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GEOLOGY OF THE WARRAWAGINE 1:100 000 SHEET

by I. R. Williams

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GEOLOGY OF THE WARRAWAGINE 1:100 000 SHEET

by
I. R. Williams

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Cover photograph:
Welded volcanic agglomerate (trachybasalt), Baramine Volcanic Member of Jeerinah Formation; 2.5 km south of the abandoned Barramine Homestead.

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Geology of the Warrawagine 1:100 000 sheet

by

I. R. Williams

Abstract

The WARRAWAGINE 1:100 000 sheet lies along the northeastern margin of the Archaean Pilbara Craton. Although the basement beneath about 92% of the area is the Pilbara Craton, Phanerozoic rocks of the Canning Basin and Westralian Superbasin restrict exposures of it to about 36% of the sheet area in the southwestern and southeastern quarters. Similarly, the Proterozoic Paterson Orogen, which is faulted against the Pilbara Craton and underlies the remaining 8% of the sheet area, is almost completely covered by Phanerozoic rocks of the Canning Basin.

The exposed Pilbara Craton comprises the Warrawagine Granitoid Complex (c. 3655–3242 Ma) unconformably overlain by very poorly exposed Gorge Creek Group (<3240 Ma) of the East Pilbara Granite–Greenstone Terrane. These are, in turn, unconformably overlain by volcano-sedimentary rocks of the Fortescue Group (c. 2772–2687 Ma) and sedimentary rocks (<2541 Ma) of the Hamersley Group, both part of the Hamersley Basin.

New geochronological data for the Warrawagine Granitoid Complex have revealed the oldest U–Pb ages, so far recognized, for the East Pilbara Granite–Greenstone Terrane. These were obtained from xenoliths of banded tonalite gneiss (c. 3655–3576 Ma) associated with c. 3303–3242 Ma monzogranite, granodiorite, and tonalite plutons.

In the southwestern quarter, the Fortescue Group comprises the basal Mount Roe Basalt, the Hardey Formation including the Bamboo Creek Member, the Kylena Formation, the Tumbiana Formation including the Mingah Tuff and Meentheena Carbonate Members, the Maddina Formation including the Kuruna Member, and the Jeerinah Formation. This volcano-sedimentary succession occupies the easterly plunging Oakover Syncline. In contrast, the Fortescue Group of the Gregory Range Inlier in the southeastern quarter consists of exposed Kylena Formation, Maddina Formation including the Kuruna Member, and the Jeerinah Formation including the Baramine Volcanic and Isabella Members. The fold style and strong faulting in this region account for the absence of the Tumbiana Formation. Observations recorded in adjoining areas of the Gregory Range Inlier show that the Kylena Formation overlies the Koongaling Volcanic Member of the Hardey Formation. The Hardey Formation, in turn, overlies the Gregory Granitic Complex (c. 2760 Ma) rather than components of the East Pilbara Granite–Greenstone Terrane or Mount Roe Basalt.

The Hamersley Group, represented by the Carawine Dolomite and closely related Pinjian Chert Breccia, disconformably overlies the Fortescue Group in both areas.

The tectonically complex Paterson Orogen in the northeastern corner consists of unexposed Mesoproterozoic to Neoproterozoic sedimentary rocks of the Throssell Group of the Yeneena Basin, deformed and metamorphosed during the Miles Orogeny (c. 1250–800 Ma), and the Neoproterozoic sedimentary rocks of the Tarcunyah Group (c. 800 Ma) of the Officer Basin, deformed during the Paterson Orogeny (c. 550 Ma).

The Canning Basin, unequally divided between the Wallal Embayment (mainly over Pilbara Craton) and the Wallal Platform (over Paterson Orogen) on WARRAWAGINE, is occupied by the fluvioglacial Permian Paterson Formation.

The northwestern corner of the sheet is occupied by the Lambert Shelf, a subdivision of the Westralian Superbasin. The Lambert Shelf is covered by a thin Mesozoic succession of fluvial Jurassic–Cretaceous Callawa Formation and shallow-marine Cretaceous Parda Formation. These two units extend eastwards to overlie the Permian rocks of the Canning Basin.

WARRAWAGINE has been explored for iron, manganese, copper, lead, zinc, nickel, gold, uranium, bauxite, and diamonds.

KEYWORDS: Warrawagine Granitoid Complex, Fortescue Group, Carawine Dolomite, Paterson Orogen, Canning Basin, regional geology, geochronology, copper.

Introduction

The WARRAWAGINE* 1:100 000 sheet (SF 51-1, 3056) bounded by latitudes 20°30' and 21°00'S, and longitudes 120°30' and 121°00'E, occupies the south-central part of YARRIE (1:250 000). The sheet straddles the boundary between the northeastern Pilbara Region and the southwestern part of the Great Sandy Desert.

WARRAWAGINE derives its name from Warrawagine Homestead (AMG 600926†). The Warrawagine pastoral lease, first taken up around 1871, was established as a sheep station in 1882. Now a cattle station, Warrawagine occupies most of the southern half of the sheet, where it includes the broad floodplains that surround the confluence of the Nullagine and Oakover rivers. These north to northwesterly flowing rivers combine to form the westerly flowing De Grey River. The unoccupied (as of 1997) Callawa Homestead (AMG 398165) and Aboriginal pastoral lease lies 8 km north of the De Grey River, close to the western boundary of the sheet. The ruins of the abandoned Barramine Homestead (AMG 890922) are situated 2 km west of the Ulalling Hills, on the southeastern margin of WARRAWAGINE. The dune-covered Great Sandy Desert, in the northeastern quarter of the sheet, is uninhabited.

The pastoral country is, with some exceptions, well serviced by graded roads and station tracks. The Port Hedland – Woodie Woodie manganese mining road, which also services the Telfer gold and Nifty copper mines, runs southeasterly across the southwestern quarter of WARRAWAGINE. A poorly maintained graded track, bearing east-southeasterly across the centre of the sheet, links Callawa Homestead to the uninhabited Myijimaya Community, 3 km east of Mount Cecelia (AMG 910011) on ISABELLA. Callawa Homestead is connected to the Yarrie iron mine to the west, and to the Port Hedland – Woodie Woodie road to the southwest by poorly maintained tracks. A sandy track, bearing northeast from Callawa Homestead, follows the abandoned Marble Bar – La Grange telegraph line, constructed in 1927. This track gives access to a number of poor, sandy exploration tracks and cut lines in the Great Sandy Desert region. The rough, trackless, hilly country in the southwestern and southeastern corners of WARRAWAGINE, and in the headwaters of Callawa Creek, is difficult to access by four-wheel drive vehicles.

Previous and current investigations

Initial descriptions of WARRAWAGINE are recorded in the exploratory journal of F. T. Gregory who, in 1861, discovered and named the Oakover River, which he followed downstream to the junction with the De Grey River (Gregory and Gregory, 1884). The Oakover River was also followed to safety by Colonel P. E. Warburton's expedition in 1873 after his difficult crossing of the Great Sandy Desert (named by him) from Alice Springs in central Australia (Feeken et al., 1970). A. W. Canning reconnoitred the area north of the Oakover River in 1903 and, in 1905, surveyed a line for the proposed No. 1 Rabbit Proof Fence. This fence, constructed under Canning's supervision in 1907, crossed WARRAWAGINE west-northwesterly from the Mount Cecelia area on the eastern margin to the northwestern corner (Broomhall, 1991). The fence was abandoned in 1948 and only remnants were found during recent fieldwork.

Although WARRAWAGINE was included in the Pilbara Goldfield, proclaimed in 1888, the first geological sketch map of the area was not published until 1898. This sketch map accompanied a report on the probability of finding artesian water between the Pilbara Goldfield and the Great (Sandy) Desert, specifically from the Oakover River valley (Smith, 1898). The lower third of WARRAWAGINE was included in a geological sketch map of the Pilbara Goldfield (Maitland, 1908) and the whole area first appeared in the preliminary geological sketch map of Western Australia (Maitland, 1919).

Reconnaissance geological investigations of WARRAWAGINE were carried out by the Bureau of Mineral Resources (BMR) in 1954 (Traves et al., 1956). Subsequently, this mapping was included in the YARRIE 4-mile geological series map (Wells, 1959). The Geological Survey of Western Australia (GSWA) remapped the Precambrian component of WARRAWAGINE in 1974 (Hickman and Chin, 1977), whereas the Canning Basin component was reassessed in 1977 by the BMR (Towner and Gibson, 1980, 1983). All these data were incorporated in the YARRIE (1:250 000) sheet (Hickman et al., 1983).

The BMR, now the Australian Geological Survey Organisation (AGSO), released preliminary Bouguer anomaly (BMR, 1979), preliminary total magnetic intensity (TMI) contour (AGSO, 1993a), and radiometric total count contour (AGSO, 1993b) maps for YARRIE (1:250 000) that covered the WARRAWAGINE area. A coloured total magnetic intensity (reduced to pole) map, (Mackey and Richardson, 1997), and a Landsat-5-TM image, directed principal components, and band ratio map (Macias, 1998), both of the Pilbara Region, also cover the WARRAWAGINE sheet. The Landsat-5-TM map has been described in detail by Glikson (1997).

Fieldwork carried out in 1997 reappraised and updated the Precambrian component of the sheet. WARRAWAGINE was compiled from 1:25 000-scale colour aerial photographs flown in 1997. Apart from scattered observations, the Phanerozoic component of WARRAWAGINE was not remapped in detail.

Climate, vegetation, and physiography

The climate on WARRAWAGINE is arid semi-desert with rainfall — due to tropical cyclones and monsoonal

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

† Localities are specified by the Australian Map Grid (AMG) standard six-figure reference system whereby the first group of three figures (eastings) and the second group (northings) together uniquely define position, on this sheet, to within 100 m. AMG coordinates of localities mentioned in the text are listed in Appendix 1.

thunderstorms — falling mainly between January and March (Beard, 1975). Lighter rains may also fall in autumn and early winter (May–June). The mean annual rainfall is around 300 mm, whereas the evaporation rate is about 3700 mm per annum. Apart from the cyclone season (December–April), humidity is low. Summers are very hot, with mean maximum temperatures in the low forties (°C), and winters are mild, with mean minimum temperatures around 12.5°C (Pink, 1992).

WARRAWAGINE straddles the boundary between the Fortescue and Canning Botanical Districts of the Eremaean Botanical Province (Beard, 1975). The botanical districts correspond directly to the Pilbara Natural and Great Sandy Desert regions respectively (Fig. 1).

The vegetation of the Great Sandy Desert is characterized by a sparsely scattered shrub steppe of mainly *Acacia pachycarpa* and soft spinifex (*Triodia pungens*) on the sandplain and between the sand dunes. The spinifex-covered dunes carry scattered desert bloodwood (*Corymbia dichromophloia*; Hill and Johnson, 1995). Scattered sandstone mesas and buttes northeast of Callawa Homestead are thinly vegetated with soft spinifex, scattered *Acacia* shrubs, and rare stunted *Eucalyptus papuana* (forma) trees. Stony colluvial areas adjacent to the larger mesas carry a sparse tree steppe of desert bloodwood, *Eucalyptus setosa*, and *Eucalyptus papuara*, with sundry *Acacia* species and *Hakea suberea*. Incised gullies in this surface carry thickets of mixed *Acacia* and *Grevillea* species (Beard, 1975).

The Fortescue Botanical District in this part of the Pilbara encompasses a wide floral range. These include sclerophyll woodlands of coolabah (*Eucalyptus microtheca*) growing along disused anabranches and flats north of the Oakover River, and narrow riverain woodlands of *Eucalyptus camaldulensis* (river gum) and *Melaleuca leucodendron* (paperbarks) fringing the Oakover, Nullagine, and De Grey rivers. In contrast, the wide, flat floodplains, surrounding the confluence of the Nullagine and Oakover rivers with the De Grey River, are largely treeless grass plains. Gravelly and sandy surfaces support soft spinifex (*Triodia pungens*), whereas red swelling-clay or gilgai (crabhole) country carries Roebourne Plains grass (*Eragrostis xerophila*), neverfail (*Erogrostis setifolia*), and other annual and perennial grasses. Introduced buffel grass (*Cenchrus ciliaris*) is common along the banks of creeks and gullies on the plains. Away from the floodplains in the southern half of WARRAWAGINE, the vegetation is predominantly a shrub steppe of mainly *Acacia pyrifolia* (kanji), with soft spinifex (*Triodia pungens*) in the southwest, and mixed soft and buck spinifex (*Triodia wiseana*) in the southeast of the sheet. Hilly country carries a more diverse flora including scattered snappy gum (*Eucalyptus brevifolia*) and mixed *Acacia* and *Grevillea* species. The low tablelands of the Oakover Formation are thinly covered with soft spinifex, scattered snappy gum, and shrubby *Acacia* species (Beard, 1975).

The schema adopted for the physiographic divisions shown in Figure 1 is based on Hickman (1983) and Williams (2000).

The Great Sandy Desert (Beard, 1975) occupies over a third of WARRAWAGINE. The desert, which is restricted to the northern half of the sheet, is divided between largely dune-free sandplain to the west and a sandplain covered with longitudinal (seif) and chain dunes in the east. The sand dunes trend between 285° and 270° and are typically spaced about 1 km apart. Individual dunes are up to 27 km long and average 13 m in height. Overall, the elevation of the Great Sandy Desert rises gradually from 140 m Australian Height Datum (AHD) in the west to over 270 m in the northeastern corner. Rocky mesas and buttes, with local relief up to 90 m above the sandplain, lie northeast of Callawa Homestead in the headwaters of Callawa Creek.

The Pilbara Natural Region (Beard, 1975) is unevenly divided between the extensive floodplains of the De Grey, Nullagine, and Oakover rivers in the central and central-southern parts of the sheet, and smaller areas of low granitoid hills west of the Nullagine River, dissected plateau and eroded hills and ridges in the southwestern corner and along the southeastern margin, and a zone of low tablelands and mesas, comprising dissected Oakover Formation, in the southeastern quarter of the sheet (Fig. 1).

The maximum height above sea level on WARRAWAGINE is located in the southeastern corner where the dissected plateau division (Fig. 1) reaches 335 m AHD, 9 km south (AMG 907830) of the abandoned Barramine Homestead. This locality is close to a large, unnamed natural arch, roughly 25 m wide and 9 m high, that pierces a ridge of weathered Pinjian Chert Breccia. Local relief in this area is around 116 m, similar to that attained in the headwaters of Five Mile Creek (316 m AHD; AMG 491818) in the southwestern corner of the sheet. In contrast, the bed of the De Grey River, where it crosses onto the adjoining MUCCAN to the west, is less than 120 m AHD. This indicates an overall relief of 215 m between the lowest and highest points on WARRAWAGINE.

As previously stated, the De Grey River commences at the confluence of the Nullagine and Oakover rivers. Of the three rivers, the Oakover Drainage Basin occupies the largest area within WARRAWAGINE. All three rivers can be incised up to 12 m within the adjacent floodplains, where they flow between well-developed levee banks. Large, semipermanent waterholes are prominent in all three rivers. A number of large, ephemeral creeks disgorge from the elevated, dissected plateau and eroded hill and strike-controlled ridge divisions to join the Nullagine and Oakover river systems in the southwestern and south-eastern parts of WARRAWAGINE (Fig. 1).

Sand dunes from the Great Sandy Desert encroach on the northern margin of the De Grey and Oakover river floodplains east of Callawa Homestead. These dunes have blocked Callawa Creek, the only large creek draining from the Great Sandy Desert on WARRAWAGINE, to form a long (5 km), narrow, vegetated claypan, 3 km east of Eva Well (AMG 408164).

The eastern margin of the Great Sandy Desert on WARRAWAGINE falls within the Percival Palaeodrainage Basin, which hosts the extensive Percival Palaeoriver (van de Graaff et al., 1977; Fig. 1). This palaeoriver, which can be traced over 800 km east-southeasterly across the

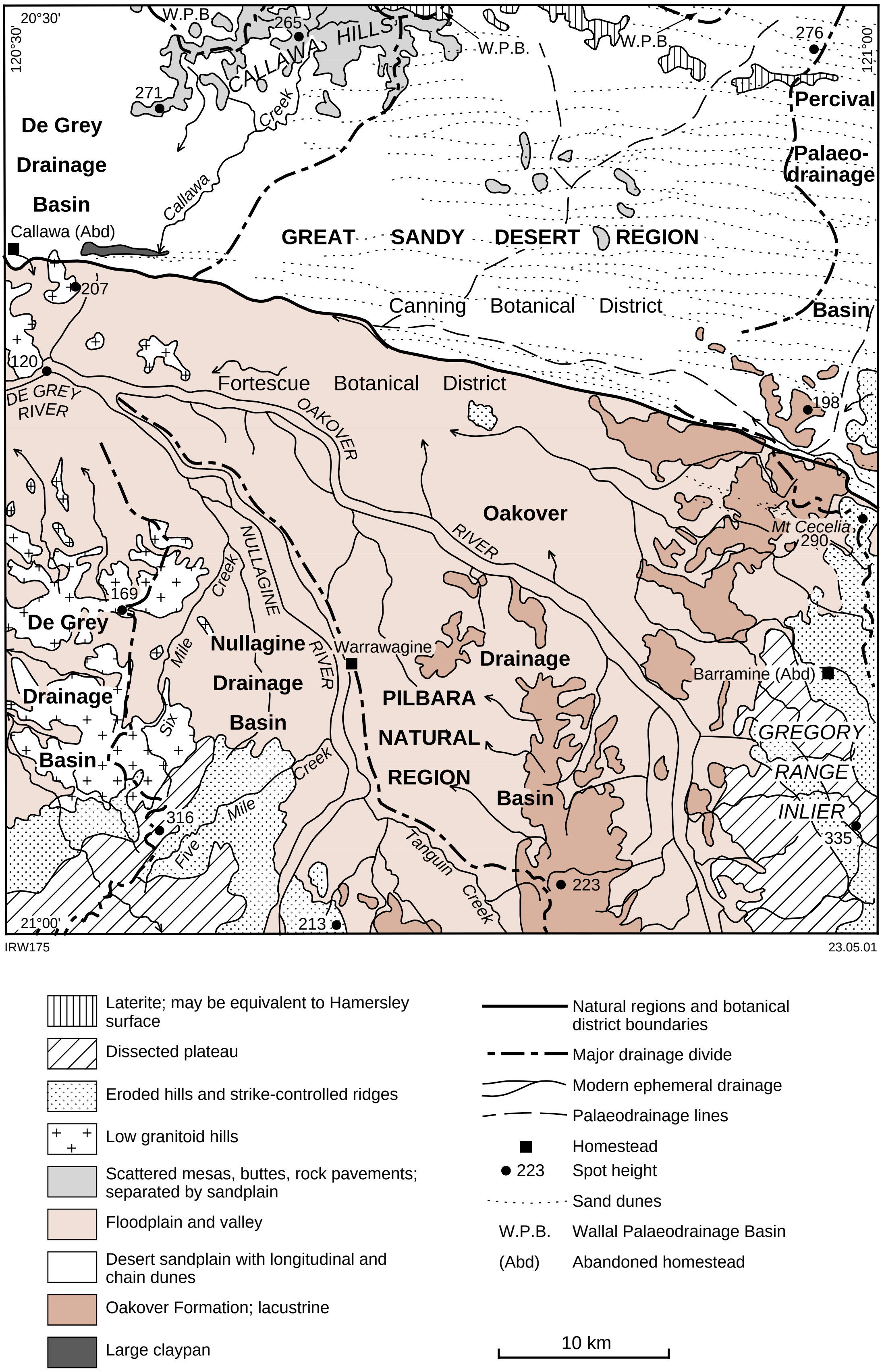

Figure 1. Natural regions, botanical districts (Beard, 1975), physiography, and drainage map of WARRAWAGINE

Canning Basin (Myers and Hocking, 1988), is probably the ancestral eastward continuation of the present-day De Grey River. Hence the north-flowing Oakover and Nullagine rivers were, at that time, southern tributaries of the large west-flowing De Grey – Percival palaeoriver. This palaeoriver system probably ceased to flow in the desert regions east of WARRAWAGINE after the onset of arid climatic conditions about Middle Miocene (van de Graaff et al., 1977). The Percival Palaeoriver channel contains remnants of the Oakover Formation northwest and northeast of Mount Cecelia (Williams and Trendall, 1998a).

Regional geological setting

Components of four tectonic units, the Archaean Pilbara Craton (Trendall, 1990a), Proterozoic Paterson Orogen (Williams and Myers, 1990), Phanerozoic Canning Basin (Towner and Gibson, 1983; Middleton, 1990), and Mesozoic Westralian Superbasin (Hocking et al., 1994) are exposed on WARRAWAGINE, where they cover approximately 36%, 1%, 61%, and 2% of the sheet area respectively. However, if the Phanerozoic basin cover is ignored, regional magnetic (TMI) data (Mackey and Richardson, 1997) and basement intersections from mineral exploration drilling (Sentinel Mining Company, 1967; Johnson, 1993) show that the northeasterly quadrant of WARRAWAGINE straddles the north-northwesterly trending faulted boundary between the Archaean Pilbara Craton and the Proterozoic Paterson Orogen. In this case, the two units would occupy about 92% and 8% of the sheet by area respectively.

The regional setting for these tectonic units is shown in Figure 2, the major structural elements are presented in Figure 3, and a regional TMI image is given in Figure 4.

On WARRAWAGINE, the Pilbara Craton comprises components of the early to middle Archaean East Pilbara Granite–Greenstone Terrane (Hickman, 2000), and late Archaean – early Palaeoproterozoic Hamersley Basin (Trendall, 1990b). The East Pilbara Granite–Greenstone Terrane is dominated by the large Warrawagine Granitoid Complex (c. 3655–3242 Ma*; Nelson, 1999). On WARRAWAGINE, the complex is exposed in the central-western area, mostly west of the Nullagine River, although regional TMI data (Fig. 4) suggest that the complex extends to the north and northeast beneath Permian and Mesozoic cover rocks. Xenoliths of banded tonalite gneiss within a foliated monzogranite, collected 4 km west-northwest (AMG 468966) of Six Mile Well, yielded the oldest zircon population ages (c. 3655–3637 Ma and 3595–3576 Ma for xenocrystic zircons) so far obtained from the granitoid complexes in the east Pilbara (Nelson, 1999).

On the western margin of the sheet between the De Grey River and Callawa Homestead, the complex contains numerous metamorphosed and deformed mafic and ultramafic xenoliths and rafts. This mixed zone of granitoid rocks, gneiss, and mafic–ultramafic xenoliths may represent a root zone of an eroded greenstone belt of the Pilbara Supergroup (Hickman, 1983). Metamorphosed ultramafic dykes in the same area may be feeders to the greenstone belt.

A prominent exposure of banded iron-formation (BIF) at Mount Cecelia on the eastern margin of WARRAWAGINE is correlated with the Nimingarra Iron Formation of the Gorge Creek Group, 80 km to the west on MUCCAN (Williams, 1999). The BIF, as with the Nimingarra Iron Formation, overlies weathered tonalite of the Warrawagine Granitoid Complex.

Hamersley Basin rocks in this area are represented by the Fortescue Group (c. 2772–2678 Ma; Arndt et al., 1991), the Carawine Dolomite (c. 2541 Ma; Jahn and Simonson, 1995) of the younger Hamersley Group, and the Palaeoproterozoic Pinjian Chert Breccia. On WARRAWAGINE, these lithostratigraphic components are exposed in the southwestern corner, where they occupy the south-dipping limb of the large, southeasterly plunging Oakover Syncline (Hickman et al., 1983; Blake, 1990; Williams, 1999). Here the basal Fortescue Group unconformably overlies the Warrawagine Granitoid Complex and the projected, subsurface extension of the Gorge Creek Group (see **Gorge Creek Group**).

The Fortescue Group, Carawine Dolomite, and Pinjian Chert Breccia are also exposed in the southeastern corner of the sheet, where they occupy the Gregory Range Inlier (Williams and Trendall, 1998a,b). In this area, all the rocks are intersected by numerous northwesterly to north-northwesterly trending faults. These are mostly transpressional faults that post-date west-southwesterly directed folds. The initial deformation is attributed to the Proterozoic Miles Orogeny (c. 1250–800 Ma; cf. Bagas and Smithies, 1998). This event was followed by further compressive reactivation during the Paterson Orogeny (c. 550 Ma; Bagas, 2000). Near Mount Cecelia on the eastern margin of WARRAWAGINE, the Fortescue Group, Carawine Dolomite, and Pinjian Chert Breccia are faulted against the BIF of the Gorge Creek Group. About 5 km further north (AMG 911067), Fortescue Group rocks are faulted against the Neoproterozoic Tarcunyah Group, a component of the Paterson Orogen.

The Fortescue Group in the Gregory Range Inlier is postulated to be underlain by the late Archaean Gregory Granitic Complex (Williams and Trendall, 1998b,c).

The two exposed areas of Hamersley Basin rocks on WARRAWAGINE are continuous beneath the Permian and Cainozoic rocks that occupy the broad Nullagine and Oakover River valleys (see map).

There are components of the Proterozoic Paterson Orogen along the central-eastern margin around and north of Mount Cecelia. These are the faulted, exposed Tarcunyah Group (Officer Basin) and the subsurface Throssell Group (Yeneena Basin) that is extrapolated northwestward from exposures on the adjoining ISABELLA (Williams and Trendall, 1998a). The latter unit has been intersected in an exploration drillhole, 25 km north (AMG892261†) of Mount Cecelia (Johnson, 1993). Both

* All ages given in this publication are from sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon geochronology, unless stated otherwise.

† The exploration drillhole shown at AMG 896216 on the WARRAWAGINE 1:100 000 sheet is incorrectly positioned.

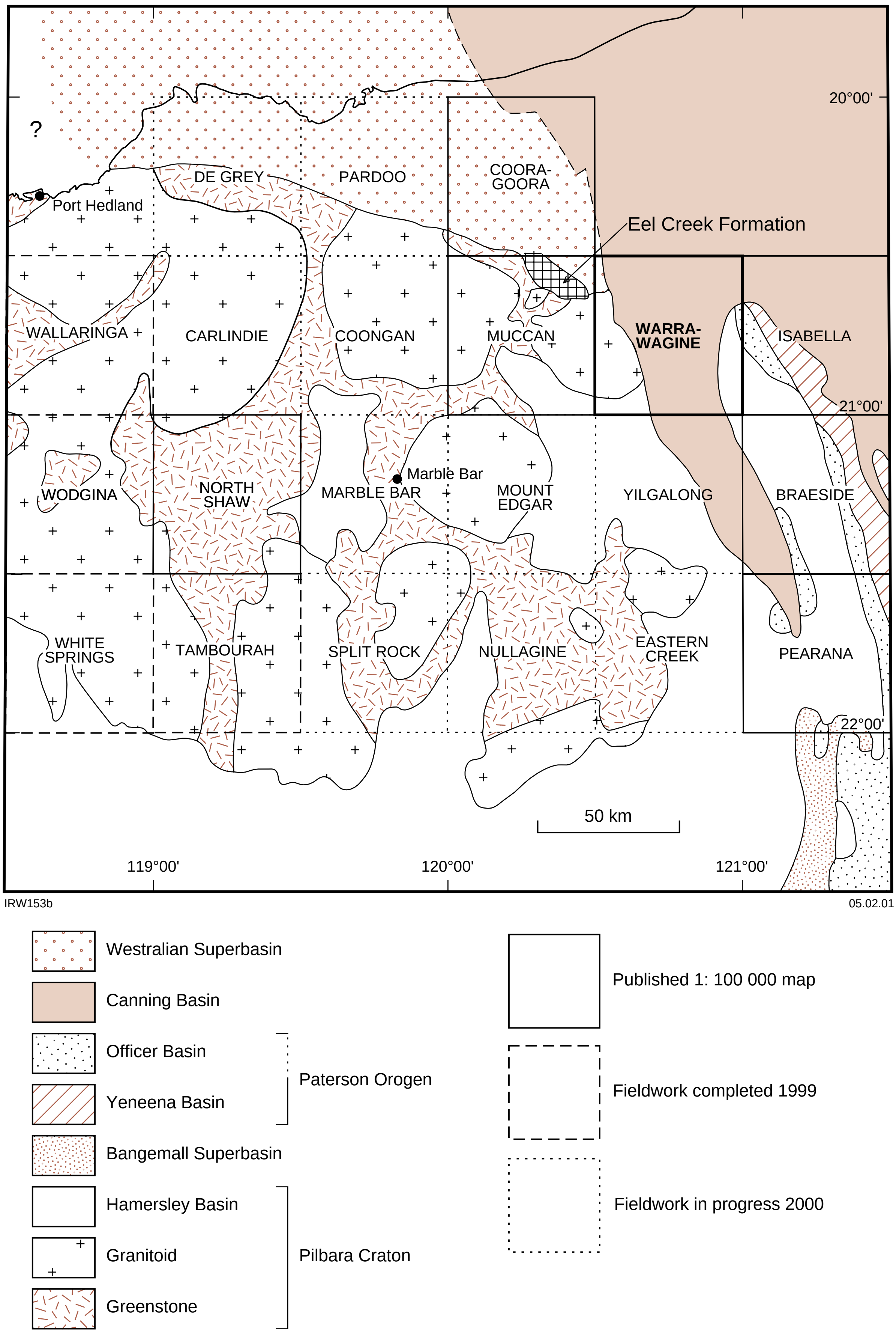

Figure 2. Regional geological setting of WARRAWAGINE

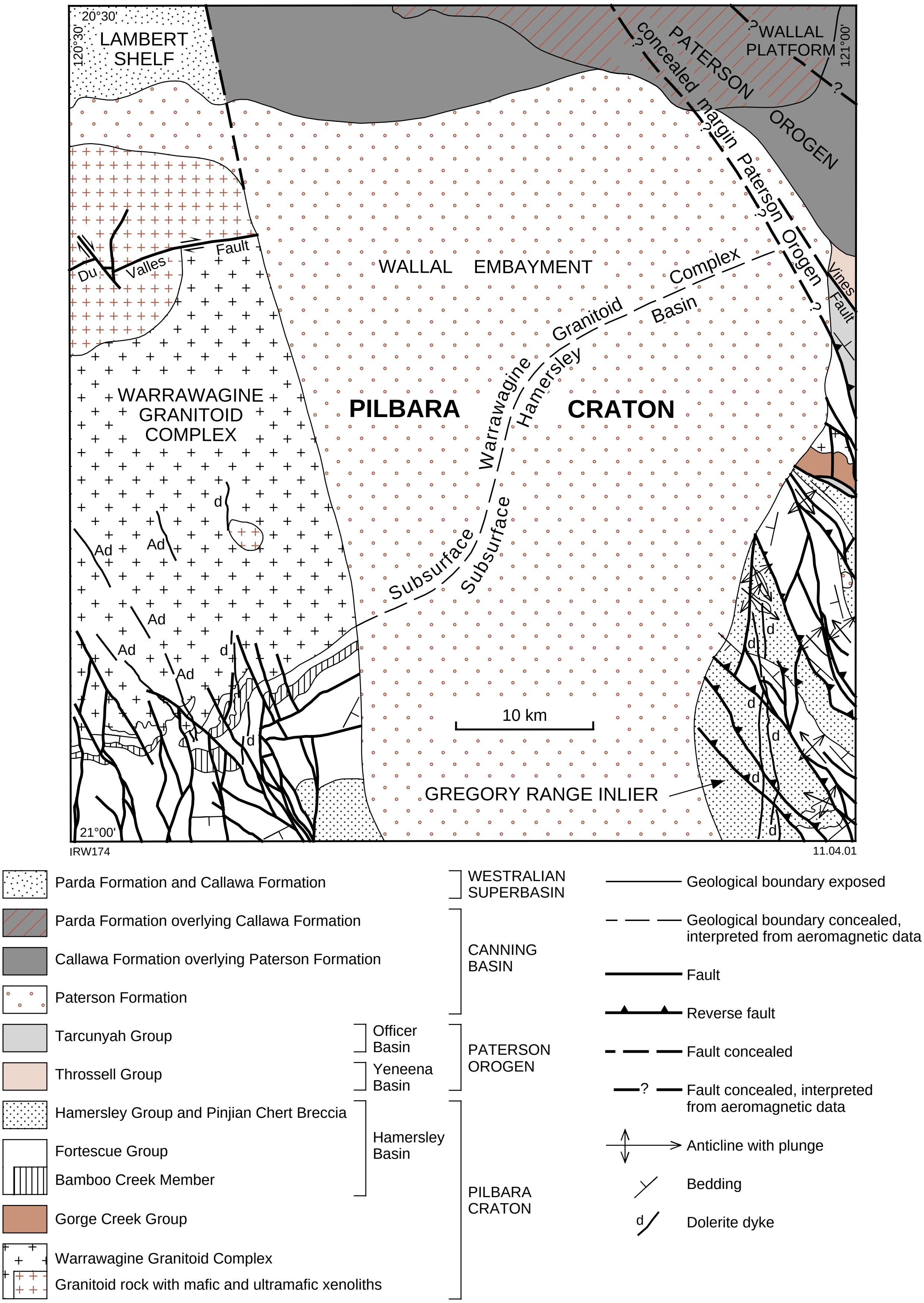

Figure 3. Structural sketch map with major tectonic units for WARRAWAGINE

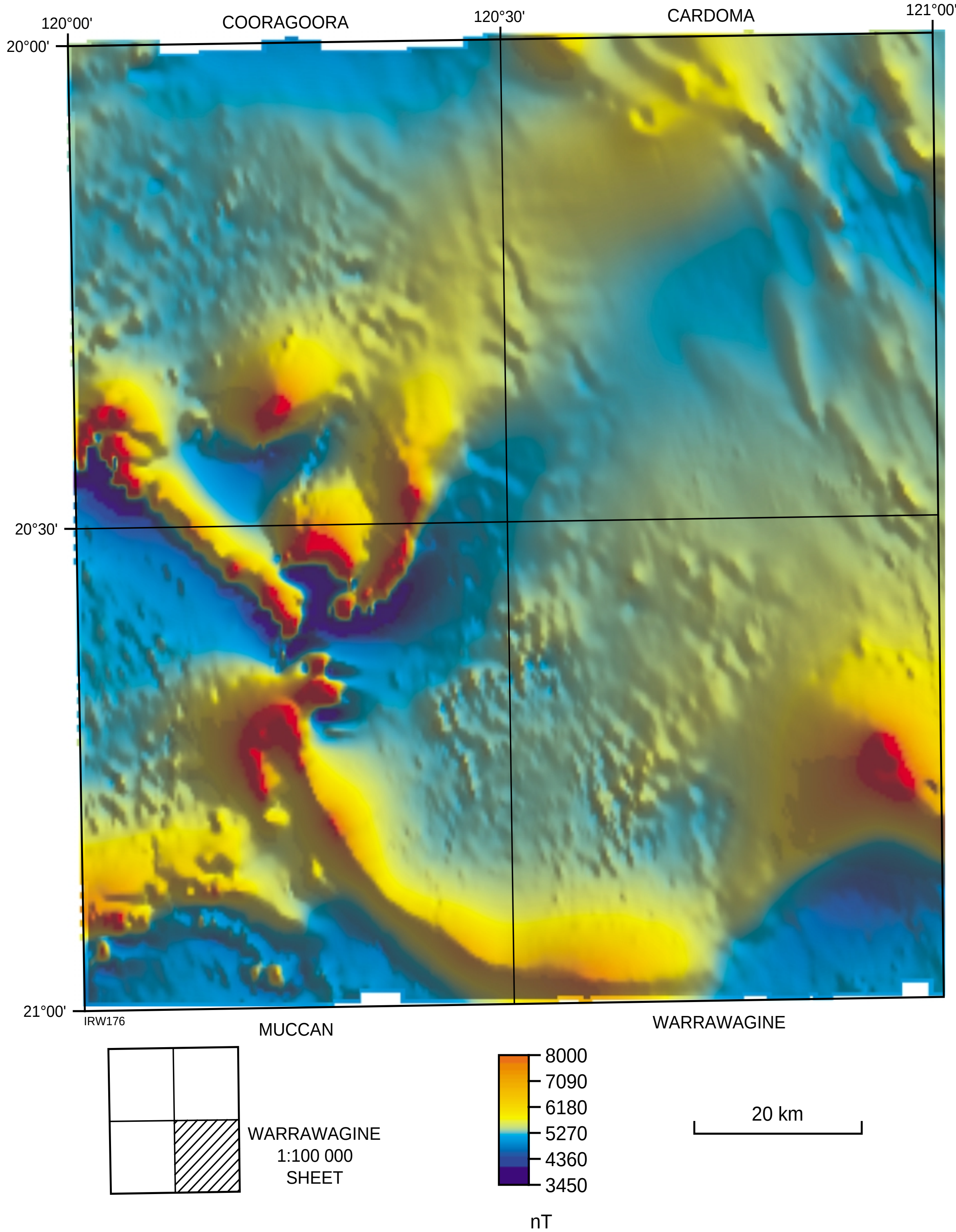

Figure 4. Total magnetic intensity image: regional setting for WARRAWAGINE

groups, as part of the Paterson Orogen, extend north-northwesterly beneath the sedimentary rocks of the Canning Basin.

Tectono-stratigraphic modelling, based on data collected on the adjoining MUCCAN (Williams, 1999) and COORAGOORA (Williams, 2000), suggests that the Neoproterozoic Eel Creek Formation probably extends eastwards at depth beneath the Mesozoic Callawa Formation in the northwestern corner of WARRAWAGINE, although its full extent is unknown. The Eel Creek Formation has been correlated with the Tarcunyah Group on the eastern margin of WARRAWAGINE (Williams, 1999).

Although the fluvioglacial Permian Paterson Formation is poorly exposed, the outcrop distribution, together with Permian rock intersections in exploration drillholes in the Oakover River valley (Sentinel Mining Company, 1967), indicates that the formation is widespread beneath the Cainozoic surficial material. On WARRAWAGINE, the Permian Paterson Formation was deposited on the Wallal Platform and in the Wallal Embayment structural units of the Canning Basin (Hocking et al., 1994). The Paterson Formation on the western margin, north of Callawa Homestead, and in the central and southern parts of WARRAWAGINE, is confined to palaeoglacial valleys eroded in the Pilbara Craton (Williams and Trendall, 1998a,b; Williams, 1999).

The northwestern corner of WARRAWAGINE is occupied by Mesozoic rocks of the Lambert Shelf. This structural unit is part of the Westralian Superbasin (Hocking et al., 1994) that has onlapped the Pilbara Craton. The sedimentary rocks of the Jurassic–Cretaceous Callawa Formation and Cretaceous Parda Formation, deposited on the Lambert Shelf, also extend eastward to unconformably overlie the Permian rocks of the Canning Basin.

A summary of the geological history of WARRAWAGINE is given in Table 1.

Archaean rocks

East Pilbara Granite–Greenstone Terrane

On WARRAWAGINE, there are exposed Archaean rocks in the southwestern quarter, south of Callawa Homestead and west of the Nullagine River, and in the southeastern quarter, south of Mount Cecelia and east of the Oakover River. Poor to moderately exposed, lower to middle Archaean granitoid rocks and minor greenstone belt remnants of the East Pilbara Granite–Greenstone Terrane (Hickman, 2000) are confined to the southwestern quarter. In this area, the granitoid rocks (Warrawagine Granitoid Complex) are unconformably overlain by the well-exposed upper Archaean Fortescue Group.

Mount Cecelia, on the eastern margin of WARRAWAGINE, is a small faulted inlier of the Middle Archaean Gorge Creek Group.

Unassigned mafic and ultramafic rocks within granitoid rocks (*Aba, Aus, Aut, Auc*)

Between Callawa Homestead and the De Grey River on the western margin of WARRAWAGINE, and just north of Six Mile Well (AMG 509959), the Warrawagine Granitoid Complex contains numerous mafic and ultramafic xenoliths and rafts that cannot directly be connected to established greenstone belts. These xenolith-rich zones are hosted by mixed foliated and gneissic granodiorite and monzogranite (*AgWx*). The granitoid rocks in these zones also host older banded tonalitic and granodioritic gneiss and migmatite xenoliths and rafts. Such xenolith-rich zones are considered to be remnants of root zones of greenstone belts (Hickman, 1983).

The mafic and ultramafic xenoliths consist of amphibolite, banded amphibolite, and hornblende–plagioclase schist (*Aba*), serpentinite and serpentinized peridotite (*Aus*), tremolite–serpentine–chlorite (talc) schist (*Aut*), and carbonate–tremolite–chlorite–talc schist (*Auc*). The mineral assemblages of the mafic xenoliths indicate prograde, middle amphibolite-facies conditions followed by retrograde greenschist-facies conditions where the prograde hornblende and clinopyroxene are extensively altered to actinolite–tremolite, chlorite, epidote, and carbonate.

Around Wongawobbin Well (AMG 416138), the granitoid rocks are intruded by several thick but discontinuous serpentinized peridotite dykes (*Aus*). Although now mainly serpentine–tremolite–chlorite–carbonate–clinopyroxene assemblages, the dykes have preserved a distinctive spotted texture. The spots were originally large poikilitic clinopyroxene crystals that are now largely replaced by secondary amphibole. These dykes are similar to metapyroxenite dykes described from the adjacent MUCCAN in the Du Valles Well area (Williams, 1999). The serpentine in these rocks forms flaky aggregates and in many cases represents completely altered olivine crystals.

Thin, east-northeasterly to northeasterly trending altered ultramafic dykes intrude granitoid rocks in the Little Junction Well area (AMG 465096) and Granite Well area (AMG 507873). Some are silicified serpentinites (*Aus*) whereas others consist of tremolite–serpentine–chlorite (–talc–plagioclase–epidote–quartz) assemblages (*Aut*). These latter dykes may be more akin to rocks with a high-Mg basaltic composition. The age of the dykes is constrained by the porphyritic biotite–oligoclase granodiorite (c. 3303 Ma), which they intrude near Granite Well, and the unconformably overlying Mount Roe Basalt (c. 2770 Ma) of the Fortescue Group. Such metamorphosed dykes are probably feeder dykes for Archaean greenstone belts.

Granitoid rocks

All granitoid rocks on WARRAWAGINE are components of the Warrawagine Granitoid Complex. Geochronological data, obtained from five samples collected during this study and subjected to SHRIMP U–Pb zircon dating (Nelson, 1999), are summarized in Table 2.

Table 1. Summary of the geological history on WARRAWAGINE

Age range (Ma)	*Geological events*
<3655–3576	Early felsic plutonism; tonalite, granodiorite
<3576	Deformation and metamorphism produced banded tonalite gneiss; now preserved as xenoliths and remnants in foliated and gneissic plutons of the Warrawagine Granitoid Complex
c. 3470–3430	Eruption and deposition of mafic–ultramafic subaqueous Warrawoona Group intruded by synvolcanic sills and plutons (>3438 Ma); progressive deformation and metamorphism to amphibolite facies; these rocks are now only preserved as xenoliths, remnants, and mafic–ultramafic dykes in xenolith-rich granitoids of the Warrawagine Granitoid Complex
c. 3325–3300	Widespread felsic plutonism (monzogranite, granodiorite); major period of inflation for Warrawagine Granitoid Complex; accompanied by uplift and followed by erosion and unroofing of granitoid complexes after the removal of the greenstone-belt cover
c. 3252–3242	Renewed felsic plutonism; monzogranite, granodiorite, tonalite plutons in the Warrawagine Granitoid Complex
<3235–2850	Gorge Creek Group; epiclastic, chemical, and mafic volcanic deposition under shallow- to moderate-depth marine shelf or basin conditions; intermittent deformation and erosion producing local unconformities; greenschist-facies metamorphism
c. 2772	Extensional faulting, intrusion of Black Range Dolerite Suite (on adjacent MUCCAN) and deposition of Mount Roe Basalt, basal Fortescue Group; erosion
c. 2770–2750	Continued extensional faulting leading to ?rifting along the eastern margin of the Pilbara Craton; genesis and emplacement of the subvolcanic alkaline (A_2-type) Gregory Granitic Complex in the region of the Gregory Range Inlier; consanguineous with the Koongaling Volcanic and Bamboo Creek Members of the sedimentary–volcanic Hardey Formation; erosion
c. 2750–2687	Deposition of the remainder of the volcano-sedimentary Fortescue group; erosion
c. 2561	Deposition of Carawine Dolomite, Hamersley Group
<2500 (Palaeoproterozoic)	Erosion, karstification, development of Pinjian Chert Breccia
c. 2772 – <2500	Fortescue and Hamersley Groups accompanied by broad folding and faulting due to continued greenstone-basement sag between granitoid complexes; very low grade greenschist-facies metamorphism
<1300 (Mesoproterozoic to Neoproterozoic)	Deposition of sedimentary Throssell Group in the strike-slip Yeneena Basin, a component of the Paterson Orogen, east of the Pilbara Craton
c. 1250–800	Miles Orogeny (*ꝐD*$_{3-4}$), strong west- to- southwest-directed transpressional deformation, low-grade greenschist-facies metamorphism; uplift of Gregory Granitic Complex (c. 1226–1194); corresponds to the collisional assemblage of the North Australian Craton with the West Australian Craton as part of Rodinia; uplift and erosion
<800 (Neoproterozoic)	Deposition of sedimentary Tarcunyah Group in the intracratonic Officer Basin overlying the eastern margin of the Pilbara Craton, part of the Paterson Orogen; deposition of the sedimentary volcaniclastic Eel Creek Formation on the Pilbara Craton; intrusion of large mafic sills
c. 550	Paterson Orogeny (*ꝐD*$_{6}$) reactivated west- to southwest-directed folds and transpressional faults in the Tarcunyah Group; mild folds in Eel Creek Formation; corresponds to intracratonic deformation during breakup of Rodinia; uplift and erosion
c. 290–270 (Permian)	Block faulting along the southwestern margin of the Canning Basin; fluvioglacial Paterson Formation deposited in Wallal Embayment and on the Wallal Platform of the Canning Basin; fluvioglacial rocks restricted to palaeoglacial valleys on the Pilbara Craton
c. 152–112 (Jurassic–Cretaceous)	Alternating fluvial continental deposits (Callawa Formation) and shallow-marine deposits (Parda Formation) on the Lambert Shelf (Westralian Superbasin) and adjoining Canning Basin
c. 65 (Upper Cretaceous)	Laterite development widespread
c. 59–23 (Palaeocene–Oligocene)	Moist temperate to tropical long-term weathering, large palaeorivers flowing, e.g. Percival Palaeoriver
<23 (Miocene–Pliocene)	Increasing aridity; lacustrine Oakover Formation deposited during stillstand period
<1 (Pleistocene–Holocene)	Generally arid, erosion of older weathered surfaces, unconsolidated dunefields of the Great Sandy Desert

SOURCE: See text for details

Warrawagine Granitoid Complex (AgW, AgWm, AgWx, AgWc, AgWp, AgWt)

The Warrawagine Granitoid Complex (*AgW*) occupies over half (approximately 53%) of the map sheet. Although most exposures lie in the area bounded by the western margin, Callawa Homestead in the north, Nullagine River to the east, and the Fortescue Group unconformity to the south, regional TMI data (Fig. 4) suggest that the complex also extends northerly beneath the Mesozoic rocks of the Lambert Shelf, and northeasterly beneath Permian rocks of the Wallal Embayment. Permian rocks also mask the faulted contact between the Warrawagine Granitoid Complex and the Proterozoic Paterson Orogen in the northeastern corner (Fig. 3). Two small granitoid outcrops, situated unconformably beneath the Nimingarra Iron Formation of the Gorge Creek Group on the northern side of Mount Cecelia, are included with the Warrawagine Granitoid Complex.

The intrusive margins of the Warrawagine Granitoid Complex are not exposed on WARRAWAGINE due to younger cover rocks. The unconformably overlying Mount Roe Basalt (c. 2770 Ma; Arndt et al., 1991) of the Fortescue Group marks the southern boundary of the complex. However, the Fortescue Group rocks in this area are also postulated to mask a second, and now subsurface, unconformity between the older Gorge Creek Group (<3235 Ma; Van Kranendonk, 2000) and the Warrawagine Granitoid Complex (Williams, 1999; see **Gorge Creek Group**).

The oldest dated material in the Warrawagine Granitoid Complex has been obtained from a xenolith of banded tonalite gneiss, which is hosted by the mixed foliated and gneissic granitoid unit (*AgWm*). A sample, collected 4.1 km west-northwest (AMG 468967) of Six Mile Well, yielded xenocrystic zircon populations of c. 3576 Ma, c. 3595 Ma, c. 3637 Ma, and c. 3655 Ma (Nelson, 1999). The c. 3655 Ma zircon population is the oldest zircon age so far determined for early protoliths for the Pilbara granitoid complexes using the SHRIMP U–Pb zircon method (Table 2).

The banded tonalite gneiss also yielded a slightly younger zircon date of c. 3410 Ma. This is interpreted to be the maximum time for deformation and metamorphism that produced the banded gneiss (Nelson, 1999). The c. 3655–3576 Ma age range of the protoliths is attributed to different precursor components within the composite banded gneiss (Nelson, 1999). These rocks also point to the existence of crustal material older than supracrustal rocks recorded, so far, from the greenstone belt successions (c. 3515 Ma; Buick et al., 1995; Van Kranendonk, 2000).

The mixed foliated and gneissic granitoids (*AgWm*) are closely associated with the xenolith-rich granitoids (*AgWx*). Together these two units occupy a broad zone extending south-southeasterly from near Callawa Homestead to southeast of Ten Mile Well (AMG 444931).

Petrographically, most of the granitoids in the mixed granitoid unit (*AgWm*) and xenolith-rich unit (*AgWx*) are orthogneiss. Although the igneous precursors can be identified, they are all recrystallized and deformed with incipient to prominent mineral segregation and strong, micaceous mineral orientation emphasizing the foliation. The granitoids are syn-kinematic bodies and have been subjected to regional prograde metamorphism under upper greenschist- or lower amphibolite-facies conditions. Most samples also show subsequent retrograde lower greenschist-facies recrystallization. Biotite, replaced in places by

Table 2. Summary of SHRIMP U–Pb zircon geochronological data from WARRAWAGINE

Sample number	*Locality*	*Lithology*	*Age (Ma)*	*Interpretation*
142875	4.2 km north of Simpson Well AMG 417099	Quartz–feldspar porphyry; dyke intruded into Warrawagine Granitoid	2758 ± 4	Age of crystallization
142874	4.3 km northwest of 10 Mile Well AMG 424950	Hornblende–oligoclase granodiorite; Warrawagine Granitoid Complex	3242 ± 4	Age of crystallization
142869	4.1 km west-northwest of 6 Mile Well AMG 468965	Porphyritic biotite–oligoclase granodiorite dyke; Warrawagine Granitoid Complex	3244 ± 3	Age of crystallization
142871	160 m north of Granite Well AMG 507875	Porphyritic biotite–oligoclase granodiorite; Warrawagine Granitoid Complex	3303 ± 5	Age of crystallization
142870	4.1 km west-northwest of 6 Mile Well AMG 468967	Banded tonalite gneiss; xenolith in foliated monzogranite; Warrawagine Granitoid Complex	i) 3410 ± 7 ii) 3576 ± 6 iii) 3595 ± 4 iv) 3637 ± 12 v) 3655 ± 6	(i) is interpreted as the maximum time for deformation and metamorphism (ii–v) zircons from different precursor components within the composite banded gneiss

NOTE: Dates from Nelson (1999)

chlorite, is the main ferromagnesian mineral, although some hornblendes are present in the granitoids associated with the xenolith-rich bodies (*AgWx*). These early plutons range compositionally from monzogranite through granodiorite to tonalite. Successive generations of pegmatite are evident in the mixed granitoid unit (*AgWm*).

The mixed granitoid (*AgWm*) and xenolith-rich granitoids (*AgWx*) are intruded by a range of foliated to massive, fine- to coarse-grained monzogranite and granodiorite, and minor syenogranite and tonalite plutons and dykes.

A large pluton of pinkish-grey, medium- to coarse-grained, foliated monzogranite and granodiorite (*AgWc*) lies southwest of Ten Mile Well and west of Granite Well. Plagioclase and microcline are the principal minerals. Quartz is abundant and minor biotite is the only ferromagnesian mineral. The mild deformation is expressed in some recrystallization. Chlorite partly replaces biotite and the plagioclase is generally saussuritized. Although the texture is typically even grained, some seriate and minor porphyritic phases are present. Similar rocks in the Warrawagine Granitoid Complex on MUCCAN to the west have yielded a 3313 ± 6 Ma zircon age (Nelson, 1998; Williams, 1999).

Some texturally and compositionally distinct smaller intrusions have yielded younger ages (Table 2). An example is a pink-grey, porphyritic biotite–oligoclase granodiorite (*AgWp*) that forms large scattered tors in the vicinity of Granite Well. The principal minerals in this rock are plagioclase (oligoclase) and microcline, with abundant quartz. The microcline is present both in the groundmass and as large (up to 15 mm) phenocrysts. Biotite is minor and muscovite is an accessory. This pluton has yielded a zircon age of 3303 ± 5 Ma (Nelson, 1999; Table 1); an age shared with plutons dated from the Muccan and Mount Edgar Granitoid Complexes (Nelson, 1998, 2000; Williams, in prep.).

The mixed granitoid rock (*AgWm*), which hosts the xenoliths of the 3655–3576 Ma banded tonalite gneiss, is also intruded by a porphyritic oligoclase–biotite granodiorite. This dark-grey, porphyritic rock is characterized by widely spaced, large (up to 20 mm) microcline phenocrysts and coarse oligoclase set in a fine-grained groundmass. Plagioclase is the principal mineral, whereas quartz and microcline are abundant and biotite is a minor component. The rock is only weakly deformed and partially recrystallized. However, this porphyritic granodiorite yielded a zircon age of 3244 ± 3 Ma (Nelson, 1999; Table 2). This is the same age as the Wolline Monzogranite, a pluton in the Muccan Granitoid Complex on MUCCAN, and the Strelley Granite on NORTH SHAW (Van Kranendonk, 2000).

A distinctive pluton of speckled greenish-grey and white, coarse-grained hornblende–oligoclase granodiorite and tonalite (*AgWt*) lies around and northwest of Ten Mile Well. The principal mineral is coarse-grained, saussuritized plagioclase (oligoclase) that tends to dominate the rock texture. Quartz and hornblende are abundant, and pale-green chlorite, probably after biotite, is minor. The rock is mildly deformed and partly recrystallized. The pluton yielded a 3242 ± 4 Ma age, which is within error of the c. 3244 Ma porphyritic granodiorite dyke described earlier (Table 2).

To summarize, the Warrawagine Granitoid Complex on WARRAWAGINE and MUCCAN comprises a series of coalescing plutons ranging from c. 3313 Ma through c. 3303 Ma to c. 3242 Ma (Nelson, 1998, 1999; Williams, 1999; Table 1). Unlike the neighbouring Muccan and Mount Edgar Granitoid Complexes, older (c. 3470–3430 Ma) granitoid bodies have not yet been identified in the Warrawagine Granitoid Complex. Although the synkinematic foliated and gneissic monzogranite and granodiorite (*AgWm*) could be expected to include such ages, so far the data have proved to be inconclusive. However, these foliated and gneissic bodies (*AgWm*) contain xenoliths of older crustal material with zircons ranging back to c. 3655 Ma (Nelson, 1999; Table 2).

Gorge Creek Group (*AG*)

The lithological similarity of BIF, jaspilite, and banded chert at Mount Cecelia, on the eastern margin of WARRAWAGINE, with the extensive outcrops of similar rocks in the Yarrie district on MUCCAN, over 75 km to the west, has been commented on by a number of workers (Hickman et al., 1983; Williams and Trendall, 1998a).

The identification of Gorge Creek Group rocks on WARRAWAGINE is supported by TMI data (AGSO, 1993a). The regional TMI image map (Fig. 4) shows an almost continuous magnetic high swinging southwest from the Mount Cecelia area, then west across to the southwestern corner of WARRAWAGINE. From here the magnetic high trends northwesterly across MUCCAN towards the Yarrie area, where the Nimingarra Iron Formation (BIF, jaspilite, chert) of the Gorge Creek Group is well exposed. In this area (AMG 148020 on MUCCAN), the Nimingarra Iron Formation strikes southeastwards to pass unconformably beneath the rocks of the upper Archaean Fortescue Group. The magnetic-high signature follows the arcuate-trending Fortescue Group around the southern margin of the Warrawagine Granitoid Complex. However, a close inspection of the Fortescue Group rocks has shown that rocks within this group cannot account for the strong magnetic signature shown on the TMI image map (Fig. 4). Hence it is concluded that the strong magnetic anomaly is due to the subsurface continuation of the Gorge Creek Group beneath the Fortescue Group. On WARRAWAGINE, this magnetic anomaly becomes weaker in the area between the Nullagine and Oakover rivers, where non-magnetic Permian fluvioglacial rocks occupy a deeply incised (approximately 660 m) palaeoglacial valley.

The Gorge Creek Group was redefined on MUCCAN (Williams, 1999) and has recently been shown to be younger than c. 3235 Ma (Van Kranendonk, 2000) and older than c. 3048 Ma (Williams, 1999). On WARRAWAGINE, exposures of the Gorge Creek Group are restricted to the Mount Cecelia area, where it comprises well-exposed Nimingarra Iron Formation and several small exposures of the overlying Cundaline Formation.

Nimingarra Iron Formation (AGn)

The Nimingarra Iron Formation (*AGn*; Williams, 1999) consists of BIF, jaspilite (banded hematite and red jasper), white, cream, grey, red, and black chert and banded chert. A greenish-grey chert lying towards the base of the formation on the northern side of Mount Cecelia appears to be a finely recrystallized quartzite.

The Nimingarra Iron Formation overlies weathered, altered granitoid rocks of the Warrawagine Granitoid Complex on the northwestern and north-northeastern side of Mount Cecelia. The contact is poorly exposed in this area, although the abrupt nature and presence of quartzites close to the base suggests a tectonized unconformity similar to that in the Yarrie district on MUCCAN (Williams, 1999). There is no evidence for an intrusive contact.

The Nimingarra Iron Formation exposure at Mount Cecelia is a fault-bounded upthrusted block. The succession has been juxtaposed against units of the younger Fortescue and Hamersley Groups. A small fault-bounded outcrop (?a klippe) of the Neoproterozoic Tarcunyah Group overlies the Nimingarra Iron Formation on the northern side of Mount Cecelia. Within the fault block, the formation is moderately to tightly folded. There is a general younging of the succession towards the west-southwest away from the underlying granitoid rocks.

Cundaline Formation (AGu)

Overlying the Nimingarra Iron Formation on the west-southwesterly margin are several exposures of weathered, ferruginous purple and brown pelitic and psammitic schist. Although at a slightly higher metamorphic grade (upper greenschist facies), these rocks resemble the metamorphosed shale, siltstone, and wacke of the Cundaline Formation (*AGu*; Williams, 1999) in the Yarrie district on MUCCAN to the west (Williams, 1999). The contact between the Cundaline Formation and Nimingarra Iron Formation is sheared.

Minor felsic intrusive rocks (*Ape, Apff*)

A small felsite dyke (*Ape*) has intruded the Warrawagine Granitoid Complex, 2 km southwest (AMG 398041) of Simpson Well. The dyke lies along strike from a suite of northerly trending felsic dykes described on the adjoining MUCCAN (Williams, 1999). The dykes are fine grained with a spherulitic or micropoikilitic (snowflakes) textured matrix and rhyolitic to dacitic composition. A similar textured dyke, trending north-northwesterly, lies 3.5 km west (AMG 474957) of Six Mile Well.

Several quartz–feldspar porphyry dykes (*Apff*) lie adjacent to a major northeasterly trending, quartz-bearing shear zone in the Warrawagine Granitoid Complex, 5 km north-west of Ten Mile Well. A small intrusion of similar quartz–feldspar porphyry lies 4 km northwest of Ten Mile Well.

These porphyritic rocks contain quartz, potash feldspar, and minor plagioclase phenocrysts set in a weakly spherulitic-textured matrix of potash feldspar and quartz. Similar northeasterly trending quartz–feldspar porphyries lie along strike 10 km to the southwest on MUCCAN. These porphyries contain accessory fluorite.

Hamersley Basin

Gregory Granitic Complex (*AgG, AgGy*)

Although the upper Archaean Gregory Granitic Complex (*AgG*, Hickman, 1978, 1983;. Williams and Trendall, 1998a,b,c) is not exposed on WARRAWAGINE, it is postulated to underlie the Fortescue Group rocks that occupy the northern end of the Gregory Range Inlier (Fig. 3) in the southeastern corner of WARRAWAGINE. The nearest exposures of the complex lie 13 km east of the abandoned Barramine Homestead, on the adjacent ISABELLA (Williams and Trendall, 1998a). These outcrops are the northernmost exposures of a long, narrow belt of granitoid rocks that stretches for 160 km along the eastern margin of the Pilbara Craton.

Geochemical (Williams and Trendall, 1998b) and geochronological (Nelson, 1996; Williams and Trendall, 1998c) data have shown that the Gregory Granitic Complex is comagmatic and coeval with the overlying Koongaling Volcanic Member of the Hardey Formation. The Gregory Granitic Complex is the subvolcanic edifice upon which, and from which, the overlying Koongaling Volcanic Member was deposited and derived. The Gregory Granitic Complex and Koongaling Volcanic Member form an igneous suite that is petrologically and chemically alkaline, silicic (SiO_2 range 70–77%), and potassic (K_2O range 4.9–5.9%) (Williams and Trendall, 1998b). These rocks can be assigned to the A_2 Group of the alkaline A-type felsic igneous rock category. Felsic rocks belonging to this category imply a tensional anorogenic setting (Eby, 1992).

The Gregory Granitic Complex and overlying Koongaling Volcanic Member have yielded zircon U–Pb ages ranging between c. 2764 and c. 2757 Ma (Nelson, 1996; Williams and Trendall, 1998c). Such ages are within error of the 2756 ± 8 Ma age derived for the Bamboo Creek Member of the Hardey Formation on MUCCAN (Arndt et al., 1991), and a quartz–feldspar porphyry intrusion (2757 ± 7 Ma) in the Coppin Gap Granodiorite, also on MUCCAN (Nelson, 1998).

A major component of the Gregory Granitic Complex on the adjacent ISABELLA is a coarse-grained granophyre (*AgGy*; Williams and Trendall, 1998a). The granophyre consistently overlies the medium- to coarse-grained and porphyritic syenogranites of the complex and underlies the Koongaling Volcanic Member. It may have been the hypabyssal equivalent of the extrusive rhyolite and dacite lavas of the Koongaling Volcanic Member (Williams and Trendall, 1998a). The Gregory Granitic Complex, granophyre, and Koongaling Volcanic Member are included in the cross section accompanying the WARRAWAGINE 1:100 000 map sheet (Williams, 1999b).

Several quartz–feldspar porphyry dykes (*Aph*) have intruded the mixed granitoids (*AgWm*) of the Warrawagine Granitoid Complex in an area approximately 4 km north

Yarrie 1:250 000 Hickman et al. (1983)	Warrawagine 1:100 000 Williams (this publication)	Sequence stratigraphy Blake (1993)		
Lewin Shale *(Ƥfl)* Baramine Volcanic Member *(Ƥflv)*	Jerrinah Formation *(AFj)* Isabella Member *(AFji)* Baramine Volcanic Member *(AFjv)*	Marra Mamba Supersequence package		Chichester Range Megasequence
Maddina Basalt *(Ƥfm)* Pearana Basalt *(Ƥfp)* Kuruna Siltstone *(Ƥfs)* Nymerina Basalt *(Ƥfn)*	Maddina Formation *(AFm)* Kuruna Member *(AFmk)* Maddina Formation *(AFm)*	Maddina sequence package	Mount Jope Supersequence	
Tumbiana Formation *(Ƥft)* Meentheena Carbonate Member *(Ƥftc)* Mingah Tuff Member *(Ƥftt)*	Tumbiana Formation *(AFt)* Meentheena Carbonate Member *(AFtc)* Mingah Tuff Member *(AFtt)*	Tumbiana sequence		
Kylena Basalt *(Ƥfk)*	Kylena Formation *(AFk)*	Kylena sequence		
Hardey Sandstone *(Ƥfh)* Bamboo Creek Porphyry *(Ƥp)*	Hardey Formation *(AFh)* Bamboo Creek Member *(AFhb)*	Hardey sequence package	Nullagine Super-sequence	
Mount Roe Basalt *(Ƥfr)*	Mount Roe Basalt *(AFr)*	Mount Roe sequence		

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Figure 5. Fortescue Group correlation chart: a historical comparison

(AMG 416098) of Simpson Well. These have yielded a zircon U–Pb zircon age of 2758 ± 4 Ma (Nelson, 1999; Table 1), which is indistinguishable in age from the Gregory Granitic Complex to the southeast (Williams and Trendall, 1998c).

The porphyry consists of quartz, albite, and feldspar phenocrysts, with sparse amphibole crystals, set in a spherulitic-textured quartzofeldspathic matrix. Fluorite is an accessory.

Fortescue Group (*AF*)

Upper Archaean Fortescue Group rocks of the Hamersley Basin (Trendall, 1990a,b) are exposed west of the Nullagine River in the southwestern corner and along the southeastern margin of WARRAWAGINE in several north-northwesterly trending fault-controlled zones that lie at the northern end of the Gregory Range Inlier (Williams and Trendall, 1998a; Fig. 3). In the southwestern corner, the Fortescue Group is represented by the complete succession, from the base, of Mount Roe Basalt, Hardey Formation including the Bamboo Creek Member, Kylena Formation, Tumbiana Formation including the Mingah Tuff and Meentheena Carbonate Members, Maddina Formation including the Kuruna Member, and the Jeerinah Formation. The East Pilbara Granite–Greenstone Terrane is basement to the Fortescue Group in this area.

In contrast, only the Kylena Formation, the Maddina Formation including the Kuruna Member, and the Jeerinah Formation including the Isabella and Baramine* Volcanic Members are exposed along the southeastern margin. However, it can be inferred from the structure and good exposures on the adjacent ISABELLA to the east (Williams and Trendall, 1998a) that the Tumbiana Formation and Koongaling Volcanic Member of the Hardey Formation are present at depth on WARRAWAGINE.

* So spelt (Hickman et al., 1983)

The Fortescue Group in this region is floored by the upper Archaean subvolcanic Gregory Granitic Complex, a relationship established throughout the Gregory Range Inlier (Williams and Trendall, 1998a,b,c). The Mount Roe Basalt, the basal unit of the Fortescue Group on the western side of WARRAWAGINE, is absent from the Gregory Range Inlier.

Fortescue Group rocks were deposited between c. 2772 and c. 2687 Ma (Arndt et al., 1991; Trendall et al., 1998) and have undergone prehnite–pumpellyite facies metamorphism (Smith et al., 1982).

The relationships between earlier (Hickman et al., 1983) and current lithostratigraphic terminology and the sequence stratigraphic model proposed by Blake (1990, 1993) are shown in Figure 5.

Mount Roe Basalt (AFr, AFrk)

The basal Mount Roe Basalt (*AFr*; Kriewaldt, 1964) is restricted to the southwestern corner of WARRAWAGINE, where it unconformably overlies the Warrawagine Granitoid Complex. Outcrops can be traced almost continuously over 16 km from 10.5 km southwest (AMG 400820) of Ten Mile Well on the western margin to 3 km southwest (AMG 545872) of Three Mile Well.

A small, isolated exposure of rubbly basalt, 500 m southeast (AMG 575890) of Three Mile Well, is correlated with the Mount Roe Basalt. In the southwestern part of WARRAWAGINE, the Mount Roe Basalt is exposed along the southerly dipping limb of the large Oakover Syncline (Williams, 1999).

Although the base of the Fortescue Group is not exposed in the southeasterly part of WARRAWAGINE, it can be concluded from mapping carried out on the adjoining ISABELLA (Williams and Trendall, 1998a) and BRAESIDE (Williams and Trendall, 1998b) that the Mount Roe Basalt is absent from the Fortescue Group succession in this area.

The Mount Roe Basalt is up to 500 m thick on WARRAWAGINE. It consists largely of amygdaloidal, porphyritic, and massive well-jointed, black, grey to grey-green basalt and basaltic andesite. Amygdales are commonly filled with calcite or chlorite or both. These are subaerially extruded flows.

The proportion of subaqueous pillowed basalt increases eastwards. Pillow structures, up to 1 m in size, have been recorded 5.5 km south-southwest (AMG 491821) and 3 to 4 km south (AMG 506846) of Granite Well. The pillowed basalts lie directly beneath the Bamboo Creek Member of the Hardey Formation.

A dark-grey siliceous limestone and dolomite (*AFrk*) lens lies 600 m north of the Five Mile Microwave Repeater Station (AMG 530858) and close to the base of the Mount Roe Basalt (Hickman et al., 1983). Similar thin (1–2 m) white-weathering dolomite beds, interlayered with the basalt flows, are present at in several other localities.

Hardey Formation (AFh, AFhi, AFhc, AFhb, AFha, AFhu)

The Hardey Formation (*AFh*; Thorne et al., 1991; previously Hardey Sandstone; MacLeod et al., 1963) is exposed only in the southwestern corner of WARRAWAGINE, between the western margin 11 km southwest (AMG 400813) of Ten Mile Well and 2 km south-southwesterly (AMG 561875) of Three Mile Well. In this region, the formation consists of epiclastic and reworked tuffaceous rocks partly enclosing a felsic volcanic and synvolcanic intrusive succession, now assigned to the Bamboo Creek Member (*AFhb*; Thorne and Trendall, in prep.). This unit was previously mapped as the Bamboo Creek Porphyry (Hickman et al., 1983; Fig. 5). The Bamboo Creek Member is correlated with the Koongaling Volcanic Member (Williams and Trendall, 1998b), previously called Koongaling Volcanics (Hickman, 1978), of the Gregory Range Inlier. The Hardey Formation ranges from approximately 200 m thick on the western margin to approximately 600 m thick in the vicinity of the Five Mile Microwave Repeater Station.

In contrast, sedimentary rocks of the Hardey Formtion are not exposed in the Fortescue Group succession of the Gregory Range Inlier (Williams and Trendall, 1998a) in the southeastern corner of WARRAWAGINE. Instead it appears, from mapping carried out on the adjacent ISABELLA (Williams and Trendall, 1998a), that the Koongaling Volcanic Member (*AFhi*; Thorne and Trendall, in prep.) is the sole component of the Hardey Formation in this area, and lies subsurface in the southeastern corner of WARRAWAGINE. The basal Koongaling Volcanic Member on ISABELLA appears to pass gradationally downwards into granophyre (*AgGy*) of the Gregory Granitic Complex (Williams and Trendall, 1998a,b,c; see previous section on **Gregory Granitic Complex**). The dominant rock type in the Koongaling Volcanic Member (*AFhi*) is dark-grey to brown, porphyritic metarhyolite (Williams and Trendall, 1998a,b).

In the southwestern corner of WARRAWAGINE, a discontinuous basal unit of matrix-supported pebble conglomerate, red-brown sandstone, siltstone, and grey-brown mudstone (*AFhc*) underlies the Bamboo Creek Member (*AFhb*) in the area 6 km southwest (AMG 465825) of Granite Well. This broadly upward-fining sequence disconformably overlies the Mount Roe Basalt. The pebble clasts in the conglomerate are mainly chert and white vein quartz. These are probably fluvial deposits.

Bamboo Creek Member (AFhb)

The felsic Bamboo Creek Member (*AFhb*; Thorne and Trendall, in prep.) overlaps the epiclastic unit (*AFhc*) to rest disconformably on the Mount Roe Basalt. The member thickens eastwards towards Five Mile Well (AMG 561860), where it has eroded to form high rounded hills. At the same time, the erosional epiclastic rock content of the Hardey Formation decreases to the east. Epiclastic rocks are largely absent from the formation east of a north-trending fault that transects the formation, 5.5 km southwest (AMG 474830) of Granite Well. The dominance of the felsic igneous Bamboo Creek Member in the Hardey Formation in this area is similar to that of the Koongaling Volcanic Member in the Hardey Formation in the Gregory Range Inlier to the southeast (Williams and Trendall, 1998a).

Although earlier workers considered the Bamboo Creek Member (Bamboo Creek Porphyry) to be largely intrusive (Noldart and Wyatt, 1962; Hickman et al., 1983), on WARRAWAGINE the synvolcanic intrusive component is minor. Several small sills of quartz–feldspar porphyry have intruded tuffaceous rocks toward the western margin of WARRAWAGINE. A prominent hill, 6 km south (AMG 500820) of Granite Well, is probably an intrusive body of quartz–feldspar porphyry. Further east, in the Five Mile Well area, the Bamboo Creek Member consists of an interlayered pile of amygdaloidal rhyolite and rhyodacite flows, crystal, lithic, and vitric tuffs, and accretionary lapilli tuff beds. The latter are spheroidal lapilli-sized aggregates of ash ranging from 3 to 14 mm in size. In polished slabs, the lapilli are the rim-type, consisting of a core of coarse-grained ash surrounded by a rim of finer grained ash. The rims are in places partly separated from the core by half moon-shaped cavities now filled with clear chalcedonic silica. The scattered amygdales in the rhyolite are filled with quartz and banded agate.

The felsic lavas and primary pyroclastic deposits in this part of the Bamboo Creek Member are subaerial. The pyroclastic rocks are probably the result of phreatomagmatic eruptions (McPhie et al., 1993).

Close to the western margin of WARRAWAGINE, the Bamboo Creek Member is disconformably overlain by a thin-bedded pebble and cobble conglomerate, purple-red, very coarse grained sandstone, and red-brown feldspathic sandstone succession (*AFha*). The clasts in the conglomerate are mainly porphyry, felsite, and chert. As noted on MUCCAN (Williams, 1999), the clastic material in this succession appears to be derived mainly from the underlying Bamboo Creek Member. The coarse epiclastic succession (*AFha*) is probably a fluvial deposit.

This coarse epiclastic succession (*AFha*) is in turn disconformably overlain by a finer grained mixed epiclastic and volcaniclastic succession (*AFhu*). The succession consists of thin-bedded, brown tuffaceous sandstone, khaki-brown siltstone, reworked brown-grey bedded lapilli tuff beds, and thin-bedded dark-grey carbonate. This succession overlaps the coarse clastic succession (*AFha*) eastwards to disconformably overlie the Bamboo Creek Member. This upper mixed volcanogenic sedimentary succession has been interpreted as lacustrine with a minor fluvial input (Blake, 1984).

Kylena Formation (AFk, AFkc)

The Kylena Formation (*AFk*; Kojan and Hickman, 1998; previously Kylena Basalt; Kriewaldt and Ryan, 1967) disconformably overlies the Hardey Formation in the southwestern corner of WARRAWAGINE. A thick succession overlaps the upper clastic successions (*AFha*, *AFhu*) of the Hardey Formation eastwards, to lie disconformably on the Bamboo Creek Member in the Five Mile Creek area.

In contrast, the Kylena Formation is restricted to small, rubbly outcrops 5 km north (AMG 902063) of Mount Cecelia, at the northern end of the Gregory Range Inlier in the southeastern corner of WARRAWAGINE. Here it is faulted against the Waroongunyah Formation of the Neoproterozoic Tarcunyah Group.

The Kylena Formation consists mainly of subaerially extruded dark-grey to grey-green massive, amygdaloidal, and vesicular basalt and basaltic andesite. The basalts consist mainly of clinopyroxene and partly altered plagioclase. Minor sericite, epidote, chlorite, and tremolite are secondary. Some carbonate alteration, including calcite veining, is also present.

The Kylena Formation ranges from 700 to 1300 m thick in the southwestern corner of WARRAWAGINE. Individual flows, many with amygdaloidal flow tops, are up to 10 m thick. The amygdales are filled with banded agate (chalcedonic silica), quartz, chlorite, and carbonate. Quartz veins form criss-cross patterns in the flow tops.

A thin, but, in places, cliff-forming horizon of grey-white carbonate and calcareous siltstone (*AFkc*) can be traced from 11.5 km southwest (AMG 410806) to 6.5 km south-southwest (AMG 478817) of Granite Well, a distance of over 8 km. This approximately 10 m-thick unit lies towards the base of the Kylena Formation. The carbonate is veined by silica (blue chert). Microbial laminations and low-profile cumulate stromatolite forms have been preferentially replaced by the silica. A brown siltstone, overlying the carbonate, has preserved asymmetric (directional) ripple marks that consistently indicate current flow from north to south.

These deposits are probably lacustrine, indicating a local hiatus in the volcanic activity.

Tumbiana Formation (AFt)

Exposures of the Tumbiana Formation (*AFt*; Hickman and Lipple, 1975) are restricted to the southwest corner of WARRAWAGINE. Because of structural complexities, the formation is postulated to lie subsurface in the Gregory Range Inlier in the southeastern corner.

On WARRAWAGINE, the formation is divided between the lower Mingah Tuff Member (*AFtt*) and upper Meentheena Carbonate Member (*AFtc*). These two members combine to give a total thickness of about 300 m for the formation.

A characteristic feature of the Tumbiana Formation on WARRAWAGINE is that it is intruded by a number of medium- to coarse-grained dolerite sills (*Ad*). The Tumbiana Formation has been deposited in shallow coastal-marine, intertidal, and lacustrine environments (Packer, 1990). It was accompanied by localized phreatomagmatic activity, as indicated by the high accretionary lapilli-tuff content of the formation. The Tumbiana Formation disconformably overlies the subaerial mafic volcanic Kylena Formation.

Mingah Tuff Member (AFtt)

The Mingah Tuff Member (*AFtt*; Lipple, 1975) consists of pyroclastic, resedimented, syneruptive volcaniclastic and volcanogenic sedimentary rocks. These include bedded grey-green pisolitic and accretionary lapilli tuffs, blue-grey, fine-grained crystal, lithic, and vitric tuffs, and red-brown to maroon tuffaceous shale, siltstone, and fine-grained sandstone. There are rare thin beds of grey-blue carbonate towards the top of the member.

The accretionary lapilli vary from 2 to 9 mm in diameter. Many are concentrically zoned with up to eight layers of alternating fine- and coarse-grained ash; others are simple rim-type lapilli where fine-grained ash encloses a coarse-grained core (McPhie et al., 1993). Most of the lapilli beds have been reworked under subaqueous conditions.

Fine-grained basaltic flows, noted elsewhere in the Mingah Tuff Member (Williams, 1999), are absent on WARRAWAGINE. The tuffaceous sandstone and siltstone contain normal and reverse graded beds, cross-beds, and ripple marks. Palaeocurrent directions are multidirectional.

Meentheena Carbonate Member (AFtc)

The Meentheena Carbonate Member (*AFtc*; Lipple, 1975) consists of thin to thick beds of banded dark-grey to yellow-brown dolomite and limestone characterized by stromatolitic bioherms and biostromes, scattered oncolites, and microbial laminations. Commonly cliff-forming, the carbonates are interbedded, at varying scales, with brown, purple, and green tuff, tuffaceous shale, siltstone, and calcareous sandstone. Some lapilli tuff beds are also present. In many cases, the demise of the stromatolite bioherms appears to have been caused by burial beneath volcanic ash.

A wide range of stromatolite forms has been described from the Meentheena Carbonate Member (Grey, 1984; Packer, 1990; Williams, 1999). The depositional environment for the stromatolites has been described as sublittoral to supralittoral (Packer, 1990). Field mapping on the adjacent ISABELLA has located stromatolite-rich carbonate rocks interbedded with lesser volcanogenic sedimentary and reworked tuffaceous rocks. These were assigned to the Tumbiana Formation by Williams and Trendall

(1998a). The high carbonate content suggests that these rocks may be equivalent to the Meentheena Carbonate Member on WARRAWAGINE. This correlation would then imply that the Meentheena Carbonate Member is subsurface in the Gregory Range Inlier on WARRAWAGINE.

Maddina Formation (AFm)

The Maddina Formation (*AFm*; Kojan and Hickman, 1998; previously Maddina Basalt; MacLeod and de la Hunty, 1966) is exposed in the southwestern corner of WARRAWAGINE, and in the Gregory Range Inlier in the southeastern corner of the sheet. The formation is 1000 m thick in the southwestern corner, where it disconformably overlies the Meentheena Carbonate Member. A similar thickness is probably present in the faulted slices of the Maddina Formation that are exposed in the Gregory Range Inlier. The base of the formation is not exposed in these latter areas. A total thickness of 700 m has been recorded from ISABELLA to the east (Williams and Trendall, 1998a). In the Gregory Range Inlier on WARRAWAGINE the Maddina Formation is exposed along Gum Creek (AMG 910800) in the southeastern corner. Here it is faulted against the Carawine Dolomite and disconformably overlain by the Jeerinah Formation. Other exposures lie 2.8 km northwest (AMG 875946) and 3 km south-southeast (AMG 905890) of the abandoned Barramine Homestead. In all these areas, the Maddina Formation is exposed in the cores of faulted north-northwesterly plunging anticlinal structures.

The Maddina Formation consists of stacked basalt lava flows petrographically indistinguishable from basalts of the lower part of the Kylena Formation. The lava flows are subaerial and average around 20 m thick. Flow tops on individual flows are marked by brecciation, quartz veining, and scoriaceous surfaces. The basalt is amygdaloidal or vesicular. The abundance of the amygdales increases upwards within individual flows. The amygdales may be filled with quartz, banded agate (chalcedony), chlorite, calcite, epidote, and the odd sulfide fleck.

Kuruna Member (AFmk)

About two-thirds of the way up the Maddina Formation there is a distinctive horizon, between 30 and 70 m thick, of yellow, brown, and greenish-grey silicified tuffaceous sandstone, siltstone, and mudstone interbedded with thin-bedded pisolitic lapilli tuffs and silicified vitric tuffs. The unit is clearly distinguishable on aerial photographs by its pale colouration against the background of dark-coloured basalts.

This pyroclastic and volcanogenic sedimentary unit is exposed west, northwest, and north of Pinjian Pool (AMG 558770) in the southwestern corner of WARRAWAGINE. In this area, the unit is bounded on the northern side by a thick (approximately 100 m) dolerite sill (*Ad*). There are similar horizons north (AMG 915805) of Gum Creek and 5 km south-southeast (AMG 917876) of the abandoned Barramine Homestead in the Gregory Range Inlier.

This unit has been assigned to the Kuruna Member (*AFmk*; Thorne and Tyler, 1997) of the Maddina Formation. In earlier mapping, this unit was called the Kuruna Siltstone (MacLeod and de la Hunty, 1966). On YARRIE (Hickman et al., 1983), the Kuruna Siltstone had been used to separate the Nymerina Basalt from the overlying Maddina Basalt, both now superseded terms (Fig. 5).

Jeerinah Formation (AFj)

Initially, the Jeerinah Formation (*AFj*; MacLeod et al., 1963) was mapped as Lewin Shale on YARRIE (Hickman et al., 1983). However, this term was soon superseded and the formation assigned to the Jeerinah Formation (Hickman, 1983; Williams, 1989; Fig. 5).

In the southwestern corner of WARRAWAGINE, the Jeerinah Formation is restricted to a number of small outcrops, offset by faults, west and north of Pinjian Pool on the Nullagine River. In this area, the Jeerinah Formation is about 350 m thick. It disconformably overlies the Maddina Formation and is intruded by a thick, medium-grained dolerite sill (*Ad*) in the vicinity of Pinjian Pool.

The Jeerinah Formation (*AFj*) consists of red-brown, coarse-grained sandstone, siltstone, and shale, coloured chert and banded chert, and thin beds of grey, brown, and yellow dolomite and sandy dolomite. The latter include some edgewise breccia horizons. There are scattered goethite (limonite) nodules after pyrite in the surficial material overlying the weathered shale and chert beds.

In contrast to the limited exposure in the southwestern corner, the Jeerinah Formation is widespread in the Gregory Range Inlier on the southeastern corner of WARRAWAGINE. As well as the epiclastic and chemical sedimentary rock — components characteristic of the Jeerinah Formation in the west — the formation also contains two locally thick volcanic members: the lower mafic volcanic Baramine Volcanic Member (*AFjv*), and the upper felsic igneous Isabella Member (*AFji*), in the southeastern corner.

The distribution of the Jeerinah Formation in this area is controlled by northwesterly to north-northwesterly trending faults. The largest exposed area is centred around the abandoned Barramine Homestead. Here, mostly shallow, easterly dipping and some steep westerly dipping Jeerinah Formation is exposed in a faulted, asymmetric northerly plunging anticline. A similar faulted structure lies 8 km south (AMG 880850) of Barramine Homestead. A third fault-bounded area of Jeerinah Formation lies south (AMG 900770) of Gum Creek. The maximum thickness for the Jeerinah Formation in these areas is around 800 m.

In all areas, the basal Jeerinah Formation consists of interbedded sandstone, siltstone, shale, mudstone, chert, and thin-bedded dolomite (*AFj*). This basal epiclastic succession disconformably overlies, or is faulted against, the Maddina Formation.

Similar epiclastic and chemical sedimentary rocks separate the lower Baramine Volcanic Member from the upper Isabella Member. Similar rocks also overlie the Isabella Member. The sedimentary rocks lying between the two volcanic members are typically silicified khaki-green, blue, grey, and brown shale, mudstone, and siltstone. The upper part of the Jeerinah Formation is characterized by a higher proportion of multicoloured chert and thick, banded chert horizons. These are interbedded with cream to brown sandstone, siltstone, silicified white to reddish shale, and thin-bedded dolomite. Goethite nodules after pyrite weather from some of the shale and chert horizons.

Baramine Volcanic Member (AFjv)

The Baramine Volcanic Member (*AFjv*; Hickman, et al., 1983; redefined in Williams and Trendall, 1998a) is a mafic pyroclastic and resedimented syneruptive volcaniclastic unit conformably enclosed within the largely epiclastic Jeerinah Formation. The Baramine Volcanic Member is widespread in the Jeerinah Formation of the Gregory Range Inlier on WARRAWAGINE, where it reaches a maximum thickness of about 400 m. The member can be traced almost continuously from 3 km south (AMG 904975) of Mount Cecelia to the Barramine Homestead area, and from there southeast for a further 11 km onto ISABELLA (Williams and Trendall, 1998a). Other exposures lie 8 km south (AMG 880850) of Barramine Homestead and on BRAESIDE (Williams and Trendall, 1998b), 35 km to the south-southeast.

The Baramine Volcanic Member is characterized by dark-brown to dark-grey weathering pyroclastic and volcaniclastic rocks. Most exposures are well jointed and the high carbonate content of the rocks has resulted in a karst-like weathered surface. The volcanic rocks span a range of compositions, including basalt, trachybasalt, basaltic andesite, and andesite.

Welded volcanic agglomerate and breccia, with contorted clasts up to 40 cm, lie 1.5 km south (AMG 889906) of the abandoned Barramine Homestead. Larger clasts (100 cm) or volcanic bombs have been recorded elsewhere in the district (Williams and Trendall, 1998a). Many of the fragments are scoriaceous, although most vesicles are now filled with carbonate, chlorite, and quartz. In general, most rocks in the Baramine Volcanic Member are strongly carbonated (dolomite and calcite). The clasts in the volcanic agglomerate are commonly rimmed with carbonate. The welded volcanic agglomerate and breccia appear to be proximal explosive magmatic deposits.

Most of the Baramine Volcanic Member consists of a mixture of bedded vitric, lithic, and crystal tuff, with some minor accretionary lapilli tuff interlayered with fine- to coarse-grained volcaniclastic rocks. The latter are characterized by thin (cm)- to thick-bedded (approximately 10 m) units of chaotic, unstratified aggregates of mafic lava clasts. These include glassy (vitric) basalt, vesicular trachybasalt, and fine-grained, amygdaloidal or vesicular basalt and andesite.

In general, the larger clasts are in the thickest beds. Within the individual beds, the lava clasts are matrix-supported and may be either oligomictic or polymictic in character. Some of the thinner beds are cross-bedded and many of the thicker beds show normal or reverse graded bedding. Although such sedimentary structures may indicate subaqueous conditions, there is little evidence to support epiclastic water-lain turbiditic conditions (Williams, and Trendall, 1998a). Many of the bedforms in the Baramine Volcanic Member resemble pyroclastic surge deposits associated with phreatomagmatic eruptions, and debris-flow deposits generated from the collapse of volcanic edifices (McPhie et al., 1993). These are associated with subaerial explosive volcanic centres.

Isabella Member (AFji)

The Isabella Member (*AFji*; Williams and Trendall, 1998a) is a felsic igneous unit conformably enclosed within the upper part of the Jeerinah Formation. Like the lower Baramine Volcanic Member, it is restricted to the Gregory Range Inlier in the southeastern corner of WARRAWAGINE.

The Isabella Member is discontinuous along strike. It reaches a maximum thickness of around 200 m, 2.5 km south (AMG 896900) of the abandoned Barramine Homestead. It forms prominent rounded hills that trace out a series of northerly-plunging folds. The Isabella Member is also well exposed 5 km southwest (AMG 860880) of Barramine Homestead, where it constitutes a bold southeasterly trending ridge over 10 km long.

The Isabella Member consists of brown-weathering, grey to blue fine-grained or porphyritic rhyolite. There are small spherical amygdales in some horizons. These are filled with quartz, chlorite, and carbonate. Phenocrysts are potash feldspar, quartz, and rare plagioclase. Zircon is not present in the samples examined. The fine-grained matrix can be granular or spherulitic. The latter contains spherulites of potash feldspar up to 0.5 mm in diameter. Blue silicified tuffaceous shales are interlayered with the rhyolite.

A small area of leucocratic microgranite, comprising mainly quartz and potash feldspar, is present in the Jeerinah Formation 6.5 km north (AMG 888988) of Barramine Homestead. The microgranite lies at a similar stratigraphic position to that of the Isabella Member, to which it has been assigned.

The Isabella Member is interpreted to be a felsic volcanic unit that includes some synvolcanic intrusive rocks.

Thick medium- to coarse-grained dolerite and gabbro sills and dykes (*Ad*) intrude all components of the Jeerinah Formation in the Gregory Range Inlier.

Mafic intrusive rocks (*Ad*)

A suite of north-northwesterly trending, medium- to coarse-grained subophitic- to ophitic-textured dolerite dykes intrude the Warrawagine Granitoid Complex. They also extend upwards into the basal Mount Roe Basalt of the Fortescue Group, 5 km southwest (AMG 480830) of Granite Well. Although dyke segments can be traced for over 10 km, individual dykes are mostly less than a kilometre long. Single dykes tend to be gently arcuate or meander in the general strike direction.

Thick sills (up to 200 m) of medium- to coarse-grained dolerite and gabbro intrude the Tumbiana Formation, the Kuruna Member of the Maddina Formation, and the Jeerinah Formation in the southwestern corner of WARRAWAGINE. In all cases, the mafic sills seem to favour fine-grained sedimentary horizons within these formations.

Similar dolerite and gabbro sills and dykes also intrude the Maddina and Jeerinah Formations in the Gregory Range Inlier. All of these bodies show alteration commensurate with very low grade metamorphism.

Hamersley Group

Carawine Dolomite (AHc)

The Carawine Dolomite (*AHc*; Noldart and Wyatt, 1962; Hickman, 1983) is the sole representative of the Hamersley Group on WARRAWAGINE. In the southwestern corner, it is restricted to a few rocky exposures along the Nullagine River, north of Myolla Bore (AMG 566764). The Carawine Dolomite is capped and partly enclosed by the Palaeoproterozoic Pinjian Chert Breccia (*Ƥcb*).

Along the southeastern margin of WARRAWAGINE, the Carawine Dolomite, together with the closely connected Pinjian Chert Breccia, is the dominant component of the Gregory Range Inlier. The distribution of the two units is partly controlled by major northwesterly trending transpressional faults. These restrict the distribution of the Carawine Dolomite – Pinjian Chert Breccia succession to three main zones: south of Mount Cecelia, southwest of the abandoned Barramine Homestead, and along and northwest of Gum Creek. In all areas, the ratio of exposed Pinjian Chert Breccia to Carawine Dolomite is about 3:1. The Carawine Dolomite is exposed in highly irregular-shaped outcrops of cliff-forming dolomite that is enclosed within or is overlain by rubble-strewn Pinjian Chert Breccia. The latter unit forms high rounded hills.

Although the Pinjian Chert Breccia is unconformable on the Carawine Dolomite, this highly irregular contact has been recognized as a palaeokarst surface (Hickman, 1978; Williams 1989). The development of the chert breccia is thought to be, in part, coeval with the regional karstification of the Carawine Dolomite (Williams and Trendall, 1998a).

The Carawine Dolomite is well exposed along Gum Creek (AMG 891785), where it disconformably overlies bedded silicified shales of the Jeerinah Formation. A similar contact has been described in detail on BRAESIDE (Williams and Trendall, 1998b). Other significant exposures lie in areas 3.5 km northwest (AMG 860935), 3 km west (AMG 860914), and 5 km south of Barramine Homestead.

The Carawine Dolomite is mainly a brown-weathering, grey, recrystallized dolomite. Local iron and manganese impurities may stain the carbonate dark grey, orange, or red-brown. Thin shale and nodular chert beds increase towards the base of the formation. The thickness of the Carawine Dolomite on WARRAWAGINE is difficult to estimate due to the karst weathering. Over 500 m has been recorded from a drillhole on PEARANA to the south (Williams and Trendall, 1998c).

There is a wide variety of sedimentary structures in the dolomite. These include wave ripples, flat-pebble conglomerate (oncolitic), evaporitic crystal pseudomorphs after aragonite, gypsum and halite, oolites, dololaminite, and stromatolites (Simonson et al., 1993). Scattered cumulate and hemispherical stromatolites up to 1 m, and oncolites up to 20 cm, have been recorded in a number of localities. Good examples of stromatolitic dolomite lie 4.8 km southwest (AMG 856891) of Barramine Homestead and around 6 km east-southeast (AMG 840822) of White Bore, both in the Gregory Range Inlier and 2 km north (AMG 570783) of Myolla Bore in the southwestern corner of WARRAWAGINE.

The Carawine Dolomite is considered to be a shallow-water platform deposit (Simonson et al., 1993). Jahn and Simonson (1995) obtained a Pb–Pb isochron age of 2541 ± 32 Ma from the Carawine Dolomite. This is interpreted as a minimum age and may represent regional diagenesis.

Archaean–Proterozoic rocks

Sedimentary rocks

Pinjian Chert Breccia (Ƥcb)

Exposures of the Pinjian Chert Breccia (*Ƥcb*; Noldart and Wyatt, 1962) are closely tied to the regional distribution of the Carawine Dolomite of the Hamersley Group. On WARRAWAGINE, the Pinjian Chert Breccia is the dominant rock type of this relationship, both in the Myolla Bore area in the southwestern corner and in the Gregory Range Inlier along the southeastern margin.

The Pinjian Chert Breccia unconformably overlies the Carawine Dolomite. The highly irregular contact is attributed to the infilling of a coevally developing palaeokarst surface in the dolomite (Hickman, 1983; Williams, 1989). On WARRAWAGINE, the Pinjian Chert Breccia weathers to large rounded hills that cap or surround cliff-forming Carawine Dolomite.

The breccia consists of randomly mixed, angular fragments of chert and banded chert that can be chaotic or crudely bedded. The chert fragments are of mixed origin. Their sources include: primary banded chert that was locally deposited above the Carawine Dolomite before uplift and subaerial karstification and solutional collapse of the underlying dolomite; primary chert beds interlayered with the dolomite that were released during dissolution of the carbonate; and secondary chert, probably formed during diagenetic silicification of the carbonate and later released during dissolution of the remaining carbonate (Williams and Trendall, 1998b).

The age of these rocks has not been directly determined, although it is postulated that the initial process was connected with uplift, probably during the early Palaeoproterozoic. The Pinjian Chert Breccia is unconformably overlain by the Mesoproterozoic Manganese Subgroup of the Bangemall Basin on PEARANA (Williams and Trendall, 1998c). In addition, the Carawine Dolomite and Pinjian

Chert Breccia were subjected to long periods of subaerial erosion during the Cainozoic (Dammer et al., 1999). Such weathering has resulted in further brecciation and siliceous recementation of the primary and secondary chert material.

Structure

On WARRAWAGINE, access to pertinent structural data is limited to the exposed Archaean and Proterozoic rocks in the southwesterly and southeasterly corners of the sheet. An attempt has been made, using published TMI (Mackey and Richardson, 1997) and Bouguer anomaly maps (BMR, 1979), together with exploration drill data (Sentinel Mining Company, 1967; Johnson, 1993), to interpret the subsurface Precambrian basement underlying the Permian and Mesozoic rocks of the Canning Basin and the Mesozoic rocks of the Lambert Shelf that cover 63% of the sheet (Fig. 3).

Early deformation structures (D_1) are preserved in the Warrawagine Granitoid Complex (Hickman, 1983; Hickman et al., 1983; Williams, 1999). These structures are within xenoliths and remnants of moderate- to high-grade banded gneiss (c. 3655–3576 Ma) that are enclosed within younger (c. 3313–3242 Ma) monzogranites. These structures include small, tight isoclinal and rootless intrafolial folds.

Mesoscopic northwesterly and southeasterly plunging isoclinal and m-vergence folds (D_2), exposed along the northern bank of the De Grey River 7 km south (AMG 418096) of Callawa Homestead, fold both the large xenoliths and the foliated granitoid host. These xenolith-rich zones have been interpreted to be the roots of greenstone belts (Hickman, 1983). Here the folding is attributed to the main deformation episode (D_2; Hickman et al., 1983; Hickman, 1983; Williams, 1999). This complex and multiphase deformation has been interpreted to be the product of tectonic–magmatic interaction, over a long time interval, of diapirically rising granitoid bodies in conjunction and commensurate with the gravitational sinking and/or sliding-off of the overlying volcano-sedimentary supracrustal rocks or greenstones into the regions between the rising granitoid complexes (Hickman, 1984; Collins et al., 1998).

The TMI image map (Mackey and Richardson, 1997; Fig. 4) suggests that the Warrawagine Granitoid Complex probably extends northwards beneath the Mesozoic rocks of the Lambert Shelf and northeasterly beneath Permian rocks of the Canning Basin. Permian rocks also mask what is presumably a faulted contact between the Proterozoic Paterson Orogen rocks and the Warrawagine Granitoid Complex in the northeastern corner of WARRAWAGINE (Fig. 3).

A small area of tightly folded and faulted Nimingarra Iron Formation (Gorge Creek Group) at Mount Cecelia is the only exposed greenstone component of the East Pilbara Granite–Greenstone Terrane on WARRAWAGINE, apart from xenoliths in the Warrawagine Granitoid Complex.

A link between the Nimingarra Iron Formation at Mount Cecelia and the same formation in the Yarrie district on MUCCAN, 75 km to the west (Williams, 1999), is supported by a strong, almost continuous magnetic signature (Fig. 4) between the two localities (see **Gorge Creek Group**). In both areas, the Nimingarra Iron Formation unconformably overlies the Warrawagine Granitoid Complex.

The Warrawagine Granitoid Complex is cut by the east-northeasterly trending Du Valles Fault (Fig. 3), 2.5 km south of Callawa Homestead (Fig. 1). This dextral strike-slip fault is marked by large quartz-filled shear zones. These form quartz ridges up to 70 m high. On the adjoining MUCCAN to the west, the Du Valles Fault has a dextral offset of over 5 km. The fault post-dates the deformation of the Gorge Creek and De Grey Groups on MUCCAN (Williams, 1999). The Du Valles Fault is offset on WARRAWAGINE by late northwesterly and northerly trending faults with apparent dextral displacements. These faults may be related to the Proterozoic tectonism of the Paterson Orogen region that lies to the east.

In the southwestern corner of WARRAWAGINE, the upper Archaean Fortescue Group and overlying Carawine Dolomite of the Hamersley Group occupy the northern limb of the southeasterly plunging Oakover Syncline (Hickman et al., 1983; Williams, 1999). The Oakover Syncline overlies a pre-existing D_2 synclinorium containing supracrustal rocks of the Warrawoona and Gorge Creek Groups (Hickman, 1983; Williams, 1999). These are sandwiched between the Mount Edgar, Warrawagine, and Yilgalong Granitoid Complexes in this area.

The south to southeasterly dipping Fortescue Group – Carawine Dolomite succession is truncated by a number of north to northwesterly trending normal and reverse faults. The age of these faults remains uncertain. In some cases they may correspond to reactivated basement faults (Williams, 1999). Others post-date the upper Archaean Carawine Dolomite and are parallel to the major transpressional faults of the Gregory Range Inlier to the east.

The exposed Fortescue Group and Carawine Dolomite in the southwestern corner are separated from identical rocks in the Gregory Range Inlier, 23 km to the east, by a broad valley containing the Nullagine and Oakover rivers. Seismic-refraction profiles and some exploration drillholes (Sentinel Mining Company, 1967) have shown that the depth to Precambrian basement is up to 660 m below the present-day surface. The valley contains fluvioglacial Permian Paterson Formation overlain by evaporative, lacustrine, and alluvial Cainozoic deposits. Two exploration drillholes (Sentinel Mining Company, 1967) 18.5 km (AMG 744041) and 27 km (AMG 848011) northeast of Warrawagine Homestead have intersected medium-grained and amygdaloidal mafic rocks, at 255 m and 68 m below the surface respectively. The mafic rocks are interpreted to be basalts of the Fortescue Group. Their presence points to the continuation of the Fortescue Group rocks beneath the thick Phanerozoic cover in this area.

The distribution of the Fortescue Group rocks and Carawine Dolomite in the Gregory Range Inlier is controlled to some extent by large, subparallel northwest to north-northwesterly trending and steep northeasterly dipping reverse faults. In most cases these faults have a measurable sinistral strike-slip component. Such reverse faults truncate earlier north-trending, vertical, and steep reverse (east-dipping) faults. The northwesterly trending reverse faults are oblique (approximately 20°) to and post-date northwesterly and southeasterly plunging folds. These folds have asymmetric profiles with steep southwesterly and shallow northeasterly dipping surfaces. Overall, the bedding strike of the Fortescue Group and Carawine Dolomite is northwesterly. Folding and faulting in the Gregory Range Inlier is mainly attributable to events taking place in the adjacent Proterozoic Paterson Orogen. (see **Structure**, p. 22).

Trendall (1991) also suggested that some of the larger faults in the Gregory Range Inlier may have originally been growth faults during the early depositional stages of the Fortescue Group. This would have corresponded to the outpouring of the felsic Koongaling Volcanic Member, exposed on the adjacent ISABELLA (Williams and Trendall, 1998a), and the emplacement of the anorogenic (A-type) subvolcanic Gregory Granitic Complex during crustal extension (?rifting; Williams and Trendall, 1998b). Subsequent complex and multiple compressive events, originating from within the adjacent Proterozoic Paterson Orogen and attributed to crustal collision brought about by plate convergence (Myers, 1993; Hickman et al., 1994; Bagas and Smithies, 1998), are thought to have reactivated these faults. This resulted in reversal of movement along many of the pre-existing normal listric fault surfaces (Trendall, 1991; Williams and Trendall, 1998a).

Proterozoic rocks

Paterson Orogen

On WARRAWAGINE, Proterozoic rocks are represented by faulted outliers of exposed Neoproterozoic Tarcunyah Group around and north of Mount Cecelia. Subsurface Mesoproterozoic Throssell Group underlies Permian rocks of the Canning Basin in the northeastern corner of the sheet. Both the Tarcunyah and Throssell Groups belong to the Paterson Orogen, an arcuate northwesterly trending belt, about 1200 km long, of folded and metamorphosed sedimentary and igneous rocks. These range in age from Palaeoproterozoic to Neoproterozoic and have a common tectonic history (Williams and Myers, 1990). The exposures on WARRAWAGINE lie at the northern end of the Paterson Orogen.

It is also probable that the Neoproterozoic Eel Creek Formation underlies Mesozoic rocks of the Lambert Shelf in the northwestern corner of the sheet (Williams, 2000). The Eel Creek Formation is correlated with the Tarcunyah Group that lies along the eastern margin of WARRAWAGINE (Williams, 1999).

Throssell Group (*ЁT*)

The Throssell Group (*ЁT;* Williams and Bagas, 1999), together with the overlying Lamil Group (Bagas, 2000), constitute the Yeneena Supergroup (Williams and Bagas, 1999) of the Yeneena Basin (Williams, 1990). The sedimentary rocks of the Throssell Group have undergone low-grade greenschist-facies metamorphism and deformation during the Miles Orogeny (Proterozoic D_3–D_4) and later deformation during the Paterson Orogeny (Proterozoic D_6; Bagas and Smithies, 1998; Williams and Bagas, 1999).

The extension of metasedimentary Throssell Group rocks north-northwesterly across the northeastern corner of WARRAWAGINE can be projected from exposures on the adjacent ISABELLA (Williams and Trendall, 1998a). The regional TMI image (Fig. 4) shows a regional north-northwesterly trending magnetic signature in this area, which extends and parallels the regional strike of the exposed Throssell Group to the southeast on ISABELLA (Williams and Trendall, 1998a).

A shallow exploration drillhole (150 m) intersected 51 m of micaceous quartzite beneath 99 m of Permian sandstone, 25 km north (AMG 892261) of Mount Cecelia (Johnson, 1993). The quartzite, assigned to the Throssell Group, underlies the western edge of the Wallal Platform of the Canning Basin.

The western margin of the Throssell Group is bordered by the east-dipping, dextral transpressional Vines Fault (Williams and Trendall, 1998b).

Tarcunyah Group (*ЁU*)

The Tarcunyah Group (*ЁU*; Williams and Bagas, 1999) has recently been correlated with Supersequence I of the Centralian Superbasin (Bagas et al., 1999) and is a northwestern extension of the Officer Basin (Bagas et al., 1995, 1999; Williams and Bagas, 1999). The Tarcunyah Group was deformed during the Paterson Orogeny (Proterozoic D_6; Bagas and Smithies, 1998).

Exposures of the Tarcunyah Group are restricted to the central-eastern margin of WARRAWAGINE. The largest exposure is centred 7 km north (AMG 915080) of Mount Cecelia, where it is faulted against the Kylena Formation of the Fortescue Group. In addition, two small fault-bounded exposures lie just south (AMG 908000) and on the northern flank (AMG 909015) of Mount Cecelia. In all areas, the exposed succession belongs to the Waroongunyah Formation of the Tarcunyah Group.

Waroongunyah Formation (ЁUw, ЁUwd, ЁUws)

The Waroongunyah Formation (*ЁUw*; Williams, 1989) is a mixed fine- to medium-grained clastic carbonate succession. The small fault-bounded slice, south of Mount Cecelia, consists of thin-bedded, grey, mauve, and white dolomite, and uncommon medium-grained, cross-bedded red-brown sandstone (*ЁUwd*).

The small exposure on the northern flank of Mount Cecelia consists of khaki-green to grey, banded sandy and argillaceous dolomite with thin beds of chert and calcite-rich carbonate breccia. This unusual outcrop also appears to be completely surrounded by faults. The dolomite is recumbently folded. Small thrust faults in the succession indicate transport from north to south. The whole exposure may be a thrust klippe preserved on the steeply dipping Nimingarra Iron Formation of the Gorge Creek Group.

The largest exposure of Waroongunyah Formation, centred about 7 km north of Mount Cecelia, consists of two distinct assemblages. Brown, cream, and grey thin-bedded dolomite with uncommon beds of red-brown siltstone and sandstone (*ĿUwd*) is interlayered with thick-bedded, mauve to purple-red, bouldery, fine- to medium-grained sandstone and siltstone (*ĿUws*). The red-brown sandstone is commonly cross-bedded. On the adjacent ISABELLA, poorly preserved stromatolites have been found in brown dolomite (*ĿUwd;* Williams and Trendall, 1998a).

The Waroongunyah Formation is a transgressive shallow-marine succession that was probably deposited shorewards of carbonate build-ups. These may have been barrier islands or carbonate platforms marginal to the Pilbara Craton. This unit can be traced at least 200 km to the south (Williams and Trendall, 1998c; Williams and Bagas, 1999).

Structure

The Proterozoic Paterson Orogen that underlies the northeastern corner of WARRAWAGINE has yielded evidence for at least six major deformation episodes and three regional metamorphic events (Bagas and Smithies, 1998; Hickman and Bagas, 1999). These events have, in various ways, impinged upon the eastern margin of the Pilbara Craton and are responsible for the transpressional deformation recorded in the Gregory Range Inlier; an area largely composed of upper Archaean Fortescue Group, Carawine Dolomite, Pinjian Chert Breccia, and underlying Gregory Granitic Complex.

The earliest episode, the Yapungku Orogeny (D_{1-2}; c. 2000–1760 Ma) has only been recognized in the Rudall Complex (Bagas and Smithies, 1998), 220 km southeast of WARRAWAGINE. The magmatic, metamorphic, and deformational history of the Rudall Complex has been described in terms of plate-tectonic processes (Myers et al., 1996). This involved the initial collision and amalgamation of the southeast Pilbara Craton with continental crust from the east and northeast (?North Australian Craton; Smithies and Bagas, 1997; Bagas and Smithies, 1998; Hickman and Bagas, 1998). This event does not appear to be recorded on the northeastern margin of the Pilbara Craton.

Following the collisional events of the Yapungku Orogeny, subduction (Hickman et al., 1994; Smithies and Bagas, 1997; Bagas and Smithies, 1998) was replaced by strike-slip faulting. The Yeneena Basin, which hosts the Throssell Group on WARRAWAGINE, may be the product of such strike-slip movement (Hickman et al., 1994). The Throssell Group unconformably overlies the Rudall Complex.

Both the Rudall Complex and Throssell Group were deformed and metamorphosed by the Miles Orogeny (D_{3-4}; c. 1250–800 Ma; Bagas et al., 1995; Smithies and Bagas, 1998), during which there was a continuation of the southwesterly to westerly compressional regime. This event is postulated to be connected with the assembly of the North, South, and West Australian Cratons as part of the Rodinian Supercontinent (Myers et al., 1996).

On WARRAWAGINE, the asymmetric, northwesterly trending folds, with steep southwesterly and shallow northeasterly dipping surfaces that were recorded from Fortescue Group rocks and the Carawine Dolomite in the Gregory Range Inlier, are attributed to the Miles Orogeny (D_4). After the initial folding, continued compression saw the development of brittle fracturing and subsequent uplift along steep reverse faults. This involved southwestern transport and measurable sinistral strike-slip movement (Williams and Trendall, 1998a,b,c). Such structures are also briefly described in the section on **Structure** (p. 20).

The throw on the steep reverse faults, in many cases, is considerable. South of Mount Cecelia, steep reverse faults have juxtaposed Nimingarra Iron Formation of the Gorge Creek Group against the Pinjian Chert Breccia and Carawine Dolomite of the Hamersley Group; a vertical movement in excess of 3500 m. South of the abandoned Barramine Homestead, lower units of the Maddina Formation are faulted against Pinjian Chert Breccia, and are indicative of at least 1500 m of vertical movement.

Further south on PEARANA (Williams and Trendall, 1998a), Rb–Sr mineral-isochron biotite ages of 1226 and 1194 Ma have been obtained from the Gregory Granitic Complex. These ages probably correspond to the time of uplift of the granitoid body, an event attributed to the Miles Orogeny.

Although the Tarcunyah Group rocks (c. 800 Ma) are faulted against Fortescue Group rocks on WARRAWAGINE, elsewhere they unconformably overlie both the Fortescue Group and Gregory Granitic Complex (Williams and Trendall, 1998a,b,c). Recent studies have concluded that the Tarcunyah Group is a northwestern extension of the Officer Basin (Bagas et al., 1995, 1999). Hence, the observation that the Waroongunyah Formation of the Tarcunyah Group is a shallow-marine succession (Williams and Trendall, 1998a,b) indicates that there was a pause in the episodic compressional events that are recorded in the Paterson Orogen and reflected in older rocks along the eastern margin of the Pilbara Craton. The eastward extent of the Tarcunyah Group is unknown since it has been truncated and overridden by older Throssell Group rocks along the Vines Fault. The Tarcunyah Group may have been deposited in a narrow seaway or strait linking the intracratonic Officer Basin to the south with the open ocean to the north.

The Paterson Orogeny (D_6; c. 550 Ma; Bagas and Smithies, 1998) revived the strong southwest- to west-directed compressional regime, similar to the earlier Yapungku and Miles Orogenies. The intracratonic Paterson Orogeny is thought to be connected with the break-up of Rodinia (Myers et al., 1996).

On WARRAWAGINE, the main response to this event has been the reactivation of some of the major faults that intersect the Fortescue Group rocks. The small klippe of the Tarcunyah Group on the northern flank of Mount Cecelia has probably been transported at least 3 km to its present site during this event. Also, the older Throssell Group rocks have been upthrusted over the Tarcunyah Group along the dextral, transpressional Vines Fault. The Vines Fault is projected to extend subsurface northwestwards onto WARRAWAGINE, 10.5 km north (AMG 916116) of Mount Cecelia (Fig. 3), from ISABELLA (Williams and Trendall, 1998a).

Unassigned dolerite dykes (*d*), quartz veins (*q*), and gossanous quartz veins (*qgo*)

Scattered dolerite dykes (*d*) of unknown age intersect the Warrawagine Granitoid Complex, Fortescue Group, and Carawine Dolomite – Pinjian Chert Breccia. The dykes all trend in a northerly direction and lack evidence of metamorphism.

Individual dykes in the southwestern corner of WARRAWAGINE are typically sinuous and 1–2 km long. Trains of such dykes can be traced for 10 km, extending from the Warrawagine Granitoid Complex into the overlying Fortescue Group, southeast of Granite Well.

Two large, roughly parallel dolerite dykes intrude the Pinjian Chert Breccia in the Gregory Range Inlier. There, dykes can be traced over a distance of 16 km, with some individual dykes continually exposed for over 10 km. They post-date some of the reverse faults (Miles Orogeny; c. 1300–800 Ma) but are offset by others that may have been reactivated during the Paterson Orogeny (c. 550 Ma).

The east-northeasterly to northeasterly Mundine Well Suite (Hickman, 1983) and west-northwesterly to northwesterly Round Hummock Suite (Hickman, 1983), described on the adjoining MUCCAN to the west (Williams, 1999), appear to be absent from WARRAWAGINE.

Large white quartz veins (*q*), consisting of massive or faintly banded cryptocrystalline quartz, occupy faults, brittle-ductile shear zones, and tension gashes in the Warrawagine Granitoid Complex. Most quartz veins trend in northwesterly, northerly, northeasterly, and east-northeasterly directions. The largest quartz vein on WARRAWAGINE occupies the east-northeasterly Du Valles Fault (Fig. 3), a dextral strike-slip fault cutting the Warrawagine Granitoid Complex, 2.5 km south of Callawa Homestead. The quartz forms a ridge that rises 70 m above the plain.

Gossanous quartz veins (*qgo*) lie 5 km southwest (AMG 415875) of Ten Mile Well and 600 m north (AMG 518879) of Granite Well. The gossanous quartz vein 5 km southwest of Ten Mile Well forms a sharp ridge, over 4.5 km long, that marks the position of a northwesterly trending fault line. This fault extends southeasterly to intersect the Fortescue Group unconformity. The quartz vein is composed of yellow-brown stained, goethite-bearing, vuggy and sugary recrystallized quartz. Annealed quartz-breccia zones are present at irregular intervals along the ridge. Freshly broken quartz contains scattered fine-grained pyrite crystals in places.

The Granite Well locality consists of an east-trending low ridge of very fine grained chloritic, cherty quartz veins. The veins contain flecks and crystals of pyrite and chalcopyrite. Some thin cross-cutting blue-green siliceous veins suggest minor secondary copper mineralization.

Palaeozoic rocks

Canning Basin

Permian rocks

Although exposures of Permian rocks are limited to a few widely scattered mesas and low rubbly rises in the northern and central parts of WARRAWAGINE, exploration drilling data (Sentinel Mining Company, 1967; Johnson, 1993) and palynological investigations (Backhouse, 1974, 1976) indicate that a thick Permian succession underlies Mesozoic rocks in the north and Cainozoic surficial deposits in the central and eastern parts of the Great Sandy Desert. In addition, these data show that Permian rocks extend southwards beneath Cainozoic surficial deposits, including the Oakover Formation, that occupy the broad valley containing the Oakover and Nullagine rivers. This subsurface Permian succession is exposed further south on BRAESIDE, in the Oakover River valley (Hickman, 1978; Williams and Trendall, 1998a,b).

The main depocentre for Permian rocks on WARRAWAGINE was the Canning Basin (Towner and Gibson, 1983). The basin occupies the northeastern corner and northern-central parts and extends south through the centre of the sheet to the southern boundary and beyond. In the northeastern corner, the Proterozoic Paterson Orogen is basement to the Canning Basin, whereas in the remainder of the sheet the basin overlies the Archaean Pilbara Craton (Fig. 3). These two areas roughly correspond to the Wallal Platform and the Wallal Embayment respectively (Hocking et al., 1994). However, the distribution of Permian rocks on the Pilbara Craton basement is characterized by their restriction to palaeoglacial valleys (Williams and Trendall, 1998a,b; Williams, 1999), the largest of which underlies the present-day Nullagine and Oakover river valleys.

A second palaeoglacial valley lies 8 km north (AMG 400248) of Callawa Homestead. This westerly trending valley can be traced from scattered pebbles and cobbles overlying a clay–silt surface (*Qcp*) derived from the underlying subsurface Permian rocks. This palaeoglacial valley probably links up with similar valleys in the Shay Gap area on MUCCAN (Williams, 1999). The abrupt western margin of the Permian rocks on WARRAWAGINE is probably a combination of faulting and glacial erosion (Fig. 3).

Permian rocks are probably absent from the northwestern corner of WARRAWAGINE, where Mesozoic rocks of the Westralian Superbasin overlie the Neoproterozoic Eel Creek Formation and the Warrawagine Granitoid Complex (Williams, 2000).

The Permian rocks on WARRAWAGINE consist solely of fluvioglacial Paterson Formation.

Paterson Formation (Pa)

The Paterson Formation (Traves et al., 1956; Towner and Gibson, 1980) is poorly exposed on WARRAWAGINE and generally strongly silicified (silcretized). North of the Oakover River, low rocky outcrops and mesas consist of interbedded sandstone, pebbly sandstone, pebble conglomerate, and siltstone. Cross-bedding, slumping, and minor graded bedding are recorded in these clastic units. In addition, thick, grey-green and chocolate-brown shale and mudstone, and white claystone, are intercalated in places with the coarser grained clastic units.

The exposed succession appears to be a distal fluvioglacial deposit rather than the proximal boulder- and cobble-bearing diamictite and tillite that is typical of the lower or basal parts of the Paterson Formation further south (Williams and Trendall, 1998b,c) and west (Williams 1999).

A stratigraphic borehole, drilled during iron–manganese exploration in the Oakover River valley, 3.5 km southwest (AMG 746911) of Chukuwalyee Well, reached a depth of 259 m. The borehole intersected poorly bedded diamictite (rare pebbles and cobbles in mudstone), shale, siltstone, sandstone, and thin conglomerate beds (Sentinel Mining Company, 1967). A second hole, 13.2 km to the north (AMG 744041), recorded 255 m of shale, with scattered pebbles and cobbles, siltstone, and sandstone, before intersecting basalts of the Fortescue Group. From the log descriptions, both the shale and siltstone could be diamictite (Sentinel Mining Company, 1967).

Palynological studies carried out on this second hole (AMG 744041) showed that the rocks were nonmarine. They gave late Sakmarian to middle Artinskian ages (Backhouse, 1974, 1976) indicative of lower Permian rocks. In both holes, the Permian rocks were weathered to a depth of approximately 60 m. Secondary gypsum was found in both holes to a depth of around 167 m. Seismic refraction lines, passing east–west through both boreholes, indicate that the major refractor, interpreted to be the contact between the basin fill (Permian Paterson Formation) and basement (Archaean Pilbara Craton), reaches a maximum depth beneath the present-day surface of 661 m, about 11 km west-southwest of Chukuwalyee Well (AMG 770933; Sentinel Mining Company, 1967).

The original floor of the palaeoglacial valley appears to lie midway between the present-day Nullagine and Oakover rivers. The valley axis trends in a north-northwesterly direction.

A third exploration hole was drilled 25 km north (AMG 892261) of Mount Cecelia (Johnson, 1993). This drillhole recorded 99 m of sandstone and siltstone, assigned to the Paterson Formation, before encountering a basement of micaceous quartzite. The quartzite probably belongs to the Throssell Group. The basement high in this area corresponds to the western margin of the Wallal Platform (Hocking et al., 1994; Fig. 3).

The Paterson Formation is part of depositional Sequence Pz5 (Middleton, 1990). The formation has recently been correlated with equivalent rocks in the Carnarvon Basin that have an early Sakmarian–Asselian age (Mory and Backhouse, 1997).

Mesozoic rocks

On WARRAWAGINE, Mesozoic rocks are represented by the Jurassic–Cretaceous Callawa Formation and the overlying Cretaceous Parda Formation (Towner and Gibson, 1983). These rocks are distributed along the northern margin and are best exposed in the Callawa Hills (AMG 330590), 23 km northeast of the abandoned Callawa Homestead.

The Mesozoic rocks are a component of the Lambert Shelf of the Westralian Superbasin (Hocking et al., 1994), which underlies the extreme north-western corner of WARRAWAGINE (Fig. 3). In this area, a thin cover of Callawa Formation is postulated to overlie the Neoproterozoic Eel Creek Formation and the Warrawagine Granitoid Complex (Williams, 1999; Williams, 2000). The Jurassic–Cretaceous Callawa Formation extends eastwards from this area, without apparent break, to lie with low-angle unconformity on the poorly exposed Permian Paterson Formation of the Canning Basin. The thin Mesozoic cover extends across both the Wallal Embayment and Wallal Platform divisions of the Canning Basin and into the adjacent ISABELLA area (Williams and Trendall, 1998a).

Jurassic–Cretaceous rocks

Callawa Formation (JKc)

The Callawa Formation (*JKc*; Reeves, 1951; Traves et al., 1956; Towner and Gibson, 1980, 1983) is well exposed in the Callawa Hills that surround the headwaters of Callawa Creek. The formation erodes to form prominent mesas, buttes, and cliff-lined tablelands.

Recent studies (Williams, 1999, 2000) have found that the Callawa Formation is divisible into lower and upper units. The lower unit consists of a basal conglomerate overlain by interbedded fine- to coarse-grained sandstone, siltstone, thin conglomerate beds, plant-fossil bearing ferruginous sandstone, and bioturbated claystone and sandy claystone. These rocks are well exposed 12.5 km northeast (AMG 488250) of Callawa Homestead, where there are fossil leaves and stems in ferruginous sandstone. Small straight burrows are preserved in a reddish-cream claystone at the top of this unit. The lower unit of the Callawa Formation also unconformably overlies colour-banded, silicified mudstone of the Permian Paterson Formation at this locality.

There are also good exposures of the lower unit in the upper reaches of Callawa Creek (AMG 580285). Here, thick claystone units, interbedded with cross-bedded sandstone, contain large burrows up to 75 cm long. The bioturbated claystone lies towards the top of the lower unit. Palaeocurrent data from cross-bedding are variable for the lower unit.

The upper unit forms the main cliffs and erosion-resistant cappings of the mesas and buttes. The Callawa Formation here consists of thick beds of matrix-supported pebble and cobble conglomerate, separated by medium- to coarse-grained red-brown sandstone, commonly cross-bedded. Minor intercalations of white claystone commonly carry plant fossils (Traves et al., 1956). The conglomerate clasts are chert, banded chert, BIF, and quartzite. Palaeocurrents, derived from common cross-beds, are consistently directed towards the north. High-energy conditions are in evidence in some areas, where the large cross-beds are asymptotic and include some pebbles in the cross-bedded layers of the sandstone.

The maximum thickness of the Callawa Formation on WARRAWAGINE is probably around 70 m. Reeves (1951) recorded 94 m from the No. 3 Desert Bore on COORAGOORA (Williams, 2000) and Hickman et al. (1983) estimated a thickness of about 100 m for the Callawa Formation on MUCCAN (Williams, 1999), to the west.

Recent studies of the Callawa Formation (Williams, 1999) concluded that the fluvial depositional environment attributed to the Callawa Formation (Traves et al., 1956; Hickman et al., 1983) only became fully established in the upper part of the formation. The lower unit, including the bioturbated claystones, is more likely to have been deposited in an environment of interfingering lacustrine or littoral shallow-marine conditions that were increasingly encroached upon by an advancing high-energy fluvial regime, as expressed by the upper unit.

The Callawa Formation is part of depositional sequence Mz4 (Middleton, 1990) and is Upper Jurassic to Lower Cretaceous in age (Towner and Gibson, 1983).

Cretaceous rocks

Parda Formation (Kp)

The Parda Formation (*Kp*; McWhae et al., 1958; Towner and Gibson, 1983; Hickman et al., 1983) is poorly exposed in a restricted area along the central-northern margin of WARRAWAGINE, where it disconformably overlies the Callawa Formation. The formation has a distinctive white airphoto pattern. It is commonly capped by laterite (*Czrf*). The laterite capping low hills east of the Callawa–Wallal track possibly overlies the Parda Formation.

The Parda Formation consists of thin-bedded to massive white mudstone and claystone intercalated with lenticular, fine-grained sandstone and siltstone. The thickness of the formation on WARRAWAGINE could not be measured reliably, but a thickness of 20 m has been recorded on COORAGOORA (Williams, 2000). The Parda Formation is probably a shallow-marine deposit (Hickman et al., 1983). The recent discovery of an ammonoid on COORAGOORA confirms this conclusion (Backhouse, 1999; Williams, 2000) and indicates that the Parda Formation is a correlative of the Windalia Radiolarite (Northern Carnarvon Basin) and Bejah Claystone (Gunbarrel Basin; Hocking et al., 1994).

The Parda Formation is part of depositional Sequence Mz5 (Middleton, 1990) and is probably of late Aptian age (Backhouse, 1999). The formation is the youngest preserved component of the Lambert Shelf of the Westralian Superbasin (Hocking et al., 1994). On WARRAWAGINE, the Parda Formation extends from the Lambert Shelf eastwards onto the adjoining Canning Basin divisions of the Wallal Embayment and Wallal Platform.

Cainozoic rocks

Cainozoic deposits, predominantly riverine floodplain and desert sand, cover over 80% of WARRAWAGINE. Superficial material includes consolidated lacustrine–fluvial deposits and laterite, consolidated and semi-consolidated alluvial, colluvial, and residual deposits, and unconsolidated Quaternary alluvial, colluvial, eluvial, and eolian deposits.

The distinctive Oakover Formation (Noldart and Wyatt, 1962; *Czos* upper unit, *Czoc* lower unit; Williams and Trendall, 1998b) is widespread in the southeastern quarter of WARRAWAGINE. The formation has eroded to form a prominent dissected tableland 60 m above and west of the Oakover River, on the southern margin of WARRAWAGINE. Further north towards Brown Well (AMG 665983), outliers of the Oakover Formation form scattered mesas and buttes rising above the Oakover River floodplain. Similar landforms also lie just east of Chukuwalyee Well (AMG 770933), on the northeastern side of the Oakover River. Between this locality and extending to about 10 km north (AMG 890100) of Mount Cecelia, a broad zone of the Oakover Formation is exposed in low mesas, buttes, west-facing escarpments, and low rubbly hills between sand dunes. North of Mount Cecelia, the Oakover Formation occupies the Percival Palaeoriver valley (Fig. 1; Williams and Trendall, 1998a).

The remnants of the Oakover Formation, now preserved between the Oakover River and Percival Palaeoriver, represent the eastern margin of what must have been a much larger outcrop that extended westwards across the Oakover River valley. The eastern margin of the formation is now encroached upon by longitudinal sand dunes (*Qs*) and is overlain by dissected, consolidated older colluvium (*Czcg*), primarily eroded from the Fortescue Group rocks to the east. Although not clearly exposed, the Oakover Formation appears to overlie, in some areas, ferruginous and carbonate-cemented consolidated alluvium (*Czag*). West of the Oakover River, the formation may directly overlie weathered Permian Paterson Formation. Most outcrops of the Oakover Formation are surrounded by recent scree (*Qc*). This masks the basal contact.

Recent work has subdivided the Oakover Formation into lower and upper units (Williams and Trendall, 1998b). The upper unit is a cliff-forming grey and white to bluishwhite, locally translucent vuggy opaline silica and chalcedony, with minor calcareous sandstone (*Czos*). Although some of the silica appears to be replacing carbonate in this unit, much of the silica is probably primary silica precipitated from solution.

The lower unit consists of blue, grey, and fawn limestone and calcareous sandstone (*Czoc*). It tends to form rubbly outcrops and low rounded hills, and occupies the scree slopes beneath the cliff-forming opaline silica (*Czos*). Some minor silicification of the carbonate has been recorded. The lower calcareous unit intertongues with coarse consolidated gravel and sand (*Czag*, *Czcg*), particularly along the eastern margin between Chukuwalyee Well and Mount Cecelia.

The thickness of the upper unit is mostly less than 8 m, whereas the lower unit may be up to 40 m thick. The upper siliceous unit is more restricted in area, being preserved only on the highest outcrops. Most exposures of the Oakover Formation on WARRAWAGINE belong to the lower calcareous unit.

The Oakover Formation is postulated to be a lacustrine deposit (Towner and Gibson, 1983). It possibly formed during a stillstand event with little or no concurrent erosion. The original western boundary of the Oakover Formation on WARRAWAGINE is unknown.

The age of the Oakover Formation is still conjectural, but it has been postulated to be post-Miocene (Cockbain, 1978; Williams and Trendall, 1998b).

Consolidated alluvial deposits (*Czaa*) of clay, silt, and sand are exposed in the incised banks of major streams and side tributaries in the northern half of WARRAWAGINE. Examples can be found in Callawa Creek and in the lower reaches of the Oakover River.

Related higher energy consolidated gravel, sand, and silt deposits (*Czag*) are more widespread. They are exposed along the incised banks in the upper parts of the Nullagine and Oakover rivers on WARRAWAGINE. This unit (*Czag*) also forms low mounds and rises of carbonate-cemented gravel and sand that parallel or diverge from the present-day active river beds. These elongated deposits are thought to be old gravel banks marking the position of disused, and now eroding, river channels. An example of an older course of the Oakover River runs north from around Toombingidgee Well (AMG 766991) and then west to the Oakover Bore area (AMG 618118).

Patchy dissected valley calcrete (*Czak*; Butt et al., 1977) is in two small drainage lines. These are around Wongawobbin Well and 2 km northwest and 500 m northeast of Myolla Bore. The calcrete is a secondary grey-white pisolitic, nodular and laminar carbonate. Valley calcretes are normally formed under arid conditions and may have periodically formed between the Pliocene and Pleistocene (Hocking and Cockbain, 1990).

A dissected and elevated tongue of silica- and iron-cemented alluvial channel deposit (*Czaz*) lies downstream from Ulalling Rockhole (AMG 902012), on the western side of Mount Cecelia. This deposit consists of cemented subangular and subrounded clasts of chert, jaspilite, and BIF eroded from the nearby Nimingarra Iron Formation.

Dissected consolidated colluvium (*Czc*) occupies aprons and intervening valleys between mesas and buttes of the Callawa Formation, particularly in the Callawa Hills (AMG 530590). These deposits are presumably old scree and talus deposits not specifically related to drainage lines. They consist of poorly stratified silt, sand, and pebbly sand with a clay or silica cement.

Where the mesas and buttes are capped with laterite there is a closely related dissected and consolidated iron-cemented scree (*Czcf*). This deposit consists of recemented (ferruginous) broken laterite rubble and ironstone pebbles mixed with sand, silt, and clay. The unit is confined to the Callawa Hills and Great Sandy Desert areas.

There is a third dissected and consolidated coarse colluvium (*Czcg*) along the western margin of the strongly dissected and elevated Gregory Range Inlier, south of Mount Cecelia. These high-level deposits consist of poorly stratified silt, sand, and pebbles with a silicious and clay cement. The surface of the unit is commonly covered with a lag of rock fragments, mainly chert, and quartz pebbles. The deposits are probably broad outwash fans supplemented with locally derived scree, and are indicative of an earlier, higher energy erosion cycle. The colluvium (*Czcg*) overlies and partly intertongues with the Oakover Formation.

Remnants of a ferruginous duricrust surface (*Czrf*), consisting of massive pisolitic and nodular laterite, overlie the Parda Formation in the Callawa Hills. Ferruginous duricrust is also exposed in a series of low hills stretching eastwards through the Great Sandy Desert. These hills lie along a major palaeodrainage divide in the northeastern corner of WARRAWAGINE.

Grey silcrete (*Czrz*) caps isolated mesas of Permian Paterson Formation or forms low mounds amongst the sand dunes. The silcrete consists of angular quartz grains set in a hard siliceous cement. The rock has a conchoidal fracture.

Residual calcrete (*Czrk*) overlies Carawine Dolomite west and northwest of Barramine Homestead. The calcrete forms sheets and encrustations on the dolomite and nearby volcanic rocks. Some may be calcareous tufa deposits precipitated from carbonate-charged waters issuing from the nearby Carawine Dolomite.

Quaternary deposits

Unconsolidated surficial deposits are widespread on WARRAWAGINE. They include sheetwash, colluvium, eolian, lacustrine, and riverine deposits.

Low-slope sheetwash deposits (*Qw*) lie between the Nullagine River and Tanguin Creek along the southern margin of WARRAWAGINE. They also extend 7 km north from Tanguin Creek along the western side of the prominent low tableland formed by the Oakover Formation. Small patches of sheetwash also lie to the west of the Callawa Hills. The sheetwash areas (*Qw*) have a distinctively banded vegetation pattern called 'tiger-bush' pattern (Wakelin-King, 1999). The banding is developed at right angles to the general sheetwash flow. The bare sandy and silty ground is characteristically covered with a veneer of scattered quartz and small rock pebbles. A similar low-gradient sheetwash deposit, comprising a veneer of white vein quartz and weathered granitoid rock (*Qwg*), overlies the Warrawagine Granitoid Complex upslope from the Nullagine and De Grey rivers, in the central-western part of WARRAWAGINE.

Recent colluvium (*Qc*), in the form of scree and talus mixed with silt and sand, is confined to valleys in the hilly country in the southwestern corner and Gregory Range Inlier in the southeastern corner of WARRAWAGINE. Wide colluvial aprons (*Qc*) carrying fragmented chert surround many of the mesas and low tablelands of the Oakover Formation in the southeastern quarter of the sheet.

A specific type of colluvium surrounds large quartz veins marking major faults in the Warrawagine Granitoid Complex. An example is the Du Valle Fault (Fig. 4) south of Callawa Homestead. Such scree slopes are steep and consist of pebbles and fragments of white quartz embedded in sand and silt (*Qcq*).

A mixed colluvial and eluvial deposit, comprising scattered pebbles, cobbles, and rare small boulders embedded in unconsolidated clay, silt, and silty clay (*Qcp*), overlies weathered fluvioglacial Paterson Formation. Some of the larger boulders show glacial striations and faceting. These deposits are confined to a buried west-trending palaeoglacial valley lying about 7 km north (AMG 410240) of Callawa Homestead.

Many scattered granitoid outcrops of the Warrawagine Granitoid Complex, particularly those southwest of the Nullagine River, are surrounded by residual medium- to coarse-grained quartz and feldspar sand that sometimes also carries a sparse veneer of white quartz pebbles and granitoid rock fragments (*Qrg*). Although the unit is mainly eluvial, being derived directly from weathering of the underlying granitoid rocks, there is some reworking of the finer components by wind action.

North of the Oakover River floodplains, the Great Sandy Desert (Fig. 1) covers the northern third of WARRAWAGINE and is characterized by fine- to medium-grained, red to red-brown eolian sand (*Qs*) or eolian sand partly covered with a thin veneer of ironstone, quartz, and rock fragments. (*Qsf*). The eolian sand (*Qs*) occupies the sandplain in the western half of the sheet and constitutes the large and continuous longitudinal and chain dunes in the eastern half. The lag-covered eolian sand (*Qsf*) is in interdunal areas in the eastern half of the sheet. This area contains small scattered exposures of Permian rocks and laterite, which are the probable source for the pebble-lag veneer. Red-brown, medium- to coarse-grained sand sheets (*Qsg*) are located distal to some granitoid exposures, particularly east and south of Six Mile Well. Although these are eolian, the coarse nature of the sand grains suggests a close affinity with the nearby granitoid outcrops.

WARRAWAGINE is dominated, in the central and central-southern areas, by extensive riverine deposits associated with the large Oakover, Nullagine and De Grey rivers. Such deposits include a wide range of alluvial and lacustrine material. The fluvial unit (*Qaa*) consists of unconsolidated clay, silt, sand, and gravel alluvium in creeks and anabranches, where the channel-fill, overbank, and adjacent floodplain deposits have not or cannot be separated. This unit particularly covers the drainage lines away from the large rivers. Unconsolidated silt, sand, and gravel (*Qaas*) has been mapped in the incised channels of the Oakover, Nullagine, and De Grey rivers. This material becomes coarser upstream. The surface of these deposits may be over 12 m below the top of the overbank deposits on the adjacent levee banks and floodplains. Gravel and sand in banks and point bars within these channels may be up to 5 m high.

The Nullagine and Oakover rivers, and to a lesser degree the De Grey River, are surrounded by wide floodplains. The overbank deposits, including the levee banks that parallel the main river channels, consist of clay, silt, and silty sand (*Qao*). Shallow channels on this surface are typically vegetated and have a high clay and silt content.

Large areas of the floodplain are covered with numerous small, circular, elongate or irregular-shaped claypans (*Qaoc*). They contain clay, silt, and silty sand surfaces, and a locally developed quartz-pebble or gravel veneer. Anastomosing erosion channels 1–2 m deep intersect the claypan-covered surface in places. Larger claypans (*Qac*) are rimmed with lunette dunes in places. They may hold water for longer intervals and have a clay surface in most cases.

Swelling-clay and silt deposits (*Qaob*) occupy large areas between the Oakover and Nullagine rivers, and between the Oakover River and the edge of the Great Sandy Desert. Many of these areas appear to be old, abandoned anabranches of the Nullagine and Oakover rivers. Such swelling-clay deposits are also called 'gilgai' or 'crabhole'. These widespread clay-rich floodplains correspond to the subsurface occurrence of the clay-rich diamictites of the fluvioglacial Permian Paterson Formation that underlies the Oakover River, and, to a lesser extent, the Nullagine River valleys on WARRAWAGINE.

There are several types of lacustrine deposits in the poorly drained Great Sandy Desert region. These include single bare claypans (*Qlc*), vegetated gilgai-surfaced claypans (*Qlb*), and mixed eolian deposits with numerous small claypans (*Qls*). The latter unit consists of small claypans separated by low mounds and small silt and sand dunes. They are mostly in interdunal areas where older drainage lines have been blocked by longitudinal dunes.

Economic geology

Although prospecting has probably been carried out on WARRAWAGINE for nearly 100 years, the only direct evidence for such activities in the area is the shallow workings associated with the Barramine copper prospects, 3.2 km and 4 km south of the abandoned Barramine Homestead (Blatchford, 1925; Finucane, 1938; Low, 1963; Marston, 1979). These discoveries were the outcome of the initial discovery of lead (galena; Ostlund, 1902) and development of the Braeside lead field (Blatchford, 1925; Blockley, 1971) that included the Gregory Range Inlier in the southeastern corner of WARRAWAGINE.

Over the last 40 years, WARRAWAGINE has been the focus of modern exploration techniques in the search for iron, manganese, copper, lead, zinc, nickel, gold, uranium, bauxite, and diamonds.

Exploration company data submitted to GSWA since 1967 are held in the WAMEX open-file system at the GSWA library. The information covering WARRAWAGINE is summarized in Appendix 2. Updated data on mines and mineral deposits in Western Australia are held in the Department of Minerals and Energy MINEDEX database (Townsend et al., 2000).

Iron and manganese

The Nimingarra Iron Formation at Mount Cecelia has been investigated for its iron-ore potential. However, the high chert content, apparent lack of large secondary surficial deposits, and the remoteness from existing infrastructures limit the economic potential. Shallow drilling of a strong magnetic anomaly northwest of Mount Cecelia intersected dolerite and amygdaloidal basalt, probably from the Fortescue Group, at about 70 m. (Sentinal Mining Company, 1967). The source of the strong magnetic signature in this area remains unexplained.

A search for stratified secondary manganese and ferromanganese deposits in the approximately 660 m deep Permian–Cainozoic sedimentary basin underlying the Oakover River, west of Mount Cecelia, proved negative (Sentinel Mining Company, 1967).

Small pods and surface encrustations of manganese oxides were located in Carawine Dolomite and Pinjian Chert Breccia, around 3.5 km northwest (AMG 857935) of Barramine Homestead and on the south bank (AMG 902782) of Gum Creek in the Gregory Range Inlier, and in Carawine Dolomite, 2.5 km north (AMG 572788) of Myolla Bore.

Copper

Copper mineralization was first recorded from south of Barramine Homestead (AMG 890922) by Blatchford (1925). Further reports on this mineralization are in Finucane (1938), Low (1963), and Marston (1979).

Two prospects are recorded: the Barramine prospect, 3.2 km south (AMG 887889), and the Barramine South prospect, 4 km south (AMG 890882) of the abandoned homestead. On the accompanying 1:100 000-scale geological map (Williams, 1999b), the Barramine prospect is incorrectly shown as the Barramine South prospect. The actual Barramine South prospect is not shown on the map. However, it lies 800 m south-southeast of the Barramine prospect along the fault that separates the Carawine Dolomite from the Isabella Member of the Jeerinah Formation. Both prospects were difficult to locate during recent fieldwork because the workings are gradually disappearing. Some recent drilling has taken place near the Barramine South prospect.

The mineralization at the Barramine South prospect is in a silicified fault zone striking about 340°. It was obvious from the recent mapping that both prospects lie in the same fault zone; a steep reverse fault that juxtaposes the older Jeerinah Formation against the Carawine Dolomite –Pinjian Chert Breccia to the west.

The Barramine South prospect contains secondary malachite and cuprite. A channel sample, collected by Blatchford (1925), assayed 25.32% copper, 279 g/t silver, and a trace of lead.

During this study, an east-trending gossanous quartz vein, carrying pyrite and chalcopyrite, was found 600 m north (AMG 510879) of Granite Well, in the Warrawagine Granitoid Complex. Cross-cutting blue-green siliceous veins may be chrysocolla.

Road material

Gravel pits for road material are at irregular intervals along the Woodie Woodie – Port Hedland road. Consolidated alluvial gravels (*Czag*) are favoured for surfacing the clay-rich floodplains of the Nullagine River and Tanguin Creek areas.

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Appendix 1

Gazetteer of localities

Place name	*AMG Coordinates* *Easting*	*Northing*
Barramine Homestead (abd)	289000	7692200
Brown Well	266500	7698300
Callawa Homestead (abd)	239800	7716500
Chukuwalyee Well	277000	7693300
Eva Well	240800	7716400
Five Mile Microwave Repeater Station	253000	7685800
Five Mile Well	256100	7686000
Granite Well	250700	7687300
Little Junction Well	246500	7709600
Mount Cecelia	291000	7701100
Myolla Bore	256600	7676400
Pinjian Pool	255800	7677000
Six Mile Well	250900	7695900
Ten Mile Well	244400	7693100
Three Mile Well	257100	7689300
Toombingidgee Well	276600	7699100
Ulalling Rockhole	290200	7701200
Warrawagine Homestead	260000	7692600
Wongawobbin Well	241600	7713800

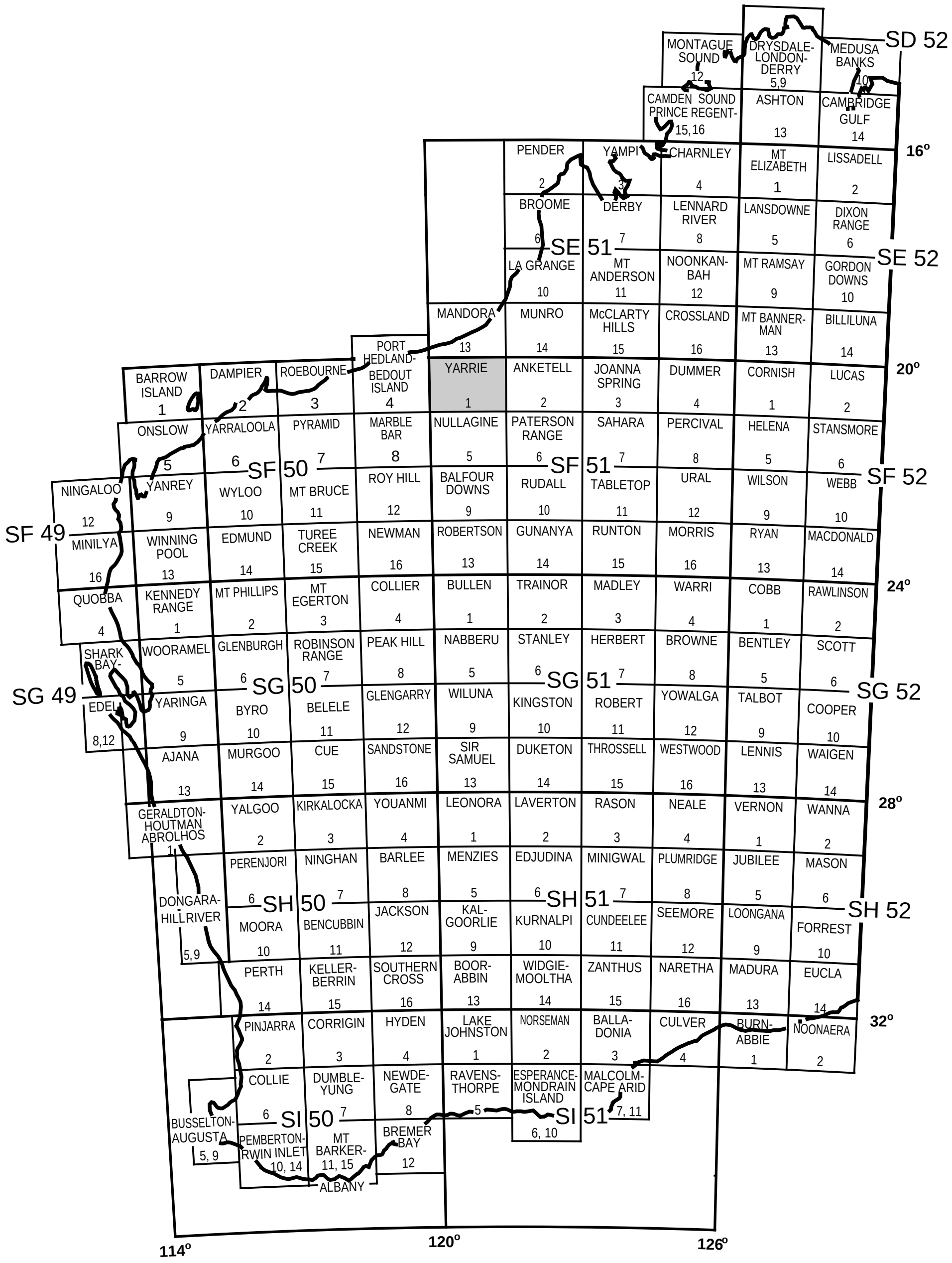
NOTE: abd: abandoned

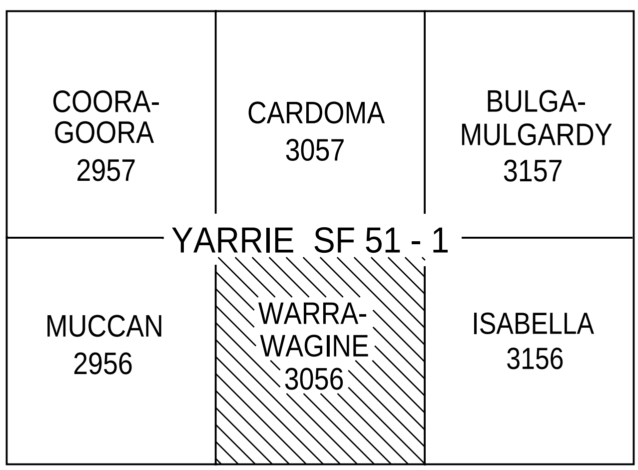
Appendix 2

Company data on GSWA WAMEX open file for WARRAWAGINE

GSWA WAMEX Item number [(a)]	*Duration*	*Title*	*Company*
1840	1966–1973	Nullagine and Balfour Downs iron–manganese exploration	Goldsworthy Mining, Sentinel Mining
274	1967	Mount Cecelia iron exploration	Sentinel Mining
1308	1967–1968	Fence iron–nickel–copper exploration	Sentinel Mining
966	1969–1972	Ragged Hills copper–lead exploration	Western Mining Corporation
2331	1972–1974	Baramine copper–zinc exploration	Australasian Minerals
3224	1974–1982	Ragged Hills lead exploration	Hancock and Wright Prospecting
2412	1978	Yarrie bauxite reconnaissance	CSR Exploration
1601	1978–1981	Warrawagine diamond exploration	Australian Selection, Seltrust Mining Corporation
1128	1979–1980	Canning Basin diamond–uranium exploration	CRA Exploration
1202	1979–1981	De Grey River diamond exploration	Westmex
6882	1979–1992	Nifty copper–lead–zinc exploration	Western Mining Corporation, WMC Resources
2457	1981–1982	Muccan–Yukerakine copper–molybdenum–tungsten exploration	Duval Mining Australia
3194	1982–1983	Rocky Pool – Coonanbunna Creek lead–zinc exploration	CRA Exploration
2345	1982–1984	Bamboo Creek gold exploration	Carpentaria Exploration
2614	1984–1985	Yarrie east copper exploration	CRA Exploration
5588	1987–1991	Isabella Range base metal – gold exploration	Carpentaria Exploration, MIM Exploration
4044	1988–1989	Shay gold–uranium exploration	CRA Exploration
4870	1989	Anketell Shelf diamond exploration	Australian Consolidated Minerals
4765	1989–1990	Anketell Shelf diamond exploration	Australian Consolidated Minerals
5851	1990–1991	Carawine gold – base metal exploration	MIM Exploration
6989	1991–1993	Bulgamulgardy gold exploration	Broken Hill Company
7479	1991–1994	Bulgamulgardy gold – base metals exploration	BHP Minerals
9673	1991–1998	Bulgamulgardy base metal exploration	Broken Hill Company, BHP Minerals
8042	1992–1995	Bulgamulgardy gold – base metals exploration	Broken Hill Company, BHP Minerals
7576	1993	Callawa diamond exploration	CRA Exploration
8855	1993–1996	Gingarrigan Well manganese exploration	Valiant Consolidated
9384	1993–1996	Bulgamulgardy copper exploration	BHP Minerals
9193	1993–1997	Gingarrigan Well manganese exploration	Valiant Consolidated
9541	1993–1997	Bulgamulgardy copper exploration	BHP Minerals

NOTE: (a) Information available from Department of Minerals and Energy Library, Mineral House, 100 Plain Street, East Perth. WA. 6004.

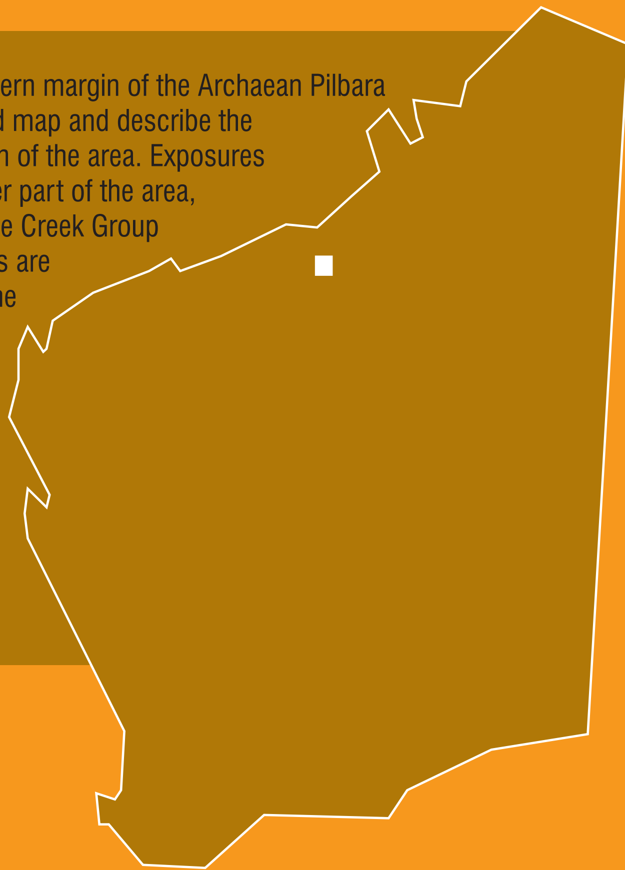




IRW177

30.03.01

The WARRAWAGINE 1:100 000 sheet lies along the northeastern margin of the Archaean Pilbara Craton. These Explanatory Notes complement the published map and describe the stratigraphy, structure, tectonic evolution, and mineralization of the area. Exposures of the Pilbara Craton, which is basement beneath the greater part of the area, comprise the Warrawagine Granitoid Complex and the Gorge Creek Group of the East Pilbara Granite–Greenstone Terrane. These rocks are unconformably overlain by volcano-sedimentary rocks of the Fortescue Group and sedimentary rocks of the Hamersley Group, both of the Hamersley Basin. Metasedimentary rocks of the Proterozoic Paterson Orogen, faulted against the Pilbara Craton, constitute a minor component of the basement on WARRAWAGINE. Phanerozoic sediments of the Canning Basin cover much of the sheet area. WARRAWAGINE has been explored for iron, manganese, copper, lead, zinc, nickel, gold, uranium, bauxite, and diamonds.



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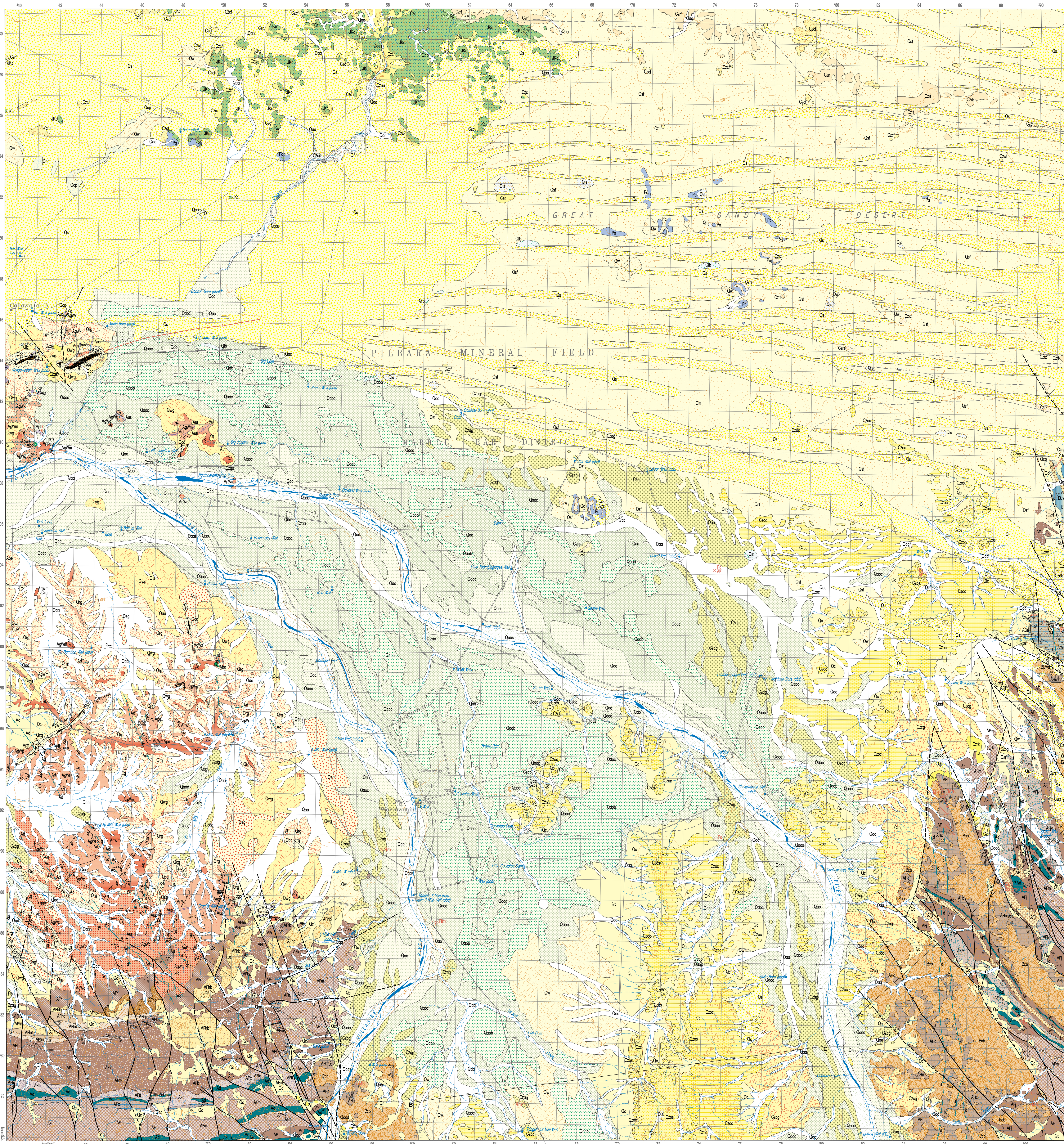
AUSTRALIA 1:100 000 GEOLOGICAL SERIES

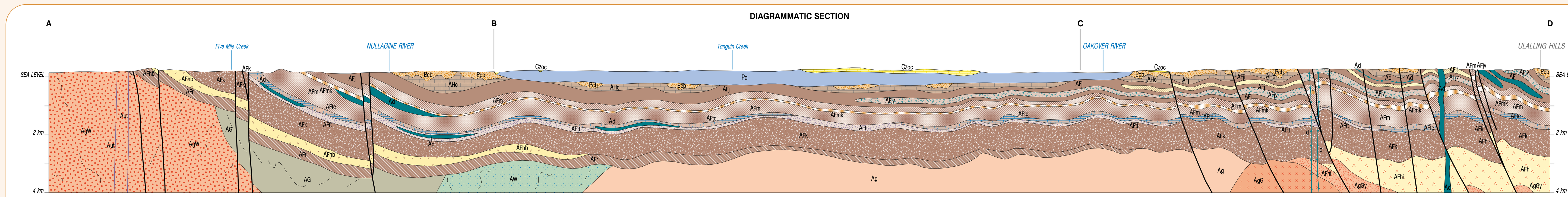
WARRAWAGINE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 3056



DIAGRAMMATIC SECTION



Qlc	Lacustrine clay, silt, and sand in large, non-vegetated claypans
Qlb	Lacustrine clay and silt with gilgai (crabhole) surface in claypans; generally vegetated
Qls	Mixed lacustrine and eolian deposits; clay, silt, and sand
Qaa	Alluvium; undivided clay, silt, and gravel in rivers and creeks
Qaas	Unconsolidated sand, silt, and gravel in discrete channel beds
Qac	Claypan deposits; generally on floodplains
Qao	Overbank deposits; alluvial sand, silt, and clay on floodplains adjacent to main drainage channels
Qaoc	Alluvial sand, silt, and clay; mixed floodplain deposits (lao) characterized by numerous small claypans
Qaob	Alluvial clay and silt deposits on floodplains with gilgai (crabhole) surface in areas of expansive clay
Qw	Sheetwash deposits—silt, sand, and pebbles on distal fans; no defined drainage
Qwg	Sheetwash sand and quartz pebbles overlying and derived from granitoid rocks
Qc	Colluvium—sand, silt, and gravel on outwash fans; scree and talus; proximal mass-wasting deposits
Qcq	luartz debris adjacent to large quartz veins
Qcp	Colluvium and eluvium derived from weathered **PATERSON FORMATION**; scattered boulders, cobbles, and pebbles in clay and silt matrix
Qrg	luartzofeldspathic eluvial sand, with quartz and rock fragments; overlying and derived from granitoid rocks
Qs	Eolian sand—light to dark red sand in sheets, and longitudinal (seif) and chain dunes
Qsf	Eolian sand with lag deposits; ironstone-pebble, rock-fragment, or quartz-pebble veneer; in sheets and between dunes
Qsg	Mixed eolian and eluvial sand; red-brown quartz sand in sheets; overlying and derived from granitoid rock
Czos	**OAKOVER FORMATION:** upper unit; vuggy, white to grey opaline silica, silicified carbonate, and minor calcareous sandstone
Czoc	**OAKOVER FORMATION:** lower unit; blue, grey, and fawn limestone and calcareous sandstone
Czaa	Consolidated alluvial clay, silt, and sand; dissected
Czag	Consolidated alluvial gravel, sand, and silt; local carbonate cement; dissected
Czak	Calcrete; massive, nodular, and cavernous limestone, variably silicified; dissected valley calcrete
Czaz	Silicified and ferruginized channel deposits; cemented chert and banded iron-formation clasts in conglomerate; dissected stream channel deposits
Czc	Colluvium—dissected consolidated clay, silt, and sand deposits; derived from adjacent outcrop
Czcf	Consolidated ferruginous colluvium; recemented fragmented laterite, ironstone pebbles, clay, silt, and sand; dissected
Czcg	Consolidated pebble, sand, and silt deposits; dissected scree and outwash fan deposits
Czrf	Ferruginous duricrust; includes massive, pisolitic, and nodular laterite
Czrz	Siliceous duricrust; includes silcrete
Czrk	Calcrete; massive, nodular, and cavernous limestone; variably silicified; residual origin

PHANEROZOIC — CAINOZOIC — QUATERNARY

MESOZOIC — JURASSIC–CRETACEOUS — WESTRALIAN SUPERBASIN

Kp **PARDA FORMATION:** white, thin-bedded or massive mudstone and claystone, and minor lenses of fine-grained sandstone; macrofossils; shallow-marine deposits

JKc **CALLAWA FORMATION:** very fine to coarse grained sandstone, ferruginous towards base; siltstone and conglomerate interbeds; plant and trace fossils; mainly fluvial deposits

PALAEOZOIC — PERMIAN — CANNING BASIN

Pa **PATERSON FORMATION:** diamictite, mudstone, siltstone, and minor conglomerate; fluvioglacial deposits

PROTEROZOIC — ARCHAEAN

THROSSELL GROUP: undivided sandstone, siltstone, dolomite, and limestone (subsurface only)

PINJIAN CHERT BRECCIA: chert breccia, and poorly bedded chert

CARAWINE DOLOMITE: massive to well-bedded, recrystallized dolomite and stromatolitic dolomite; minor chert

FORTESCUE GROUP: undivided (subsurface only)

MOUNT ROE BASALT: massive, porphyritic, vesicular, and amygdaloidal basalt; some pillow basalt

WARRAWAGINE GRANITOID COMPLEX

Geological boundary
- exposed

Fault
- exposed
- concealed
- concealed, interpreted from aeromagnetic data
- reverse, triangle on upthrown side

Strongly foliated rock

Fold, showing axial trace and generalized plunge direction
- anticline, exposed
- syncline, exposed
- overturned syncline, exposed

Small-scale fold axis, showing trend and plunge
- minor anticline
- S-vergence
- Z-vergence
- M-vergence

Bedding, showing strike and dip
- inclined
- vertical
- horizontal
- strike and dip direction from aerial photography, dip low to moderate

Palaeocurrent, showing trend and sense of direction
- from cross-bedding

Way-up indicator
- pillow-structure
- cross-bedding
- stromatolite growth

Metamorphic foliation, showing strike and dip
- inclined
- vertical

Cleavage, showing strike and dip
- inclined
- vertical
- strike coincident with bedding

Mineral lineation, showing trend and plunge

Trace fossil locality

Oncolite locality

Plant fossil locality

Stromatolite fossil locality

Isotopic age determination site with identification number — 142871

Formed road

Major track

Track

Fence, generally with track

Homestead — Warrawagine

Building

Yard — Yard

Microwave repeater station

Horizontal control; major

Sand dune

Contour line, 20 metre interval — 180

Watercourse with ephemeral pools and waterholes

Rockhole — Rockhole

Bore, well — Bore, Well

Windpump

Dam, tank — Dam, Tank

*bandoned — (abd)

Position doubtful — (PD)

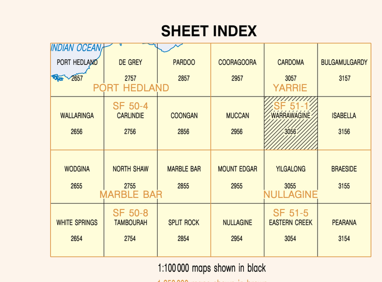
Prospect — Barramine South

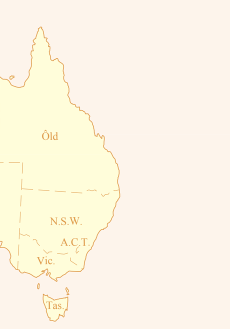
luarry

Mineral exploration drillhole, showing subsurface data — Pa

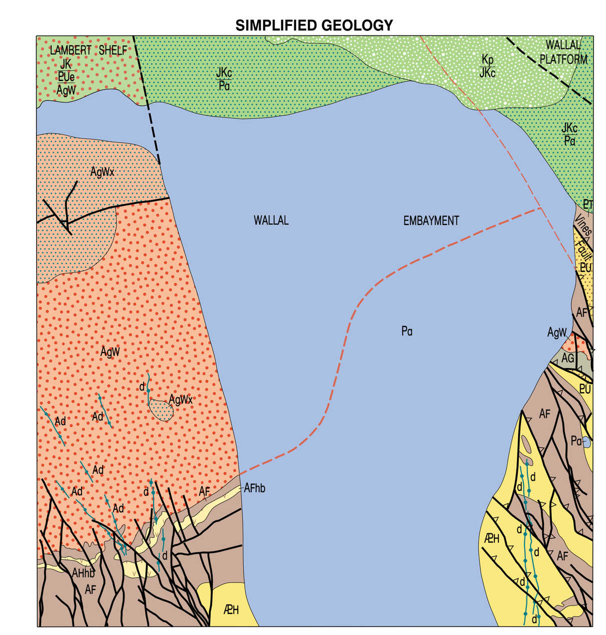
Mineral occurrence
- Copper — Cu
- Manganese — Mn
- Road metal — Rm

SHEET INDEX





SIMPLIFIED GEOLOGY



JK	Parda Formation and Callawa Formation		WESTRALIAN SUPERBASIN
Kp/JKc	Parda Formation overlying Callawa Formation		
JKc/Pa	Callawa Formation overlying Paterson Formation		CANNING BASIN
Pa	Paterson Formation		
d	Dolerite dyke		
꟒U	Tarcunyah Group; ꟒Ue Eel Creek Formation (subsurface only)	Officer Basin	PATERSON OROGEN
꟒T	Throssell Group	Yeneena Basin	
ÆH	Hamersley Group and Pinjian Chert Breccia	Hamersley Basin	PILBARA CRATON
Ad	Dolerite dyke		
AF	Fortescue Group		
AFhb	Bamboo Creek Member		
AG	Gorge Creek Group		
AgW, AgWx	AgW Warrawagine Granitoid Complex; exposed, concealed; AgWx Granitoid rock with mafic and ultramafic xenoliths		

Interpreted concealed margin of the PATERSON OROGEN

Interpreted concealed margin of the HAMERSLEY BASIN

Geology by I. R. Williams 1997

Edited by N. Tetlaw and C. Brien

Cartography by S. Collopy, P. Taylor and D. Ladbrook

Topography from the Department of Land Administration Sheet SF 51-1, 3056, with modifications from geological field survey

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WILLIAMS, I. R., 1999, Warrawagine, W.A. Sheet 3056: Western Australia Geological Survey, 1:100 000 Geological Series

GOVERNMENT OF WESTERN AUSTRALIA
HON. NORMAN MOORE, M.L.C.
MINISTER FOR MINES

DEPARTMENT OF MINERALS AND ENERGY
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NGMA
PRODUCT OF THE NATIONAL GEOSCIENCE MAPPING ACCORD

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
DAVID BLIGHT, DIRECTOR

SCALE 1:100 000

TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: AUSTRALIAN GEODETIC DATUM 1984
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

Grid lines indicate 1000 metre interval of the Australia Map Grid Zone 51

WARRAWAGINE

SHEET 3056 FIRST EDITION 1999