et al., 1993; Smithies et al., 2007a,b; Champion and Smithies, 2007).

Granitic rocks of the Callina Supersuite are exposed within the Muccan Granitic Complex in the south-central and southeastern parts of COONGAN. These rocks consist of tonalitic to granodioritic orthogneiss (ACL -mgtn [AgMn]) with migmatitic to diatexitic textures derived through intrusive and/or in situ sheets of leucogranite or leucosome, and with common xenoliths of amphibolite and less common quartzite. These rocks are strongly deformed along the southern margin of the complex, where they are interleaved with slivers of amphibolite-facies greenstones derived from the lower part of the Warrawoona Group.

Pilbara Supergroup

Warrawoona Group

Salgash Subgroup

The Salgash Subgroup is the youngest of the four subgroups of the Warrawoona Group, with an age range of 3458–3426 Ma (Van Kranendonk et al., 2006a). The name derives from the Salgash mining centre, about 15 km south of the town of Marble Bar (Lipple, 1975). Previously defined to include several formations, the Salgash Subgroup has been redefined to include only two formations: the lower Apex Basalt and the conformably overlying felsic volcanic and volcaniclastic rocks of the Panorama Formation (Van Kranendonk et al., 2006a). Rocks of the subgroup conformably, or paraconformably, overlie the Coongan Subgroup and are unconformably overlain by the Strelley Pool Formation. The type area of the Salgash Subgroup is in the Marble Bar greenstone belt, due west of the town of Marble Bar, where it is up to 3750 m thick.

Rocks of the Salgash Subgroup outcrop in the Warralong and Marble Bar greenstone belts on COONGAN. In the Warralong greenstone belt they are both west-facing and overturned (eastern limb of the Warralong Syncline), and east-facing and right way up (western limb of the Warralong Syncline). On the eastern limb of the Warralong Syncline, the Apex Basalt is 2500 m thick, whereas it is absent on the western limb and the Panorama Formation lies directly on the Duffer Formation.

Apex Basalt (AWAa-b [AWa, AWab], AWAa-bb [AWab], AWAa-bk [AWabk], AWAa-mbms [AWabks], AWAa-mwsc [AWabs], AWAa-uk [AWauk], AWAa-od [AWdd], AWAa-ccb [AWacc], AWAa-zc [AWacch], AWAa-sc [AWasc])

The Apex Basalt (Hickman, 1977; name from the Apex mine on MARBLE BAR) (AWAa-b [AWa]) forms the basal formation of the Salgash Subgroup of the Warrawoona Group (Van Kranendonk et al., 2006a). This formation comprises up to 3250 m of low-grade, dominantly pillowed, basalt, pyroxene spinifex-textured komatiitic basalt, peridotitic komatiite, and thin horizons of chert, black shale, and felsic volcaniclastic rocks. Sills of dolerite and gabbro locally intrude the underlying Coongan Subgroup and extend upwards into the formation.

Rocks of the Apex Basalt outcrop in the Warralong and Marble Bar greenstone belts on COONGAN, reaching a maximum thickness of 2165 m in the latter, and nearly the same thickness in the former. The Apex Basalt lies conformably or paraconformably on the Duffer Formation, or is interbedded with felsic volcanic rocks of the Duffer Formation in some places, and it is conformably or unconformably overlain by the Panorama Formation (Marble Bar greenstone belt), or is cut out by faults (Warralong greenstone belt). The absence of this formation in the Doolena Gap greenstone belt is due to the downcutting erosional nature of the unconformably overlying Strelley Pool Formation.

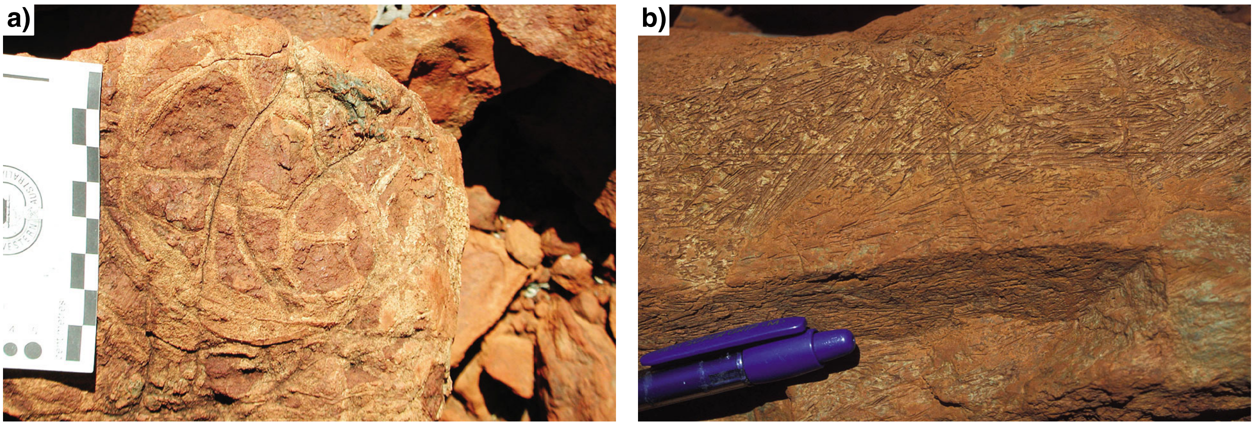

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Figure 11. a) Outcrop view of undeformed, pillowed, komatiitic basalt of the Apex Basalt (AWAa-bk [AWAbk]), showing perlitic cooling cracks on the outside of the pillows (MGA 798290E 7683455N); b) close-up outcrop view of coarse pyroxene spinifex texture in weakly metamorphosed komatiitic basalt of the Apex Basalt (AWAa-bk [AWAbk]).

The Apex Basalt consists predominantly of greenschist facies metamorphosed komatiitic basalt (AWAa-bk [AWabk]) that is remarkably well preserved and commonly pillowed. Pillows show all of the classic features, including chilled pillow margins, marginal vesicles, interpillow hyaloclastite, lava drainage tubes, and even perlitic cooling cracks on the outside of some pillows (Fig. 11a). Pyroxene spinifex texture is common in the cores of pillows and in massive flows, where individual pyroxene needles can reach lengths of 4 cm (Fig. 11b). Ocelli, up to 2.5 cm, are also common in pillows.

Schists derived from strongly deformed komatiitic basalt (AWAa-mbms [AWabks]) outcrop in the northern part of the Warralong greenstone belt and in one panel in the southern part of the belt. These rocks are characteristically orange-weathering, pale green schists, composed of tremolite–chlorite–serpentine mineral assemblages.

Massive and pillowed basalt (AWAb-bb [AWab]) is present near the top of the formation in the Warralong greenstone belt. These rocks are darker brown-weathering and contain fewer discernable features compared with the komatiitic basalts.

Chlorite–actinolite schist (AWAa-mwsc [AWabs]) in the Warralong greenstone belt is derived from mafic volcanic or intrusive rocks and metamorphosed at greenschist facies. The schist is commonly well foliated and lineated.

Weakly metamorphosed komatiite with olivine spinifex texture (AWAa-uk [AWauk]) is present in the Warralong greenstone belt about 3 km north of the Marble Bar Road and 1.5 km east of the western edge of the map sheet area (MGA 762400E 7698000N). This unit dominantly consists of massive, pale-brown weathered serpentinized peridotite. However, crude layering is locally preserved between knobbly-textured metaperidotite (coarse-grained, cumulate-textured peridotite), smooth-textured, finer grained metaperidotite, and greeny blue-black metaperidotite with bladed textures perpendicular to layering, representing olivine-spinifex texture.

Swarms of variably metamorphosed dolerite dykes (AWAa-od [AWdd]) cut through the Duffer Formation in the Marble Bar greenstone belt. These rocks are fine to medium grained, with local plagioclase phenocrysts up to 1 cm. The dykes also intrude the Callina Supersuite, Mont Ada Basalt, and the Talga Talga Subgroup (Hickman and Van Kranendonk, 2008), and are interpreted to be feeder dykes to the Apex Basalt, based on a more complete crustal section just outside of Marble Bar (see Locality 1.1 in Van Kranendonk et al., 2006b; Hickman and Van Kranendonk, 2008a).

Interflow units of bedded chert (AWAa-ccb [AWacc]) are common in the Apex Basalt and are typically composed of centimetre-thick, alternating layers of blue-black, grey, and white metachert. At one locality, about 6 km north of the Marble Bar Road and 2.5 km east of the western edge of the map sheet area (MGA 762100E 7700850N), interbedded brown and white chert contains metre-thick units of centimetre- to decimetre-bedded carbonate (Fig. 12a). This is considered to represent the protolith material to much of the white, grey, blue-black, brown, and red layered metachert in this, and other, chert units.

Bedded cherts are commonly fed by swarms of thin, grey to black hydrothermal chert veins (AWAa-zc [AWacch]) that taper downwards from the bedded units into the underlying host rocks (Fig. 12b). These veins vary from massive, homogeneous chert to brecciated chert formed by multiple generations of silica veining. Similar vein arrays have been described for many chert units across the EPT, including the economically significant cherts of the Dresser Formation on North Shaw (Van Kranendonk, 2000, 2006). Basaltic rocks adjacent to such veins are commonly extensively altered and, in places, almost completely replaced by silica (Fig. 12c).

An unusual unit, 10 m thick, of angular to subrounded, matrix-supported, conglomerate and breccia (AWAa-sc [AWasc]) has an erosional lower contact on a bedded blue-black and white layered metachert unit in the Apex Basalt of the Marble Bar greenstone belt, about 7 km west

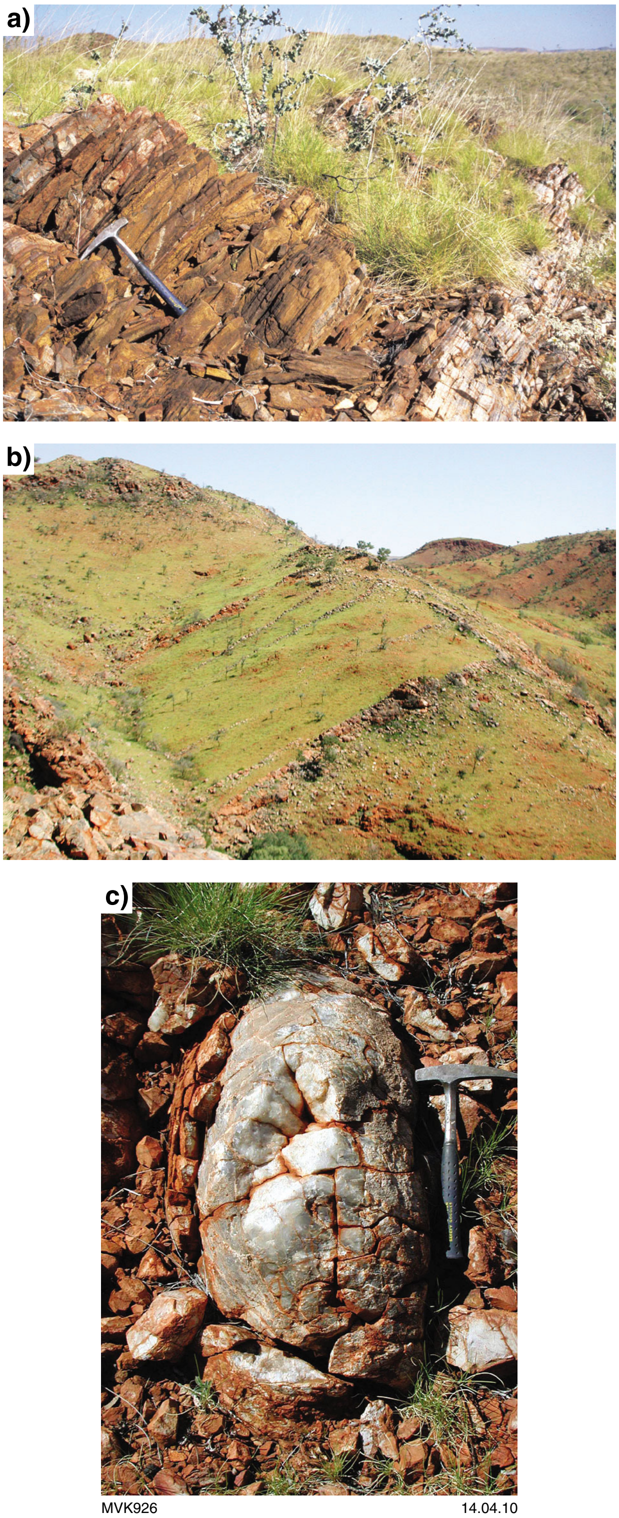

Figure 12. a) Outcrop view of bedded sedimentary rocks of the Apex Basalt in the Warralong greenstone belt, consisting of interlayered carbonate and chert (AWAa-ccb [AWacc]; MGA 762100E 7700850N); b) view southwest, along strike, of a series of four hydrothermal chert veins (AWAa-zc [AWacch]) that taper downwards from top right to lower left of the central part of the photograph in pillowed and hydrothermally altered metabasalt of the Apex Basalt (MGA 781140E 7678355N). These veins were the feeders to the unit of bedded chert (AWAa-ccb [AWacc]) that forms the ridge from upper left to lower right of the central part of the photograph, which dips to the right; c) outcrop view of a completely silicified pillow of the Apex Basalt (MGA 781360E 7678035N).

of the Coongan River and 1 km north of the southern edge of the map sheet area (MGA 781350E 7676600N). This unit contains angular boulders to pebbles of layered blue-black and grey metachert and other types of fragments, mainly silicified metabasalt, in a sand-size matrix. Some fragments show jigsaw puzzle fit, indicating at least partial in situ brecciation. Map data suggest that this unit is bounded by growth faults and thus probably represents a fault breccia deposited during periods of active growth faulting.

Panorama Formation (AWAp-f [AWp], AWAp-frp [AWpfr], AWAp-mfs [AWpfs], AWAp-fntt [AWpft], AWAp-zc [AWpcch], AWAp-sl [AWpsh], AWAp-frtt [AWpsv], AWAp-fnck [AWpsv])

The Panorama Formation (Lipple, 1975: name from Panorama Ridge in the North Pole Dome on NORTH SHAW) forms the upper formation of the Salgash Subgroup of the Warrawoona Group (Van Kranendonk et al., 2006a). It is present in almost all greenstone belts across the EPT, and is up to 2000 m thick (Kelly greenstone belt). This formation consists predominantly of rhyolitic and dacitic volcaniclastic rocks and massive rhyolite and dacite (AWAp-f [AWp]), distributed in distinct compositional (eruptive) centres (Smithies et al., 2007b). The Panorama Formation conformably overlies the Apex Basalt, or is disconformable on rocks of the Duffer Formation or Mount Ada Basalt. In most greenstone belts, the Panorama Formation is disconformably to unconformably overlain by rocks of the Kelly Group or by younger supracrustal rocks. U–Pb zircon age data indicate a range in age of the Panorama Formation of 3458–3426 Ma (Thorpe et al., 1992; data summarized in Van Kranendonk et al., 2002).

Rocks of the Panorama Formation outcrop in the Warralong and Marble Bar greenstone belts on COONGAN, reaching a maximum thickness of 680 m in the latter. The Panorama Formation lies conformably on the Apex Basalt in the Marble Bar greenstone belt, but unconformably overlies the Duffer Formation in the Warralong greenstone belt. The absence of this formation in the Doolena Gap greenstone belt is due to the downcutting erosional nature of the unconformably overlying Strelley Pool Formation.

Felsic volcaniclastic units of the Panorama Formation reach a maximum thickness of 150 m in the east-facing, western limb of the Warralong Syncline in the Warralong greenstone belt on COONGAN. These rocks lie disconformably on the Marble Bar Chert Member of the Duffer Formation, and are cut by a quartz-filled fault on their eastern (stratigraphic top) side. The rocks here consist of coarse felsic sandstone and conglomerate, and volcaniclastic sandstone, with a carbonate cement (AWAp-fnck [AWpsv]). Coarse, lower beds contain angular jasper clasts derived from the Marble Bar Chert Member, whereas the overlying lithology consists of quartz-rich volcaniclastic sandstone and finer grained felsic volcaniclastic sandstone and siltstone, and felsic schist. In the western part of the Marble Bar greenstone belt, felsic volcaniclastic rocks of the Panorama Formation are typically finer-grained, consisting of grey, and minor black, silicified tuffaceous siltstone and sandstone (AWAp-frtt [AWpsv]), locally grading to porcelinite. Cross-bedding is locally evident in 2–6 cm thick bedsets. Hydrothermal barite veins and gossanous, silicic hydrothermal veins locally cut bedding in these rocks, for example at about 2 km east of Warralong Creek and 3.4 km north of the southern edge of the map sheet area (MGA 780000E 7678750N). Fuchsite staining of these rocks is developed over an area of 100 m in the northern part of this outcrop panel.

Massive, homogeneous quartz-phyric rhyolite (AWAp-frp [AWpfr]) with spherulitic devitrification texture forms the base of the Panorama Formation in the northwestern part of the Marble Bar greenstone belt.

Cutting through the felsic volcanic rocks are several thin veins of black hydrothermal chert (AWAp-zc [AWpcch]). These typically massive veins vary in orientation from perpendicular to bedding, to subparallel to bedding. Some contain a distinctive breccia texture of angular to subrounded, silicified host rock fragments in a matrix of black to grey chert.

A unit of shale and siltstone (AWAp-sl [AWpsh]), less than 100 m thick, forms the top of the Panorama Formation in the western part of the Marble Bar greenstone belt. This unit consists of folded and lateritized Fe-rich shales and thinly bedded banded iron-formation, with sandy interbeds, that is overlain by an approximately 10-m thick unit of bedded, grey pebbly sandstone and gritty conglomerate with beds 5–30 cm thick. The base of this unit consists of pebbly sandstone with subangular black chert clasts.

The Panorama Formation is represented in the central part of the Marble Bar greenstone belt, about 1.4 km south of the Marble Bar Road and east of the Coongan River (MGA 791100E 7683200N), by a unit of well-bedded, grey, felsic tuff and volcaniclastic sandstone, including ash beds (AWAp-fntt [AWpft]).

East of the Talga River, near Talga Peak (MGA 808000E 7684350N), the Panorama Formation consists of well-foliated quartz–sericite schist (AWAp-mfs [AWpfs]), locally derived from thinly bedded tuffaceous siltstone.

Tambina Supersuite (ATA-mgt [AgMt], ATA-mggl [AgMlh]), and named subunit

The Tambina Supersuite consists of granitic rocks emplaced into the EPT at 3450–3420 Ma (Van Kranendonk et al., 2006a). The Tambina Supersuite is dominantly composed of TTG, but is markedly less affected by migmatization than the older TTG of the Callina Supersuite (e.g. Van Kranendonk, 2003a). Widespread leucogranite in the Shaw Granitic Complex, and to a lesser degree in other granitic complexes, is included within the Tambina Supersuite and interpreted to represent melt derived from Callina Supersuite protoliths.

The Tambina Supersuite on COONGAN is represented by massive to strongly foliated, hornblende-porphyroblastic to schlieric textured metatonalite to metagranodiorite (ATAmgt [AgMt]) that outcrops in a central north–south corridor of the Muccan Granitic Complex (Fig. 2). There are good exposures of this unit in the southern part of the complex, about 2 km northeast of the Talga River (MGA 794000E 7689500N) and in the Talga River about 10 km north of the Marble Bar Road (MGA 784200E 7700000N).

Medium-grained, biotite–hornblende leucocratic metagranodiorite with seriate to weakly porphyritic textures (ATA-mggl [AgMlh]) forms an outer rind along the southernmost margin of the Muccan Granitic Complex. Schlieric textures in this unit suggest derivation through melting of older migmatitic orthogneisses of the Callina Supersuite.

Wilson Well Gneiss (ATAww-mgtn [AgLwi])

An area of Tambina Supersuite rocks is inferred for an unexposed part of the Carlindi Granitic Complex on COONGAN (Fig. 2), based on map data from NORTH SHAW and CARLINDIE, and interpretations of aeromagnetic data. This unit is interpreted to be an extension of the Wilson Well Gneiss (ATAww-mgtn [AgLwi]), which on NORTH SHAW is a heterogeneous unit of weakly migmatitic tonalite gneiss containing sparse enclaves of homogeneous, medium-grained quartz diorite and cut by numerous dykes of various texture and composition. Typically, the bulk of the unit is well foliated and contains less than 10%, 0.5 – 2 cm wide leucogranite veinlets that define a gneissic layering. The host tonalite is medium grained and thoroughly recrystallized to an equigranular, granoblastic texture. Relicts of feldspar-porphyritic texture are locally preserved. As many as six intrusive granitic phases are recognized in outcrops of the Wilson Well Gneiss, in addition to enclaves of still older amphibolite, as described by Van Kranendonk (2000).

Pilbara Supergroup

Strelley Pool Formation (APls-xs-c [AWs], APls-kdz [AWsc], APls-stq [AWsst, AWsstq])

The Strelley Pool Formation (Hickman, 2008; renamed from the Strelley Pool Chert of Lowe, 1980, 1983, and Van Kranendonk and Morant, 1998) (APls-xs-c [AWs]) was deposited across an area of at least 40 000 km^2, and lies across a regional, angular, erosional unconformity on rocks of the Warrawoona Group and, in one locality, granitic rocks of the Callina Supersuite (Buick et al., 1995; Van Kranendonk, 2000; Van Kranendonk et al., 2002, 2006a). This unconformity represents a 75 Ma hiatus in volcanism between the Warrawoona and Kelly groups. The 30–1000 m-thick sedimentary formation comprises a general succession of lower fluviatile to shallow-marine conglomerates and quartz-rich sandstone, a middle unit of stromatolitic marine carbonates, and an upper unit of coarse clastic rocks that were deposited, at least locally, on a series of receding alluvial fans (Lowe, 1983; Hofmann et al., 1999; Van Kranendonk et al., 2001b, 2003; Allwood et al., 2006; Van Kranendonk, 2006, 2007). In some greenstone belts, silicified carbonates are interbedded with quartz-rich sandstones, indicating depositional conditions that fluctuated between higher energy input of clastic detritus, versus chemical precipitation under relatively more quiet water conditions. The Strelley Pool Formation is conformably or paraconformably overlain by mafic volcaniclastic rocks and pillow basalt of the Euro Basalt.

Quartz-rich sandstone (APls-stq [AWsstq]) forms thick units in the Gorge Range (MGA 783000E 7685000N and 793500E 7683750N) and in the southern part of the Warralong greenstone belt, just south of the Marble Bar Road (MGA 760400E 7694000N). These rocks are bright white, with fine- to coarse-grained quartz sand cemented by silica. The rocks typically display 30-cm thick bedding and cross-stratification, locally including herringbone cross-stratification, suggesting nearshore deposition (Fig. 13). Quartz-pebble conglomerate is locally developed. A sample of quartz-rich sandstone from COONGAN returned detrital zircon populations with ages of 3602 ± 5 Ma (24 zircons) and 3426 ± 10 Ma (7 zircons), the latter providing a maximum age of deposition of the sediment (Nelson, 1998a; MGA 760480E 7694950N). Quartz arenite (APls-stq [AWsst]) in the Doolena Gap greenstone belt south of the Marble Bar Road and west of the Coongan River (MGA 784500E 7684400N), weathers a light brown colour in contrast to the bright white quartzites along strike. However, both units share the same general features, such as thick bedding and local cross-stratification, the only difference being the degree of later silica cement, which may reflect variations in the degree of Cenozoic weathering.

Overlying the quartz-rich sandstone is a unit of silicified sedimentary carbonate rocks (APls-kdz [AWsc]), consisting of thinly bedded blue-grey and white laminated chert with characteristic wavy to distinctly flexed textures. Sets of silicified, weakly radiating crystal fans are also locally present in the chert, and may be up to 10 cm long.

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Figure 13. Outcrop view looking down on quartz-rich sandstone of the Strelley Pool Chert (AKEs-stq [AWsstq]), showing well-developed herringbone cross-stratification (MGA 796290E 7683855N).

Evidence that these rocks were derived from carbonate protoliths comes from observations made on North Shaw; silicification was the result of later hydrothermal fluid circulation (Van Kranendonk, 2000, 2006). The chert is affected by local brecciation and by silica veining, the thicker of which display void-space infill textures.

Kelly Group

Rocks of the 3350–3315 Ma Kelly Group (Van Kranendonk et al., 2006a) stratigraphically overlie the Strelley Pool Formation, but where the Strelley Pool Formation is absent (ie through non-deposition, or erosion), the group directly overlies the Warrawoona Group across a regional angular erosional unconformity (Buick et al., 1995; Van Kranendonk, 2000; Van Kranendonk et al., 2002). The Kelly Group includes the dominantly mafic volcanic rocks and subordinate cherts of the Euro Basalt, and sandstones and felsic volcanic rocks of the Wyman Formation, metamorphosed at greenschist facies. The Euro Basalt consists of a basal unit of komatiite up to 1500 m thick and up to 5000 m of overlying, interbedded komatiitic basalt and tholeiitic basalt. These basaltic rocks were erupted in approximately 25 Ma, from 3350–3325 Ma. This was followed by eruption of the 3325–3315 Ma rhyolitic Wyman Formation and by the emplacement of genetically related, voluminous monzogranitic plutons of the Emu Pool Supersuite (3325–3290 Ma). Basaltic volcanism continued with eruption of the conformably overlying, but undated, Charteris Basalt, which is locally 1000 m thick (Hickman, 1983).

On Coongan, rocks of the Kelly Group are well preserved in the Doolena Gap greenstone belt, both west of the Coongan River (MGA 784000E 7684000N) and east of the Talga River (MGA 796400E 7683800N), but they are also present as thin slivers in the Marble Bar greenstone belt west of the Coongan River and south of the Marble Bar Road (MGA 780500E 7680300N). Kelly Group rocks are exposed at Talga Peak (MGA 806000E 7684250N), and in the southernmost and central parts of the Warralong greenstone belt north of the Marble Bar Road in the western part of the map sheet area (MGA 760200E 7695000N and 760500E 7699650N).

Euro Basalt (AKEe-b [AWe], AKEe-bk [AWebk], AKEe-mbms [AWebks], AKEe-bbo [AWeb], AKEe-mbbq [AWebz], AKEe-mwsc [AWebs], AKEe-uk [AWeuk], AKEe-ccb [AWecc, AWeccw], AKEe-zc [AWecch], AKEe-ss [AWess])

The Euro Basalt (Hickman, 1977) (AKEe-b [AWe]) consists of up to 9400 m-thick interbedded komatiite, komatiitic basalt, and tholeiitic basalt with several thin, silicified, interflow sedimentary units and minor, felsic, tuffaceous sandstone. The thickest sections of this formation are in the Panorama greenstone belt on North Shaw and around the Corunna Downs Granitic Complex on Split Rock and Marble Bar. The main thickness of the Euro Basalt was erupted in approximately 25 Ma, from 3350–3325 Ma; the older age is given by zircons from a basal unit of felsic tuff on North Shaw (Nelson, 2005a), whereas the younger age is given by several dated rocks from the conformably overlying Wyman Formation. Olivine spinifex-textured komatiite forms a locally thick flow unit at the base of the formation. The Euro Basalt lies conformably on the Strelley Pool Formation and is conformably overlain by felsic volcanic rocks of the c. 3325 Ma Wyman Formation of this group.

On Coongan, the Euro Basalt lies conformably or paraconformably on the Strelley Pool Formation (Doolena Gap greenstone belt), or the uppermost units of the Panorama Formation (Marble Bar greenstone belt, east and west), and is either conformably overlain by the Wyman Formation (Doolena Gap greenstone belt), or is faulted against the Warrawoona Group in the Warralong greenstone belt. The Euro Basalt reaches a maximum thickness of approximately 1000 m in the Doolena Gap greenstone belt, and approximately the same thickness is present in the northern part of the Panorama greenstone belt in the far southwestern corner of the sheet area, but this represents a much higher part of the formation.

The dominant lithology of the Euro Basalt on Coongan is weakly metamorphosed (greenschist facies) komatiitic basalt (AKEe-bk [AWebk]). Pillows are common and typically very well preserved, including way-up direction indicators such as pillow tails, convex pillow tops, and lava drainage tubes (now infilled by quartz and carbonate). Many pillows show marginal vesicles, pillow rind alteration, and amygdaloidal devitrification textures; hyaloclastite commonly fills interpillow spaces. These rocks are light green on fresh surfaces and weather a light orange-brown colour.

Strongly sheared tremolite–chlorite–serpentine–carbonate rocks with a well-developed schistosity and elongate mineral lineations, were derived from komatiitic basalt protoliths (AKEe-mbms [AWebks]) and occupy the core of the Warralong Syncline along the western edge of the map sheet area, north of the Marble Bar Road (MGA 760500E 7699500N). They weather light orange and are light green on fresh surfaces.

Overturned, northeast-facing, pillowed tholeiitic metabasalt (AKEe-bbo [AWeb]) outcrops in the Panorama greenstone belt, in the far southwestern corner of the map sheet area (MGA 760500E 7676000N), with subordinate interflow sedimentary rocks described below. These pillow basalts are dark green on fresh surfaces, weather dark brown, and consist of chlorite–actinolite–epidote–carbonate–quartz–ilmenite assemblages. As with pillowed komatiitic basalts of this formation, pillowed tholeiitic basalts preserve good way-up indicators such as pillow tails, convex pillow tops, and lava drainage tubes (now infilled by quartz and carbonate). Scattered outcrops of pillowed to massive basalt in the westernmost part of the Doolena Gap greenstone belt, on either side of Pear Creek to the south of the Marble Bar Road (e.g. MGA 770000E 7685800N), are also assigned to the Euro Basalt.

Strongly sheared mafic schist, deformed under greenschist facies conditions and recrystallized to chlorite schist (AKEe-mwsc [AWebs]), is present in the far eastern part of the sheet area, at Talga Peak, within the core of the Eight Mile Creek Syncline near Talga Peak (MGA 806000E 7684250N).

Units of highly altered quartz–sericite rock derived from pillowed, tholeiitic basalt (AKEe-mbbq [AWebz]) outcrop in the northeastern part of the Panorama greenstone belt in the far southwestern corner of the map sheet area (MGA 761000E 7676500N), and in part of the Doolena Gap greenstone belt about 5 km south of the Marble Bar Road and 2 km west of the Coongan River (MGA 786500E 7683000N). This quartz–sericite rock also extends beneath the unconformity with the Fortescue Group.

Quartz–carbonate breccia veins (not shown separately on map) are also present in this area (Fig. 14), together with ridges of blue-black hydrothermal vein chert (AKEe-zc [AWecch]), indicating significant hydrothermal fluid processes in this area.

Weakly metamorphosed, but undeformed, komatiite with bladed olivine spinifex texture (AKEe-uk [AWeuk]) outcrops in the far western part of the Doolena Gap greenstone belt, just east of Pear Creek and 7 km south of the Marble Bar Road (MGA 773250E 7685900N). This unit outcrops in an area of extensive calcrete and, where exposed, is heavily affected by carbonate alteration. However, the original textures are locally perfectly preserved and consist of olivine blades up to 5 cm in length.

Silicified metasedimentary rocks, or 'cherts', are common throughout the Euro Basalt in all greenstone belts and include more-common, layered to massive, white, grey, and blue-black units (AKEe-ccb [AWecc]), as well as less-common units of centimetre-layered white and grey chert (AKEe-ccb [AWeccw]). Based on comparisons with similar units elsewhere in the Pilbara Supergroup, most of the layered cherts are thought to derive from silicified carbonate rocks.

Massive blue-black hydrothermal chert veins (AKEe-zc [AWecch]) up to several metres wide by hundreds of metres long cut through pillowed metavolcanic rocks of the Euro Basalt in the Panorama greenstone belt in the far southwestern corner of the map sheet area (MGA 760000E 7676600N). Such veins from elsewhere throughout the Pilbara Supergroup are known to be derived from seafloor hydrothermal fluid circulation (e.g. Van Kranendonk, 2006), an interpretation that accords well in this case with the presence of highly altered basalts in the area (AKEe-mbbq [AWebz]).

A 20–30 m thick unit of thinly bedded, silicified, grey-green sandstone and siltstone (AKEe-ss [AWess]), included within Euro Basalt, outcrops in the Doolena Gap greenstone belt, about 5.7 km south of the Marble Bar road and 5 km east of Warralong Creek (MGA 780500E 7685050N).

Wyman Formation (AKEw-f [AWw], AKEw-stq [AWwstq], AKEw-fnt [AWwft, AWwstv])

The Wyman Formation (Lipple, 1975; name derived from Wyman Well on Marble Bar) (AKEw-f [AWw]) consists of weakly metamorphosed rhyolitic flows and volcaniclastic rocks, pillowed komatiitic basalt, and minor chert. The formation reaches a maximum thickness of 1000-m on the southern limb of the Warrawoona Syncline in the northwestern part of the Kelly greenstone belt, and is up to 1750-m thick in the core of the Warralong Syncline on Carlindie (Van Kranendonk, 2004a). The Wyman Formation lies on rocks of the Euro Basalt across a contact that varies from conformable to unconformable (Van Kranendonk, 2004a). It is conformably overlain by the Charteris Basalt at the top of the Kelly Group in the eastern part of the Kelly greenstone belt on Nullagine, and is unconformably overlain by younger rocks of the Sulphur Springs, Gorge Creek, Croydon, or Fortescue Groups across the rest of the EPT. Several dates on the Wyman Formation give a consistent age of c. 3325–3315 Ma (Thorpe et al., 1992; McNaughton et al., 1993; Nelson, 2001, 2002a; Buick et al., 2002).

Figure 14. Outcrop view of quartz–carbonate hydrothermal breccia vein from the north-eastern part of the Panorama greenstone belt in the southwestern part of the sheet area (MGA 761000E 7676500N).

Undated felsic volcaniclastic rocks that are interpreted to belong to the Wyman Formation outcrop in the western and central parts of the Doolena Gap greenstone belt, south of the Marble Bar Road, about 5 km south of the Marble Bar Road and 2.5 km west of Pear Creek (MGA 769500E 7688200N and MGA 780000E 7684600N), where they unconformably to disconformably overlie the Euro Basalt and reach a maximum preserved thickness of approximately 520 m. Way-up indicators show younging is towards the south-southwest, although the rocks are overturned and dip approximately 60° north-northeast. They are unconformably overlain by the Farrel Quartzite of the Gorge Creek Group (De Grey Supergroup).

The stratigraphically lowest part of the Wyman Formation is a 50–200 m thick unit of quartz-rich sandstone and silicified, fine-grained sandstone to siltstone (AKEw-stq

[AWwstq]) that outcrops in the Dooleena Gap greenstone belt about 6 km south of the Marble Bar Road and 3.5 km west of the Coongan River (MGA 786000E, 7682900N). This unit includes minor silicified felsic volcaniclastic sandstone and siltstone, possibly with tuffaceous components.

Elsewhere on COONGAN, the Wyman Formation includes a heterolithic assemblage of silicified felsic volcaniclastic rocks, quartz arenite, and felsic volcanic rocks (AKEw-fnt [AWwft, AWwstv]). This unit is best developed in the western part of the Doolena Gap greenstone belt, about 5.5 km south of the Marble Bar Road and 2.5 km west of Pear Creek (MGA 769500E 7688000N). Rock types there include coarse-grained quartz arenite with scattered larger clasts of black chert, white chert and quartz, laminated banded iron-formation, and grey, clastic sedimentary rock, but also include pebble conglomerate beds, silicified grey-black, faintly bedded siltstones, and massive felsic volcanic rocks with spherulitic devitrification textures.

Unassigned Pilbara Supergroup (API-mc [Acc and Accw], API-ci [Aci], API-mtq [Asq], API-mfs [Afs], API-mwa [Aba], API-mwas [Abas], API-mbms [Abks], API-xmus-mbs [Aubs], API-mog [Aog], API-xma-moa [Aou], API-mapt [Aup], API-madt [Aupd], API-mats [Aus], API-muts [Aut], API-max [Aux])

Unassigned rocks of the Pilbara Supergroup occupy areas where high degrees of deformation and metamorphism, and/or intrusion by granitic rocks, has made lithostratigraphic assignation uncertain. Most of these units probably belong to the Warrawoona Group, but intrusive components may relate to younger magmatic events in the supergroup.

On COONGAN, unassigned rocks of the Pilbara Supergroup are present in the northern part of the Warralong greenstone belt where they have been metamorphosed to amphibolite facies and strongly sheared. These rocks probably belong to the Talga Talga, Coongan, or Salgash subgroups (formerly Talga Talga and Salgash subgroups)) of the Warrawoona Group, but some components may belong to the Kelly Group, such as interlayered mafic and ultramafic schists derived from volcanic rocks at MGA 770000E 7689500N (API-xmus-mbs [Aubs]).

Massive to weakly layered grey metachert (API-mc [Acc]) and well-layered grey, white, and blue-black chert (API-mc [Accw]) form thin units within metabasalt and metabasaltic komatiitic schists along the eastern margin of the Warralong greenstone belt. These rocks contain a fine-grained, recrystallized mosaic of interlocking quartz grains and show a well-developed foliation and lineation defined by streaky textures and elongate quartz grains.

A thin unit of weakly metamorphosed banded iron-formation and minor banded chert (API-ci [Aci]) is present in the southernmost part of the Warralong greenstone belt, approximately 1 km west of Pear Creek and 4 km south of the Marble Bar Road (MGA 770200E 7688900N), at the boundary between metabasalt of the Euro Basalt and unassigned mafic and ultramafic schists. This unit is dark-brown weathering and consists of finely layered red, brown, and yellow iron-rich layers, and blue-grey and white cherty layers. It is possible that much of the iron in this unit may come from Cenozoic weathering as there are laterite-capped hills nearby.

Panels of white to bluish-grey quartzite (API-mtq [Asq]) outcrop in amphibolites in the northern part of the Warralong greenstone belt. These rocks are medium-grained and contain well-developed foliations and lineations. The quartzites probably represent recrystallized cherts, based on better-preserved stratigraphy along strike to the south.

Highly strained, quartz–sericite schist derived from metamorphosed felsic volcanic rocks (API-mfs [Afs]) forms a thin unit along the western edge of the sheet area, about 7.5 km north of the Marble Bar Road (MGA 760450E 7703400N). It locally contains centimetre-size porphyroblasts of kyanite and abundant muscovite (see figure 23 in Van Kranendonk, 2004a) and is interpreted as metamorphosed felsic volcanic rock. These rocks probably represent a northerly continuation of either the Duffer or Panorama Formations of the Warrawoona Group, but the high strain state precludes conclusive determination which of these it is.

Panels of strongly deformed amphibolite (API-mwa [Aba]) and derived amphibolite schists (API-mwas [Abas]) in the Warralong greenstone belt, about 9 km north of the Marble Bar Road along the western edge of the map sheet area (MGA 760100E 7705000N), may contain layers of ultramafic schist and chert, indicating derivation from a succession of supracrustal rocks. The amphibolites are strongly foliated and lineated, with equigranular, but well-aligned, grains of hornblende–plagioclase and titanite.

Amphibolite schists (API-mwas [Abas]) are strongly deformed rocks, with an S>L tectonic fabric, adjacent to contacts with sheared granitic rocks. These rocks are homogeneous in texture and composition, with medium-grained hornblende and plagioclase as the dominant minerals, and accessory titanite (and ilmenite plus ?magnetite).

Tremolite–chlorite–serpentine and talc–carbonate–chlorite schists (API-mbms [Abks]) along the eastern contact of the Warralong greenstone belt are interpreted as metamorphosed and deformed komatiitic basalts. They enclose subordinate chlorite–epidote–plagioclase–quartz (–carbonate) schists (metabasalt), massive to weakly layered grey chert (API-cc [Acc]), and well-layered grey, white, and blue-black chert (API-ccb [Accw]).

Units of interleaved mafic (chlorite–epidote (± actinolite)) and ultramafic (tremolite–chlorite–serpentine and talc–carbonate–chlorite) schists (API-xmus-mbs [Aubs]) contain subordinate, thin chert units and thus are interpreted to represent sheared, originally interbedded basaltic and komatiitic basalt flows.

Metamorphosed gabbro (API-mog [Aog]) outcrops in the northern part of the Warralong greenstone belt, about

12 km north of the Marble bar Road near the western edge of the map sheet area (MGA 761800E 7708000N). This is a massive unit of medium-grained, 'salt-and-pepper' amphibolite, derived from a gabbroic to doleritic protolith.

Thin dykes of metamorphosed, fine-grained mafic (dolerite) or ultramafic composition (API-xma-moa [Aou]) cut through the northern part of the Muccan Granitic Complex on COONGAN. These dykes are very dark-green to black weathering and extend north onto PARDOO, where they appear to be affected by c. 2930 Ma shear deformation within the Lalla Rookh – Western Shaw structural corridor.

Serpentinized peridotite (API-mapt [Aup]) is mapped in several places on COONGAN, most notably in the Doolena Gap greenstone belt, south of the Marble Bar Road, from about 3 km west of the Coongan River to just west of the Talga River (from MGA 787000E 7686300N to 793400E 7684800N). This unit contains pods of chromitite at several places along strike (MGA 788200E 7686110N and 792300E 7685020N). The rocks are medium- to coarse-grained and light orange-brown weathering, with a smooth weathering surface. Fresh surfaces are dark green and consist of serpentine and chlorite, with fine-grained magnetite.

Metaperidotite also outcrops within the Muccan Granitic Complex, both as isolated pods (approximately 4 km south of Bendhu Creek and 10 km west of Stoneyard Creek; MGA 797200E 7712800N) that represent parts of much larger inclusions recognized from aeromagnetic images (see Interpreted Bedrock Geology on published map), and as linear units that may represent dykes cutting through older granitic components (e.g. MGA 794500E 7692500N). Strongly foliated metaperidotite (API-mapt [Aup]) in the Warralong greenstone belt north of the Marble Bar Road is either intruded by undated granitic rocks (MGA 761300E 7707000N), or in fault contact with Warrawoona Group greenstones (MGA 761600E 7705000N).

These metaperidotites are locally quite coarse grained in the cores of larger bodies, with serpentinized original olivine crystals up to 1 cm rimmed by magnetite and enclosed in a fine-grained serpentine–chlorite groundmass. The margins of these bodies are wholly recrystallized to serpentine–chlorite–magnetite and serpentine–chlorite schists. Locally, serpentinized peridotite clearly cuts across bedded metasedimentary rocks (MGA 762100E 7701000N), indicating an originally intrusive origin for these ultramafic rocks.

Serpentinized dunite (API-madt [Aupd]) forms a 250 m wide sheet in the Warrawoona Group of the Warralong greenstone belt, about 8 km north of the Marble Bar Road and 10 km west of Pear Creek (MGA 764300E 7702600N). This unit weathers to a distinctive light green-brown (dun) colour, but is dark green on fresh surfaces and displays a relict cumulate texture of rounded, elongate olivine crystals up to 4 mm long.

Strongly foliated serpentine(–chlorite) schist (API-mats [Aus]) was derived from sheared metaperidotite along the contact between the Warralong greenstone belt and the Muccan Granitic Complex, about 3 km north of the Marble Bar Road and 3 km west of Pear Creek (MGA 770000E 7696400N).

Talc-rich schist (talc–serpentine–chlorite–carbonate; API-muts [Aut]) is cut by thick quartz veins emplaced into brittle faults in one locality within the Muccan Granitic Complex, about 8.5 km southeast of Eginbah Well (MGA 806000E 7696300N). These dark-brown weathering, very soft rocks are medium grained and massive to weakly foliated.

Metapyroxenite (API-max [Aux]) forms layers either within greenstones — for example in the Warralong greenstone belt, approximately 3.5 km north of the Marble Bar Road (e.g. MGA 762200E 7698000N) — or as trains of folded linear inclusions within the Muccan Granitic Complex, about 9 km due south of Eginbah Well (MGA 800000E 7692150N). These rocks are dark-brown weathering and almost black on fresh surfaces, composed predominantly of chlorite–actinolite, and locally contain a relict, medium-grained igneous texture of originally interlocking pyroxene crystals.

Emu Pool Supersuite (AEM-gmp [AgMmp, AgMmc], AEM-gmli [AgMmpl], AEM-gmj [AgMmt], and named subunits)

The Emu Pool Supersuite (3.32 – 3.29 Ga) of granitic rocks is developed in the eastern half of the EPT, where it overlaps in space and time with the Wyman Formation of the Kelly Group (Van Kranendonk et al., 2006a). These rocks have not been identified from the western part of the EPT. Compositionally, the Emu Pool Supersuite is dominated by monzogranite, although rock types range from trondhjemite through diorite to syenite (see table 2 in Van Kranendonk et al., 2006a; Champion and Smithies, 2007). E_{Nd} model age and petrogenetic modelling data show that these rocks are largely derived from melting of older granitic crust (Collins, 1993; Barley and Pickard, 1999; Smithies et al., 2003). Rocks of the Emu Pool Supersuite vary from undeformed, coarse-grained K-feldspar monzogranites throughout much of the Corunna Downs Granitic Complex, to foliated rocks, and heterogeneous, multicomponent rocks mixed with older and/or younger components (e.g. middle of the Mount Edgar Granitic Complex).

Granitic rocks of the Emu Pool Supersuite were emplaced into the cores of developing domical granitic complexes during a major episode of partial convective overturn of the middle and upper crust (see **D_3**, below). The granitic rocks include both high-Al and low-Al suites and are interpreted to be derived from melting of lower crustal sources, including pre-existing granitic rocks and basaltic volcanics (Champion and Smithies, 2007). Granite intrusion and deformation was accompanied by contact-style metamorphism that reached upper amphibolite facies along the southern margin of the Mount Edgar Granitic Complex (Collins and Van Kranendonk, 1999).

On COONGAN, rocks of the Emu Pool Supersuite are exposed within the northern part of the Mount Edgar Granitic Complex (Coppin Gap Granodiorite and

Munganbrina Monzogranite), and in the Muccan Granitic Complex, around its southwestern and northwestern margins, in the central part of the complex (northeastern part of the sheet area), and as small intrusions within the southeastern part of the complex.

Massive to foliated, and typically weakly deformed, granitic rocks of the Emu Pool Supersuite occupy the far northern and southwestern parts of the Muccan Granitic Complex. Broad areas of massive to weakly foliated, porphyritic, pink-grey monzogranite and syenogranite (AEM-gmp [AgMmp]) in the northern part of the complex, about 3 km west of Nimingarra Homestead along the northern boundary of the map sheet area (MGA 800500E 7730000N), preserve igneous flow banding defined by slightly more mafic layers (biotite–hornblende) in typically leucocratic granite. A sample of this unit from Pardoo returned an igneous zircon U–Pb SHRIMP age of 3315 ± 3 Ma (Nelson, 2005b).

Within this northern area, about 1 km northwest of the Nimingarra Homestead (MGA 803000E 7730250N), is an approximately 500 m-wide strip of foliated and lineated leucocratic monzogranite and syenogranite with abundant inclusions of schlieric tonalite (AEM-gmli [AgMmpl]). These inclusions are probably derived from older components belonging to either the Callina or Tambina Supersuites.

In the southwestern part of the complex, about 3 km south of the Marble Bar Road and 1 km west of Pear Creek (MGA 770600E 7690200N), medium- to coarse-grained monzogranite to syenogranite (AEM-gmp [AgMmc]) show intrusive contacts with amphibolite-grade greenstones. At this locality, the rocks show a well-developed, moderately to shallowly east dipping foliation, parallel to that in greenstones. This foliation is contiguous with commonly overturned foliations along the southern margin of the Muccan Granitic Complex. Similar rocks intrude older granitic rocks along the eastern edge of the sheet area about 3 km north of the track to Yarrie Homestead (MGA 812250E 7690750N) and are correlated with rocks on Muccan dated at 3313 ± 3 Ma (Nelson, 1998b; Williams, 1999).

A distinct unit of cream- to white-grey, magnetite-bearing monzogranite (AEM-gmj [AgMmt]) forms distinct, dark-weathering tors in the southeastern part of Coongan, for example about 5 km north of the old Eginbah–Yarrie Track near the eastern edge of the map sheet area (e.g. MGA 809000E 7694000N). These fine- to medium-grained rocks are typically only weakly foliated and show clear intrusive relationships with older, more-strongly deformed rocks of the Callina Supersuite (ACL -mgtn [AgMn]). A dated sample of this unit from Muccan returned an age of 3303 ± 2 Ma (Nelson, 1998c; Williams, 1999).

Coppin Gap Granodiorite (AEMco-gg [AgEco], AEMco-ggi [AgEcox])

The Coppin Gap Granodiorite (AEMco-gg [AgEco]), originally described under the 'Coppin Gap Suite' (Collins, 1983; Williams and Collins, 1990), is a non-foliated to weakly foliated, pink and cream, granodiorite and tonalite in the northern part of the Mount Edgar Granitic Complex. This medium-grained, equigranular to seriate-textured unit has intrusive contacts with older greenstones of the Warrawoona Group, and is intruded by the c. 3310 Ma Munganbrina Monzogranite and younger plutonic components of the Cleland Supersuite within the complex (see Williams, 1999; Williams and Bagas, 2007). The intrusion has a U–Pb SHRIMP zircon date of 3314 ± 13 Ma (Williams and Collins, 1990) and is the source of significant porphyry Cu–Mo mineralization on Muccan.

On Coongan, the Coppin Gap Granodiorite forms three small plugs emplaced into the Coongan Subgroup of the Warrawoona Group in the Marble Bar greenstone belt. These small (1 × 3 km) intrusions are elongate in plan view along a north-northwesterly direction, and have faulted margins that probably represent the emplacement routes of the magmas. Drilling results from around one small intrusion on Muccan show that these bodies were emplaced perpendicular to bedding prior to tilting of the greenstones off from above the Mount Edgar Granitic Complex (see figure 32 in Van Kranendonk et al., 2006b).

Along the narrow, southern part of the easternmost intrusion, medium-grained granodioritic rocks of the Coppin Gap Granodiorite contain abundant xenoliths of amphibolite-grade greenstones that have been metamorphosed and net-veined by a variant lithology (AEMco-ggi [AgEcox]) of the intrusive granitic rock.

Munganbrina Monzogranite (AEMmu-gm [AgEmu])

The Munganbrina Monzogranite (AEMmu-gm [AgEmu]), originally described under the 'Munganbrina Suite' (Collins, 1983, 1993), is typically a weakly foliated, medium- to coarse-grained, biotite monzogranite and granodiorite. It has intrusive contacts with greenstones of the lower part of the Warrawoona Group, including those of the Talga Talga and Coongan Subgroups, and has a U–Pb SHRIMP zircon date of 3310 ± 10 Ma (Bodorkos et al., 2006a). This unit is intruded by the c. 3240 Ma Bishop Creek Monzogranite of the Cleland Supersuite, but has not been affected by migmatization. The Munganbrina Monzogranite varies from leucocratic, biotite monzogranite in the north, through schlieric-layered monzogranite, to quite dark monzogranite–granodiorite in the south, where it is cut by leucogranite veins and pegmatites (Fig. 15).

Gap Intrusion (AEMga-a [AaG], AEMga-ad [AaGpd], AEMga-ax [AaGx])

The Gap Intrusion (Williams, 1999; Van Kranendonk et al., 2006a) is a thick sill of serpentinized peridotite, dunite, and pyroxenite (AEMga-a [AaG]) in the Marble Bar greenstone belt. It is principally composed of apple-green serpentinized dunite (AEMga-ad [AaGpd]), weathering to a light greenish yellow colour, that reaches a maximum original thickness of 500 m, just east of the Coongan River, 3 km south of the Marble Bar Road (MGA 790000E 7681700N). In this area, farthest from penetrative strain associated with the Talga Peak Fault, the rocks are medium to coarse grained (≤5 mm grain size), show relict olivine adcumulate texture, and are undeformed. To the west,

Figure 15. Outcrop view of the Munganbrina Monzogranite (dark phase; AEMmu-gm [AgEmu]), cut by leucogranite veins (MGA 806320E 7675500N).

these rocks display a penetrative schistosity and have a faulted northern contact.

Thicker parts of the Gap Intrusion contain pyroxenite layers (AEMga-ax [AaGx]), up to a maximum of 50 m thick (e.g. MGA 801500E 7683400N). These units are dark-brown weathering and black on fresh surfaces, with a maximum grain size of 1 cm, consisting of close-packed, coarse-grained pyroxene crystals, dominantly augite metamorphosed to a mixture of chlorite–actinolite and epidote, in a fine-grained interlocking matrix of metamorphic chlorite.

Strutton Intrusion (AEMst-xo-a [AaT])

The Strutton Intrusion (Williams, 1999; Van Kranendonk et al., 2006a) is a thick sill of gabbro, pyroxenite, and peridotite in the Marble Bar greenstone belt. It is located immediately beneath the Gap Intrusion on Coongan, although these intrusions are separated locally by thin screens of greenstones on this map sheet and are more widely separated by greenstones on the adjacent Muccan sheet area (Williams, 1998). The two intrusions may be genetically related and contemporaneous, but this is unconfirmed: they are interpreted to represent subvolcanic intrusions to the Euro Basalt. The Strutton Intrusion is principally composed of medium- to coarse-grained metagabbro and pyroxenite (AEMst-xo-a [AaT]). The metagabbro contains euhedral pyroxene crystals 1–2 mm across (both augite and enstatite) in plagioclase oikocrysts (to >1 cm), now altered to epidote and ?albite. Pyroxenes are locally well preserved, but are largely replaced by an intergrowth of actinolite–Mg-chlorite–titanite–carbonate. Finer-grained dolerite phases show subophitic textures of plagioclase laths in augite crystals to greater than 1 cm, and contain leucoxene after titano-ilmenite.

Cleland Supersuite (ACE-mgm [AgM], ACE-xmg-mgn [AgMi]), and named subunits)

The 3275–3225 Ma Cleland Supersuite includes granodiorite and monzogranite found throughout the EPT, and tonalite and granodiorite in the Karratha Terrane of the West Pilbara Superterrane (Van Kranendonk et al., 2006a). Granitic rocks include both high-Al and low-Al suites and are interpreted to be derived from from partial melting of lower crustal sources, including pre-existing granitic rocks and basaltic volcanics (Champion and Smithies, 2007). These rocks were emplaced within the cores of large granitic complexes, but also form discrete subvolcanic intrusions, including the c. 3240 Ma Strelley Monzogranite in the EPT and the c. 3265 Ma Karratha Granodiorite in the Karratha Terrane. These rocks commonly show mild effects of deformation, and locally display widespread igneous textures such as flow banding, igneous layering, and local magma mixing and mingling.

Small outcrops of medium- to coarse-grained metamonzogranite to metagranodiorite and metatonalite (ACE-mgm [AgM]) intrude the eastern margin of the Warralong greenstone belt, approximately 7 km west of Pear Creek and 9 km north of the Marble Bar Road (e.g. MGA 766900E 7703200N). These weakly foliated, but undated rocks, are considered to most likely be part of the Cleland Supersuite, on the basis of strain state, but may be part of the Emu Pool Supersuite or Sisters Supersuite.

Outcrops of mixed granitic rocks (ACE-xmg-mgn [AgMi]) along the eastern edge of Coongan in the Muccan Granitic Complex are here ascribed to the Cleland Supersuite, as at least some of the principal lithologies are likely to be of this age (Williams, 1999). These outcrops comprise a mixture of foliated to migmatitic orthogneiss in addition to less deformed components, predominantly monzogranite, tonalite, and pegmatite veins, in variable proportions.

Wolline Monzogranite (ACEwo-gmp [AgMwo], ACEwo-mgms [AgMwof], ACEwo-mgml [AgMwol])

The principal component of the Cleland Supersuite on Coongan is the Wolline Monzogranite in the Muccan Granitic Complex. This intrusion underlies a large area in the southeastern part of the sheet area, where it predominantly consists of weakly deformed, porphyritic and seriate monzogranite and syenogranite (ACEwo-gmp [AgMwo]). These medium- to coarse-grained, leucocratic rocks display igneous flow banding and igneous mineral alignment of K-feldspar phenocrysts over a wide area about 2 km south of Eginbah Well (e.g. MGA 800250E 7699250N). Two samples of this unit from the adjacent Muccan sheet area returned ages of 3252 ± 3 Ma and 3244 ± 3 Ma (Nelson, 1998d,e; Williams, 1999).

A subunit of the Wolline Monzogranite includes strongly foliated monzogranite and syenogranite, with local pegmatite banding (ACEwo-mgms [AgMwof]). This subunit is well developed within the central parts of the complex, about 5 km northeast of Eginbah Well (MGA 803500E 7704000N).

Another subunit of the Wolline Monzogranite is foliated monzogranite with schlieric tonalite inclusions of the Callina Supersuite (Fig. 16a; ACEwo-mgml [AgMwol]). Rocks of this subunit show distinct compositional layering at a decimetre to metre scale, defined by changes in mafic mineral content (Fig. 16b), but with primary igneous textures throughout. Two samples of this unit,

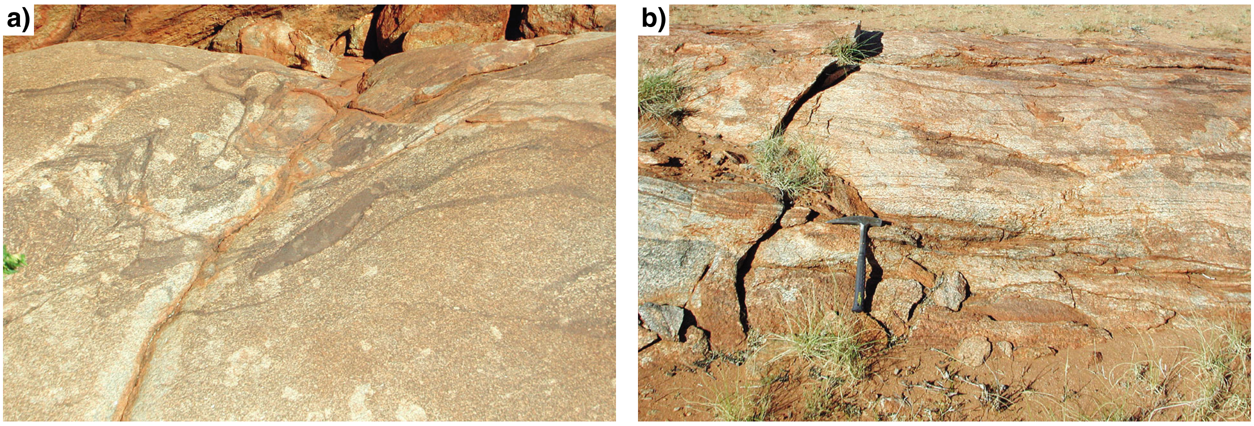

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Figure 16. Outcrop views of the Wolline Monzogranite (Cleland Supersuite) in the Muccan Granitic Complex: a) foliated monzogranite with schlieric tonalite inclusions of the Callina Supersuite (ACEwo-mgm/ [AgMwol]; width of view approximately 1 m); b) distinct compositional layering at a decimetre to metre scale that is defined by changes in mafic mineral content, but with primary igneous textures throughout.

representing an older phase of medium-grained biotite monzogranite and a younger phase of foliated biotite-rich granodiorite, were collected from near Eginbah Well on Coongan (MGA 800050E 7701000N) and returned ages of 3251 ± 2 Ma and 3250 ± 2 Ma, respectively (Nelson, 2005c,d).

East Pilbara evolution

The time period between 3525–3235 Ma encompasses a set of stages that resulted in formation of the ancient nucleus of the Pilbara Craton, known as the East Pilbara Terrane. This set of events includes deposition of three groups (Warrawoona, Kelly, and Sulphur Springs) and one formation (Strelley Pool Formation), emplacement of four supersuites of intrusive igneous rocks (Callina, Tambina, Emu Pool, and Cleland), and four periods of deformation and metamorphism (D_1–D_4) (Hickman and Van Kranendonk, 2008b). Episodes of deformation and metamorphism are directly linked to, and follow on from, major magmatic events that resulted in deposition of the three lowest groups and emplacement of associated granitic supersuites. These major magmatic and deformation events (Warrawoona, Kelly, and Sulphur Springs) are interpreted to represent the effects of three major mantle plume events, the last of which led to, and was followed by, rifting of the EPT margins and deposition of the Soanesville Group, and intrusion of the Mount Billroth Supersuite (Van Kranendonk et al., 2006a, 2007, 2010).

Warrawoona Stage (c.3525–3420 Ma)

The oldest event in construction of the EPT is the Warrawoona Stage, which encompasses eruption of the 5000 – 15 000 m thick, dominantly volcanic, Warrawoona Group at 3525–3426 Ma, emplacement of dominantly sodic granitic rocks (TTG) of the 3490–3460 Ma Callina and 3450–3420 Ma Tambina supersuites, and two periods of deformation and metamorphism (D_1, D_2) over the time period 3460–3400 Ma. Geochemical and stratigraphic evidence from the Warrawoona Group indicates derivation from continuous mantle melting events that erupted through older continental crust (Green et al., 2000; Van Kranendonk and Pirajno, 2004; Hickman and Van Kranendonk, 2004; Van Kranendonk et al., 2007; Smithies et al., 2009).

Emplacement of the Callina and Tambina Supersuites was accompanied by periods of deformation and contact-style metamorphism during early periods of doming of granitic complexes and the onset of partial convective overturn of the upper and middle crust.

D_1 deformation and metamorphism: syn-volcanic deformation (c.3470 Ma)

D_1 structures in the EPT include a set of tight folds in the Coonterunah Subgroup and curved bedding in these rocks that wraps around the southeastern edge of the Carlindi Granitic Complex (see figure 24 in Van Kranendonk, 2006). These rocks are cut by undeformed, 3469 Ma granitic rocks of the Carlindi Granitic Complex (Buick et al., 1995; Van Kranendonk, 2000), and are unconformably overlain by the 3420–3350 Ma Strelley Pool Formation, which provides a minimum age of D_1 deformation in this area. D_1 deformation farther east resulted in gentle tilting of rocks older than c. 3469 Ma and gave rise to the non-deposition, or erosion, of the c. 3.25 km-thick Apex Basalt in the western part of the EPT (e.g. East Strelley greenstone belt; Di Marco and Lowe, 1989) and the erosional unconformity at the base of the Panorama Formation in the Coongan greenstone belt (Van Kranendonk et al., 2004).

North of Marble Bar, D_1 structures include a set of recumbent isoclinal folds of bedding in the c. 3477 Ma McPhee Formation, which verge to the northwest away from the Mount Edgar Granitic Complex (Collins, 1989). Although undated, these structures are interpreted to have formed by gravitational sliding during an early period of doming of the Mount Edgar Granitic Complex, probably at c. 3465 Ma (Collins, 1989; Collins et al., 1998). Soft-sediment deformation in c. 3480 Ma Dresser Formation rocks accompanied growth faulting and caldera formation. D_1 structures are also preserved in the core of the Shaw Granitic Complex, where folded leucosomes in migmatitic tonalitic gneisses of the 3490–3460 Ma Callina Supersuite are cut by non-migmatitic components of the 3450–3420 Ma Tambina Supersuite (see figure 16a in Van Kranendonk et al., 2004). Similar relationships have been observed in the Mount Edgar, Muccan, and Warrawagine granitic complexes.

Rocks of the Talga Talga and Coongan Subgroups are conformable on COONGAN, indicating minimal tectonic disturbance during deposition. An exception to this is in the Warralong greenstone belt, about 3.5 km north of the Marble Bar Road, near the western edge of the map sheet area (MGA 760800E 7699000N). At this locality, the Panorama Formation lies directly on the Duffer Formation and includes a coarse, clastic, basal unit that contains clasts derived from the underlying Marble Bar Chert Member. Growth faults in the Duffer Formation may relate to local extension during deformation at this time, during the onset of doming. Leucosome generation in Callina Supersuite rocks of the Muccan Granitic Complex is also thought to, at least in part, derive from this early period of deformation, as they are cut by c. 3300 Ma, non-migmatitic granites (Williams, 1998).

D_2 deformation and metamorphism: synvolcanic doming and uplift (c. 3430–3400 Ma)

D_2 deformation was synchronous with, or post-dated, deposition of the Panorama Formation and intrusion of the Tambina Supersuite (i.e. 3450–3420 Ma), but pre-dated deposition of the Kelly Group (3350 Ma), as these younger rocks unconformably overlie folded and tilted rocks of the Warrawoona Group. D_2 deformation resulted in tilting of bedding and erosion or non-deposition of the Panorama Formation in the west and south, and produced a locally strong foliation in pyrophyllite-altered schists of the Mount Ada Basalt in the North Pole Dome. D_2 deformation also resulted in the onset of doming of the Shaw Granitic Complex, which was accompanied by partial melting of Callina Supersuite protoliths and generation of leucogranite veins to as young as 3420 Ma (Zegers, 1996; Pawley et al., 2004; Van Kranendonk et al., 2004). Doming of other granitic complexes may also have taken place at this time.

The effects of D_2 deformation are not evident on COONGAN, but can be inferred by the erosional unconformity between the Strelley Pool Formation and the underlying Duffer Formation in the Doolena Gap greenstone belt, about 5 km south of the Marble Bar Road and 5 km west of the Coongan River (MGA 785500E 7684500N).

Kelly Stage (c. 3350–3290 Ma)

The second major stage in construction of the EPT is the Kelly Stage, which encompasses deposition of the Kelly Group (3350–3315 Ma), emplacement of the 3325–3290 Ma Emu Pool Supersuite, and a significant period of deformation and metamorphism (D_3: 3325–3290 Ma) associated with partial convective overturn of the upper and middle crust (Collins, 1989; Collins et al., 1998; Collins and Van Kranendonk, 1999; Van Kranendonk et al., 2004).

The Kelly Group is a thick (5–8 km) succession of komatiitic to basaltic volcanic rocks (Euro Basalt), and high-K felsic volcanic rocks of the Wyman Formation that was deposited between 3350–3315 Ma, paraconformably on the Strelley Pool Formation. Geochemical and geochronological evidence indicates that the volcanic component of the group resulted from the eruption of a mantle plume through older continental crust (Van Kranendonk and Pirajno, 2004; Smithies et al., 2007b). This followed an initial period of uplift and erosion under at least partly subaerial conditions and initial basin subsidence during which the Strelley Pool Formation was deposited. Felsic volcanic components of the group are dominated by high-K rhyolites derived from melting of pre-existing felsic crust. Volcanism was accompanied, and outlasted, by widespread and voluminous granitic magmatism in the eastern part of the EPT, from 3325–3290 Ma.

D_3 deformation and metamorphism: partial convective overturn

Structural studies in the EPT have shown that a major period of deformation is related to partial convective overturn of the middle to upper crust during the mantle plume event that gave rise to the Kelly Group at 3350–3315 Ma and Emu Pool Supersuite at 3325–3290 Ma (Collins et al., 1998; Van Kranendonk et al., 2004, 2007). This regional D_3 deformation resulted in development of penetrative metamorphic mineral foliations and lineations in most greenstones of the Warrawoona Group, gneissic fabrics and mineral elongation lineations in most rocks of the Callina and Tambina Supersuites, and foliations (and minor lineations) in many granitic rocks of the Emu Pool Supersuite. Metamorphic D_3 foliations of greenstones and the outer rinds of granitic complexes are oriented parallel to the margins of granitic complexes, and lineations plunge in a radial fashion away from the cores of granitic complexes (Van Kranendonk et al., 2004). Other D_3 structures include large-scale, tight, steeply plunging folds of greenstones around some granitic complexes (e.g. Corunna Downs Granitic Complex), shear zones along some granite–greenstone contacts (e.g. southern Mount Edgar Granitic Complex), and ring faults within the axial zone of greenstone synclines between granite-cored structural domes (see Van Kranendonk et al., 2004). Quantitative evidence for deformation at this time is given by the angular erosional unconformity between the Kelly Group and the Sulphur Springs Group on CARLINDIE (Van Kranendonk, 2004a), and by the 3324 ± 2 Ma age of a syn-kinematic granite within the Mount Edgar Shear Zone (Collins et al., 1998).

Structures developed during D_3 are widespread on COONGAN. Tilting of older greenstones at this time is evidenced by the unconformity at the base of the Gorge Creek Group where it overlies folded rocks of the Wyman Formation in the Dooleena Gap greenstone belt, about 6.5 km south of the Marble Bar Road and 4.5 km east of Warralong Creek (MGA 779700E 7684500N).

The curviplanar Garden Creek Fault, which wraps around the northwestern part of the Mount Edgar Granitic Complex (Fig. 4), separates amphibolite-facies tectonites (schists) with well-developed foliations and metamorphic mineral elongation lineations adjacent to the complex to the south, from lower grade rocks with well-preserved primary textures to the north. This fault is interpreted to represent the northern continuation of the major D_3 ring fault that wraps around the western, southern, and eastern, higher grade parts of the Mount Edgar Granitic Complex, and to have formed at c. 3300 Ma during emplacement of much of the granitic complex (Collins et al., 1998; Van Kranendonk et al., 2004; Williams and Bagas, 2007). A splay off this fault to the northeast, which passes through Eight Mile Creek to the east of the Talga River, is interpreted to probably also be of this age (MGA 806000E 7680000N).

The high-grade metamorphic structural fabric elements inside the Garden Creek Fault, in greenstones adjacent to the Mount Edgar Granitic Complex and within the complex itself, are interpreted to have formed at, or just before, c. 3310 Ma, as they are cut by the very weakly deformed Munganbrina Monzogranite, which is dated at 3310 ± 5 Ma (Bodorkos et al., 2006a). From west to east, these D_3 lineations change plunge from west-northwesterly, through northerly, to northeasterly, reflecting the radial pattern of lineations formed during this event.

Greenstones that flank the southern margin of the Muccan Granitic Complex on COONGAN face away from the complex, but have been overturned so that they dip to the north. This includes the eastern limb of the Warralong Syncline in the Warralong greenstone belt, where rocks dip 60–75°E but face west, and the Doolena Gap greenstone belt where rocks dip 26–75°N, but face south. Overturning of these greenstones took place in large part during later regional deformational events, but some tilting during D_3 is indicated by the angular erosional unconformity between folded rocks of the Wyman Formation and the overlying Gorge Creek Group in the Dooleena Gap greenstone belt, about 6.5 km south of the Marble Bar Road and 10 km west of the Coongan River (MGA 779800E 7684500N).

Shear deformation of Warrawoona Group greenstones and Callina Supersuite granitic rocks along the southern margin of the Muccan Granitic Complex, within what is referred to here as the South Muccan Shear Zone (Fig. 4), is interpreted to result from D_3 deformation. Kinematic indicators within the central part of this zone on the west bank of the Talga River (e.g. MGA 793550E 7685000N) show north (granite)-side-up, reverse movement on north-dipping foliations (Fig. 17a), and well-developed, steeply-plunging metamorphic mineral elongation and stretching lineations (Fig. 17b). This is consistent with diapiric rise of the Muccan Granitic Complex, following the models of partial convective overturn proposed for the EPT (Collins et al., 1989; Van Kranendonk et al., 2004). Callina Supersuite gr`anitic rocks of the Muccan Granitic Complex are deformed into migmatitic gneisses, showing well-developed gneissic textures, penetrative foliations, and metamorphic mineral-elongation lineations. These rocks and structures are cut by

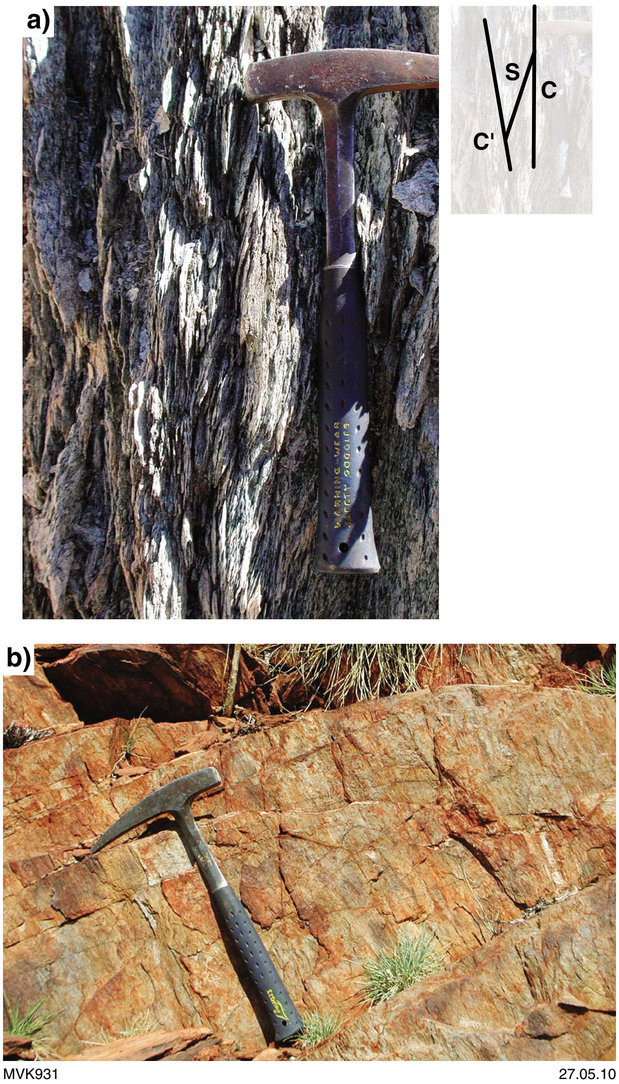

Figure 17. a) View west of sheared ultramafic schist derived from massive peridotite (Amapt-P [Aup]) along the west bank of the Talga River (MGA 793550E 7685000N), showing S–C–C' textures indicative of north (granite)-side-up, reverse displacement; b) outcrop view, looking south, of penetrative metamorphic mineral elongation lineations (parallel to hammer handle) in strongly sheared, silicified metabasalts from the shear zone immediately to the north of the Talga Peak Fault (MGA 807190E, 7684400N).

3315 Ma granitic rocks, which are only mildly deformed, showing that deformation of the gneisses was largely effected prior to, or during emplacement of, c. 3315 Ma granitic rocks, consistent with observations elsewhere in the EPT.

An absolute age of deformation along the Talga Peak Fault is difficult to determine, as movement across this fault continued until deposition of the Kylena Basalt of the Fortescue Group (see **Fortescue Group** below). Blewett (2002), therefore, argued that all deformation postdates deposition of the Fortescue Group. However, the displacement of the Fortescue Group across the fault is on the order of 1–2 km and associated deformation is brittle, whereas shear deformation in the rocks to the north of, and within, the Talga Peak Fault is ductile and must account for several kilometres of offset based on the asymmetry of the preserved stratigraphic sections on either side of the fault. The long-lived nature of deformation along this syncline axis is exemplified by the presence of multiple unconformities in the Doolena Gap and Warralong greenstone belts (particularly on CARLINDIE), commencing with deposition of the Kelly Group at c. 3350 Ma (Van Kranendonk et al., 2004, 2006a).

Sulphur Springs Stage (3275–3225 Ma)

The third major event in construction of the EPT is the Sulphur Springs stage, which encompasses deposition of the Sulphur Springs Group, emplacement of the Cleland Supersuite, and a significant period of deformation and metamorphism (D_4) over the time period 3275–3225 Ma.

D_4 deformation: partial convective overturn (c. 3240 Ma)

Structural studies in the EPT have shown that a major period of deformation, D_4, is related to partial convective overturn of the middle to upper crust towards the end of the mantle plume event that gave rise to the Sulphur Springs Group (Van Kranendonk et al., 2002, 2004, 2007). This deformation accompanied intrusion of the Cleland Supersuite, producing weak metamorphic foliations in these rocks, and included a component of doming of granitic complexes (e.g. Collins and Gray, 1990; Van Kranendonk et al., 2002, 2004).

The effects of D_4 deformation are not readily apparent on COONGAN. However, it is probable that part of the cumulative strain in sheared rocks around the southern and western margins of the Muccan Granitic Complex is due to this event, although this is unconstrained by absolute age data.

Soanesville Event: rifting of East Pilbara Terrane at c. 3200–3165 Ma

The Soanesville Event is a period of rifting that affected the East Pilbara Terrane at 3200–3165 Ma and may have resulted in separation of the Karratha Terrane and Kurrana Terrane from the EPT nucleus (Van Kranendonk et al., 2007, 2010). In the process, this event resulted in the formation of MORB-type basaltic rocks that may include the Regal Formation (Regal Terrane), and also resulted in the emplacement of granitic rocks of the Mount Billroth Supersuite along the western margin of the EPT and in the Kurrana Terrane (Van Kranendonk et al., 2006a). Associated extension within the EPT resulted in deposition of the Soanesville Group and intrusion of the Dalton Suite. This extension was accompanied by horst-and-graben faulting (Wilhelmij and Dunlop, 1984).

The Prinsep Orogeny: terrane accretion and deformation at c. 3070–3050 Ma

Regional structural studies, based on 1:100 000 mapping of the entire Pilbara Craton and extensive geochronology, have identified a regional deformational event that post-dates formation of the East Pilbara Terrane and deposition of the 3130–3110 Ma Whundo Group in the West Pilbara Superterrane (WPS), but predates deposition of the c. 3020 Ma Gorge Creek Group (Van Kranendonk et al., 2006a). This event is called the Prinsep Orogeny and is inferred to relate to accretion of the West Pilbara Superterrane with the EPT across a suture buried beneath the Mallina Basin. This event was also responsible for inferred thrusting of the Regal Terrane over the Karratha Terrane, and for the early sinistral component of shear deformation across the Sholl Shear Zone (Hickman, 2004). The Prinsep Orogeny is interpreted to have taken place at c. 3070–3050 Ma, based on sparse geochronological data, and to have been accompanied by intrusion of the Elizabeth Hill Supersuite in the WPS. In the EPT, effects of the Prinsep Orogeny are restricted to tilting of the Pilbara Supergroup and resetting of Ar–Ar systematics in some rocks of the Pilbara Supergroup.

On COONGAN, the effects of the Prinsep Orogeny are manifest as the high-angle erosional unconformity between the Pilbara and De Grey Supergroups. This is particularly evident where the Gorge Creek Group overlies the Pilbara Supergroup at almost 90° angles in the western part of the sheet area, about 1 km south of the Marble Bar Road and 600 m west of Gorge Creek (MGA 762450E 7693600N).

De Grey Superbasin tectonic units

The De Grey Superbasin is composed of five superposed sedimentary basins that were deposited across the Pilbara Craton from 3020–2930 Ma (Van Kranendonk et al., 2006a, 2007). The oldest, and stratigraphically lowest, basin is the c. 3020 Ma Gorge Creek Basin that is developed across much of the Pilbara Craton, including the West Pilbara Superterrane and EPT. The dominantly sedimentary rocks of the Gorge Creek Basin belong to the Gorge Creek Group (Van Kranendonk et al., 2006a). A period of deformation separates the Gorge Creek Basin from the unconformably overlying, c. 3.01 Ga Whim Creek Basin (Hickman, 1997), which represents a volcanic rift basin (Barley, 1987) between the West Pilbara Superterrane and the younger Mallina Basin that is filled by bimodal mafic and felsic volcanic rocks. Deposition of the Mallina Basin was accompanied by rifting and normal faulting (Smithies et al., 1999; Pike and Cas, 2002).

Overlying these two older basins are three geographically separate, but temporally and tectonically linked, dominantly clastic sedimentary basins deposited from 2970–2930 Ma. In the west, the Mallina Basin separates the West Pilbara Superterrane from the EPT. This basin is filled by the Croydon Group, which is dominated by coarse- to fine-grained clastic sedimentary rocks (turbidities), but also contains mafic (Bookingarra

Formation) and felsic (Cistern Formation, Cattle Well Formation, and Kialrah Rhyolite) volcanic rocks. Detrital zircon data indicate derivation of sediment from both the East Pilbara Terrane and West Pilbara Superterrane (Smithies et al., 2001). The Lalla Rookh Basin, comprising coarse- to fine-grained clastic sedimentary rocks (Lalla Rookh Sandstone of the Croydon Group), is developed within the core of the EPT. Deformation of these two basins occurred at 2950–2930 Ma (Van Kranendonk and Collins, 1998; Smithies et al., 2001).

The Mosquito Creek Basin separates the EPT from the Kurrana Terrane in the southeastern part of the craton (Hickman, 1983). This basin is filled by the Nullagine Group, consisting of dominantly coarse- to fine-grained clastic sedimentary rocks (turbidites), and was deformed during north–south compression at 2930–2905 Ma (Huston et al., 2002; Van Kranendonk et al., 2007).

Stratigraphic, detrital zircon, and geochemical data, combined with field relationships, show that deposition of the De Grey Superbasin occurred under predominantly extensional conditions in basins developed on, and within, the craton. Initial deposition (Gorge Creek and Whim Creek basins) followed collisional orogenesis, and is thought to reflect the effects of crustal extension due to slab breakoff and mantle influx (Van Kranendonk et al., 2007). Extensional conditions continued through deposition of the lower part of the Mallina Basin (and ?Mosquito Creek Basin), but alternated with periods of compression (Smithies et al., 1999). The upper part of the Mallina Basin, the Lalla Rookh Basin, and the upper part of the Mosquito Creek Basin are interpreted to have been deposited during the onset of the North Pilbara Orogeny, at c. 2940 Ma (Van Kranendonk and Collins, 1998; Van Kranendonk et al., 2007).

Gorge Creek Basin

The Gorge Creek Basin is filled by low-grade clastic and chemical metasedimentary rocks and minor felsic volcaniclastic rocks of the Gorge Creek Group, forming the base of the De Grey Supergroup. These rocks unconformably overlie the volcanic rocks of the c. 3200 Ma Regal and c. 3120 Ma Sholl Terranes of the West Pilbara Superterrane, as well as the much older rocks (3520–3220 Ma) of the EPT (Pilbara Supergroup and pre-3.2 Ga granitic supersuites). The Gorge Creek Group consists of a basal, coarse, clastic unit known as the Farrel Quartzite, and a conformably overlying unit of shale, banded iron-formation, felsic volcaniclastic rocks, and minor siltstone and sandstone of the Cleaverville Formation. Felsic volcanic rocks and associated felsic porphyries within the Cleaverville Formation have been dated at c. 3020 Ma (Hickman, 1997; Van Kranendonk et al., 2002). Deposition of the Farrel Quartzite was accompanied by normal faulting, indicating extension (Van Kranendonk, 2004a). A maximum age of deposition of this unit is 3058 Ma, which is the age of the youngest dated detrital zircon (Nelson, 1997). The Gorge Creek Basin is unconformably overlain by the Whim Creek Basin in the west, by the Mallina Basin in the central part of the craton, the Lalla Rookh Basin in the core of the EPT, and by the Mosquito Creek Basin along the southeastern margin of the EPT.

Lalla Rookh Basin

The Lalla Rookh Basin outcrops in the central part of the EPT. This basin is filled by very coarse- to fine-grained clastic sedimentary rocks ascribed to the Lalla Rookh Sandstone of the Croydon Group (Figs 2, 4). The grain size of the basin fill changes upsection from very coarse-grained, polymictic conglomerates at the base through a thick section of interbedded sandstone and conglomerate, to interbedded shale, siltstone, and sandstone at higher stratigraphic levels. The basin fill was deposited on an erosional unconformity with relict topography developed in older rocks of the Pilbara Supergroup and Gorge Creek Group. Sedimentological studies and considerations of regional mapping suggest deposition before and during active tectonism associated with the North Pilbara Orogeny. The Lalla Rookh Basin is unconformably overlain by c. 2775–2630 Ma volcanic and sedimentary rocks of the Fortescue Group deposited in the Marble Bar Sub-basin of the Fortescue Basin.

De Grey Superbasin lithostratigraphic units

De Grey Supergroup

The 3020–2930 Ma De Grey Supergroup of dominantly clastic sedimentary rocks, banded iron-formation and chert, and subordinate mafic and felsic volcanic rocks occupies the De Grey Superbasin that overlies the WPS, EPT, and Kurrana Terrane (KT) of the Pilbara Craton across a regional unconformity (Hickman, 1983; Van Kranendonk et al., 2006a). The supergroup is composed of four groups, deposited in five basins: the 3020 Ma Gorge Creek Group, deposited in the Gorge Creek Basin across the WPS and EPT; the 3010 Ma Whim Creek Group, deposited in the localized Whim Creek Basin on the southeastern margin of the WPS; the 2970–2940 Ma Croydon Group, deposited in the Mallina Basin between the WPS and EPT, and in the Lalla Rookh Basin within the EPT; and the greater than, or equal to, 2926 Ma Nullagine Group, deposited in the Mosquito Creek Basin between the EPT and KT.

The De Grey Supergroup is unconformably overlain by volcanic and sedimentary rocks of the 2775–2400 Ma Mount Bruce Supergroup. The maximum thickness of the De Grey Supergroup varies greatly across the craton, reaching at least 3000 m in the Lalla Rookh Basin, and between 5000–8000 m thick across the Gorge Creek, Whim Creek, and Mallina Basins in the west Pilbara.

The 3.02 Ga Gorge Creek Group (AGC-xci-s [AG]) consists of the Farrel Quartzite and the Cleaverville Formation (Hickman, 1983; Van Kranendonk et al., 2006a). The Gorge Creek Group was deformed prior to deposition of the unconformably overlying Whim Creek and Croydon Groups (Hickman, 1997).

The c. 3.01 Ga Whim Creek Group consists of the Warambie Basalt and Red Hill Volcanics in the Whim Creek Basin along the southeastern margin of the WPS (Hickman, 1983; Van Kranendonk et al., 2006a). The age of deposition of this group is constrained by a 3009 ± 4 Ma age from the Red Hill Volcanics (Nelson, 1998f). Previously interpreted to represent either an intracratonic pull-apart basin (Barley, 1987) or a continental arc (Pike and Cas, 2002), the Whim Creek Group is interpreted here as an intracratonic basin that formed as a result of extension caused by breakoff of the subducted slab associated with formation of the c. 3.13 – 3.11 Ga Whundo Group intra-oceanic arc (Van Kranendonk et al., 2007).

The 2970–2940 Ma Croydon Group (Van Kranendonk et al., 2006a) (ACD-xs-b [AD]) consists of a variety of clastic sedimentary and volcanic rocks.

Deposition of the De Grey Supergroup took place during periods of extension alternating with periods of compressional deformation (Hickman, 1997; Smithies et al., 1999). The earliest of these deformed rocks of the c. 3.02 Ga Gorge Creek Group, but pre-dated deposition of the c. 3010 Ma Whim Creek Group. In the Mallina Basin, c. 2950 Ma granitic rocks crosscut two earlier generations of folds that affect the lower part of the clastic sedimentary basin fill, but are superseded by younger components of the group, including clastic sedimentary rocks and the c. 2940 Ma Kialrah Rhyolite that have been affected by a later set of folds developed during regional transpressional deformation at 2930 Ma (North Pilbara Orogeny: Smithies et al., 1999). The history of the Mosquito Creek Basin is less well established, but commenced with rifting of the EPT at c. 3200 Ma, followed by deposition of the Coondamar Formation (mixed assemblage of siliciclastic and mafic and ultramafic volcanic and intrusive rocks). The overlying Mosquito Creek Formation is an entirely siliciclastic succession that fills most of the basin, and includes moderate-depth to deep-water turbidite deposits. Detrital zircon populations in the Mosquito Creek Formation indicate a depositional age of ≤2930 Ma (Bagas et al., 2004). Compressional deformation affected the Mosquito Creek Basin at c. 2905 Ma (Huston et al., 2002).

The De Grey Supergroup hosts a variety of economic mineral deposits, including Fe-enriched banded iron formation in the Cleaverville Formation of the Gorge Creek Group, volcanogenic Cu–Zn massive-sulfide deposits in the Whim Creek Group, and shear-zone hosted, epigenetic and epithermal gold deposits in the Croydon and Nullagine Groups.

Gorge Creek Group (AGC-xci-s [AG] *and named subunits*)

The 3020 Ma Gorge Creek Group (AGC-xci-s [AG]; Hickman, 1983; Van Kranendonk et al., 2006a) was deposited unconformably on older rocks of the WPS and EPT across the north Pilbara Craton. It consists of the Farrel Quartzite, and the Cleaverville Formation (dominantly banded iron-formation). Deposition of this group followed soon after accretion of the WPS and collision of it with the EPT (3.05 Ga Prinsep Orogeny). Evidence of growth faults in the lower part of the group indicates deposition during extensional relaxation following collisional orogenesis. The group was deformed prior to deposition of the unconformably overlying Whim Creek and Croydon Groups (Hickman, 2004). The maximum thickness of the group is approximately 1900 m on ROEBOURNE in the west Pilbara, but approximately 1000 m in the EPT, on COONGAN.

Farrel Quartzite (AGCf-stq [AGcstq], AGCf-scp [AGcsc], AGCf-ss [AGcss *and* AG(st)])

The Farrel Quartzite (Van Kranendonk et al., 2006a) represents the basal formation of the Gorge Creek Group in the west and northern part of the EPT. It consists of up to 1000 m of quartz-rich sandstone and is named after Farrel Well on CARLINDIE (MGA 763750E 7695000N). This formation forms the main part of the Gorge Range on CARLINDIE and COONGAN. Originally assigned to the Corboy Formation of the Gorge Creek Group (Hickman, 1983), this unit was recently re-assigned to the Farrel Quartzite because it shows an unconformable relationship with the Sulphur Springs and Soanesville Groups on NORTH SHAW (Van Kranendonk et al., 2006a). The Farrel Quartzite contains detrital zircon populations dated at 3582, 3481, 3458, 3430, 3410, and 3403 Ma (Nelson, 1998h, 2002b). Deposition of the Farrel Quartzite was accompanied by significant extension and basin formation, which was accommodated by normal growth faults that cut through to the top of the formation, but not into the overlying rocks of the Cleaverville Formation (Van Kranendonk et al., 2004).

On COONGAN, the Farrel Quartzite consists of a discontinuous, basal unit of polymictic pebble to boulder conglomerate, up to 20 m thick, a conformably overlying unit of white quartzite and quartz-rich sandstone up to 1000 m thick, and a local unit of interbedded sandstone and siltstone up to 150 m thick. Syndepositional extensional growth faults are well developed in the westernmost part of the Gorge Range south of the Marble Bar Road and just west of Gorge Creek (MGA 761400E 7691600N), although they have been reactivated during later events at this locality.

The basal unit of polymict pebble to boulder conglomerate (AGCf-scp [AGcsc]) is only locally preserved beneath the Quaternary scree deposits that line the northern edge of the Gorge Range, for example in outcrops approximately 1 km on either side of Gorge Creek, and 2.5 km west of Pear Creek, all to the south of the Marble Bar Road (e.g. at MGA 761500E 7692500N, 762550E 7693500N, and 768300E 7692800N). These deposits are massive, with no visible bedding. Clasts are up to 30 cm across and consist of a variety of lithology derived from underlying rock units, including grey and white layered chert, fragments of pillows (some with marginal vesicles preserved) derived from pillowed metabasalt units, and felsic volcanic rocks. The matrix is composed of sand to silt sized clastic sediment and weathers a dark brown colour.

The bulk of the Farrel Quartzite consists of quartzite and quartz-rich sandstone (AGCf-stq [AGcstq]). On COONGAN, well-developed ripples are preserved in quartz-rich sandstone near the base of this unit in some places (e.g. 500 m east of Gorge Creek, approximately 1 km south of the Marble Bar Road; MGA 762500E 7693450N), where pebbly sandstone beds up to 30 cm thick are developed. Thick bedding (30 cm to 1 m) and large-scale cross-bedding is common throughout the quartzite, which locally contains scattered pebbles of black chert. The ripples and crossbeds, together with the supermature nature of the formation, and the high degree of sorting of detrital zircon populations, indicates deposition in a nearshore, high energy (probably a beach) environment. Quartz-rich sandstone of this unit is also interpreted to form the ridge within the core of the Talga Fault between the Mount Edgar and Muccan domes, east of the Talga River (MGA 797000E 7683500N).

Interbedded quartz-rich sandstone and siltstone (AGCf-ss [AGcss]) form the top of the formation in one locality 3.2 km south of the Marble Bar Road and 3 km west of Pear Creek (MGA 768200E 7690600N), where it is approximately 150 m thick. These rocks are distinctly finer grained than the quartz-rich sandstone of the bulk of the formation, and suggest a fining-up gradation prior to deposition of the Cleaverville Formation.

Cleaverville Formation (AGCe-cα [AGpci, AG(ci), AG(cis)], AGCe-sh [AG(sh)], AGCe-st [AG(st)], AGCe-mk [AG(sk)])

The Cleaverville Formation (Hickman, 1983; Van Kranendonk et al., 2006a) is the most widely developed unit of the Gorge Creek Group, interpreted to extend across the whole of the exposed Pilbara Craton. It reaches a maximum of approximately 1900 m thick in the west Pilbara on ROEBOURNE, where it consists of banded iron-formation, shale, sandstone, and minor felsic volcanic and volcaniclastic rocks. Elsewhere, the Cleaverville Formation consists almost exclusively of banded iron-formation. The type area of the formation is on Cleaverville Beach on DAMPIER, although it is strongly deformed in this area on the northern limb of a tight anticline. The Cleaverville Formation rests conformably on the Farrel Quartzite in parts of the EPT, or unconformably on older rocks of the Pilbara Supergroup, or on still older granitic rocks (Dawes et al., 1995). In previous stratigraphic schemes, parts of this formation were referred to as either the Nimingarra Iron-Formation or the Paddy Market Formation of the Gorge Creek Group.

The age of the Cleaverville Formation is well known in the west Pilbara, from samples of interbedded and interlayered felsic volcanic rocks dated at c. 3020 Ma (Nelson, 1997, 1998i). Detrital zircon populations from clastic sedimentary layers within the Cleaverville Formation vary across the north Pilbara Craton. In the EPT, quartzite layers contain detrital zircon populations dated at 3457, 3438, 3415, and 3362 Ma (Nelson, 1998j; Williams, 1999). At Nunyerry Gap on the western margin of the EPT, a sandstone unit underlying the Cleaverville Formation was interpreted to have a maximum depositional age of c. 3016 Ma (Nelson, 1998k). In the west Pilbara, detrital zircon populations are dated at 3251, 3236, 3195 ± 15, 3058, 3022, and 3015 Ma (Nelson, 1998l,m; Kiyokawa et al., 2002).

On COONGAN, the Cleaverville Formation (AGCe-cα) consists of banded iron-formation and minor interbedded ferruginous shale within the Gorge Range in the western part of COONGAN ([AGpci]; MGA 768900E, 7690000N), as well as dismembered slices along the axis of the faulted syncline between the Mount Edgar and Muccan domes to the east of the Talga River ([AG(ci) and AG(cis)]; MGA 796500E 7683700N). The banded iron-formation is typically a centimeter- to millimeter-layered unit of red-black and white iron oxide minerals (magnetite and hematite) alternating with chert, or more correctly microquartz. Layering is very regular and continuous, indicating deposition under quiet water conditions, which is in stark contrast to the depositional environment of the underlying Farrel Quartzite.

Rocks interpreted as belonging to the Cleaverville Formation are also present on COONGAN in the Marble Bar greenstone belt, just east of the unconformably overlying rocks of the Fortescue Group in the Marble Bar Sub-basin, east of Warralong Creek and 12 km south of the Marble Bar Road (MGA 779000E 7679000N). The rocks in this area are tightly folded into a northeast-plunging anticline, and are in faulted contact with metamorphosed pyroxene spinifex-textured basalt of the Euro Basalt (Kelly Group) to the east, and with thick flows of vesicular basalt of the Fortescue Group to the west. The most widespread lithology in this area is a weakly metamorphosed shale (AGCe-sh [AG(sh)]) that is interbedded over quite a wide area with less than 5-cm thick beds of siltstone and fine-grained sandstone. Coarse-grained sandstone and pebbly sandstone (AGCe-st [AG(st)]) with cross-bedding form thicker bedsets locally, and comprise mappable units within the central and eastern limb of the main anticline. Map relationships of an interdigitated contact with shales across this fold limb suggest the presence either of an earlier phase of folding, or of a lateral facies variation between sandstone and shale at this locality (MGA 779500E 7679700N).

In the southeastern part of this area of outcrop is an unusual unit of carbonate-rich, metamorphosed, clastic sedimentary rocks (AGCe-mk [AG(sk)]; MGA 791000E 7678750N). In outcrop, massive units of brown carbonate-rich rocks are interbedded with pebbly layers, and rocks with well-preserved fine-scale bedding and abundant cross-bedding at 2–5 cm scale, possibly including climbing ripples. These give way- up directions to the east that are consistent with graded bedding and cross-bedding in sandy units elsewhere on the eastern limb of the large anticline. However, some layers are light green in colour, with significant amounts of chlorite and local porphryoblastic textures. In thin section, these greenish rocks are clearly schistose, containing carbonate–microquartz–white mica–opaques, and carbonate–chlorite–white mica with porphyroblasts of what are now Fe-carbonate–microquartz–chlorite, but that were originally possibly either garnet or ?cordierite intergrown with plagioclase. Another rock unit contains scattered, small, round quartz clasts in a matrix of white mica (?pyrophyllite) and microquartz, with porphyroblasts of what are now opaque minerals, but which may have originally been garnet. The eastern contact of this unit is a silicified fuchsitic shear zone.

Croydon Group **(ACD-xs-b [AD]** ***and named subunit*****)**

The 2970–2940 Ma Croydon Group (Van Kranendonk et al., 2006a) (ACD-xs-b [AD]) consists of a variety of clastic sedimentary and volcanic rocks. On the western margin of the Mallina Basin are the c. 2964 Ma Cistern Formation of quartz-rich clastic sedimentary and felsic volcaniclastic rocks, the Rushall Slate, the Bookingarra Formation of silicic high-Mg basalts, and the Kialrah Rhyolite. The eastern margin of the basin on the northeastern margin of the EPT consists of coarse clastic rocks of the Constantine Sandstone. The main part of the basin fill consists of the Constantine Sandstone and Mallina Formation (fine sandstone and shale), with subordinate amounts of mafic volcanic rocks (Bookingarra Formation) and felsic volcanic rocks (Kialrah Rhyolite). The small Lalla Rookh Basin remnant within the core of the EPT is filled by coarse conglomerate, sandstone and minor shale of the Lalla Rookh Sandstone. The central part of the Mallina Basin is intruded by a variety of unusual syndepositional igneous rocks of the 2950–2920 Ma Sisters Supersuite, including sanukitoids of the Indee Suite, LREE-enriched gabbros (Millindinna Intrusion), and alkaline granite of the Portree Suite.

The Croydon Group was deposited during periods of extension, but these episodes alternated with periods of compressional deformation. In the Mallina Basin, c. 2950 Ma granitic rocks crosscut two earlier generations of folds that affect the lower part of the clastic sedimentary basin fill, but are superseded by younger components of the group, including clastic sedimentary rocks and the c. 2940 Ma Kialrah Rhyolite, which have been affected by a later set of folds developed during regional transpressional deformation associated with the North Pilbara Orogeny.

Lalla Rookh Sandstone (ACDl-sg [ADlsc], ACDl-sp [ADlst], ACDl-stq [ADlstq], ACDl-sh [ADlsh])

On Coongan, the Croydon Group is represented by the Lalla Rookh Sandstone (Hickman, 1983; Van Kranendonk et al., 2006a), which consists of a thin basal unit of pebble to boulder conglomerate, a thick unit of sandstone, including local quartzite, and relatively minor amounts of shale. The formation reaches a maximum thickness of approximately 2000 m in the southwestern part of the sheet area, where it unconformably overlies the Gorge Creek Group and is unconformably overlain by basal sandstones of the Fortescue Group. The rocks do not contain a penetrative foliation.

The basal conglomerate unit of the Lalla Rookh Sandstone on Coongan (ACDl-sg [ADlsc]) contains dominantly pebble- to rare boulder-size clasts of siliceous lithology in a sand-size clastic matrix. Larger clasts include quartzite derived from the underlying Gorge Creek Group, layered black-and-grey chert, more massive black chert, and white quartz. Bedding is well developed, with sandstone interbeds and lesser proportions of shale. Locally, the basal unit consists of more angular clasts of grey-and-white, layered, siliceous metasediment derived from the underlying Gorge Creek Group, for example in the Gorge Range, 2.7 km south of the Marble Bar Road and 2.5 km east of Gorge Creek (MGA 765150E 7692000N). The unconformity with the underlying Gorge Creek Group is well preserved across the western part of the Gorge Range, 2.3 km south of the Marble Bar Road and approximately 1 km east of Gorge Creek (MGA 763000E 7692250N). The basal unit consists of quartz-pebble conglomerate where it directly overlies the Farrel Quartzite in the westernmost part of the Gorge range, approximately 3.7 km south of the Marble Bar Road and 1 km west of Gorge Creek (e.g. MGA 761000E 7691200N; Fig. 18).

The dominant component of the Lalla Rookh Sandstone is a brown-weathering, medium- to coarse-grained pebbly sandstone (ACDl-sp [ADlst]) that shows well-developed bedding at a 2–100 cm scale and variations to fine-grained sandstone, pebbly sandstone, and siltstone.

Quartz-rich sandstone (ACDl-stq [ADlstq]) forms a unit approximately 100 m thick in the western part of Coongan. In addition to its quartz-rich original composition, it is heavily silicified. However, it is plane bedded and homogeneous, without conglomeratic interbeds.

Brown-weathering shale (ACDl-sh [ADlsh]) forms units several tens of metres thick in the middle part of the formation approximately 3.6 km south of the Marble Bar Road and 2 km east of Gorge Creek (e.g. at MGA 764600E 7691200N). These fine-grained clastic rocks are interbedded with siltstone and rare sandstone beds, and exhibit a weak slaty cleavage parallel to bedding.

De Grey Superbasin events

D_6: growth faulting

Deposition of the Farrel Quartzite of the Gorge Creek Group was accompanied by the development of growth faults that are most evident on Carlindie and Coongan. These faults are recognized as syndepositional structures because they separate along-strike panels of similar lithology with markedly different sedimentary thicknesses (Van Kranendonk, 2004a; Van Kranendonk et al., 2004). On Coongan, these D_6 growth faults (Hickman and Van Kranendonk, 2008b) are present in the far western

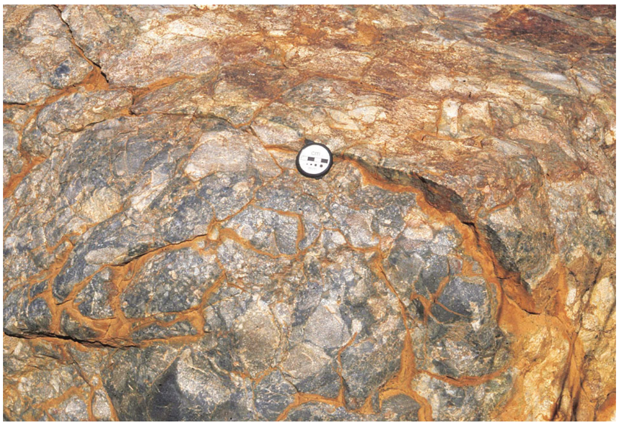

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Figure 18. Coarse conglomerate–breccia unit at the base of the Lalla Rookh Sandstone in the Gorge Range, consisting of angular to rounded clasts of the underlying Farrel Quartzite in a blue-grey matrix of metachert (now megaquartz; MGA 761000E 7691200N).

part of the Gorge Range, approximately 2 km south of the Marble Bar Road and 500 m west of Gorge Creek (MGA 761700E, 7692200N).

D_7: tilting of bedding

A D_7 set of structures include tight to isoclinal folds of the c. 3020 Ma Cleaverville Formation of the Gorge Creek Group in the western part of the Gorge Creek Basin. These folded rocks are unconformably overlain by rocks of the 3010 Ma Whim Creek Group (Hickman, 2004). In the EPT, the D_7 event resulted in gentle tilting and folding of greenstones in the Coppin Gap Syncline on MUCCAN, prior to deposition of the Coonieena Basalt Member of the Bookingarra Formation in the Croydon Group (Williams, 1999).

On COONGAN, the D_7 event caused gentle tilting of the Gorge Creek Group prior to deposition of the unconformably overlying Croydon Group. This is seen in the downcutting nature of the unconformity at the base of the Croydon Group and progressive west to east excision of the Cleaverville Formation along the western half of the map sheet in the Gorge Range.

Sisters Supersuite (AST-gm [AgL, AgLmp], AST-mgm [AgLmpf])

The 2955–2920 Ma Sisters Supersuite (Van Kranendonk et al., 2006a) consists of a wide variety of igneous rocks distributed across the western-central part of the northern Pilbara Craton, including a major component that intruded the Mallina Basin and western part of the EPT. The oldest components of the supersuite were emplaced into clastic sedimentary rocks of the Mallina Basin at 2955–2945 Ma. These include high-Mg diorite (sanukitoid) rocks of the Indee Suite, alkaline granite of the Portree Suite, and ultramafic–mafic intrusions of the Langenbeck Suite. The Indee and Langenbeck Suites host PGE and orthomagmatic gold deposits. This magmatism was followed by widespread and voluminous granitic magmatism (2946–2923 Ma) that was dominant in the western half of the EPT, but is continuous across the Mallina Basin and into the WPS. The youngest component of the supersuite is the Radley Suite of layered mafic–ultramafic intrusions in the WPS, which host PGE and Ni–Cu mineralization.

On COONGAN, granitic rocks along the northern edge of the sheet area in the Carlindi Granitic Complex are interpreted as part of the Sisters Supersuite, as are some small intrusions within the Warralong greenstone belt, although this latter assignation is less confident. No age dating has been conducted on these rocks, but they are thought to belong to this supersuite on account of their monzogranitic composition and lack of evidence for contained structures older than those interpreted to belong to the North Pilbara Orogeny (see below).

The most widely exposed lithology is strongly foliated biotite metamonzogranite to metagranodiorite (AST-mgm [AgLmpf]), which is well exposed north of Pardoo Creek, approximately 5 km east-northeast of Ettrick Homestead (MGA 784000E 7729500N). These fine- to medium-grained rocks have common pegmatite sheets oriented parallel to the foliation.

Much less strongly deformed rocks are present further west, in outcrops on the De Grey River (MGA 772900E 7728750N). These K-feldspar porphyritic to seriate-textured biotite monzogranites (AST-gm [AgLmp]) have well preserved igneous alignment of phenocrysts, commonly at an angle to the regional foliation.

Massive, fine-grained granite (AST-gm [AgL]) occupies the core of an upright anticline in the north-central part of the Warralong greenstone belt (MGA 761000E 7706500N). This granite, and smaller apophyses to the north, have well preserved intrusive contacts with Warrawoona Group greenstones and a locally developed axial planar foliation.

North Pilbara Orogeny: regional compression at 2.95 – 2.93 Ga

The North Pilbara Orogeny is the name given to an event that resulted in the development of a prominent set of structures across the western half of the Pilbara Craton at about 2.93 Ga that was accompanied by widespread granitic magmatism (Van Kranendonk et al., 2002, 2006a, 2007). Structures created by this event include northeast-trending upright folds, north- to north-northeast-striking sinistral shear zones, and east- to northeast-striking dextral shear zones, indicating an overall west-northwesterly direction of maximum compression (Van Kranendonk and Collins, 1998). Deformation was in part preceded by, and accompanied by, dominantly granitic magmatism of the Sisters Supersuite, emplaced at 2950–2920 Ma across the WPS, Mallina Basin, and western half of the EPT. Significant mesothermal to epithermal gold mineralization is associated with shear zones developed during this event, particularly within the Mallina Basin (Huston et al., 2002).

On COONGAN, the most direct evidence of the North Pilbara Orogeny is the erosional angular unconformity between the underlying sedimentary rocks of the Gorge Creek Group and overlying, syn-orogenic Lalla Rookh Sandstone of the Croydon Group, south of the Warralong greenstone belt and Marble Bar Road, near the western edge of the map sheet (MGA 761700E 7691250N). Although growth faulting affected the underlying Gorge Creek Group rocks in this area, this cannot account for the highly variable orientation in bedding of these rocks and thus implies a period of compressional deformation prior to deposition of the Lalla Rookh Sandstone. Evidence for rapid facies variations and internal unconformities within the Lalla Rookh sandstone and dated, contemporaneous rocks of the Mallina Basin (Croydon Group) to the west, provide evidence for syn-orogenic deposition of these rocks (e.g. Van Kranendonk and Collins, 1998; Van Kranendonk et al., 2004).

Far more prominent structures that developed during the North Pilbara Orogeny include north-northwest-striking, sinistral, brittle–ductile faults that offset the Gorge Creek Group to the west of Pear Creek (e.g. MGA 767800E

7691200N) and cut through the northeastern part of the Warralong greenstone belt (e.g. MGA 765000E 7702800N). Indeed, most of the faults that cut through the Warralong greenstone belt are interpreted to relate to the North Pilbara Orogeny.

A set of northeast-trending aeromagnetic lineaments that transect the northwestern corner of COONGAN are interpreted to be the result of sinistral transpressional deformation at c. 2940 Ma, forming part of the extended network of shears and folds known as the Lalla Rookh – Western Shaw structural corridor (Fig. 4; Van Kranendonk and Collins, 1998; Van Kranendonk et al., 2004).

Mosquito Creek Orogeny

Deformation continued until after the North Pilbara orogeny, as indicated by the angular unconformity that separates the Lalla Rookh Sandstone from the overlying, basal sedimentary units of the Fortescue Group at a locality approximately halfway between Gorge and Pear Creeks, 4 km south of the Marble Bar Road (MGA 766000E 7690200N; Fig. 19). This younger deformation is ascribed to the effects of the c. 2905 Ma Mosquito Creek Orogeny (Van Kranendonk et al., 2007). The degree of tilting of the Lalla Rookh Sandstone varies considerably across COONGAN and CARLINDIE (Van Kranendonk, 2004a), such that the contact of these rocks with the overlying Fortescue Group is locally paraconformable on the map view, but can still be recognized as an unconformity by a change in the amount of dip of the bedding between these units (e.g. 63° versus 45°, respectively, as seen in exposures approximately 1 km east of Gorge Creek and 4.8 km south of the Marble Bar Road; MGA 762700E 7689600N).

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Figure 19. View, looking east, of the basal unconformity of the Bellary Formation, Fortescue Group (to right of dashed line with half circles, dipping to right) on more steeply dipping rocks of the Lalla Rookh Sandstone (long dashes; MGA 766000E 7690200N).

Mount Bruce Supergroup

The 2775–2300 Ma Mount Bruce Supergroup (MacLeod et al., 1963; Trendall, 1979) is a thick succession of low-grade sedimentary and volcanic rocks that were deposited on older granite–greenstone rocks of the Pilbara Craton. The supergroup is divided into three groups that were deposited in three basins (Tyler and Hocking, 2007). These basins include, from base to top: the 2775–2630 Ma Fortescue Group (Fortescue Basin); the 2630–2450 Ma Hamersley Group (Hamersley Basin); the Turee Creek Group (Turee Creek Basin), which is undated but interpreted to be approximately 2300 Ma (Trendall et al., 2004). The Mount Bruce Supergroup is unconformably overlain by the 2200–1800 Ma Wyloo Group. Rocks of the Fortescue Group were deposited in four sub-basins (Thorne and Trendall, 2001).

Fortescue Basin

The c. 2775 to 2629 Ma Fortescue Basin is the depositional basin of the Fortescue Group in the Pilbara region of Western Australia, the lowest group of the Mount Bruce Supergroup. The Fortescue Group lies with marked angular unconformity on 3520–2830 Ma granite–greenstone basement of the Pilbara Craton and is conformably overlain by c. 2630–2450 Ma rocks of the Hamersley Basin (Thorne and Trendall, 2001). The Fortescue Basin is divided into four major sub-basins, each showing a distinct stratigraphy of low grade metasedimentary and metavolcanic rocks (Thorne and Trendall, 2001); the Northeast Pilbara Sub-basin, Northwest Pilbara Sub-basin, Marble Bar Sub-basin, and South Pilbara Sub-basin. The lithological character and regional variability is thought to result from deposition in a continental rift-related setting.

Marble Bar Sub-basin

The Marble Bar Sub-basin of the Fortescue Basin is a broadly synclinal structure of Neoarchean volcanic and sedimentary rocks of the Fortescue Group that overlies basement greenstone synclines composed of the Pilbara and De Grey Supergroups (Thorne and Trendall, 2001; Van Kranendonk, 2003b; Van Kranendonk et al., 2004). The Fortescue Group in this area unconformably overlies rocks of the Pilbara Supergroup (EPT), the De Grey Supergroup, and Paleoarchean granitic rocks of the Shaw Granitic Complex. The Marble Bar Sub-basin includes two late depocentres of coarse clastic sedimentary rocks in the Pear Creek (northern depocentre, on COONGAN and MARBLE BAR) and Shady Camp (southern depocentre, on MARBLE BAR) centroclines. Eight periods of deformation accompanied, or postdated the deposition of each of the formations of the Fortescue Group in the Marble Bar Sub-basin, caused by basin subsidence along long-lived normal faults (Van Kranendonk, 2003b). The Pear Creek Fault, along the southern margin of the Pear Creek Centrocline, shows stratigraphic evidence of north-side-down, normal displacement during accumulation of the Fortescue Group (Van Kranendonk, 2003b).

Fortescue Group

The Fortescue Group (MacLeod et al., 1963; Thorne and Trendall, 2001) is a thick sequence of Archaean mafic and felsic volcanic and associated sedimentary rocks, which unconformably overlies Pilbara Craton granite–greenstones in the northwest of Western Australia. The succession has a maximum thickness of about 6.5 km and is divided into ten formations, some of which are laterally equivalent. These have been grouped into four major tectono-stratigraphic units. From the base upwards: Unit 1 incorporates the Mount Roe Basalt and pre-Mount Roe Basalt sedimentary units, including the Bellary Formation; Unit 2 comprises the Hardey Formation; Unit 3 consists of the Kylena, Tumbiana, and Maddina Formations, and their lateral equivalents the Boongal, Pyradie, and Bunjinah Formations; and Unit 4 is the Jeerinah Formation. Uranium–lead zircon geochronology indicates that the Fortescue Group was deposited between about 2775 and 2630 Ma (Arndt et al., 1991; Thorne and Trendall, 2001; Blake et al., 2004; Trendall et al., 2004).

The Fortescue Group outcrops over an area of about 40 000 km^2 of the Pilbara region, but its actual depositional extent was at least 200 000 km^2. The principal outcrop area forms an irregular, elongate, east–west strip lying mainly to the north of the Fortescue River, with apophyses extending farther northwards at each end: in the west into the Dampier Archipelago, and in the east along the western side of the Oakover River catchment. To the north, a number of outliers rest on the north Pilbara granite–greenstone terrain, including the large and important outlier west of Marble Bar (the Marble Bar Sub-basin). In addition to these, four smaller areas of outcrop are physically separated from the main strip by the overlying Hamersley Group and younger groups. These are: the Gregory Range area; the area adjacent to the northern and western edges of the Sylvania Inlier; an inlier in the core of the Wyloo Dome, in the southwest; and a major irregular inlier in the southwestern part of the Hamersley Ranges.

Each of the four sub-basins of the Fortescue Basin shows a distinctive variation on the overall stratigraphic framework. However, the Mount Roe Basalt is generally up to 2.5 km thick and consists largely of subaerial basaltic lavas, subaqueous basaltic (pillow) lavas, and water-lain volcaniclastic rocks. These are overlain by the Hardey Formation, which is up to 3 km thick, and consists of a wide range of sedimentary and volcanic (both mafic and felsic) rocks laid down in a continental to shallow-marine setting. Middle to upper parts of the Fortescue Group are dominated by subaerial basaltic flows (Kylena and Maddina Formations) and coastal, nearshore-shelf, and lacustrine sedimentary and volcaniclastic rocks (Tumbiana Formation) in the north Pilbara, and by subaqueous basaltic to komatiitic lavas and volcaniclastic rocks (Boongal, Pyradie, and Bunjinah Formations) in the south. The uppermost Jeerinah Formation consists largely of argillaceous rocks in the north, whereas basaltic lava and volcaniclastic rocks are abundant in the south.

Bellary Formation (AFOb-xs-b [AFb], AFOb-sg [AFbsc], AFOb-sr [AFbst])

The Bellary Formation (Thorne et al., 1991) represents the basal unit of the Fortescue Group that underlies the Mount Roe Basalt and consists of dominantly clastic sedimentary rocks and subordinate mafic volcanic and volcaniclastic rocks (AFOb-xs-b [AFb]). Conglomerate and sandstone of this formation were deposited in braided fluviatile and lacustrine settings (Blake, 1993; Thorne and Trendall, 2001).

On COONGAN, the Bellary Formation is up to 556 m thick and consists predominantly of polymictic pebble to cobble conglomerate with clasts of chert and white quartz (AFOb-sg [AFbsc]), and well-bedded coarse to pebbly sandstone with abundant channels (AFOb-sr [AFbst]), deposited in a fluvial environment with migrating point bars. The base of the formation at the far northern margin of the Marble Bar Sub-basin (e.g. MGA 766300E 7690000N) is marked by a thin unit of sandstone and shale and a discontinuous unit, locally up to 5 m thick, of dark-grey, silicified chert breccia that consists of angular pieces of layered white and grey chert in a slightly granular cherty matrix (Fig. 20). The rock locally has the appearance of a silicified banded iron-formation, although it may be a silicified mudstone or siltstone. This unit is distributed as a series of discontinuous, highly contorted and folded lenses and pods, forming a rough 'bed' along 1500 m or more of strike length. Neither sandstone beds above or below this unit are in any way deformed, such that the folding and brecciation of the cherty-banded iron-formation represents a period of considerable soft-sediment deformation and thus deposition of the formation during tectonic unrest.

Mount Roe Basalt (AFOr-b [AFr], AFOr-bbg [AFrb], AFOr-bbx [AFrbx], AFOr-bbfz [AFrbz])

The Mount Roe Basalt (Kriewaldt, 1964) is a thick sequence of predominantly basalt and basalt-andesite flows (AFOr-b [AFr]) deposited under predominantly subaerial conditions, although local pillow basalts at the base of the formation indicate deposition in local

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Figure 20. Outcrop view of silicified chert breccia from the Bellary Formation at the base of the Fortescue Group, consisting of angular pieces of layered white and grey chert in a slightly granular cherty matrix (unit not identified on map; MGA 764790E, 7692000N).

lacustrine basins. Interbedded with the flows are minor tuff, hyaloclastite, and epiclastic rocks, as well as non-volcanogenic sedimentary rocks, including conglomerate, sandstone, and argillite. In places, the Mount Roe Basalt rests directly on the granite–greenstone basement, but in many places it lies conformably to unconformably on sedimentary rocks of the Bellary Formation. Sedimentary rocks of the c. 2760 Ma Hardey Formation disconformably to unconformably overlie the Mount Roe Basalt, which shows local evidence of folding prior to deposition of the overlying unit (Van Kranendonk, 2003b). Thin units of felsic tuff and sedimentary rock are locally developed within the formation, the former of which has yielded an age of 2775 ± 10 Ma (Arndt et al., 1991) that is considered the best estimate for the age of eruption of the formation.

On COONGAN, the Mount Roe Basalt consists predominantly of massive, plagioclase-porphyritic, amygdaloidal, tholeiitic basalt flows (AFOr-bbg [AFrb]) that lie disconformably to unconformably on clastic sedimentary rocks of the underlying Bellary Formation (see Van Kranendonk, 2004a). Locally, flows of the Mount Roe Basalt are coarsely plagioclase phyric (Fig. 21a) and contain pipe vesicles (Fig. 21b). The base of the formation in the northern part of the Marble Bar Sub-basin contains pillowed basalt (Fig. 21c) where it fills paleovalleys in the underlying rocks, for example 4.7 km south of the Marble Bar Road and 5 km west of Pear Creek (MGA 766900E 7689400N). Rapid lateral thickness variations of the formation across a prominent north–south fault just to the east of this locality (MGA 767000E 7687500N) indicate deposition during growth faulting. The formation reaches a maximum thickness of 2580 m on the northern margin of the Pear Creek Centrocline, but thickness varies significantly across strike. The dip of beds varies from moderate in the axis of the syncline, to vertical at the far eastern part of the Marble Bar Sub-basin where it is tightly pinched in an inter-diapir syncline axis.

Two isolated outcrops of basalt breccia and agglomerate (AFOr-bbx [AFrbx]), approximately 2–4 km northeast of the northeastern margin of the Marble Bar Sub-basin (MGA 772000E 7687700N and MGA 770700E 7689700N), consist of angular basalt fragments, typically 5–10 cm across, in a fine-grained hyaloclastite matrix (Fig. 21d). Given that this type of rock is so common at the base of the Kylena Formation, it is possible that these isolated outcrops are of this younger formation.

Just south of the centre of the Pear Creek Centrocline (MGA 766900E 7677000N) is a hill of bleached and silicified, massive basalt (AFOr-bbfz [AFrbz]) that is rimmed by clastic sedimentary rocks inferred to belong to the Hardey Formation. A possible alternative interpretation is that the hill consists of altered basement greenstones (possibly Euro Basalt) rimmed by clastic sedimentary rocks of the Bellary Formation, but this can not be determined from presently available information.

Black Range Dolerite Suite (ABL -od [AFdb])

Doleritic to gabbroic dykes of the Black Range Dolerite Suite (Williams, 1999; ABL -od [AFdb]) outcrop across the map sheet area, striking most commonly north-northeast. The largest of these is the Black Range Dyke, which traverses the eastern part of COONGAN, primarily as a single, straight to curving dyke, or locally as en echelon dyke segments, cutting across the Muccan Granitic Complex, but also intruding the Doolena Gap and Marble Bar greenstone belts in a more discontinuous fashion. Rocks of the Black Range Dolerite Suite display pristine igneous textures of interlocking titanaugite and plagioclase crystals, with titano-ilmenite and small intercrystalline patches of quartz–K-feldspar granophyre. The dykes have undergone a degree of deuteric alteration that has altered titanaugite crystals to chlorite, and resulted in minor sericitic alteration of plagioclase. U–Pb dating of baddeleyite from the Black Range Dyke has yielded an igneous emplacement age of 2772 ± 2 Ma (Wingate, 1999).

The geometry of emplacement of the Black Range Dyke and parallel dykes of the suite is interesting. The southern end of the main segment of the Black Range Dyke forms a prominent bulge against an easterly striking fault on the eastern bank of the Talga river, approximately 1 km northeast of the Marble Bar Road (MGA 795200E 7684500N), and then is offset to the west by 1.8 km across the Talga River, giving it the appearance of having been affected by faulting. However, the dyke is coarse grained all along the southern contact of the bulge and is undeformed, indicating that the bulge and offset are primary features of the dyke emplacement. Farther south into the greenstones, the dyke continues as a series of short segments and pods, all of which are undeformed. Again, this indicates a primary, transgressive style of dyke emplacement within the greenstones, most likely due to the inability of fractures to propagate cleanly across a multilayered medium.

Hardey Formation (AFOh-xs-f [AFh], AFOh-sg [AFhsc], AFOh-sp [AFhst], AFOh-shv [AFhsh])

The Hardey Formation (Thorne et al., 1991) of the Fortescue Group consists predominantly of clastic sedimentary rocks, but includes felsic volcanic and volcaniclastic rocks of the Koongaling Volcanic Member, Bamboo Creek Member (components of which have been dated at 2768–2756 Ma; Pidgeon, 1984; Arndt et al., 1991) and Lyre Creek Member (AFOh-xs-f [AFh]). This formation lies disconformably to unconformably on older rocks of the Fortescue Group, or, in places, on basement granite–greenstone rocks. It is disconformably to unconformably overlain by the Kylena Formation. In the Gregory Range area of the east Pilbara, the Koongaling Volcanic Member and sedimentary rocks of the Hardey Formation are intruded by granitic rocks of the coeval Gregory Range Suite (granitic).

On COONGAN, the unconformity between the Hardey Formation and folded rocks of the Mount Roe Basalt is clearly visible in several places in the Pear Creek Centrocline (e.g. MGA 765600E 7676600N, 772900E 7681500N, and 775000E 7676400N). The formation reaches a maximum of 360 m thick, but this has been inflated by intrusion of dolerite sills.

The basal unit of the Hardey Formation on COONGAN is polymict pebble conglomerate (clasts of black chert, white

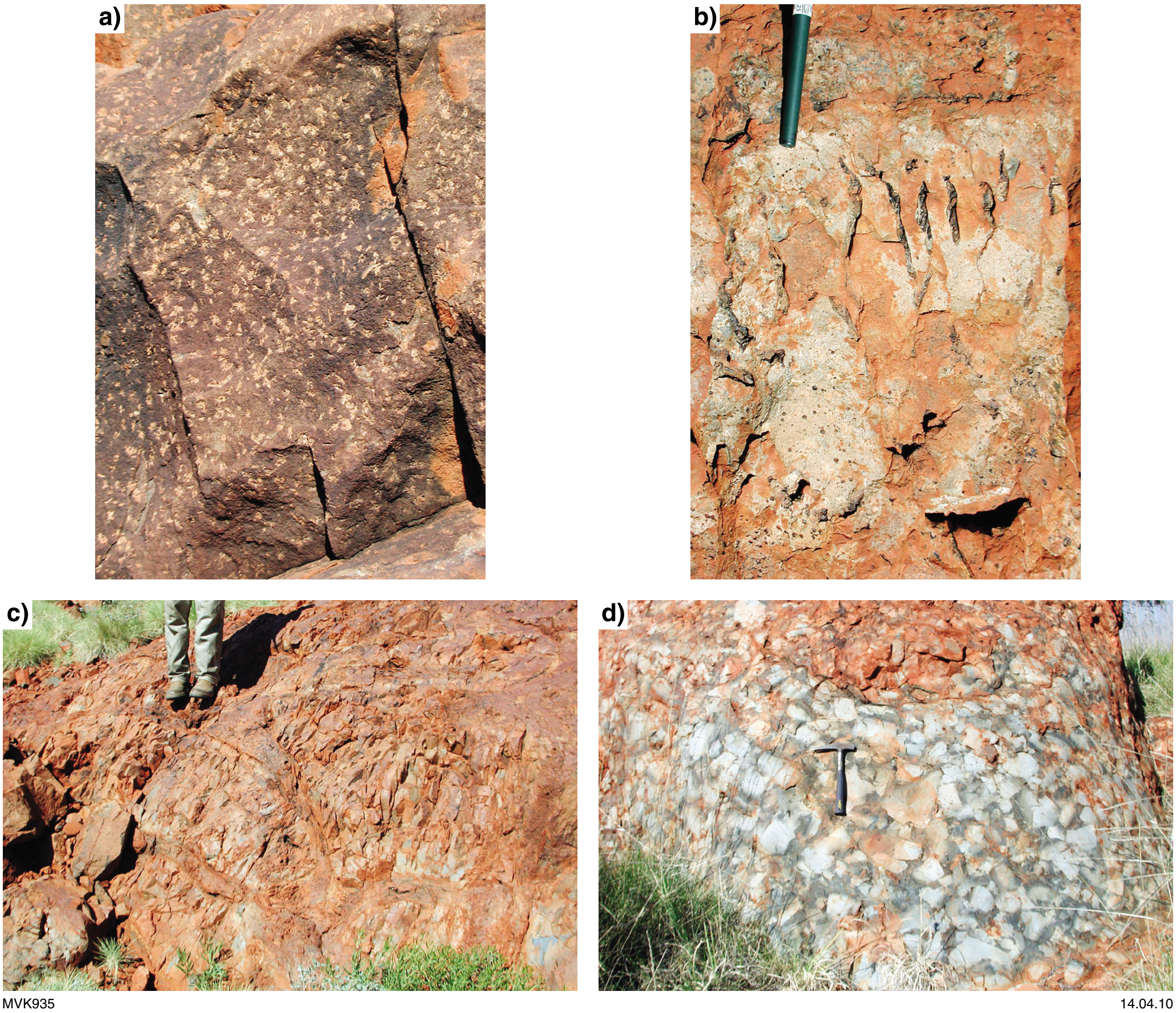

Figure 21. Outcrop features of the Mount Roe Basalt of the Fortescue Group (AFOr-bbg [AFrb]): a) plagioclase-phyric basalt (plagioclase laths are 1 cm long); b) gas pipe vesicles (MGA 763390E 7682900N); c) outcrop view of pillows from the base of the formation (MGA 766900E 7689400N); d) outcrop view of fresh surface of basaltic hyaloclastite pillow breccia from the base of the Kylena Formation (AFOk-bbz [AFkbx]; MGA 770690E 7689755N).

quartz, banded iron-formation, quartzite, and less common volcanic rocks in a sandy quartz-feldspar matrix) and sandstone (AFOh-sg [AFhsc]).

The basal conglomerate passes up into coarse-grained, orange-weathering sandstone with pebbly sandstone and less common siltstone interbeds (AFOh-sp [AFhst]) that form the bulk of the formation on Coongan. Bedding is well developed, typically at a 4–20 cm scale, and cross-bedding is common.

Thin units (<25 m) of brown-weathering shale interbedded with siltstone and sandstone (AFOh-shv [AFhsh]) outcrop in the southern-central part of the Pear Creek Centrocline, along the southern edge of the map sheet area (MGA 767000E 7676100N).

Bamboo Creek Member (AFOhb-frp [AFhbfr])

Intruding the southeastern part of the Carlindi Granitic Complex at the northern margin of Coongan are two dykes of flow-banded rhyolite belonging to the Bamboo Creek Member of the Hardey Formation (AFOhb-frp [AFhbfr]). These rocks have an apple-green weathering colour and contain scattered quartz phenocrysts, up to 2 mm across, in a fine-g1rained silicic matrix that displays prominent isoclinal folds at a 10 cm scale, defined by flow-banding. These dykes are interpreted as representing feeder dykes to eruptive rhyolite lavas found elsewhere within the formation.

Kylena Formation (AFOk-b [AFk], AFOk-bb [AFkb], AFOk-bbor [AFkbx], AFOk-bbo [AFkbl], AFOk-od [AF(d)])

The Kylena Formation (MacLeod and de la Hunty, 1966) comprises predominantly subaerial basaltic andesite to basaltic lavas, but includes locally significant basaltic pillow breccia deposits, spectacular pillowed successions, interflow clastic sedimentary rocks, and minor stromatolitic carbonate rocks and volcaniclastic sedimentary rocks (AFOk-b [AFk]; see Thorne and Trendall, 2001). The volcanic rocks are dominantly basaltic andesite in composition, but range locally from basaltic komatiite to rhyolite, including samples plotting very close to shoshonite and trachyandesite fields (Kojan and Hickman, 1998; Williams, 1999). The formation is typically less than 600 m thick, but can be locally up to 1300 m thick (on MUCCAN; Williams, 1999). The Kylena Formation mostly overlies the Hardey Formation across a disconformity to angular unconformity, but locally lies unconformably on the Mount Roe Basalt (e.g. on COONGAN), or directly unconformably upon granite–greenstone basement rocks (e.g. on WARRIE). Local evidence suggests folding and faulting of underlying formations of the Fortescue Group prior to deposition of the Kylena Formation (Blake, 1993; Van Kranendonk, 2003b). The age of the Kylena Formation is 2741 ± 3 Ma, based on the age of an interflow bedded tuffaceous unit (Blake et al., 2004), which closely matches the age of dolerite dykes from the Sylvania Inlier interpreted to be feeder dykes to the Kylena Formation, dated at 2747 ± 4 Ma (Wingate, 1999).

The Kylena Formation is up to 750 m thick and was deposited after a period of folding and tilting of the older rock units, as seen for example in the southeastern part of the centrocline, approximately 2 km west of Warralong Creek and 1.5 km north of the southern edge of the map sheet area (e.g. MGA 775000E 7676900N).

At the base of the Kylena Formation on COONGAN is a thick and well exposed basaltic unit of pillow hyaloclastite breccia (AFOk-bbor [AFkbx]) in which whole pillows, or more commonly angular fragments of pillows, lie within a matrix of coarse to fine basaltic glass shards (Fig. 22a–c). A good example of this unit is found along the eastern edge of the centrocline, approximately 2.5 km west of Warralong Creek (MGA 775000E 7678000N). This unit outlines the base of the formation around the whole of the Marble Bar Sub-basin and locally has eroded down through the Hardey Formation to lie directly on the Mount Roe Basalt across an angular unconformity, for example along the eastern margin of the Pear Creek Centrocline, approximately 2.5 km west of Warralong Creek (MGA 775000E 7678800N).

Local pockets of basalt with large, beautifully preserved pillows and only minor interpillow hyaloclastite (AFOk-bbo [AFkbl]; Fig. 22d) locally form the base of the Kylena Formation (for example 3.4 km west of Warralong Creek, just within the southern edge of COONGAN; MGA 773800E 7676750N).

Overlying these basal rocks are thick flows of massive to vesicular basalt to basaltic andesite (AFOk-bb [AFkb]) that were erupted into a subaerial environment. These typically dark-brown-weathering rocks form metre-thick flow units and display vesicular to coarsely vesicular textures and local scoriaceous flowtops.

Sills of medium-grained dolerite (AFOk-od [AF(d)]) intrude the Hardey Formation and parts of the Kylena Formation. These sills have fine-grained chilled margins in Hardey Formation sandstones, which exhibit contact metamorphic effects including green epidote staining and a fused, glassy appearance (for example in the northeastern part of the centrocline, approximately 2 km east of Warralong Creek and 1.7 km south of the Marble Bar Road; MGA 772250E 7681400N). The cores of some thicker sills are coarse grained, and deuteric alteration of igneous plagioclase and pyroxenes is widespread.

Pear Creek Formation (AFOe-xsp-sb [AFp], AFOe-scp [AFpsc], AFOe-scm [AFpscb], AFOe-st [AFpst], AFOe-sb [AFpsxb], AFOe-sl [AFpsl], AFOe-sco [Afpscb])

Unconformably overlying the Kylena Formation is an approximately 1 km-thick succession of typically brown- to green-weathering, very well preserved clastic sedimentary rocks, including interbedded sandstone and conglomerate, and basaltic breccia, collectively named Pear Creek Formation (AFOe-xsp-sb [AFp]). These rocks can be subdivided into five lithologically distinct units, based on grain size, clast composition, and bounding unconformities (see Van Kranendonk, 2003b). Relationships along the northern side of the Pear Creek Centrocline indicate that there was a significant episode of faulting and tilting of the underlying Kylena Formation prior to deposition of the Pear Creek Formation (Van Kranendonk, 2003b). For this reason, the clastic rocks of the Pear Creek Formation have been ascribed formation status. However, as they differ in composition and depositional environment from rocks typical of the Tumbiana Formation, which elsewhere overlies the Kylena Formation, they have been given a new formation name. The Pear Creek Formation is equivalent to the Pear Creek Sequence of Blake (1993). Deformation continued during deposition of the Pear Creek Formation, in the form of growth faulting (Van Kranendonk, 2003b).

Forming much of the base of the Pear Creek Formation is a unit, up to 375-m thick, of fine-grained, thin-bedded, green-brown siltstone and minor sandstone (AFOe-sl [AFpsl]). Beds with rip-up clasts of mudstone are common (Fig. 23a), and there are also rare, 10 cm-thick beds of cobble conglomerate with well-developed cross bedding. Green sandstone in the upper part of this unit is typically homogeneous, with 10–30 cm-thick planar bedding, and is lithologically indistinguishable from sandstone of the overlying, thicker unit.

Sandstone with local pebble conglomerate (AFOe-st [AFpst]) forms a unit approximately 250 m thick that erodes down-section through almost the whole of the underlying siltstone unit (AFOe-sl [AFpsl]) to the underlying Kylena Formation along the southwestern side of the Pear Creek Centrocline (MGA 764600E 7678300N). The sandstone unit fines upwards from orange-weathering, medium-bedded, coarse-grained sandstone at the base, through brown-weathering, green-grey, coarse- to medium-grained turbiditic sandstone with thin pebbly beds and some trough cross bedding, to an upper unit of siltstone and mudstone with beds of rip-up clasts. Sandstone is also found in two small outcrops below the underlying siltstone unit in the southwestern corner of the centrocline (MGA 761200E 7678300N), within the core of the centrocline (MGA 767800E 7680000N), and also just to the east of the main centrocline, where it lies unconformably on basaltic lavas of the Kylena Formation on the east side of the Pear Creek Fault, within a small centrocline of its own (Fig. 23b; MGA 770500E 7679000N). This latter

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Figure 22. a) Whole pillow and b) fragmented pillow in basaltic hyaloclastite at the base of the Kylena Formation (both from MGA 763240E 7683450N); c) outcrop view of basaltic hyaloclastite pillow breccia at the base of the Kylena Formation (MGA 772290E 7681305N); d) outcrop view of shallow-dipping, undeformed pillow lavas at the base of the Kylena Formation in the Pear Creek Centrocline (AFOk-bbo [AFkbl]**; MGA 774140E 7676155N).**

occurrence is a shallow-dipping (approximately 5°) unit of orange-weathering, coarse-grained sandstone and pebble conglomerate.

Polymict boulder- to pebble-conglomerate and sandstone (AFOe-scp [AFpsc]) disconformably overlies the main, middle layer of sandstone within the Pear Creek Centrocline. The disconformity is well-exposed at approximately 12.2 km south of the Marble Bar Road and 5 km west of Pear Creek (MGA 766400E 7682000N). In places, the basal contact of this unit varies from knife-sharp to gradational over a distance of only a few metres. Across the northern side of the centrocline (MGA 765000E 7679750N), polymictic cobble- to pebble-conglomerate is up to 200 m thick and contains the same assortment of basaltic clasts as those in the monomictic basaltic conglomerate (AFOe-scm [AFpscb]) along strike to the southwest (see below), but also well-rounded clasts of basement-derived rocks, including dominantly black chert and white vein quartz, quartzite, foliated and gneissic granites, and felsic volcanic rocks (Fig. 24a,b). In the southwest, the lower part of the unit contains 95–98% of basalt clasts, with less than 5% clasts of chert and sandstone, whereas towards the top, the unit contains a

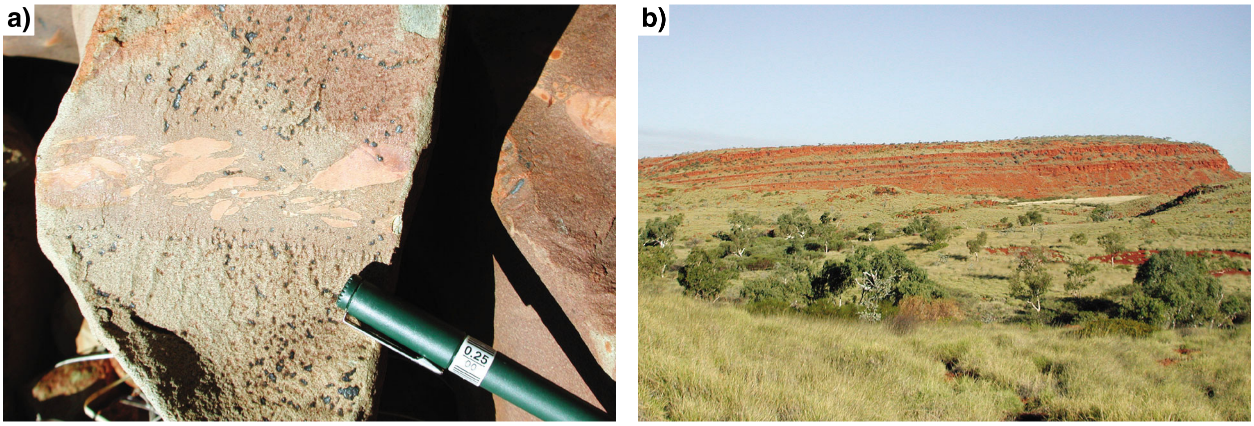

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Figure 23. a) Outcrop view of fine-grained sandstone with rip-up clasts of siltstone from the base of the Pear Creek Formation of the Fortescue Group (AFOe-sl [AFpsl]; MGA 768940E 7682656N); b) View, looking north, of shallow (5°) north-dipping sandstone and conglomerate of the Pear Creek Formation (AFOe-st [AFpst]) unconformably overlying slightly more steeply dipping (15°) basalt flows of the Kylena Formation (AFOk-bb [AFkb]) just east of the Pear Creek Fault (MGA 769240E 7679236N).

more even mixture of chert, quartzite, granitic, and basalt clasts. Clasts of basement rocks are more common to the northeast, where the unit has a sharp erosional contact with the underlying sandstone. A unit of pebbly sandstone conformably overlies the thick, lower conglomerate unit and separates it from a second, overlying unit of polymictic conglomerate. This upper unit of conglomerate is conformable on the underlying units across most of the centrocline, but this contact relationship changes along strike into a high-angle unconformity on the western and eastern limbs of the centrocline (MGA 765300E 7680000N and 770200E 7681300N).

Along strike to the south of the polymict conglomerate is a thick (≤280 m) unit of poorly bedded, oligomictic cobble to boulder breccia and conglomerate that contains angular to very well rounded clasts, up to 80 cm across, of solely basaltic composition in a fine- to medium-grained, quartz-bearing sandy matrix (Fig. 25; AFOe-sb [AFpsxb]). The basaltic clasts are undeformed and have a variety of textures including massive, doleritic, vesicular, and plagioclase-glomeroporphyritic; these basalt types are common in the underlying Mount Roe Basalt and Kylena Formation. The clasts show an increase in roundness with increasing size, with well rounded boulders and subrounded cobbles to pebbles. The unit is very coarse grained and massive at its thickest point in the southwest, and becomes finer grained and poorly bedded along strike to the north, on the western limb of the centrocline (MGA 765100E 7679600N), where it includes brown sandstone beds near the top of the unit. At this locality (MGA 765000E 7679750N), the basalt cobble conglomerate is interfingered with polymictic cobble- to pebble-conglomerate (AFOe-sco [AFpsc]).

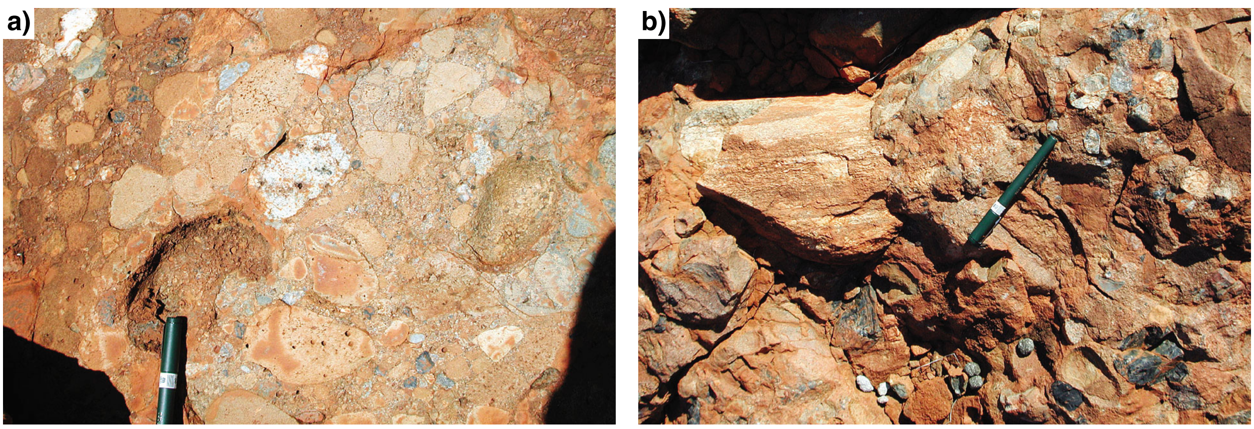

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Figure 24. a) Outcrop view of polymictic conglomerate of the Pear Creek Formation of the Fortescue Group (AFOe-scp [AFpsc]), with basaltic clasts, and clasts of granite and white quartz (MGA 768890E, 7681956N); b) outcrop view of polymictic conglomerate of the Pear Creek Formation (AFOe-scp [AFpsc]), with basalt clasts from the underlying Fortescue Group and boulders of granitic gneiss from the basement (MGA 769800E, 7680850N).

Figure 25. Outcrop view of coarse basaltic breccia/ conglomerate, consisting of a variety of basaltic lithologies in a fine sandstone matrix (AFOe-sb [AFpxsb]; MGA 766540E 7678156N).

Just east of the Pear Creek Fault (MGA 767900E 7678900N and 768650E 7679350N) and in one small outcrop north of the fault (MGA 769900E 7680800N), is a unit of coarse monomictic conglomerate (AFOe-scm [AFpscb]) with rounded cobbles of texturally variable Fortescue Group basalt in a sandy matrix, with scattered cobbles of basement rocks.

Marble Bar Sub-basin events

The Marble Bar Sub-basin is a broadly synclinal structural and erosional remnant of a once larger basin. It consists of northern (Pear Creek) and southern (Shady Camp) centroclines that are defined by stratigraphically higher formations of the Fortescue Group, for which paleocurrent data indicate deposition within the sub-basin area (Blake, 1993). These centroclines are separated by faulted and folded components of the lower formations of the Fortescue Group. Fault block topography was significant in the depositional history of the group in the Marble Bar Sub-basin and deformation proceeded throughout accumulation of the group in this sub-basin, as evidenced by the presence of eight unconformities within the group and by syndepositional faults (Van Kranendonk, 2003b).

Nine sets of structures have been identified in the Fortescue Group of the Pear Creek Centrocline (D_{FOM1} through D_{FOM9}; Table 2). D_{FOM1} resulted in tilting of the Bellary Formation prior to deposition of the Mount Roe Basalt, as evidenced in the angular unconformity preserved along the northern margin of the Marble Bar Sub-basin, 4 km south of the Marble Bar Road (MGA 766000E 7690250N; Fig. 19). Structure sets D_{FOM2}, D_{FOM3} and D_{FOM9} are restricted to the area south of the Pear Creek Fault, whereas sets D_{FOM4}–D_{FOM8} are restricted to the north of this fault (Fig. 26). The deformation style changed from southeasterly shortening during D_{FOM2} and D_{FOM3}, to easterly extension during D_{FOM4}, to northwesterly extension during D_{FOM5}–D_{FOM8}.

Previous work in the Fortescue Basin has shown that the Mount Roe Basalt and underlying sedimentary rocks of the Bellary Formation were deposited on a relict topography in the basement that was caused by topographically high granitic domes, during west-northwesterly directed extension (Blake, 1993; Thorne and Trendall, 2001). D_{FOM2} structures in the Pear Creek Centrocline, as well as in the southwestern part of the Marble Bar Sub-basin (Van Kranendonk, 2000), are consistent with a significant amount of shortening between reactivated granitic domes after deposition of the Mount Roe Basalt, but before deposition of the Hardey Formation. Data from the two areas indicate different orientations of shortening at this time (northwesterly–southeasterly in the Pear Creek Centrocline vs. north–south in the southwestern part of the Marble Bar Sub-Basin), similar to the orientation of structures in the underlying greenstones. Whereas this style of deformation is inconsistent with regional orogenesis due to plate interactions, it is consistent with folding of the Fortescue Group as a result of bed-length shortening in synclines between reactivated granitic domes during diapirism (Dixon and Summers, 1983; Hickman, 1984; Van Kranendonk et al., 2002, 2004; Van Kranendonk, 2003b).

Uplift and erosion of granitic rocks and flanking greenstones provided detritus for the Hardey Formation that was deposited in shallow basins between granitic domes. Deposition was coeval with continued uplift, which caused folding of these clastic rocks on D_{FOM3} fold axes that are subparallel to D_{FOM2} folds.

This period of uplift and erosion was followed by deposition of the Kylena Formation and a period of extension that affected the Fortescue Group throughout the Fortescue Basin (Thorne and Trendall, 2001). In the Pear Creek Centrocline, this extension was manifest as D_{FOM4} faults.

Deformation changed to northwest-side-down normal faulting throughout deposition of the Pear Creek Formation (D_{FOM5}–D_{FOM8}). A decrease in clast size from southeast to northwest in the basalt cobble conglomerate of Unit 3 on the southern side of the centrocline provides evidence for a structural control on sedimentation, indicating a source from the uplifted block on the southern side of the Pear Creek Fault. Additionally, the change from basalt cobble conglomerate to polymictic conglomerate to the north and east within Unit 3 is consistent with the structural history outlined above, which indicates the Pear Creek Centrocline formed through southeast-side down tilting of the northern block across the Pear Creek Fault and associated structures, resulting in uplifted basement rocks in the northwest and an uplifted area of the Mount Roe Basalt and Kylena Formation in the footwall to the southeast.

Syndepositional deformation: Bellary Formation

It appears that at least the lower part of the Bellary Formation was deposited during tectonic instability, as evidenced by silicified coarse angular breccias in the lower part of the formation (Fig. 20).

Table 2. Relationship between structures and lithostratigraphic units of the Fortescue Group in the Pear Creek Centrocline

Formation	Member	Basal contact	Structure set	Structures
			9	Gently tilted strata and younger east-side-down faults
Pear Creek	Unit 5	Unconformity on Kylena Formation		
			8	Tilted strata and NW-side-down faults
	Unit 4	Disconformity to angular unconformity on Unit 3 and (locally) Mount Roe Basalt		
			7	Tilted strata and NW-side-down faults
	Unit 3	Conformity to low-angle unconformity on Unit 2		
			6	Tilted strata and NW-side-down faults
	Unit 2	Disconformity to low-angle unconformity on Unit 1		
			5	Tilted strata and NW-side-down faults
	Unit 1	Disconformity to angular unconformity on Kylena Formation		
			4	Tilted strata and extensional faults
Kylena		Conformity to angular unconformity on Hardey Formation and Mount Roe Basalt		
			3	NE–SW trending folds, and younger N-side-down faults
Hardey		Disconformity to angular unconformity on Mount Roe Basalt		
			2	Tilting, NE–SW trending folds, W- to NW-side-down faults
Mount Roe Basalt		Disconformity to angular unconformity on basement rocks and Bellary Formation		
			1	Tilting, gentle folding of Bellary Formation
Bellary		Angular unconformity with underlying rocks		

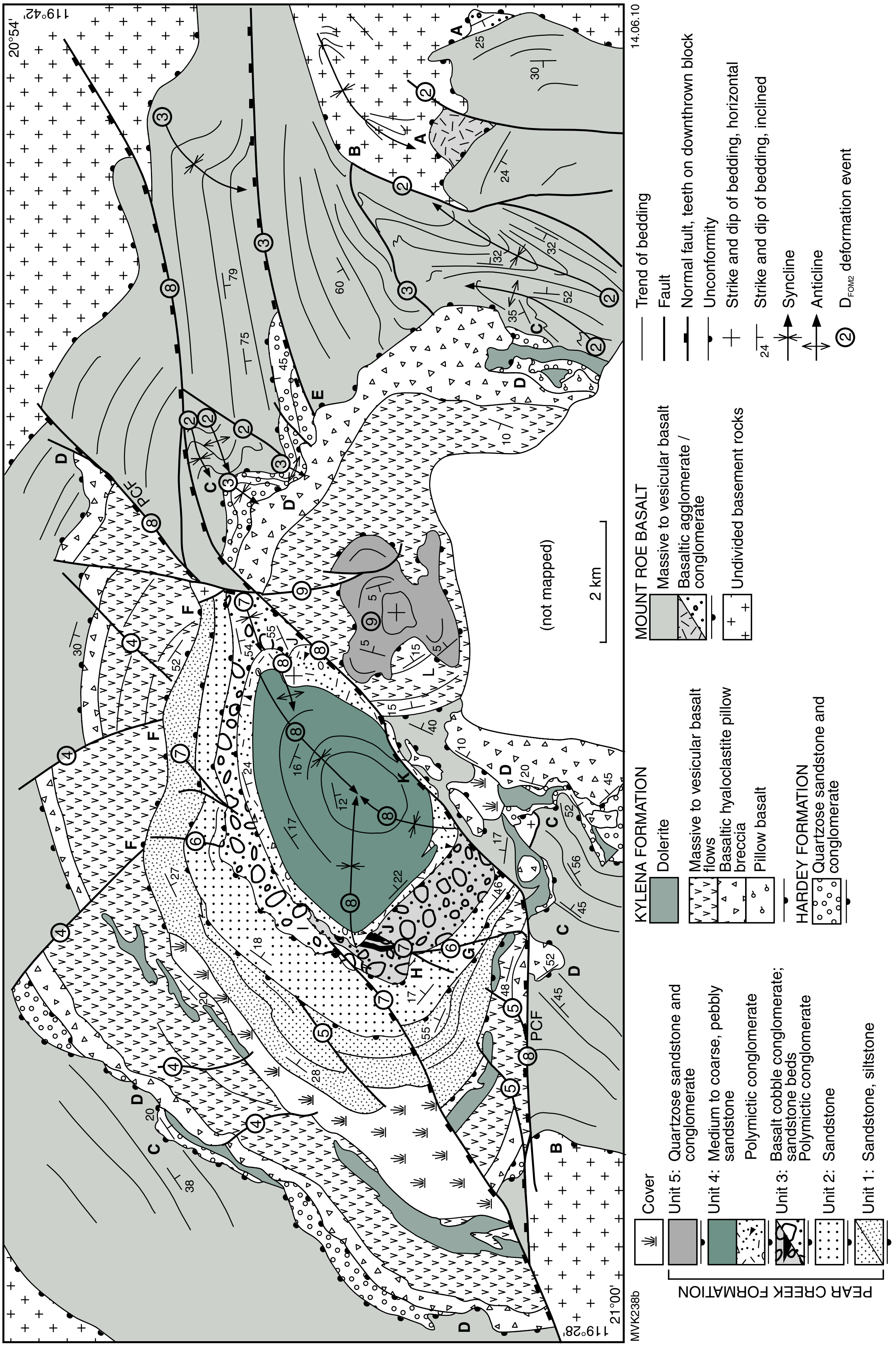

Figure 26. Geological map of the Pear Creek Centrocline. Circled numbers refer to structure sets described in text and Table 2. PCF = Pear Creek Fault. Modified from Van Kranendonk (2003b).

D_{FOM1}: *tilting of the Bellary Formation*

Tilting and open folding of Bellary Formation sedimentary rocks prior to deposition of the Mount Roe Basalt was noted on CARLINDIE (Van Kranendonk, 2004a). On COONGAN, however, rocks of the Bellary Formation and Mount Roe Basalt are broadly conformable, except at one locality where a pocket of sedimentary rocks underlies the faulted lower contact of the Mount Roe Basalt along the northern margin of the sub-basin (MGA 779850E 7677200N; Fig. 19).

D_{FOM2}: *tilting, faulting, and tight folding of the Mount Roe Basalt*

Map relationships on COONGAN show that the Mount Roe Basalt was tilted, tightly folded, and faulted prior to deposition of the unconformably overlying Hardey Formation. This is most dramatically evidenced in the southeastern part of the Pear Creek Centrocline (MGA 775000E 7676350N), where bedding of the Mount Roe Basalt has been tightly folded into a north-northeast-plunging syncline–anticline pair, with moderately dipping fold limbs (35°) that are unconformably overlain by more gently dipping, gently folded rocks of the Hardey Formation. These folds have axial traces parallel to the margin of the Pear Creek Centrocline and plunge moderately to the north-northeast. Rocks of the Mount Roe Basalt on the northeastern margin of the Pear Creek Centrocline (MGA 773000E 76815000N) display similar evidence for D_{FOM2} folding, but here a southwest-plunging anticlinal hinge in the Mount Roe Basalt is unconformably overlain by the Hardey Formation that is folded into a gentle D_{FOM3} syncline on an axis parallel to, and along strike of, the D_{FOM2} anticline in the underlying rocks. Parallel D_{FOM2} folds are present to the east (MGA 778500E 7682300N).

Elsewhere, the Mount Roe Basalt was gently tilted prior to deposition of the Hardey Formation, as evidenced by a downcutting, low-angle, angular unconformity at the base of the overlying unit on the northwestern limb of the centrocline (e.g. from MGA 761300E 7681600N to 764300E 7685300N). The southern margin of the centrocline shows a high angle unconformity between north-striking, moderately east-dipping (45°) beds of the Mount Roe Basalt, and east–west striking, moderately north-dipping beds (56°) of the Hardey Formation (MGA 765550E 7676700N).

Folding of the Mount Roe Basalt was accompanied by normal faulting, prior to deposition of the Hardey Formation or Kylena Formation. Normal faults are well developed along the eastern margin of the Pear Creek Centrocline, on the eastern limb of the tight folds in the Mount Roe Basalt (e.g. MGA 777300E 7676700N).

D_{FOM3}: *folding and tilting of the Hardey Formation, and faulting*

Evidence for folding and faulting after deposition of the Hardey Formation, but prior to deposition of the unconformably overlying Kylena Formation, is best seen in the northeastern part of the Pear Creek Centrocline (between MGA 771500E 7681750N and 775400E 7680500N). At this locality, the Hardey Formation was deformed into a series of gentle to open folds, and faulted, prior to being unconformably overlain by the basal pillow breccia unit of the Kylena Basalt. Folds plunge southeast, towards the core of the centrocline and faults are northeast- to east-striking, steeply dipping structures with north- or northwest-side-down displacement. Another such west-side-down fault through the northern margin of the centrocline (MGA 766800E 7686300N) shows greater offset of the Mount Roe Basalt than the unconformably overlying Kylena Formation, indicating activity after deposition of the Mount Roe Basalt, and reactivation after deposition of the Kylena Formation.

D_{FOM3} folding of the Hardey Formation was followed by the development of two east-northeasterly trending, north-side-down normal faults (D_{FOM3}) in the eastern part of the map area (labelled 2 on Fig. 26). Basal agglomerate of the Kylena Formation unconformably overlies D_{FOM3} structures (points D on Fig. 26), and is unaffected by them. The geometry of D_{FOM2} and D_{FG3} folds indicate approximately west-northwest–east-southeast shortening across the centrocline, whereas late D_{FOM3} faults indicate the onset of north- to northwest-side-down normal faulting.

D_{FOM4}: *folding*

The Kylena Formation was deposited under stable conditions, with texturally distinct basalt flows lying conformably on one another throughout the formation. Following deposition, the formation was affected by D_{FOM4} extensional faults across the northern part of the map area (Fig. 26). The geometry of the faults suggests approximately east-west extension across this part of the centrocline.

D_{FOM5}: *faulting*

Unit 1 of the Pear Creek Formation has a well-exposed basal contact across the northern part of the centrocline, where it unconformably overlies the Kylena Formation and D_{FOM4} faults (points F on Fig. 26). Unit 1 is affected by northeast-trending D_{FG5} faults (labelled 5 on Fig. 26) that are the oldest of a succession of faults with this same trend (D_{FOM5}–D_{FOM8}) that migrated to the southeast throughout the deposition of the Pear Creek Formation (Fig. 26, Table 2). D_{FG5} faults extend either partway up through Unit 1 (southwestern part of COONGAN), or through the entire unit to the base of Unit 2 (west-central part of COONGAN), which is unaffected by these faults.

D_{FOM6}–D_{FOM8}: *faulting*

Unit 2 is affected by D_{FOM6} faults and these are overlain by Unit 3, which is affected by D_{FOM7} faults. Unit 4 is affected only by the Pear Creek Fault (D_{FOM8}), which was probably active throughout deposition of the Pear Creek Formation. This unit was also affected by gentle downwarping in the core of the centrocline.

D_{FOM9}: *gentle downwarping*

Unit 5, located south of the Pear Creek Fault, dips radially inward at 5° (D_{FOM8} tilting) and unconformably overlies more steeply dipping bedding in the Kylena Formation (Fig. 25). The shallowly dipping bedding of Unit 5 is cut by north–south striking faults (D_{FOM9}) with east-side-down displacement. The structure of unit 5 defines a second, smaller centrocline, located to the southeast of the Pear Creek Fault, which probably formed after the Pear Creek Centrocline as suggested by the southerly shift in deformation throughout D_{FOM5}–D_{FOM8}.

Proterozoic units

Bridget Suite (ⱣBG-gnph [ⱣgBph, AFhbfr])

The name Bridget Suite was first published in a report on Proterozoic granites in Australia (Budd et al., 2002). The name was adapted from the formally defined Proterozoic Bridget Adamellite (Hickman, 1978), a discordant, rectangular-shaped stock lying just to the northeast of the Bridget Creek – Nullagine River confluence on NULLAGINE (Bagas, 2005). This body is the largest of a series of hornblende(–clinopyroxene)-bearing stocks and bosses, which have a compositional range from monzogranite to monzodiorite. These intrusive bodies are comagmatic with locally numerous porphyritic trachyandesite, trachyte, and lamprophyre dykes. The Bridget Suite intrudes the EPT, Mosquito Creek Basin (Bagas, 2005), and Mount Bruce Supergroup. Recent mapping has confirmed that Bridget Suite intrusions occupy a north-northwest-trending, roughly lenticular belt across the east Pilbara. The belt extends over 245 km, from 16 km west of Balfour Downs Homestead on BALFOUR DOWNS (Williams, 1989) to just northwest of Yarrie Village (Yarrie Iron Mine) on MUCCAN (Williams, 1999) in the north. This belt reaches a maximum width of about 48 km near the southern margin of MUCCAN (Noldart and Wyatt, 1962, p. 88; Hickman, 1983, p. 134; Rock and Barley, 1988; Budd et al., 2002).

Regionally, the Paleoproterozoic Bridget Suite trends roughly parallel to the eastern tectonic margin of the Pilbara Craton, which lies about 90 km to the east. The Pilbara Craton is faulted against the Paleoproterozoic to Neoproterozoic Paterson Orogen. The Bridget Suite may represent a far-field effect of the major continent–continent collision that took place at the eastern edge of the Pilbara Craton during the Yapungku Orogeny (Bagas, 2005).

A number of attempts have been made to date the Bridget Suite (Blake and McNaughton, 1984; Collins et al., 1988; Nelson, 2004). The first realistic date was obtained from the Parnell Quartz Monzonite near Granite Hill Well on NULLAGINE (Bagas, 2005). A hornblende–biotite quartz monzodiorite from this intrusion yielded a SHRIMP U–Pb zircon date of 1803 ± 19 Ma (Nelson, 2002c). Three further samples of the Bridget Suite were collected on MOUNT EDGAR for dating. These were from a hornblende–quartz monzonite stock, 5.1 km north-northwest of Pelican Pool on the Nullagine River, a hornblende–clinopyroxene–quartz micromonzonite stock (Mount Edgar), and a porphyritic hornblende–plagioclase trachyandesite stock (Chimingadgi Hill).

The Pelican Pool locality has a SHRIMP U–Pb zircon date of 2764 ± 6 Ma (Nelson, 2002d). However, the spread of analytical data along the concordia curve indicated a high ratio of xenocrystic to magmatic zircons in the sample. This observation, together with the age of the host Kylena Formation (c. 2749–2735 Ma) suggest that the U–Pb zircon date of c. 2764 Ma (Bamboo Creek Member age) must also be xenocrystic. Similarly the Chimingadgi Hill intrusion gave a SHRIMP U–Pb zircon date of 3315 ± 5 Ma, which, in the light of previous investigations, is also interpreted to be a xenocrystic population (Bodorkos et al., 2006b). In an attempt to gain a clearer picture of the age of the intrusions, the two samples were subjected to K–Ar and $^{40}Ar/^{39}Ar$ dating. Hornblende from the Pelican Pool intrusion has a K–Ar age of 1310 ± 27 Ma (Nelson, 2002e) and a $^{40}Ar/^{39}Ar$ date of 1760 ± 19 Ma (Nelson, 2005a). Hornblende from the Mount Edgar intrusion has a K–Ar age of 1674 ± 33 Ma (Nelson, 2002f) and a $^{40}Ar/^{39}Ar$ date of 1703 ± 3 Ma (Nelson, 2005e). The $^{40}Ar/^{39}Ar$ dates are interpreted to be the minimum age of crystallization for the igneous hornblende.

Rocks on COONGAN that are interpreted to belong to the Bridget Suite include two, metre-wide dykes of quartz phenocryst-bearing, fine-grained granitic rocks (rhyolite dykes) that have conspicuous igneous flow-banding (ⱣBG-gnph [AFhbfr]) in the northern part of the sheet area, approximately 5 km east-northeast of Ettrick Homestead (MGA 784400E 7730000N). In outcrop, these dykes are pale grey to 'green apple' green and form positive weathering ridges. Quartz phenocrysts up to 2 mm in diameter are distributed randomly throughout the rock, which contains igneous flow folds at 5–25 cm scale, defined by alternating dark and light layers between 4–20 mm wide. Previously, these dykes were thought to be associated with emplacement of the Neoarchean Bamboo Creek Member of the Hardey Formation (Fortescue Group), but the geochronological data presented above suggests this is unlikely and a Proterozoic age is ascribed to these rocks.

Mundine Well Dolerite Suite (ⱣMW-od [Ⱡdw])

Three long, east-northeast-striking dolerite dykes interpreted from aeromagnetic data in the northwestern part of COONGAN are assigned to the Mundine Well Dolerite Suite (ⱣMW-od [Ⱡdw]; Hickman and Lipple, 1978) based on their strike orientation and continuity along strike from outcropping dykes of this swarm further to the west and southwest. Tyler (1990) stated that this suite extends across the Pilbara Craton, is younger than the Bangemall Group in the Bangemall Basin, and thus likely to be younger than Mesoproterozoic in age. A date of 755 ± 3 Ma was obtained for two dykes of the Mundine Well Dolerite Suite from the Bangemall Basin, and a Pb-loss discordia estimate based on discordant inherited zircons from a dated sample from the adjacent CARLINDIE sheet indicates a similar age of emplacement in the northern part of the Pilbara Craton (sample B20 in Wingate and Giddings, 2000).

Round Hummock Dolerite Suite (ⱣRH-od [Ⱡdo])

Linear, mafic dykes of the Round Hummock Dolerite Suite (ⱣRH-od [Ⱡdo]; cf. Round Hummock Suite, Hickman,

1983) are unmetamorphosed and postdate folding of the Fortescue Group. They trend northwest to north-northwest, are up to 10 m wide, and are associated with copper mineralization on YILGALONG to the east (Williams and Bagas, 2007). The Round Hummock Dolerite Suite appears to crosscut the north-northeast-trending Mundine Well dyke swarm in the Yule Granitic Complex to the west (Van Kranendonk and Pawley, 2002), which has a SHRIMP U–Pb zircon date of 755 ± 3 Ma (Wingate and Giddings, 2000).

A prominent dolerite dyke of the Round Hummock Dolerite Suite (ƎRH-od [Ǝdo]) is interpreted from aeromagnetic data to cut across the northern part of COONGAN, based on the straight, northwest trend of the linear feature.

Unassigned units

Dykes and hydrothermal veins (od [d], xa-o [ub], ax [ux], zq [q])

Unassigned dolerite and gabbro dykes (od [d]) cut across the Muccan Granitic Complex on Coongan, and may be of various ages. These include outcropping dykes on either side of the Black Range Dyke in the southern part of the complex that change in strike from northwest-striking on the western side of the dyke, to east-northeast on the eastern side of the dyke.

An unassigned, fine-grained, ultramafic to mafic dyke (xa-o [ub]) occupies a linear fracture adjacent to the Pear Creek Fault through the central-eastern part of the Muccan Granitic Complex on COONGAN. The age of this dyke is unknown, and although it is roughly parallel to dykes of the Mundine Well Dolerite Suite, it is of different appearance, being fine-grained and dark green to almost black.

A dense swarm of pyroxenite dykes of uncertain age (ax [ux]) cut through the Muccan Granitic Complex in the southeastern part of COONGAN. These northwest- striking dykes are typically narrow (<2 m), fine-grained, and very dark green to almost black in weathered outcrops. One member of this swarm cuts the Black Range Dyke, approximately 5.2 km east-southeast of Eginbah Well (MGA 804000E 7700280N), indicating an age younger than c. 2772 Ma. It may be that these dykes are part of the Round Hummock Dolerite Suite, but this is unknown.

Large, white, quartz veins (zq [q]) on COONGAN occupy faults and or adjacent lithologies in, and east of, the Warralong greenstone belt (e.g. MGA 767400E 7701250N) and along the north-central part of the Pear Creek Fault (e.g. MGA 794400E 7702000N). Whereas some of these veins are most likely of Mesoarchean age and related to late compressional deformation during the c. 2.93 Ga North Pilbara Orogeny, others are parallel to both the Black Range Dyke (e.g. MGA 801550E 7696000N) and younger dyke swarms (e.g. Round Hummock Dolerite Suite; ƎRH-od [Ǝdo]; MGA 788500E 7730000N) and thus are most likely to be Neoarchean and/or Neoproterozoic in age.

Cenozoic deposits

Cenozoic deposits are widespread on Coongan, as cover on areas of granitic bedrock of the Muccan Granitic Complex. Well exposed areas of greenstones are transected by alluvial channels. Older deposits include consolidated alluvial, colluvial, and residual material. More recent unconsolidated Quaternary deposits include alluvial, colluvial, and eluvial material.

Alluvial deposits (*A2* [Cza, Czaa], *A2dk* [Czag], *A3ctc*$_i$ [Czaz])

Consolidated clay, silt, and sand deposits that are dissected by present-day drainage (*A2* [Cza]) occupy small areas along the western edge of the sheet area. These consist of medium-grained, dominantly quartz–feldspar and chert sand with local clay cement, dissected by Quaternary drainage and overlain by Quaternary overbank deposits (*A1f* [Qao]; see below). Older deposits of lithified, ferruginous alluvium, also designated *A2* ([Czaa]), consist of consolidated alluvial sand, silt, and gravel with local carbonate and clay cement that are dissected by present-day drainage.

Consolidated deposits overlying granitic rocks locally consist of alluvial gravel, sand, and silt with local carbonate cement, dissected by present-day drainage (*A2dk* [Czag]).

Cenozoic, lithified, alluvial fan deposits (*A3ctc*$_i$ [Czaz]) are preserved at the outflow point of gullies cut into several places along the flank of the north-facing Gorge Range (Fig. 27a; e.g. from MGA 762900E 7693400N to 769500E 7691700N). These silica- and limonite-cemented alluvial channel deposits are derived from proximal mass-wasting of chert and banded iron-formation and dissected by present-day drainage. These deposits consist predominantly of coarse (typically 15–20 cm), to very coarse (up to 50 cm), angular clasts of quartz arenite (AGCf-stq [AGcstq]) derived from the Gorge Creek Group, in a creamy-white matrix of cemented quartz sand and clay (Fig. 27b); some deposits contain clasts of banded iron-formation (AGCe-ca [AGpci]). No bedding is apparent in these deposits.

Colluvial deposits (*C2* [Czc])

Partly consolidated, dissected colluvium (*C2* [Czc]) on COONGAN is derived from adjacent rock outcrops through erosion of topographically high greenstones. Composed of colluvial sand, silt, and gravel in proximal outwash fans, as well as local scree and talus, the dissected colluvium is most widely distributed on low slopes washed off greenstone belts in the southern part of COONGAN.

Residual deposits (*R3r*$_f$[Czrf], *R2gp*$_g$ [Czrg], *R2k* [Czrk], *R2r*$_z$ [Czrz])

Four small outcrops of consolidated, ferruginous duricrust (*R3r*$_f$ [Czrf]) outcrop on the west bank of Pear Creek , approximately 6 km south of the Marble bar Road

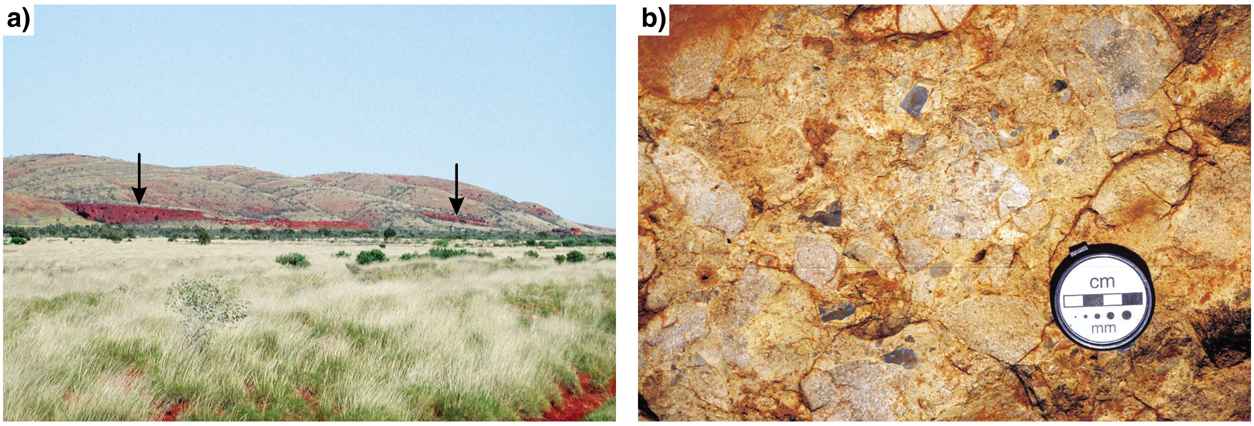

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Figure 27. a) View west-southwest from the Marble Bar Road, of two lithified alluvial fans (arrows: $A3ctc_i$ [Czaz]) shedding to the north off the Gorge Range. (Photograph taken from approximately MGA 771400E 7693350N); b) close-up outcrop view of consolidated alluvial fan material, composed of angular boulders and pebbles of quartzite and black chert in a fine-grained sand and clay matrix.

(MGA 772300E 7686800N). These form a linear chain of flat-topped mesas above the surrounding granite-derived alluvial–colluvial plains. This consolidated to partly consolidated unit consists of ferruginous duricrust and ferruginous colluvium, including local ferruginous alluvium. It is related to the Hamersley Surface and dissected by present-day drainage. Larger outcrops of this regolith unit include some pisolitic laterite and are developed on banded iron-formation of the Gorge Creek Group (AGCe-ca [AGpci]), approximately 3.5 km south of the Marble Bar Road and 3.5 km west of Pear Creek (MGA 767500E 7690700N).

Variably consolidated eluvial and colluvial sand, gravel, and silt overlies, and is derived from, granitic rock and dissected by present-day drainage ($R2gp_g$ [Czrg]).

Residual calcrete (*R2k* [Czrk]) overlies, and is derived from, altered carbonate-rich ultramafic rocks and granitic rocks over large areas bordering rivers or creeks in the southern half of COONGAN (e.g. MGA 773300E 7685900N). The calcrete formed as sheets, encrustations, and joint-fills, and is either massive or nodular, white, fine-grained calcium carbonate in irregular deposits up to probably a few metres thick and variably silicified.

Two small outcrops of grey silcrete ($R2r_z$ [Czrz]) form low mesas in the northeast part of COONGAN (MGA 792500E 7617000N) and the tops of hills of quartz-rich sandstone of the Gorge Creek Group (AGCf-stq [AGcstq]) in the southwestern part of the map sheet area (MGA 768500E 7692100N). These rocks are isolated remnants of a once much more widespread unit in this area (Williams, 1999) and on COONGAN comprise angular quartz grains set in a siliceous cement.

Quaternary units

Quaternary deposits are widespread across the northern part of the map area, resulting from extensive alluvial deposition in stream channels, overbank deposits, and broad outwash fans. Minor eolian deposits in the northeastern part of the sheet area represent the far western limit of the Little Sandy Desert.

Alluvial deposits (*A1c* [Qaa], *A1b* [Qaas], *A1f* [Qao], $A1fc_b$ [Qaob], *A1i* [Qaoc])

There are a wide range of alluvial deposits in the creek and river system on COONGAN. The major drainage channels (De Grey, Coongan and Talga Rivers, and Pear Creek) are occupied by unconsolidated sand, silt, and gravel (and minor clay; *A1b* [Qaas]) in the beds of major creeks that are reshaped every year by strong flow during cyclones.

The surface of the major channels is incised below the top of adjacent floodplains and overbank deposits of alluvial sand, silt, and minor clay. Gravel deposits locally occur adjacent to the main drainage channels (*A1f* [Qao]).

Large areas of mixed floodplain deposits consist of sand, silt, and clay adjacent to main drainage channels, with numerous small claypans (*A1i* [Qaoc]).

Larger areas of overbank deposits on floodplains contain light reddish brown to grey or white sand, silt and clay, with local gilgai surface in areas of expansive clay ($A1fc_b$ [Qaob]).

Unconsolidated alluvial sand, silt, gravel, and minor clay (*A1c* [Qaa]) occupy small to medium-size creeks and rivers, and smaller channels in flood plains. This also includes subordinate amounts of overbank deposits *A1f* [Qao]) and sheetwash sand and gravel (*W1* [Qw]; see below) in small drainage systems. Minor drainage channels commonly have a clay surface although some have a scattered quartz-pebble or rock-fragment veneer.

Sheetwash deposits (*W1* [Qw], $W1gp_g$ [Qwg], *W1q* [Qwq], $W1c_b$ [Qwb])

Low-gradient sheetwash deposits occupy large areas of COONGAN, representing the northward transport of detritus from greenstone belts in the south towards the Indian

Ocean as the result of annual flooding associated with seasonal cyclonic rains.

Deposits of silt, sand and pebbles in distal sheetwash fans with no defined drainage and mixed protolith (*W1* [Qw]) are designated separately from sheetwash deposits of quartzofeldspathic sand and quartz pebbles in fans ($W1gp_g$ [Qwg]) that overlie and are derived from mass wasting of large areas of granitic rock on COONGAN.

Low-gradient sheetwash deposits of gravel, sand, and silt dominated by white quartz-rich debris (*W1q* [Qwq]) cover large areas north of the Doolena Gap greenstone belt, on either side of the Talga and Coongan Rivers. The quartz is derived from abundant quartz veins in sheared greenstones, particularly sheared ultramafic rocks in the mixed zone of granite and greenstones.

A local area of black soil (clay and silt), which is characterized by a gilgai (crabhole) surface with half-metre-deep holes ($W1c_b$ [Qwb]), is locally present just north of the Gorge Range, north of the Marble Bar Road, in the western part of COONGAN (MGA 766500E 7696300N). This area is formed by annual flooding of Pear Creek and Gorge Creek and represents fine alluvial material that drains to the west.

Colluvial deposits (*C1* [Qc], *C1q* [Qcq])

Recent colluvium consisting of sand, silt, and gravel (*C1* [Qc]) forms outwash fans, scree, and talus, and is common in hilly areas and on the granitic-complex land surface.

A specific colluvial unit adjacent to vein quartz (*C1q* [Qcq]) consists of colluvial sand with a veneer of white quartz sand and pebbles on talus aprons around quartz ridges (*zq* [*q*]).

Residual deposits ($R1gp_g$ [Qrg])

Medium- to coarse-grained, residual quartzofeldspathic sand with scattered quartz pebbles and granitic rock fragments ($R1gp_g$ [Qrg]) overlies and/or is adjacent to, and is derived from, the main granitic exposures. Although the unit is mainly residual, there is some reworking of the finer components by water and wind action.

Eolian deposits (*E1* [Qs], Sgp_g [Qsg])

Fine- to medium-grained, red to bright orange eolian sand (*E1* [Qs]) forms undulating sheets along the northeastern edge of the map, representing the furthest western limit of the Little Sandy Desert. The variable grain size and coarser grained components of these sands suggests that they constitute a mixture of eolian and eluvial sand, including some locally derived material from dolerite dykes.

Sand derived solely from granitic rock (Sgp_g [Qsg]) in the same area consists of bright orange, mixed eolian and eluvial sand in sheets overlying and derived from granitic rocks.

Mineralization

Precious metals

Epithermal gold in the Warralong greenstone belt (WAMIN point 7441, Doms Hill; MGA 760500E 7703750N) contains an inferred resource of 15 000 t at 3 g/t Au based on a drill intersection of 18 m at 3.07 g/t Au (data from Atlas Gold Ltd. website <http://www.atlasgold.com.au/projects-farrel.html>). Mineralization is in a discordant hydraulic breccia zone between cherts and/or tuffaceous metasedimentary rocks, and sheared mafic schists. The mineralized zone contains vein quartz and sandstone fragments in a silicic, hematitic matrix with abundant vein quartz and pyrite. Drill intersections at the nearby Myrnas Hill prospect (MGA 765000E 7698100N) returned 3 m at 1.15 g/t Au and 1 m at 2.38 g/t Au from quartz veins intruding along faults in the North Star Basalt. Values up to 1.2% Ni and 2.0% Cu were recovered from strongly altered ultramafic rocks in the nearby vicinity.

The Murphy Well (Ag, Cu) prospect, approximately 5 km east-northeast of Talga Peak in the South Muccan Shear Zone (WAMIN point 6579; MGA 810897E 7685071N), contains gossan in regolith developed over mafic volcanic rocks, from which three samples at 50 m intervals contained an average of 56 ppm silver. The highest assay was 210 ppm Ag, and a nearby drillhole intersected a 2 m-thick anomalous zone with a maximum of 1750 ppm Cu. A gossan sample from the adjacent Telfer Road (Au) prospect (WAMIN point 2910; MGA 810482E 7685261N) contained 60 ppm Ag and 0.08 ppm Au, and 56 ppm Cu, in a 5 m-thick silica-rich unit parallel to bedding. The Talga King (Au) prospect at the Box Soak Razorback Ridge (WAMIN point 2904; MGA 808613E 7680707N) is in a quartz vein parallel to bedding, with anomalous Au (10.4 ppm). Other anomalous gold values have been reported from a gossanous quartz vein with malachite staining at TR 8704H, located in the Marble Bar greenstone belt east of the Talga River and south of Eight Mile Creek (WAMIN point 2903; MGA 801121E 7680348N), which also carries anomalous Cu, Pb, and Zn.

A series of gold prospects in the McPhee Formation in the Marble Bar greenstone belt includes some that are currently being exploited through alluvial mining. The Little Las Vegas to the east of the Talga River (WAMIN point 2902; MGA 800696E 7677447N) has quite low reported values of anomalous gold. The main group of six prospects, however, are located just west of the Talga River, near the southern boundary of the sheet area.

Steel industry metals

Disaggregated pods of massive chromite in serpentinized peridotite in the Doolena Gap greenstone belt (e.g. WAMIN point 7647, Talga at MGA 792300E 7685000N; WAMIN point 17018, Doolena Pool NW at 788250E 7686150N) originally formed seams and layers in the peridotite host rock. The host rocks represent either intrusive sills or the lower cumulate parts of thick volcanic flows, but the deformation state is typically too high in this region to discriminate between these two options, and mineral compositional work has not been carried out.

Thin, discontinuous chromite lenses in metaperidotite are also present on the west bank of Pear Creek, in the Doolena Gap greenstone belt (Baxter, 1978; WAMIN points 4981, Pear Creek 1 and 6033, Pear Creek 2; MGA 771100E 7688250N). The chromite in this area has historically been interpreted as hosted by intrusive ultramafic rocks emplaced along a fault zone (Baxter, 1978), but the presence of olivine spinifex textures in nearby metakomatiites of the Euro Basalt (AKEe-uk [AWeuk]; MGA 773300E 7685900N) suggest that some of the peridotitic host rocks may be cumulate zones in thick volcanic flows.

The Farrel Well Cu–Ni occurrence in the southeastern part of the Warralong greenstone belt, approximately 2 km north of the Marble Bar Road (WAMIN point 7480; MGA 763600E 7696450N), is a malachite stained, limonitic, ultramafic (komatiitic or komatiitic ?basaltic) tuff bed within pyroxene spinifex-textured, pillowed, metakomatiitic basalt of the Mount Ada Basalt. This prospect contains up to 1.46% Ni and 1.64% Cu in drill chips.

Specialty metals

Alluvial Sn, W, and Ta have been recorded in regolith cover on COONGAN. Alluvial Ta at Crawford Bore, in the southeastern part of the Warralong greenstone belt, approximately 1 km north of the Marble Bar Road (WAMIN point 7455; MGA 763000E 7695450N), is estimated to hold an inferred reserve of 19 million tons at 34.5 Ta_2O_5 per ton, based on costeaning. Alluvial Sn is also present at Garden Creek along the southern edge of the sheet area, in the northern part of the Mount Edgar Granitic Complex (WAMIN points 6064 and 6065 near MGA 805000E 7676000N), and also 1.8 km east-southeast of Talga Peak (WAMIN point 12847; MGA 807950E 7683800N).

Base metals

Dark red-brown gossan veins (AWAd-zi [AWdqgo]) with boxwork textures indicative of weathered out sulfides cut through the Duffer Formation in a few places; larger veins are shown on the map, for example in the southwestern part of the Marble Bar greenstone belt, approximately 4 km west of the Coongan River (MGA 784000E 7677800N and 784300E 7676500N). One surface sample of gossan was analyzed, but returned only low values of elevated Cu and Zn (169 and 302 ppm, respectively).

Native sulfur crystals and white sulfate crusts coat the dried up parts of the bed of a tributary to the Pear Creek (Fig. 28a,b) that drains from hills underlain by felsic volcanic rocks of the Wyman Formation, approximately 3 km south of the Marble Bar Road and 1.5 km east of Pear Creek (MGA 769250E 76908900N). Iron hydroxides coat those parts of the bed of the stream that have running water (Fig. 28c). Investigations just upstream revealed significant, but scattered, gossan material in coarsely brecciated felsic volcanic rocks with coarse blocks, up to several metres across, of quartz-porphyritic dacite–rhyolite, iron-rich shale, flow-banded rhyolite, and quartz-rich sandstone transected by black chert veins and white quartz veins with epithermal textures. Much of the

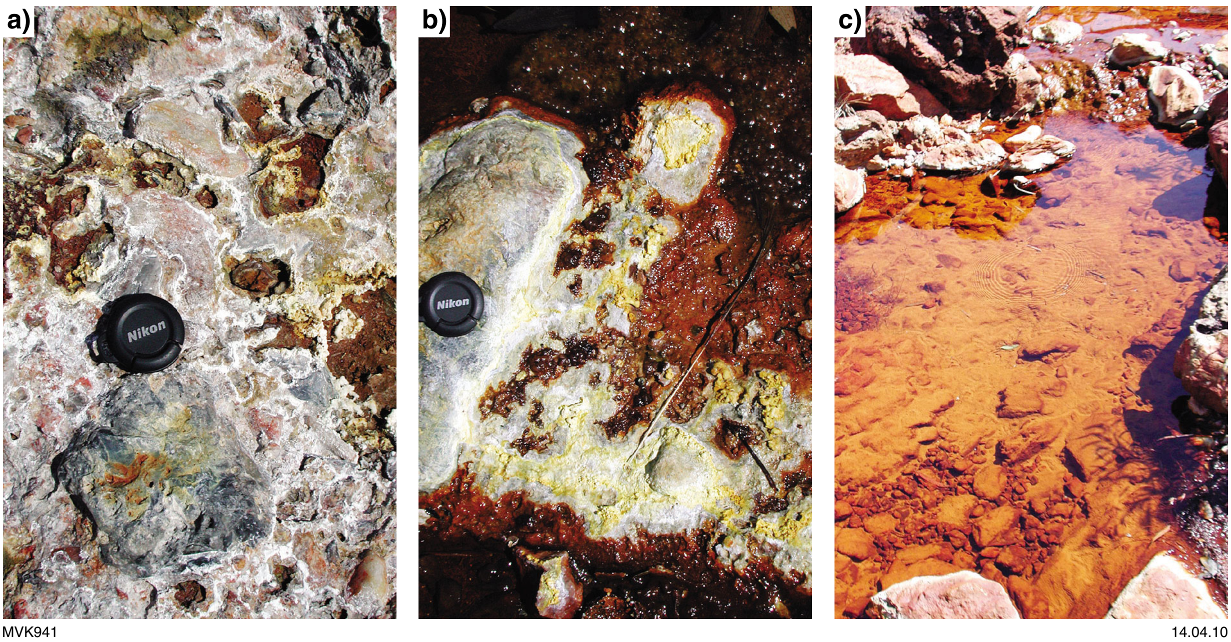

Figure 28. a) White sulfate crusts and fine, yellow, native sulfur crystals on exposed creek bed; b) close-up of fine native sulfur crystals on exposed creek bed; c) limonite coating on the bottom of the running creek. All from MGA 769250E 76908900N.

brecciation may have resulted from later faulting, the main example of which locally outcrops and contains coarse pyrite crystals in sheared host rocks.

Basal felsic volcaniclastic rocks of the Duffer Formation (AWAd-fnt [AWdft]) host historic Cu–Pb–Zn at Doolena Gap – RECK in the western part of the Dooleena Gap greenstone belt, west of the Coongan river and south of the Marble Bar Road (Minedex Site 17020; MGA 786100E 7684900N), but no reserves have been recorded.

Massive sulfides in the Warralong greenstone belt include Farrel Well North 2 Cu–Pb (WAMIN point 7469; MGA 764600E 7701920N) in carbonate-altered ultramafic rocks of the McPhee Formation. This prospect is a quartz stockwork, 450 m long by 61 m wide, which has returned samples with 17.4 – 21.4% Cu and more than 1% Pb with visible galena in outcrop. The Gorge Range Central South Cu occurrence in the central part of the Warralong greenstone belt (WAMIN point 13190; MGA 763500E 7702200N) is in metakomatiitic basalts of the Mount Ada Basalt (AWAm-bk [AWmbk]), whereas the nearby Gorge Range Central North Cu occurrence (WAMIN point 13188; MGA 763400E 7704150N) is hosted by metakomatiitic basalt of the Apex Basalt (AWAa-bk [AWabk]). Anomaly 32 South Cu is in sheared amphibolites of uncertain stratigraphic affinity in the northern part of the Warralong greenstone belt (WAMIN point 13195; MGA 761600E 7706050N).

A gossan sample of secondary Cu in malachite–limonite–cuprite rock in the Gorge Creek Group from the western part of the Gorge Range (AGCf-mtq [AGcstq]) contains 22.3% Cu, 0.14 g/t Au and 22 g/t Ag (WAMIN point 5801, Gorge Range; MGA 777800E 7683800N).

Industrial minerals

A silica prospect has been identified in the Warralong greenstone belt approximately 1 km north of the Marble Bar Road, sourced from the Marble Bar Chert Member of the Towers Formation in the southern part of the Warralong greenstone belt, approximately 800 m north of the Marble Bar Road (WAMIN point 7817, Shaw River Chert; MGA 762000E 7695550N). More details of this prospect are presented in Abeysinghe (2003).

Barite veins cut the Marble Bar Chert Member, and overlying and underlying felsic volcanic rocks of both the Duffer and Panorama Formations in the westernmost part of the Warralong greenstone belt, approximately 3 km north of the Marble Bar Road (MGA 760700E 7698850N). Several veins up to 1 m thick are continuous for at least 8 m at this locality and locally split the Marble Bar Chert Member in two.

Thin barite veins (<10 cm) are also present in the Panorama Formation in the western part of the Marble Bar greenstone belt, south of the Marble Bar Road and west of the Talga River (WAMIN point 6038, Warralong Creek; MGA 780000E 7678700N). These veins are oriented perpendicular to the strike of bedding and are steeply dipping within centimetres of 30 cm-wide hydrothermal gossan veins to which they are probably related. An assay of one such gossan vein contained only very low concentrations of Cu and Pb (23 and 17 ppm, respectively).

What was thought to be disseminated malachite staining in felsic volcaniclastic sandstones of the Panorama Formation in the Marble Bar greenstone belt (shown as Cu for WAMIN point 17019, Doolena Pool WSW; MGA 781200E 7680800N; Van Kranendonk, 2004b) has been determined from thin section petrography to be fuchsite. The fuchsite is clearly developed in the matrix of the sandstones around detrital opaque grains that are inferred, on this basis, to be chromite.

Asbestos was mined from a small operation on the east bank of the Talga River, from veins in sheared, medium- to coarse-grained metaperidotite (MGA 793530E 7684860N). A second asbestos occurrence is located 1.8 km east-southeast of Talga Peak (WAMIN point 6031; MGA 808000E 7683700N.

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Appendix

Gazetteer of localities

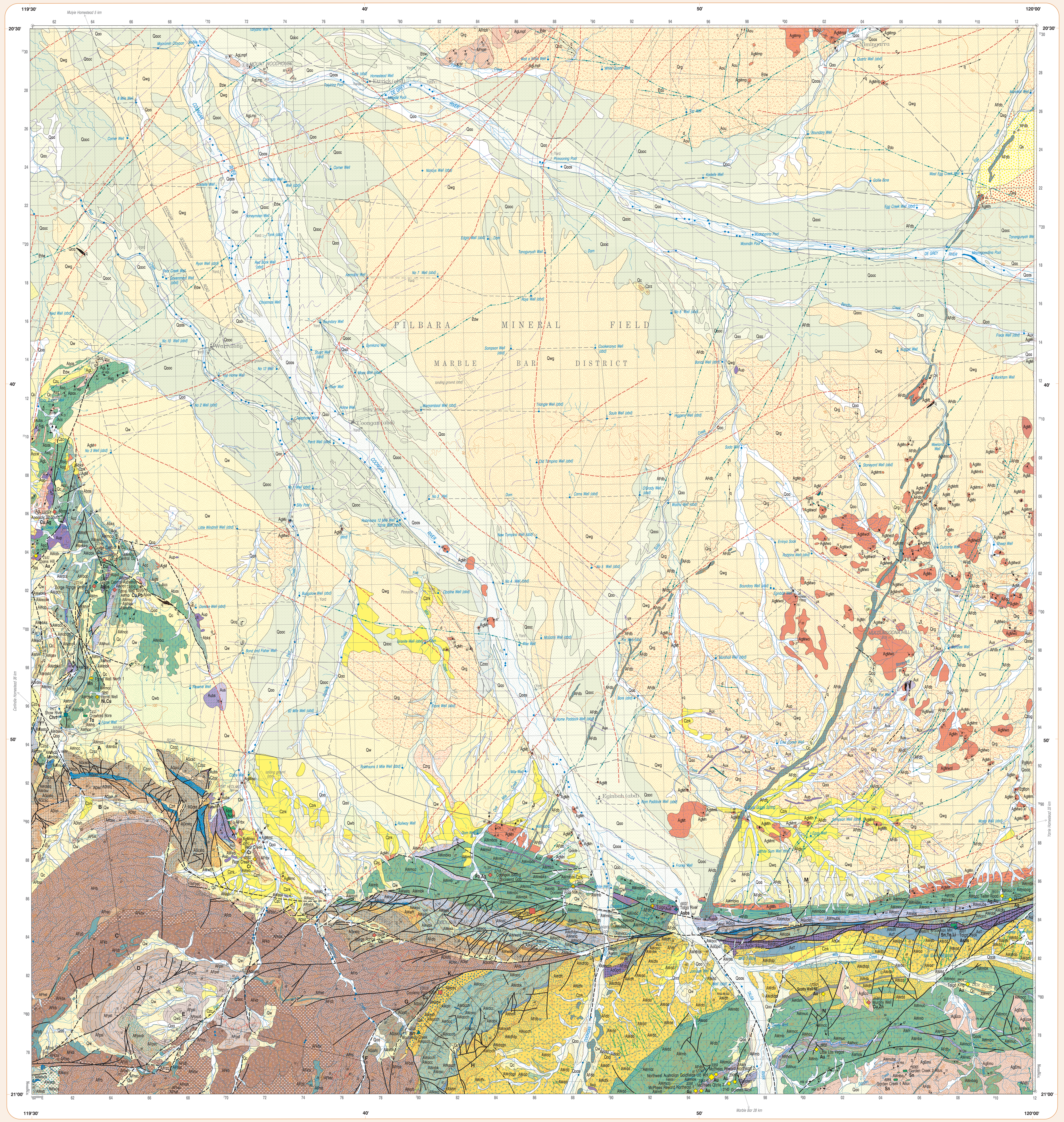
Place name	*MGA coordinates (Zone 50)*	
	Eastings	*Northings*
Box Soak Razorback Ridge	809400	7680300
Doolena Gap	783500	7683500
Doolena Peak	782920	7684456
Eginbah Homestead (abandoned)	789640	7690656
Eginbah Well	798900	7701460
Ettrick Homestead (abandoned)	778250	7728150
Nimingarra Homestead (abandoned)	803690	7729607
Talga Peak	806220	7684150
Warralong Homestead	769890	7714456

COONGAN

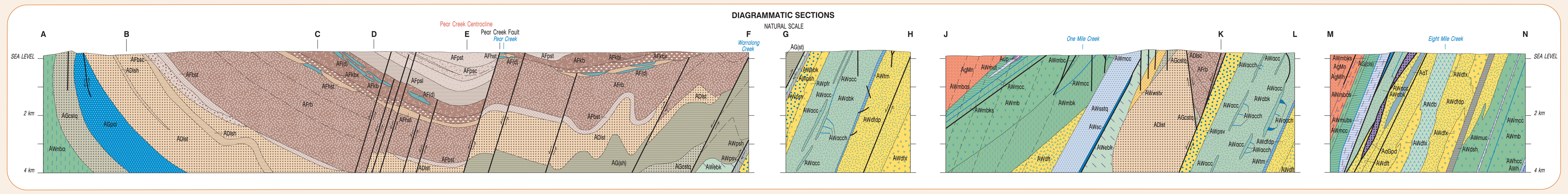
AUSTRALIA 1 : 100 000 GEOLOGICAL SERIES

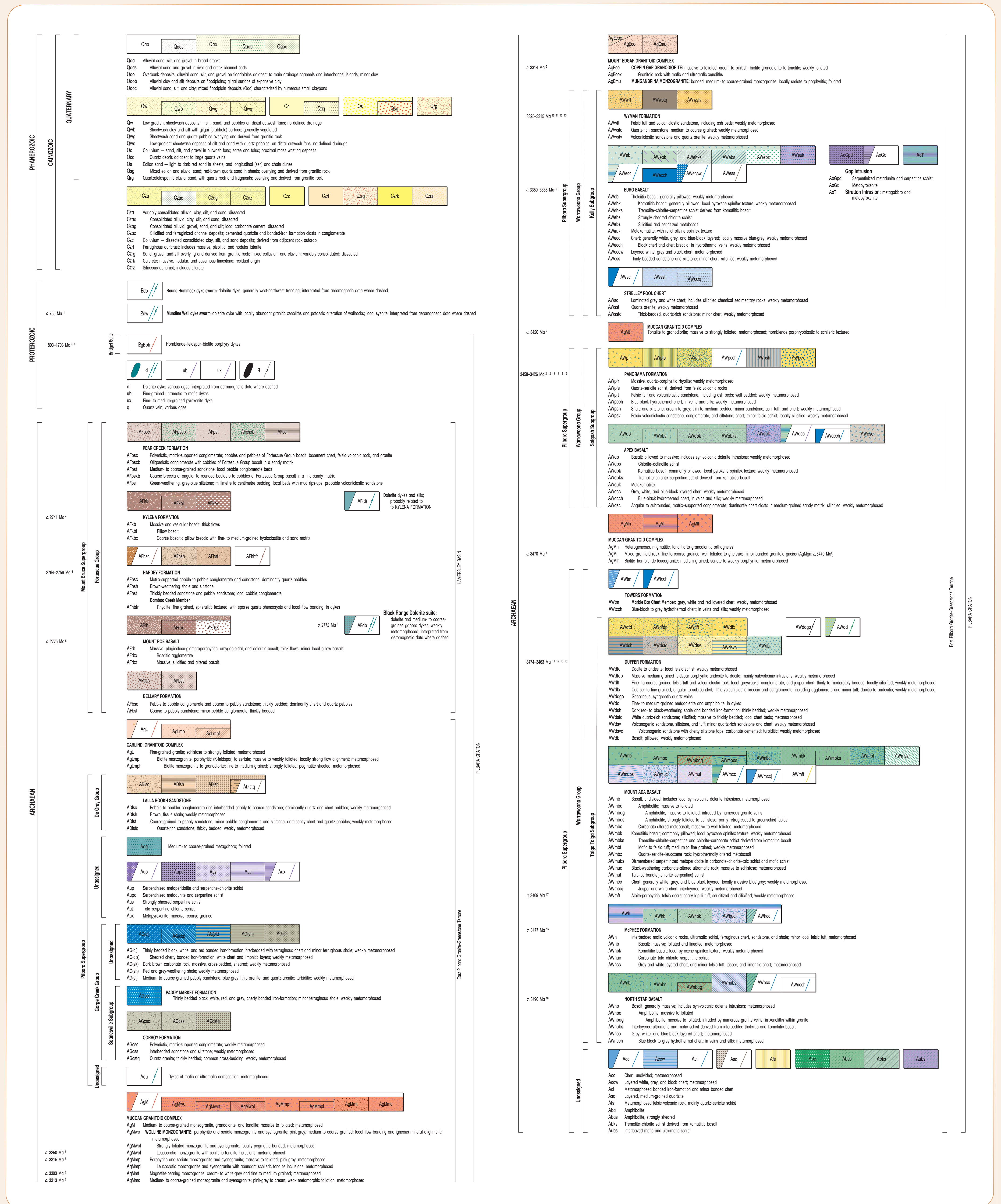
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 2856

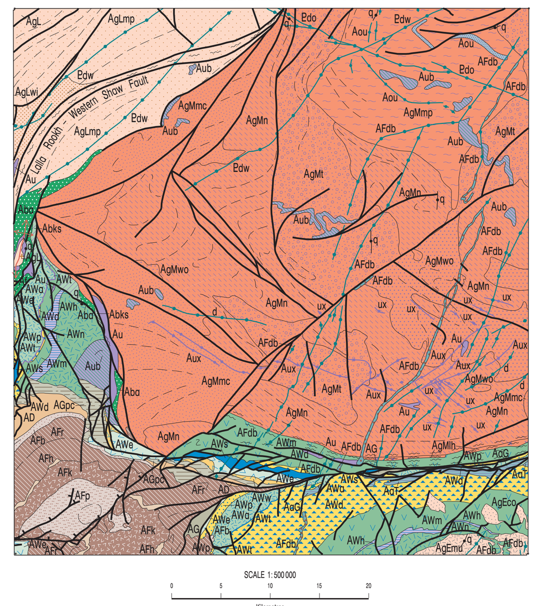


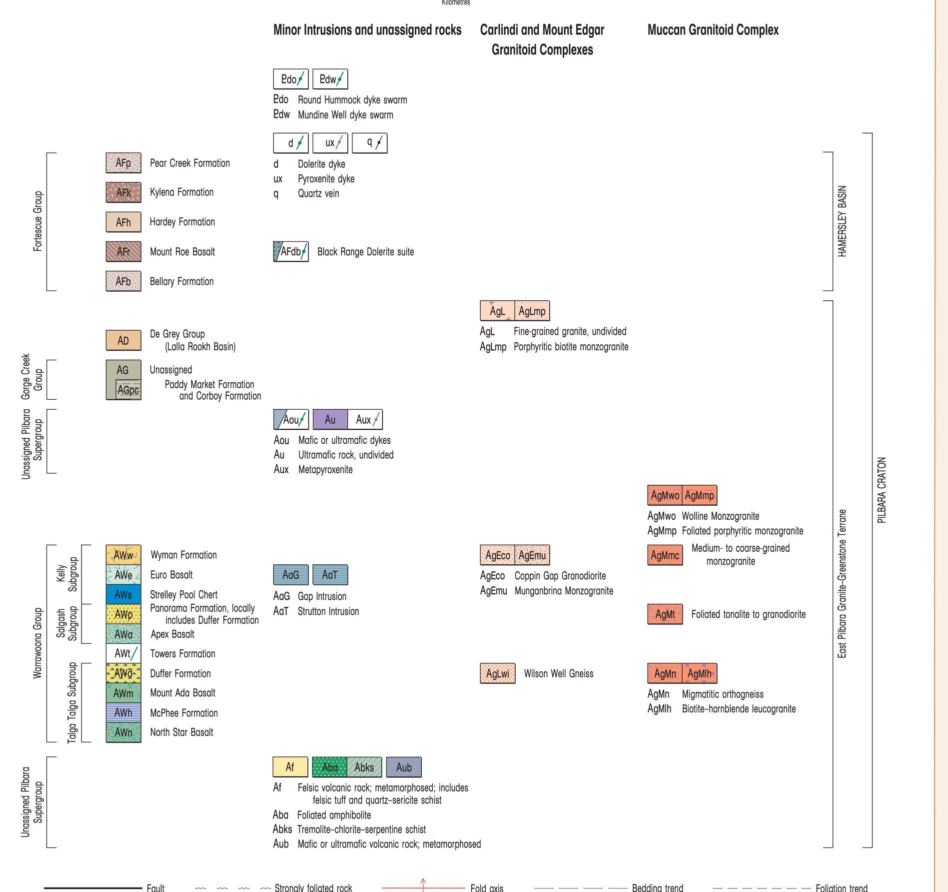
DIAGRAMMATIC SECTIONS





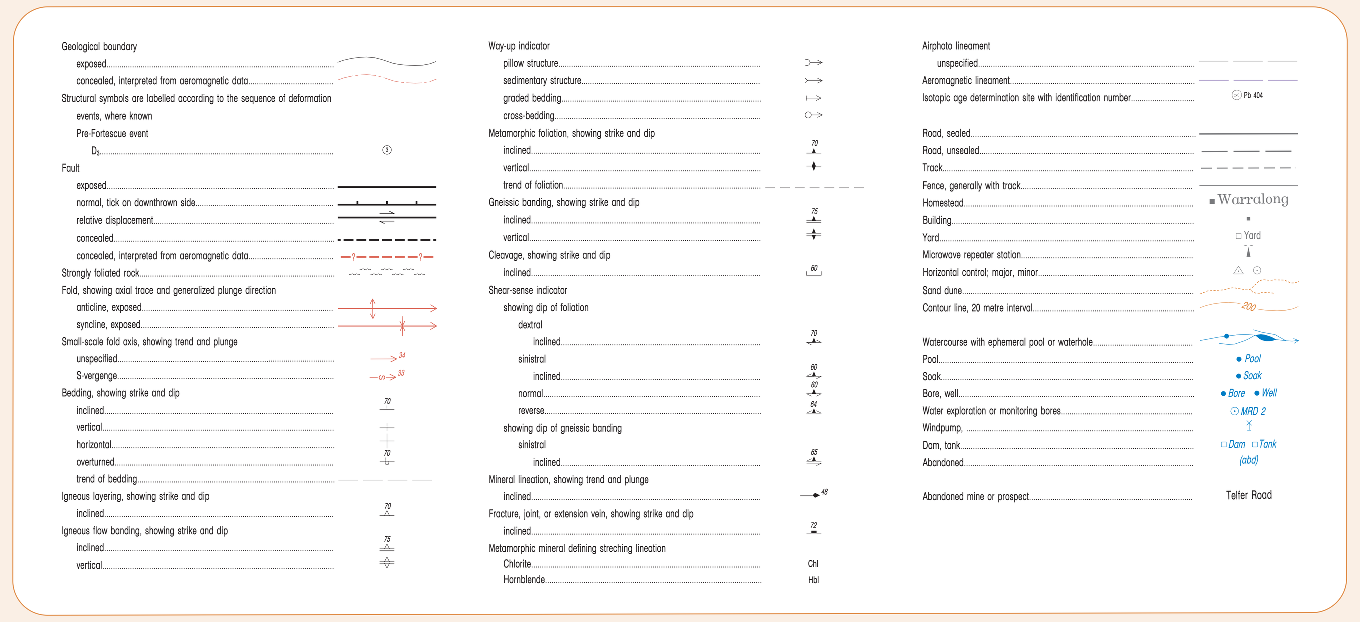
INTERPRETED BEDROCK GEOLOGY



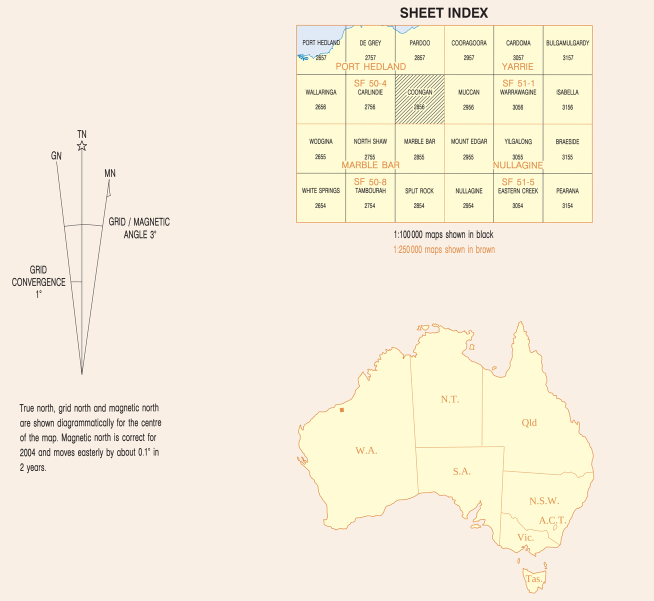


Fault — Strongly foliated rock — Fold axis — Bedding trend — Foliation trend

For further details, refer to main reference



SHEET INDEX



MINERAL OCCURRENCES

MINERALIZATION STYLES*

- Orthomagmatic mafic and ultramafic
- Vein and hydrothermal
- Stratabound volcanic and sedimentary
- Stratabound sedimentary and/or sedimentary banded iron-formation
- Regolith hosted

MINERAL AND ROCK COMMODITY GROUPS

- Precious metal
- Steel industry metal
- Specialty metal
- Base metal
- Industrial mineral

MINERAL AND ROCK COMMODITIES

Commodity is gold unless otherwise indicated on the map

Asbestos, serpentine (chrysotile)	Asbs
Barite	Brt
Chert	Chrt
Chromium	Cr
Copper	Cu
Gold	Au
Lead	Pb
Lithium	Li
Manganese	Mn
Nickel	Ni
Silver	Ag
Tantalum	Ta
Tin	Sn
Zinc	Zn

OPERATING STATUS AND SITE IDENTIFICATION NUMBER

Abandoned mine	e.g. *12345*
Mineral occurrence or prospect	e.g. *12345*

Mineral occurrences and numbers are from the GSWA WAMIN database.
*Larger symbols represent mines or deposits also in the DoIR MINEDEX database.

Geology by M. J. Van Kranendonk 2000–2002 and S. Bodorkos 2001

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Theme	Data Source	Data Currency	Agency
Geology	GSWA	2000–2002	Dept of Industry and Resourses
Structural data	WAROX	AUG 2003	Dept of Industry and Resourses
Mineral occurrences (non-confidential)	MINDEX	AUG 2003	Dept of Industry and Resourses
	WAMIN	JUN 2004	Dept of Industry and Resourses
Horizontal control	GESMAR	MAY 2004	Dept of Land Information
Topographic nomenclature	GEONOMA	MAY 2004	Dept of Land Information
Topography	DLI and GSWA field survey	2003	Dept of Land Information
Water exploratory bores	Water Information system (WIN)	2004	Dept of Environmental Protection

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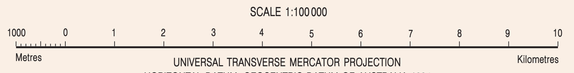
NGA

PRODUCT OF THE NATIONAL GEOSCIENCE AGREEMENT

SCALE 1:100 000



UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

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

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

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

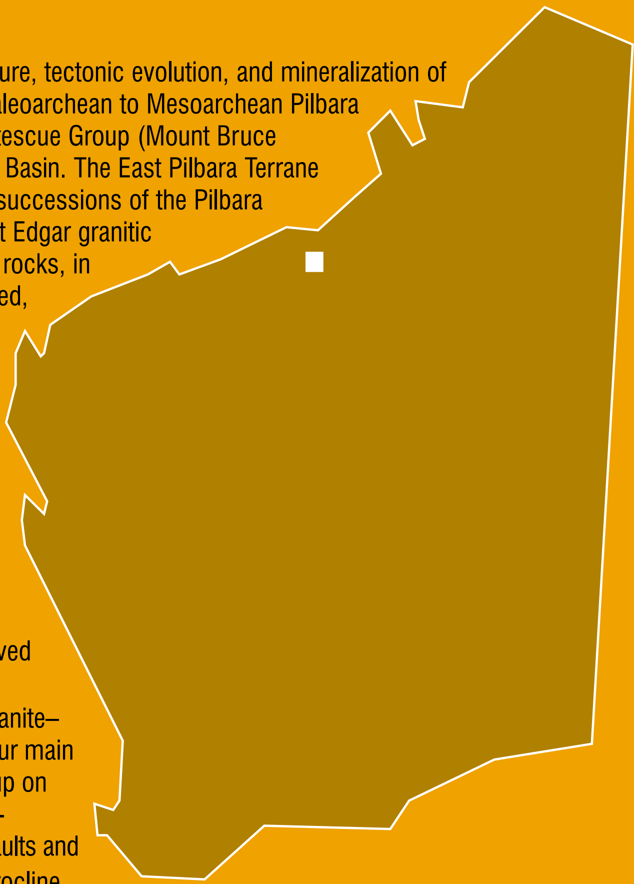
COONGAN

SHEET 2856 FIRST EDITION 2004
Version 1.0 — July 2004

VAN KRANENDONK

Geology of the Coongan 1:100 000 sheet

EXPLANATORY NOTES



These Explanatory Notes describe the stratigraphy, structure, tectonic evolution, and mineralization of the COONGAN 1:100 000 sheet, which covers part of the Paleoarchean to Mesoarchean Pilbara Craton and the unconformably overlying Neoarchean Fortescue Group (Mount Bruce Supergroup) in the Marble Bar Sub-basin of the Fortescue Basin. The East Pilbara Terrane of the Pilbara Craton on COONGAN comprises greenstone successions of the Pilbara Supergroup and parts of the Carlindi, Muccan, and Mount Edgar granitic complexes. Greenstones consist of volcano-sedimentary rocks, in which two groups and one formation have been recognized, bounded by angular unconformities and a basal intrusive contact with granitic rocks. Granitic domes consist of at least five age components, emplaced from c. 3.47–2.94 Ga.

The unconformably overlying De Grey Supergroup on COONGAN consists of the c. 3.01 Ga Gorge Creek Group and the Lalla Rookh Sandstone of the Croydon Group, deposited between 2.97–2.94 Ga. The two groups are separated by a regional unconformity and are themselves unconformably overlain by the interbedded volcanic and clastic sedimentary rocks of the Fortescue Group, preserved in the Pear Creek Centrocline.

Nine sets of structures are recognized in the basement granite–greenstone terrane on COONGAN; these are collated into four main deformation events. Rocks of the Mount Bruce Supergroup on COONGAN have been affected by a further nine sets of syn-depositional deformation (D_{FOM1}–D_{FOM9}), including growth faults and tilting of bedding during formation of the Pear Creek Centrocline. These structures only weakly affected older greenstones, but amplified the pre-existing granite dome – greenstone syncline geometry of the area.

The Archean rocks are intruded by Proterozoic rocks of the Bridget Suite, Mundine Well Dolerite Suite, and Round Hummock Dolerite Suite.

A Ni–Cu deposit is hosted by the Warrawoona Group along the eastern margin of the Warralong greenstone belt, and minor chromitite pods are present in the Doolena Gap greenstone belt. Minor Cu deposits are present in the Doolena Gap and Marble Bar greenstone belts. Most of the greenstone belts host only minor Au deposits, but more significant Au mineralisation occurs in the southern part of the Marble Bar greenstone belt, at McPhees Reward. Alluvial Sn, Ta, and Li in the Warralong and Marble Bar greenstone belts were probably derived by erosion of the post-tectonic, granitic Split Rock Supersuite, not exposed on COONGAN. Hydrothermal barite veins were observed in the Marble Bar greenstone belt.

Further details of geological publications and maps produced by the Geological Survey of Western Australia are available from:

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