EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

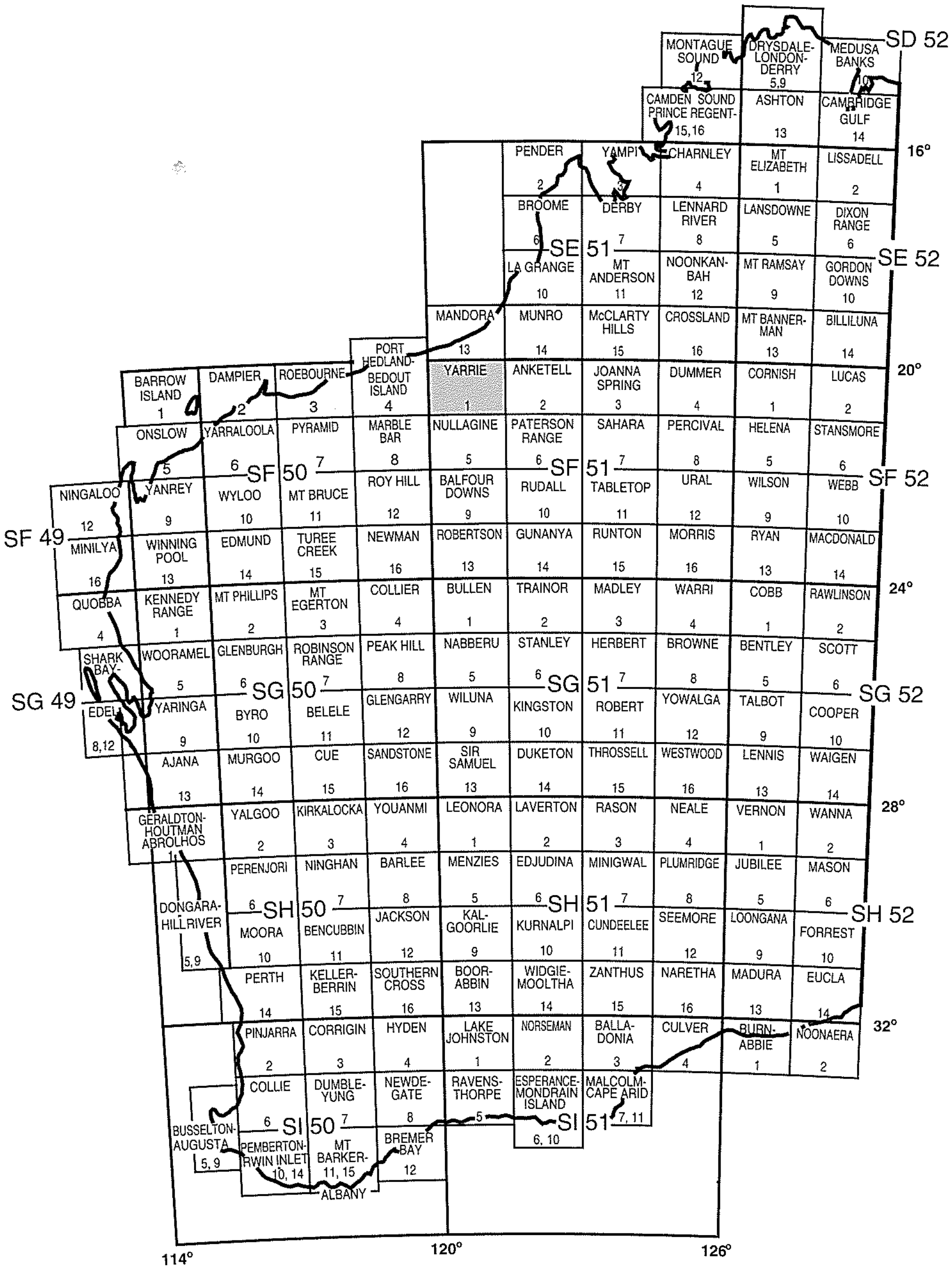
GEOLOGY OF THE MUCCAN 1:100 000 SHEET

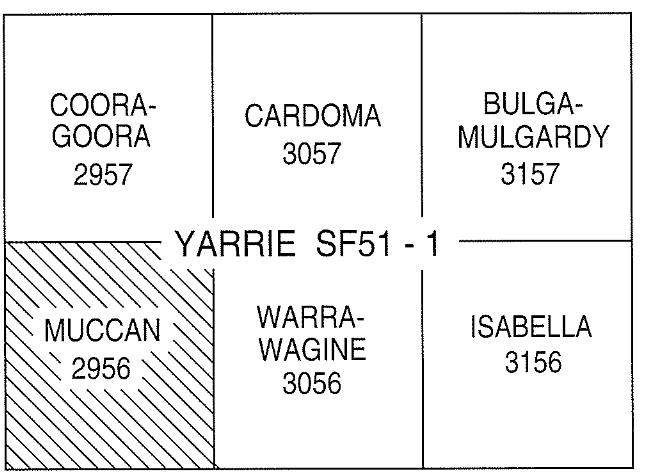
by I. R. Williams

1:100 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY





CAS70

27.01.98

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF THE MUCCAN 1:100 000 SHEET

by
I. R. Williams

Perth 1999

MINISTER FOR MINES
The Hon. Norman Moore, MLC

DIRECTOR GENERAL
L. C. Ranford

DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
David Blight

ERRATA

Page 2, paragraph 1: the map sheet index should read SF51-1-2956.

Page 23, paragraph 3, line 6: replace 'beds' with 'blebs'.

Page 2, paragraph 9, line 7: replace 1997 with 1979.

Page 15, heading at bottom right: the first three characters of the rock codes for the Muccan Granitoid Complex should read AgM, not Agw.

Copy editor: C. D'Ercole

REFERENCE

The recommended reference for this publication is:
WILLIAMS, I. R., 1999, Geology of the Muccan 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 39p.

National Library of Australia Card Number and ISBN 0 7309 6628 3

ISSN 1321–229X

The locations of points mentioned in this publication are referenced to the Australian Geodetic Datum 1984 (AGD84)

Cover photograph:

Coppin Gap incised in banded iron-formation and jaspilite of the Nimingarra Iron Formation, Gorge Creek Group.

Contents

Appendices

Figures

Table

Geology of the Muccan 1:100 000 sheet

by

I. R. Williams

Abstract

Geological mapping of the MUCCAN 1:100 000 sheet has confirmed that the bulk of the region is underlain by older than 3471 to c. 3048 Ma greenstone successions and older than 3470 to c. 3244 Ma granitoid complexes that constitute the North Pilbara granite–greenstone terrane. These are unconformably overlain by 2772–2687 Ma volcano-sedimentary rocks of the Fortescue Group (Hamersley Basin), Neoproterozoic volcanogenic sedimentary rocks of the Eel Creek Formation, the Lower Permian fluvioglacial Paterson Formation, and fluvial deposits of the Jurassic–Cretaceous Callawa Formation.

The oldest greenstone succession comprises metamorphosed mafic, ultramafic, and felsic igneous and sedimentary rocks of the Warrawoona Group. In this region, the group is subdivided into the Mount Ada Basalt, the felsic volcaniclastic Duffer Formation (c. 3471 Ma), the Apex Basalt, the felsic–sedimentary Panorama Formation (c. 3456 Ma), and the Euro Basalt. The Warrawoona Group occupies the eastern extension of the Marble Bar Belt and the newly named Yarrie Belt. The belts are intruded by the Coppin Gap Granodiorite (c. 3314 Ma) and a granodiorite (c. 3438 Ma) of the Muccan Granitoid Complex respectively.

New geochronological data for the Muccan and Warrawagine Granitoid Complexes indicate several generations of granitoid emplacement over a timespan of 230 Ma. Age clusters of c. 3314 Ma are common to the Muccan, Warrawagine, and Mount Edgar Granitoid Complexes whereas age clusters of c. 3440 Ma and c. 3300 Ma are shared by the Muccan and Mount Edgar Granitoid Complexes. The youngest plutons (c. 3244 Ma) so far recognized are confined to the central parts of the Muccan Granitoid Complex.

A regional unconformity is confirmed between the younger Gorge Creek Group and the underlying Muccan and Warrawagine Granitoid Complexes. The Gorge Creek Group, which is younger than c. 3244 Ma, occupies the Shay Gap Belt and tight Coppin Gap Syncline. The group comprises the newly defined basal Nimingarra Iron Formation, the epiclastic Cundaline Formation, and the Coonieena Basalt.

The Shay Gap Belt includes the disconformably overlying De Grey Group (<3048 Ma). This group comprises the newly defined basal epiclastic and volcaniclastic Cattle Well Formation and the epiclastic Cooragoora Formation.

Gold mineralization at the large Bamboo Mining Centre (production total about 7 t Au) is structurally controlled (the Bamboo Creek Shear Zone) and hosted by ultramafic rocks. The c. 3400 Ma age for gold mineralization places the deposits amongst the oldest in Western Australia.

Currently operating iron-ore mines at Yarrie, the Y2/3 and Y10 pits, are hosted by the Nimingarra Iron Formation and the basal Eel Creek Formation respectively.

KEYWORDS: North Pilbara granite–greenstone terrane, Warrawoona Group, Gorge Creek Group, De Grey Group, Fortescue Group, regional geology, geochronology, gold, iron ore

Introduction

The MUCCAN* 1:100 000 map sheet (SF5-1-2956) is bounded by latitudes 20°30' and 21°00'S and longitudes 120°00' and 120°30'E. It is situated along the north-northeastern margin of the Pilbara Craton adjacent to the western edge of the Great Sandy Desert Region and occupies the southwestern corner of YARRIE (1:250 000). MUCCAN derives its name from the Muccan pastoral lease, settled in 1879, which straddles the De Grey River in the northwest quadrant of the sheet area.

Portions of four pastoral leases comprising three cattle stations, Muccan, Yarrie, and Warrawagine, and one aboriginal pastoral lease, Callawa, lie within MUCCAN. The occupied Yarrie and Muccan Homesteads lie north and south of the De Grey River at Australian Map Grid (AMG)† 086114 and AMG 931155 respectively.

At the time of mapping (1996), BHP Iron Ore was working two iron-ore deposits, the Yarrie Y2/3 and Y10 opencut mines, 12.5 km and 16.5 km northeast of Yarrie Homestead respectively. The main underground gold mines at the Bamboo Mining Centre, held by Haoma Mining in 1996, were on care and maintenance. Alluvial gold prospecting was active in the Nuggety Gully and Friendly Stranger areas.

The region is well serviced by graded roads. The Port Hedland – Woodie Woodie manganese mining road, which also carries traffic to the Telfer Gold and Nifty Copper mines, crosses the sheet area from west to east, south of the De Grey River. The Bamboo Mining Centre road connects with the Woodie Woodie road 2 km west of the western boundary of MUCCAN. The Yarrie Village and iron-ore deposits are linked to the abandoned town of Shay Gap, 20 km to the northwest. The townsite, situated on and just north of the MUCCAN–COORAGOORA boundary (AMG 045307), was closed and dismantled in 1993. The abandoned townsite is linked to the Great Northern Highway and Port Hedland via the Goldsworthy road to the west, the Pardoo Roadhouse road to the northwest, and Boreline Road to the north. The Yarrie mines are also linked by graded roads, privately maintained by BHP Iron Ore, to operating opencut iron mines at Nimingarra in the southwest corner of COORAGOORA. Intermittently maintained pastoral and mining exploration tracks give reasonable four-wheel drive vehicle access to about two-thirds of MUCCAN. Some areas in the central and southeastern parts and along the northeastern margin are inaccessible to four-wheel drive vehicles.

Previous and current investigations

The bibliographies published in the Explanatory Notes for the YARRIE 4-mile Geological Series (Wells, 1959), YARRIE (1:250 000; Hickman et al., 1983), and Hickman (1983) contain early references to the MUCCAN area.

The first geological map of the Pilbara Region (Maitland, 1906) included the area covered by MUCCAN. Reconnaissance lithological mapping of the area is also in the YARRIE 4-mile Geological Series (Wells, 1959). In this publication, the granite, gneiss, and older metamorphic rocks (greenstones) were assigned to the lower Proterozoic whereas the unconformably overlying volcanic–sedimentary succession was placed in the upper Proterozoic. This latter succession was subsequently named the Fortescue Group (MacLeod et al., 1963). Twenty-five years later, Hickman et al. (1983) published a more detailed lithostratigraphic map for YARRIE. The metamorphosed volcanic, sedimentary, and intrusive rocks, previously referred to as 'greenstones' or 'layered succession', are now considered to be part of a single stratigraphic succession, the Archaean Pilbara Supergroup (Hickman, 1983).

The subsequent application of model-driven, sequence-stratigraphic techniques suggested that the Pilbara granite–greenstone terrain could be subdivided into five fault-bounded domains with largely independent tectonostratigraphic cycles (Krapez and Barley, 1987; Krapez, 1993). Blake (1993) applied sequence-stratigraphic principles to the Mount Bruce Supergroup and, specifically, on MUCCAN to the Fortescue Group stratigraphy.

Although cognizant of advances made in using sequence-stratigraphic techniques and also of the failure of the proposed models to adequately address the mappable geological relationships in detail, it is considered premature to use them in this present study. Consequently, the lithostratigraphic schemes of Hickman (1983) and Griffin (1990) have been maintained, extended, and updated for the current survey on MUCCAN.

Although electromagnetic surveys were carried out in the Bamboo Creek area in 1937 (Blazey et al., 1938), it was not until the 1970s that systematic regional geophysical surveys were undertaken in the MUCCAN area. The Bureau of Mineral Resources (BMR), now the Australian Geological Survey Organisation (AGSO), released a preliminary Bouguer anomaly map in 1997 and a total magnetic intensity contour map in 1993 over YARRIE.

The present study was carried out in 1996 using 1995 colour photography at 1:25 000 scale. AGSO — through the North Pilbara National Geoscience Mapping Accord (NGMA) Project — conducted airborne magnetic and gamma-ray spectrometry programs during this study. Coloured total magnetic intensity (reduced to the pole, RTP; Mackey, 1997a), first vertical derivative of total magnetic intensity (RTP greyscale; Mackey, 1997b), and coloured airborne gamma-ray spectrometry composite maps (Mackey, 1997c) are available at 1:250 000 scale for MUCCAN. The Geological Survey of Western Australia (GSWA) has released a total magnetic intensity image map at a 1:100 000 scale for MUCCAN (GSWA, 1997).

* Capitalized names refer to standard map sheets.

† 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.

Climate, vegetation, and physiography

The climate of MUCCAN is arid with summer rainfall due to thunderstorms or decaying tropical cyclones occurring between January and March. Winter rains are commonly lighter. The mean annual rainfall is around 300 mm and the evaporation rate reaches 3600 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 the winters are mild with mean minimum temperatures around 12.5°C (Pink, 1992).

Muccan lies within the Eremaean Botanical Province (Beard, 1975). Most of the map sheet is covered by the Fortescue Botanical District except for the northeast corner, which falls within the Canning Botanical District (Fig. 1). The vegetation of the Fortescue Botanical District can be divided into three regimes that broadly reflect the underlying geology on MUCCAN. The first regime is related to the alluvial and associated floodplain deposits of the De Grey River and is characterized by woodlands and savanna. The main channels are lined with riverain Sclerophyll woodlands of River Gum (*Eucalyptus camaldulensis*). Upstream from the Yarrie Homestead and east of prominent banded iron-formation (BIF) ranges, which bisect MUCCAN in a northerly direction, the De Grey River floodplain is covered by a mixed grassland savanna. West of Yarrie Homestead, the same floodplain is covered by a tree and shrub savanna characterized by the scattered Coolabah (*Eucalyptus microtheca*). The second, and most widespread, regime consists of a shrub steppe of Kanji (*Acacia pyrifolia*) and soft spinifex (*Triodia pungens*). This regime mainly overlies large granitoid complexes. Scattered *Grevillea* and *Hakea* species are endemic in this regime. The third regime is a tree steppe of Snappy Gum (*Eucalyptus brevifolia*) with both soft spinifex (*Triodia pungens*) and buck spinifex (*Triodia brizoides*). Scattered *Acacia*, *Grevillea*, and *Hakea* species are also present. The tree steppe is restricted to hills and narrow but prominent ranges along the northern and southern margins of the granitoid complexes, as well as to a northerly trending hilly zone of meta-igneous and metasedimentary rocks through the central part of MUCCAN.

The vegetation regime of the Canning Botanical District, which corresponds to the Great Sandy Desert Region, consists of a shrub steppe distributed across both sandplains and sandy valleys lying between sandstone mesas and buttes. The shrub steppe consists largely of *Acacia pachycarpa* and soft spinifex (*Triodia pungens*). The surface of the sandstone mesas is largely a grass steppe of soft spinifex (*Triodia pungens*).

The De Grey Drainage Basin occupies over 90% of MUCCAN (Fig. 1). The remainder, in the southwest corner, is drained by Eight Mile Creek, a tributary in the Talga Drainage Basin. All drainage in the region is ephemeral, although some permanent pools and springs are distributed along the De Grey River and major creeks.

MUCCAN is situated on the northeast margin of the Pilbara Natural Region adjacent to, and partly straddling, the southwestern boundary of the Great Sandy Desert (Beard, 1970; Fig. 1). The physiographic scheme adopted here is based on Hickman (1983) and Jutson (1950). The Pilbara Natural Region is divided into plain and valley, low granite hills, range, plateau, and dissected plateau divisions (Fig. 1).

The low relief plain and valley division occupies over 50% of MUCCAN. It includes the De Grey River floodplain and adjacent low-slope pediment plains, which abut the plateau, dissected plateau, range, and low granite hills divisions. The plain and valley division is underlain by large, ovoid granitoid complexes. The low granite hills division comprises areas of low rocky hills, scattered inselbergs, including bare 'whaleback' rocks or bornhardts, and uncommon mafic and ultramafic dykes, which form narrow but prominent strike ridges.

The range division consists of rugged, razor-backed hills, strike ridges, and hogbacks that are separated by narrow, steep-sided valleys. In most areas, the ranges are formed over steeply inclined greenstone belts. Preferential weathering of the less resistant rock types has produced a trellised drainage pattern in these areas. A more subdued range division of hogbacks and cuestas has formed over Fortescue Group rocks on the northern side of the Oakover Syncline and over the Neoproterozoic Eel Creek Formation in the headwaters of Eel Creek.

The plateau division includes remnants of the old Hamersley Surface (Campana et al., 1964). The division is commonly underlain by erosion-resistant Nimingarra Iron Formation (Appendix 1), but includes scattered tablelands and mesas of the Mesozoic Callawa Formation. The plateau division rises abruptly from the plain and valley division; the boundary is marked by prominent escarpments up to 190 m high and cliffs over 50 m high. The upper surface of the plateau is commonly ferruginized. The dissected plateau division can be identified by steep V-shaped valleys, gorges, nickpoints, dendritic drainage patterns, and abrupt margins. There is an example of a dissected plateau in the area of the Oakover Syncline, which is underlain by Fortescue Group rocks. The bedrock configuration plays an important role in the final appearance of landforms on MUCCAN.

The Great Sandy Desert consists of gently undulating eolian sandplains with minor longitudinal (seif) and chain dunes trending about 275°.

Regional geological setting

Components of two major tectonic units, the Pilbara Craton (Trendall, 1990a) and Westralian Superbasin (Hocking et al., 1994), cover about 94% and 3% of the sheet area respectively. The remaining 3% is occupied by a Neoproterozoic sedimentary basin. The relationship of MUCCAN to the regional tectonic units is shown in Figure 2. The major structural units within MUCCAN are presented in Figures 3 and 4.

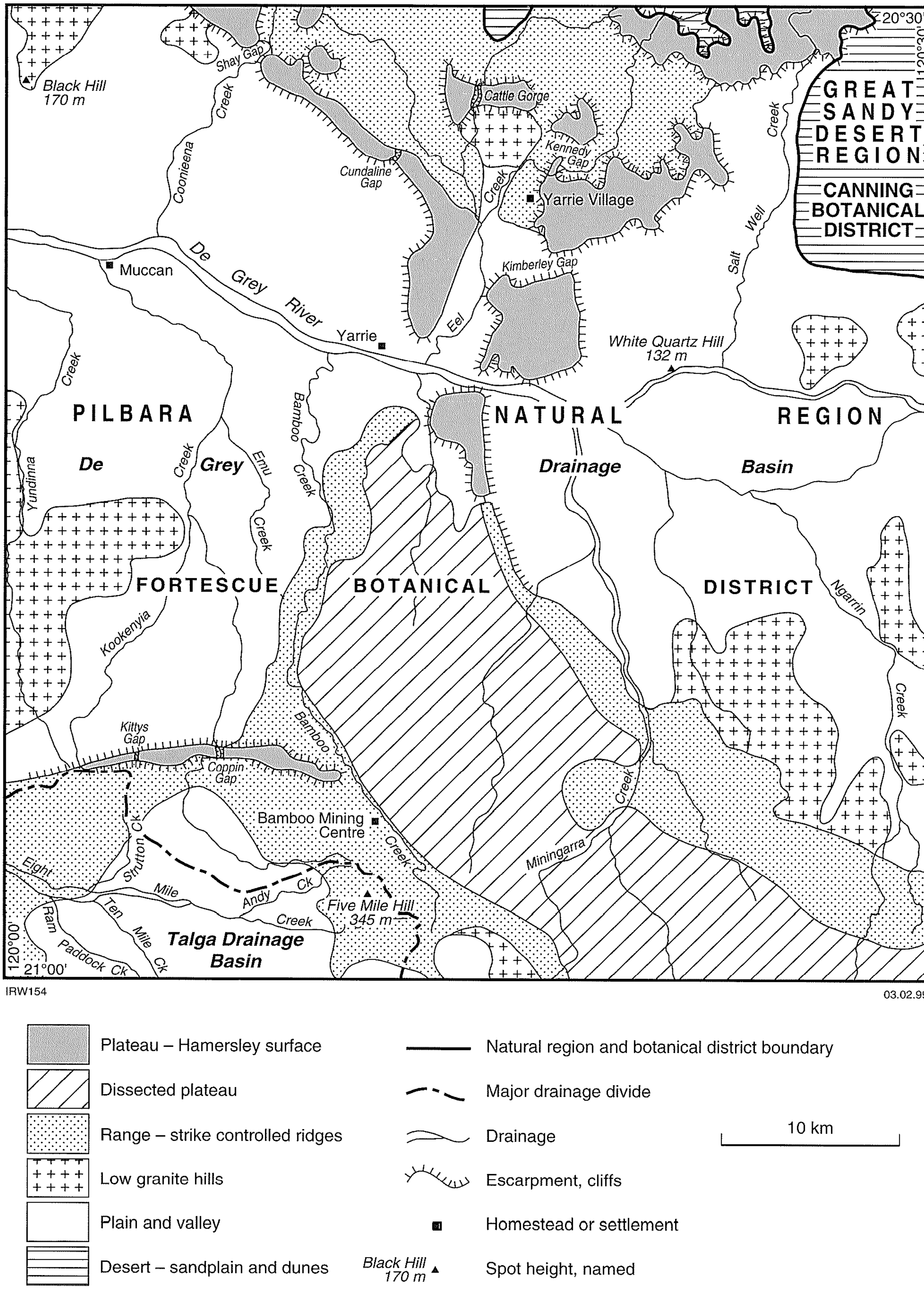


Figure 1. Natural region and botanical district boundaries; physiographic and drainage map of MUCCAN

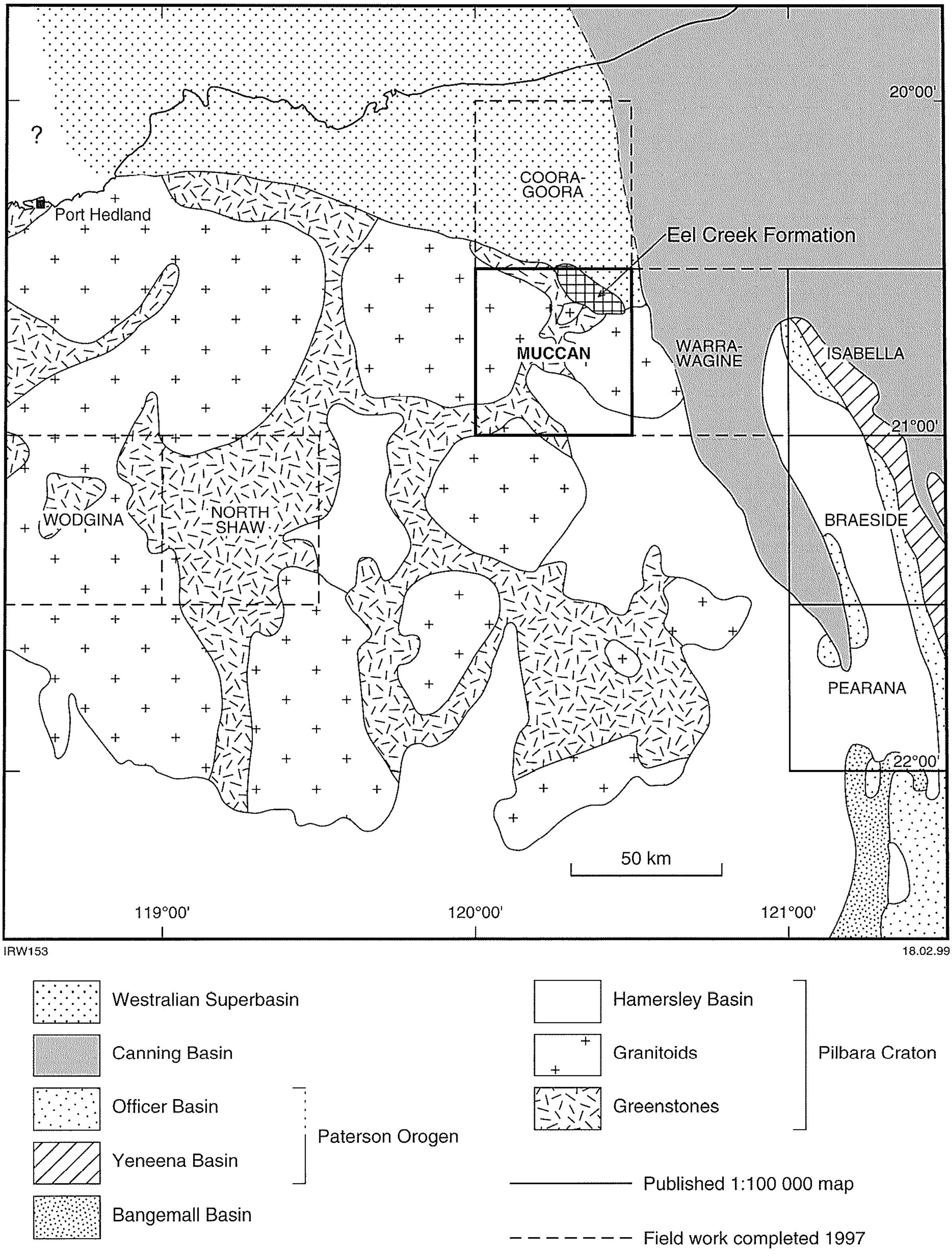
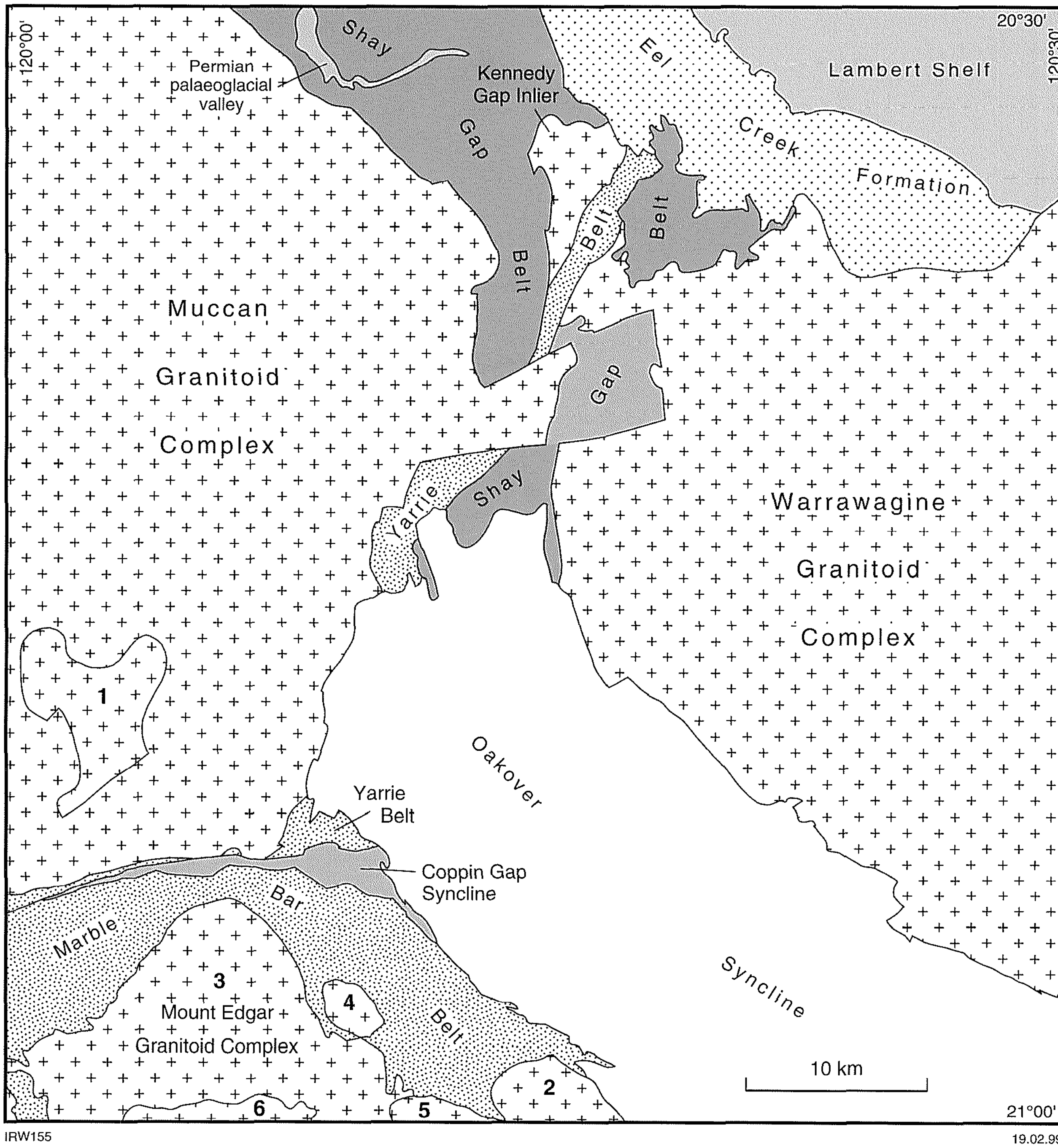


Figure 2. Regional geological setting of Muccan in the eastern part of the Pilbara Craton



Phanerozoic rocks	1 Wolline Monzogranite
Neoproterozoic Eel Creek Formation	2 Chimingadgi Trondjhemite
Archaean <2770 Ma Fortescue Group	3 Coppin Gap Granodiorite
Archaean <3240 Ma Gorge Creek – De Grey Groups	4 Bamboo airstrip pluton
Archaean c.3470–3244 Ma Granitoid rocks	5 Mullugunya Granodiorite
Archaean >3430 Ma Warrawoona Group	6 Munganbrina Monzogranite

Figure 3. Major structural units on MUCCAN

The Pilbara Craton on MUCCAN comprises components of both the older North Pilbara granite–greenstone terrane (Griffin, 1990) and the younger Fortescue Group of the Hamersley Basin (Trendall, 1990b). Metamorphosed sedimentary and mafic, felsic, and ultramafic igneous rocks, which make up the greenstone belts, are part of the Pilbara Supergroup (Hickman, 1983). Lithostratigraphic units from the Warrawoona (>3430 Ma), Gorge Creek (<3240 Ma), and De Grey Groups (<3048 Ma) were identified (Hickman, 1983). The Warrawoona Group is restricted mainly to the southwest quadrant of MUCCAN where mafic, felsic, and ultramafic rocks and chert occupy the arcuate eastern extension of the Marble Bar Belt (Hickman et al., 1983; Fig. 3). This belt is intruded by younger plutons (c. 3314 Ma) of the Mount Edgar Granitoid Complex (Mount Edgar Batholith; Williams and Collins, 1990).

Stratigraphically unassigned Warrawoona Group rocks occupy the Yarrie Belt, a narrow, linear, north-northeasterly trending belt lying between Kennedy Gap in the north and the Coppin Gap area in the south (Figs 1 and 3). Similar rocks can be traced westwards from the Coppin Gap area into a narrow strip sandwiched between the Muccan Granitoid Complex and the South Muccan Shear Zone (Fig. 4). The Yarrie Belt lies between, and is intruded by, plutons belonging to the Muccan (c. 3438 Ma) and Warrawagine Granitoid Complexes. Both the Yarrie and Marble Bar Belts are unconformably overlain by the Gorge Creek and the late Archaean Fortescue Groups.

In the southern half of MUCCAN, rocks assigned to the Gorge Creek Group (Lipple, 1975) are confined to the tight Coppin Gap Syncline (Fig. 3). In contrast, the Gorge Creek Group in the northern half is widely distributed and well exposed in the northerly to northwesterly trending Shay Gap Belt (Fig. 3).

The late Archaean Fortescue Group (2770–2678 Ma), which is the oldest component of the Mount Bruce Supergroup (Trendall, 1990b), occupies the open, southeasterly plunging Oakover Syncline (Hickman et al., 1983), also called the northwest Oakover Syncline (Blake 1993), in the central to southeastern part of MUCCAN (Fig. 3). This syncline overlies, and is superimposed on, older intruded synclinal keels containing Warrawoona and Gorge Creek Group rocks.

The Eel Creek Formation consists of epiclastic and tuffaceous sedimentary rocks that occupy a northeasterly dipping belt in the northeast corner of MUCCAN (Fig. 3). The belt is gently folded and intruded by several dolerite sills. The formation is lithologically similar to units within the Neoproterozoic Tarcunyah Group 90 km to the east-southeast. The Tarcunyah Group was recently included in the Officer Basin (Perincek, 1996) and is postulated to be part of Supersequence 1 of the Centralian Superbasin (Stevens and Grey, 1997).

The Permian Paterson Formation is restricted to palaeoglacial valleys incised in rocks of the Gorge Creek Group and the Eel Creek Formation along the northern boundary of MUCCAN (Fig. 3). These fluvioglacial rocks are peripheral and coeval with deposition of the Paterson Formation in the Canning Basin to the east of MUCCAN (Williams and Trendall, 1998a). The Paterson Formation is unconformably overlain by the Jurassic–Cretaceous Callawa Formation, which is restricted to the northern boundary of MUCCAN. These rocks were recently assigned to the Lambert Shelf of the Westralian Superbasin (Hocking et al., 1994; Fig. 3).

Archaean rocks

Archaean rocks on MUCCAN comprise well-exposed greenstone or supracrustal belts (c. 3471 to <3048 Ma) and moderately to poorly exposed granitoid complexes (3470 – c. 3244 Ma) of the North Pilbara granite–greenstone terrane, unconformably overlain by the exceptionally well-exposed Fortescue Group (c. 2772 – c. 2687 Ma) of the Hamersley Basin.

Warrawoona Group

Rocks assigned to the Warrawoona Group (Lipple, 1975), which outcrop mainly in the southwest quadrant, occupy an arcuate eastern extension of the Marble Bar Belt (Fig. 3). Other mafic and ultramafic rocks, believed to be Warrawoona Group, occupy the discontinuous Yarrie Belt. The Warrawoona Group in the Marble Bar Belt consists of the Mount Ada Basalt of the older Talga Talga Subgroup, the Duffer Formation, and the Apex Basalt, Panorama Formation, and Euro Basalt of the younger Salgash Subgroup. The mafic and ultramafic rocks of the Yarrie Belt may correlate with the Euro Basalt, which lies south of the Coppin Gap Syncline (see Fig. 3).

Mount Ada Basalt (*Awm, Awmc, Awmu*)

The Mount Ada Basalt (Hickman, 1977) probably contains the oldest rocks on MUCCAN (>3471 Ma). Massive metabasalts are restricted to the southwest corner of the sheet area, west of the Coppin Gap Granodiorite. The formation dips steeply to the northeast and is at least 2000 m thick.

The metabasalts (*AWm*) are blue–grey to dark-green–grey, fine-grained, actinolite-rich rocks with abundant to minor chlorite (clinochlore), epidote, and plagioclase. Quartz is minor and opaque minerals, including leucoxene, are accessory. Some thin units of blue–grey to green–grey metachert (*AWmc*) and serpentine–talc–chlorite rock (*AWmu*) lie 2 km west of the abandoned 3 Mile Well (AMG 892790).

The Mount Ada Basalt is discordantly intruded and contact metamorphosed by the Coppin Gap Granodiorite (c. 3314 Ma; Williams and Collins, 1990) to the southeast, and along the western margin by the Munganbrina Monzogranite (Munganbrina Suite; Williams and Collins, 1990). Both plutons are components of the Mount Edgar Granitoid Complex (cf. Batholith; Hickman, 1983; Williams and Collins, 1990). The metabasalts are

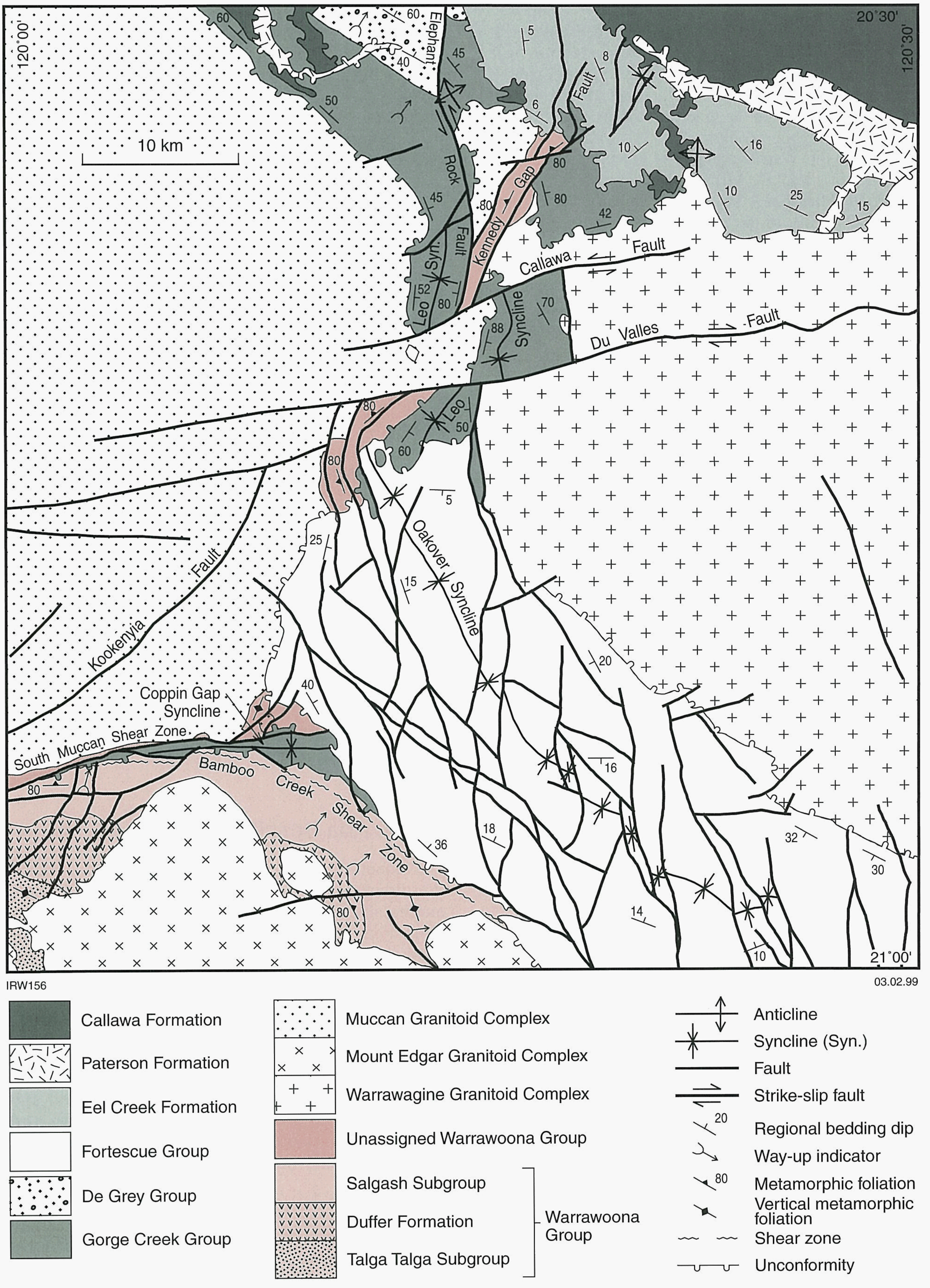


Figure 4. Structural sketch map of MUCCAN

darker coloured along strike close to the discordant contact with the Coppin Gap Granodiorite. The Mount Ada Basalt is also intruded by minor aplitic and pegmatitic dykes close to the contact.

The metabasalts have a weak but distinct metamorphic fabric. They show increased metamorphic grade adjacent to the granodiorite with metamorphism attaining upper greenschist – lower amphibolite facies.

Duffer Formation (*Awd, Awdd, Awoh*)

The main exposure of the Duffer Formation (Lipple, 1975) on MUCCAN disconformably overlies the Mount Ada Basalt west of No 2 Well (AMG 936808), where it is over 3500 m thick. A second smaller area partly rims a small ovoid apophysis of Coppin Gap Granodiorite centred on the Bamboo airstrip (AMG 048810; Fig. 3). Here, the thickness is indeterminate since the base of the formation is intruded by the granodiorite. The Duffer Formation can be traced from 3 km northwest of the airstrip (AMG 025825), where it is intruded by the Coppin Gap Granodiorite, to 8 km southeast of the airstrip (AMG 081784), where it contains dykes now composed of hornblende–plagioclase schist (*Awoh*). These dykes cut the Duffer Formation at high angles. They do not seem to intrude the overlying Apex Basalt and hence, may be feeder dykes to the overlying mafic volcanic rocks. A large layered mafic–ultramafic body, the Strutton Intrusion, has obliquely intruded the upper part of the Duffer Formation and lower units of the Apex Basalt northwest of No 2 Well (AMG 900835).

The Duffer Formation is composed of metamorphosed felsic volcanic rocks (*Awd*) with subordinate fine-grained amphibolite (*Awdd*). The felsic rocks typically consist of light-grey weathered, blue–grey, fine-grained, and porphyritic lavas. Crystal tuffs with lithic fragments are common pyroclastic components. Plagioclase, and to a lesser extent quartz, are the principal minerals whereas brownish-green biotite, green hornblende, epidote, and chlorite are abundant. Sericite, K-feldspar (microcline), and carbonate are commonly minor. Accessories include opaque minerals, titanite, apatite, and garnet. A sedimentological study of the Duffer Formation was carried out by Di Marco and Lowe (1989). A relict ophitic texture in the amphibolite component (*Awdd*) suggests that these rocks were probably dolerite sills.

A contact metamorphic aureole has formed in the Duffer Formation near the discordant contact with the Coppin Gap Granodiorite. The metamorphic grade increases from very low grade regional metamorphism with preserved igneous textures 5 km from the granodiorite, to low amphibolite facies (?hornblende hornfels) adjacent to the granodiorite. Small aplite and pegmatite dykes intrude the Duffer Formation at the contact. Garnet amphibolite lies in a strongly foliated zone between the main body of the Coppin Gap Granodiorite and the 'Bamboo airstrip' apophysis. A sample of the porphyritic dacite collected near the Bamboo airstrip (AMG 056822) yielded a zircon U–Pb age of 3471 ± 5 Ma (Thorpe et al., 1992a,b; see Table 1).

Apex Basalt (*Awa, Awac, Awaf, Awau*)

The Apex Basalt forms the lower part of the Salgash Subgroup (Hickman, 1977) and disconformably overlies the Duffer Formation in the southwest quadrant of the map. The Towers Formation, which separates the Apex Basalt from the Duffer Formation in the Marble Bar area (Hickman, 1977, 1983), is absent on MUCCAN. The Apex Basalt is discordantly intruded and contact metamorphosed by the Coppin Gap and Mullugunya Granodiorites of the Mount Edgar Granitoid Complex.

The Apex Basalt forms an arcuate belt of mainly pillowed mafic and ultramafic lavas (*Awa*) about 2 km thick. Pillowed tholeiitic basalts are fine grained or amygdaloidal. Most of the amygdales contain quartz, chalcedony, or carbonate. The rocks are commonly actinolite–plagioclase–quartz assemblages with minor chlorite and epidote. Steeply dipping pillowed basalts are common southeast of Five Mile Hill (Fig. 1) and 4 km west of Gap Bore (AMG 928855). At the latter locality, overturned, steep southerly dipping pillow basalts show way-up to the north. All pillowed basalt observations consistently young to the north and east.

Ocelli texture (Ashwal, 1991) is common in the high-magnesium (high-Mg) basalts, which consist of tremolite–chlorite assemblages. Some spinifex texture (tremolite after pyroxene) is present. The rocks are darker coloured at the contact with the granodiorite plutons and consist of a schistose amphibole–plagioclase assemblage. Thin tabular bands of tremolite–serpentine–talc–carbonate rock (*Awau*) are probably after komatiitic lavas.

A characteristic feature of the Apex Basalt is the thin (1–5 m) beds of blue chert, grey and black chert, black and white banded chert, and red and white ferruginous chert (*Awac*), which are interlayered with the metabasalts. Thin-bedded, epiclastic, green (fuchsitic) quartzite outcrops near Five Mile Hill (AMG 086800). Some thin, chert-like rocks are steeply dipping recrystallized fault zones. There is a cream–white, fine-grained metarhyolite unit (*Awaf*) near the base of the Apex Basalt (AMG 947837), southwest of Gap Bore.

Regional metamorphism is low grade, except adjacent to the Coppin Gap Granodiorite, where it has reached low amphibolite facies (?hornblende hornfels).

The Apex Basalt hosts two layered ultramafic intrusions; the chromite-bearing Nobb Well Intrusion, and the large Gap Intrusion (see Appendix 1).

Panorama Formation (*Awp, Awpc*)

The Panorama Formation (Lipple, 1975) is a discontinuous felsic volcanic and chert unit that thins eastwards across the southwest part of MUCCAN. South of Kittys Gap, the formation is about 800 m thick, but rapidly thins to less than 100 m east of the Coppin Gap track. Southeast of the Coppin Gap track, the formation is marked by a series of discontinuous felsic volcanic lenses that lie along the disconformable contact between the Apex Basalt and

Table 1. Summary of geochronology samples collected from Muccan

Sample number	*Locality*	*Lithology*	*Method*	*Age (Ma)*	*Interpretation*	*Reference*
94761	2 km southwest of Green Hole AMG 168802	Rhyolite porphyry, Bamboo Creek Member (*AFhb*), Hardey Formation	SHRIMP[a] U–Pb zircon	2756 ± 8	Age of crystallization	Arndt et al. (1991)
142825	1.7 km east-northeast from No 3 Bore AMG 026788	Granodiorite (*Agh*); intrudes Coppin Gap Granodiorite	SHRIMP U–Pb zircon	2757 ± 7	Age of crystallization	Nelson (1998)
142867	1.5 km west of Cattle Well AMG 089287	Dacite tuff, Cattle Well Formation (*ADa*), De Grey Group	SHRIMP U–Pb zircon	3048 ± 19 (3303 ± 4, 3382 ± 15 3424 ± 6, 3450 ± 4 3555 ± 3)	Maximum possible age for deposition of a detrital component within the tuff (3048 ± 19 Ma)	Nelson (in prep.)
LTU[b] nos 5570, 5571, 5573, 5574, 5575, 5578	Scattered across Coppin Gap Granodiorite	Granodiorite (*AgEco*), Coppin Gap Granodiorite, Mount Edgar Granitoid Complex	Rb–Sr whole rock isochron	Model 1 isochron age of 3204 ± 45; I_R = 0.7014 ± 7; MSWD = 1.3	Metamorphic resetting	Collins and Gray (1990)
Various (see reference)	1.5 km southwest of Coppin Gap, Cu–Mo Prospect AMG 991873	Feldspar porphyry, granodiorite, dacite porphyry (*Apd*); intruding Euro Basalt	Rb–Sr whole rock isochron	3234 ± 117; I_R = 07027 ± 0.0012; MSWD = 1.2	Minimum age for Cu–Mo mineralization	de Laeter and Martyn (1986)
143810	1.7 km north of Wolline Well AMG 944977	Porphyritic biotite monzogranite, Wolline Monzogranite (*AgMwo*), Muccan Granitoid Complex	SHRIMP U–Pb zircon	3244 ± 3	Age of crystallization	Nelson (1998)
143805	2.6 km west-southwest of Near Home Well AMG 915186	Wolline Monzogranite (*AgMwo*), Muccan Granitoid Complex	SHRIMP U–Pb zircon	3252 ± 3	Age of crystallization	Nelson (1998)
143806	2.4 km southwest of Coorina Well near Yundinna Creek AMG 886050	Magnetite-bearing monzogranite (*AgMb*), Muccan Granitoid Complex	SHRIMP U–Pb zircon	3303 ± 2	Age of crystallization	Nelson (1998)
143803	2 km southeast of Don Well AMG 958257	Monzogranite (*AgMc*), Muccan Granitoid Complex	SHRIMP U–Pb zircon	3313 ± 3 (3434 ± 19 xenocryst)	Age of crystallization	Nelson (1998)
143809	2.2 km west of Narrana Well AMG 312995	Biotite monzogranite (*AgWc*), Warrawagine Granitoid Complex	SHRIMP U–Pb zircon	3313 ± 6	Age of crystallization	Nelson (1998)
LTU[b]5577	2 km north of No 5 Well AMG 967777	Granodiorite (*AgEco*), Coppin Gap Granodiorite, Mount Edgar Granitoid Complex	SHRIMP U–Pb zircon	3314 ± 13	Age of crystallization	Williams and Collins (1990)
103279	1.5 km southwest Coppin Gap, Cu–Mo prospect AMG 991873	Rhyolitic quartz–feldspar porphyry (*Apd*); intrudes Euro Basalt	Conventional titanite U–Pb	3317 ± 1	Possible hydrothermal activity subsequent to magmatic emplacement	Thorpe, R. I., written comm. (1992)

Pb 402[c] (42193)	2.5 km south-southeast of Coppin Gap AMG 003855	Galena in quartz vein cutting Apex Basalt	Pb–Pb isotopic data; model ages	3336 ± 1 (t 7/6) 3341 ± 2 (t 6) 3276 ± 7 (t 8)		Richards (1983) Davy and Hickman (1983)
143994	1.4 km east of Kittys Gap AMG 969880	Quartzite (*AGna*) towards base of Nimingarra Iron Formation; detrital zircons	SHRIMP U–Pb zircon	3362 ± 13 3415 ± 12 3438 ± 5 3457 ± 12	Maximum time of deposition for sedimentary precursor of the quartzite (3362 ± 13 Ma)	Nelson (1998)
143996	4.2 km east-southeast of Shay Gap AMG 055265	Quartzite at top of Cundaline Formation (*AGu*); detrital zircons	SHRIMP U–Pb zircon	3395 ± 15 3434 ± 6 3455 ± 34	Maximum time of deposition for sedimentary precursor of the quartzite (3395 ± 13 Ma)	Nelson (1998)
143995	1.5 km southeast of Friendly Stranger gold mines AMG 081024	Quartzite (*AGna*) at base of Nimingarra Iron Formation; detrital zircons	SHRIMP U–Pb zircon	3403 ± 10 3430 ± 5 3458 ± 18	Maximum time of deposition for the sedimentary precursor of the quartzite (3403 ± 10 Ma)	Nelson (1998)
K1 PP1 PP2	Bamboo Creek mines K = Kitchener AMG 107822 PP = Mount Prophecy – Perseverance AMG 096834	Galena collected from gold-bearing quartz veins in talc carbonate schist, Bamboo Creek Shear Zone hosted by Euro Basalt	Pb–Pb isotopic dating, model ages	K1 3412 ± 40 PP1 3414 ± 40 PP2 3376 ± 40 3400	Age of gold mineralization	Zegers (1996)
Pb 455[c]	Bamboo Creek mine AMG 096834	Galena in quartz veins carrying gold (as above)	Pb–Pb isotopic dating, model age	3430 (1983) 3416 (1992)	Age of gold mineralization	Richards (1983) Thorpe et al. (1992a)
143807	2.5 km north of Yarrie Mining Village AMG 167224	Biotite granodiorite (*AgMr*), Muccan Granitoid Complex	SHRIMP U–Pb zircon	3438 ± 4	Age of crystallization	Nelson (1998)
94770	3.4 km west-northwest of Bamboo Creek mine AMG 061841	Felsic volcanic rock, Panorama Formation (*AWp*)	Conventional zircon U–Pb dating	3454 ± 1, contains xenocryst zircon dated at 3470 ± 2	Age of crystallization	Thorpe et al. (1992a,b)
100511	1.1 km south of Coppin Gap AMG 997866	Felsic volcanic rock, Panorama Formation (*AWp*)	Conventional zircon U–Pb dating	3458 ± 2	Age of crystallization	Thorpe, R. I., written comm. (1991)
142828	2.4 km south-southwest of Fred Well AMG 991948	Heterogeneous banded gneiss (*AgMm*), Muccan Granitoid Complex	SHRIMP U–Pb dating	3470 ± 4	Age of crystallization of granitoid precursor to the gneiss	Nelson (1998)
100512	4.2 km west-southwest of Bamboo Creek mine AMG 056822 (Bamboo airstrip area)	Fine-grained dacite, Duffer Formation (*AWd*)	Conventional zircon U–Pb dating	3471 ± 5	Age of extrusion	Thorpe et al. (1992a,b)

NOTES: (a) SHRIMP: Sensitive High-Resolution Ion Microprobe
(b) La Trobe University
(c) ANU studies

the overlying Euro Basalt. West-southwest of Kittys Gap, the Panorama Formation interfingers with the upper part of the Apex Basalt (Fig. 1). Further west, the formation was incorporated in the South Muccan Shear Zone (Zegers, 1996). A thick chert unit marks the top of the formation in the Kittys Gap region.

The felsic volcanic rocks (*AWp*) are altered, siliceous, porphyritic, and fine-grained rhyolite to dacite lavas and tuffaceous rocks. Phenocrysts are quartz or altered feldspar, and rutile, chlorite, zircon, and leucoxene are accessories. The cherts (*AWpc*) are thickly bedded, faintly banded, and tend to be buff, cream, or white.

Felsic volcanic rocks in two localities were sampled for geochronology. One sample, collected from west-northwest of Bamboo Creek (AMG 061841), yielded a zircon U–Pb age of 3454 ± 1 Ma (Thorpe et al., 1992a). A zircon xenocryst from the same sample yielded an age of 3470 ± 2 Ma, the age of the underlying Duffer Formation. A second sample, collected south of Coppin Gap (AMG 997866), yielded a zircon U–Pb age of 3458 ± 2 Ma (Thorpe, R. I., 1991, written comm.; see Table 1). These ages are interpreted as the age of crystallization for the zircons and reflect the age of extrusion for the felsic flows.

Euro Basalt (*Awe, Awec, Awea, Aweq, Aweu, Awes*)

The Euro Basalt (Hickman, 1977) constitutes the uppermost unit of the Warrawoona Group and consists of metamorphosed, pillowed tholeiitic and high-Mg basalts (tremolite–chlorite rocks) and peridotitic komatiite. These are intercalated with thin-bedded chert, black and white banded chert, fuchsitic quartzite, minor pelitic rocks (metashale and metasiltstone), and possible felsic tuff.

The Euro Basalt disconformably overlies the Panorama Formation, or where this is absent, the Apex Basalt. It is discordantly intruded in the south by the Chimingadgi Trondjhemite and Mullugunya Granodiorite. To the northwest and north, the formation is unconformably overlain by the basal clastic unit of the newly defined Nimingarra Iron Formation of the Gorge Creek Group. To the east, it is unconformably overlain by, or is in faulted contact with, units of the late Archaean Fortescue Group.

The Euro Basalt commonly resembles the underlying Apex Basalt but has a higher proportion of ultramafic and metasedimentary rocks. Pillowed and massive tholeiitic and high-Mg basalts (ocelli textured; *AWe*) comprise the bulk of the formation. The steeply dipping pillow structures in these rocks consistently indicate way-up to the north and east. Metamorphosed tholeiitic basalts consist of actinolite–plagioclase(–chlorite–quartz) assemblages whereas metamorphosed high-Mg basalts consist of tremolite–chlorite(–quartz) with ocelli and spinifex textures (after pyroxene).

The Bamboo Creek Shear Zone contains serpentine and talc-rich ultramafic rocks (Zegers, 1996). This zone, which is parallel to bedding, can be traced from near the Seven Oaks mining area (AMG 154786) — also known as Jarmans — where it is intruded by the Chimingadgi Trondjhemite, to 30 km northwest (AMG 020870) where it is overlain by the younger Gorge Creek Group. The shear zone consists mainly of a talc–chlorite mylonite schist with pods or boudins of carbonate- and silica-altered komatiites (*AWeu*). Spinifex texture (after olivine) is common in the komatiitic boudins. West of Coppin Gap the shear zone can be traced into sheared sepentinite (after peridotite) and tremolite–chlorite–serpentine–carbonate rocks after basaltic komatiite (*AWes*). Pillows occur in carbonate–tremolite–chlorite rocks (included in *AWe*) just southwest of Kittys Gap and indicate way-up to the north. One kilometre southwest of Coppin Gap, the shear zone is intruded by a fine-grained, quartz–feldspar porphyry from which titanite (sphene) gave a U–Pb age of 3317 ± 1 Ma (Thorpe, R. J., 1992, written comm.; Table 1). The Bamboo Creek Shear Zone hosts a number of gold mines in the Bamboo Mining Centre area (see **Economic geology** below). Galena, which is associated with the gold mineralization, yielded a c. 3400 Ma model age (Richards, 1983; Thorpe et al., 1992a; Zegers, 1996; see Table 1).

The chemical and epiclastic sedimentary rock components are greater higher in the formation. Metamorphosed thin-bedded, black, blue, grey, and white chert, ferruginous chert, and black and white banded chert (*AWec*) are interlayered with the silicified mafic and ultramafic rocks below, and to a lesser extent above, the ultramafic-dominated Bamboo Creek Shear Zone. Immediately overlying the ultramafic rocks at the Bamboo Mining Centre are interbedded fuchsitic quartzite, grey chert, banded chert, and ultramafic schist (*AWeq*). A 150 m-thick lens of metamorphosed thin-bedded sandstone, tuffaceous sandstone, siltstone, and shale (*AWea*) lies 3.5 km southeast of the Bamboo Mining Centre.

Unassigned Warrawoona Group (*Awba, Awbo, Awoa, Awc, Awut, Awus, Awuc*)

Small areas (about 10 km^2) of steeply dipping metamorphosed mafic and ultramafic volcanic and intrusive rocks, together with minor intercalated banded chert, outcrop in the Kennedy Gap – Yarrie Mining Village area southwest of Yarrie microwave tower (AMG 085056), and northeast of Coppin Gap (Fig. 1). The similarity of the lithologies, metamorphic grade, and foliation trend suggest that these areas are remnants of a once continuous greenstone belt that lay between, and is now intruded by, components of the Muccan and Warrawagine Granitoid Complexes. This belt, now called the Yarrie Belt (Fig. 3), is unconformably overlain by the Gorge Creek and Fortescue Groups, and the Neoproterozoic Eel Creek Formation. The Yarrie Belt is truncated by the westerly trending South Muccan Shear Zone (Zegers, 1996; Fig. 4). Adjacent to this shear zone, the Yarrie Belt is tightly folded, showing a distinct swing of the foliation westwards. It is intruded by foliated, xenolith-rich granitoid rocks (*AgMx*). Here, the belt consists mainly of fine-grained amphibolite (*AWba*) and ultramafic schists (*AWut*). The schists consist of tremolite–

serpentine–chlorite(–talc) assemblages. An unusual tremolite–serpentine–talc–clinochlore–garnet schist is exposed near Kittys Gap (AMG 951860). Serpentinized peridotite bodies (*AWus*) lie west of Kittys Gap.

The Yarrie Belt south of the De Grey River consists mainly of high-Mg basalts with ocelli textures and pillow structures. These rocks commonly contain chlorite–tremolite–quartz assemblages (*AWbo*). They are interlayered with carbonate–tremolite–chlorite (*AWuc*) and tremolite–serpentine–chlorite(–talc) schists (*AWut*). Minor thin-bedded, blue, grey, and white banded cherts (*AWc*) are also present. The ultramafic rocks in this area host gold–copper mineralization at the Battler and Friendly Stranger mines. Metagabbro (*AWoa*) intrudes ultramafic schists northeast of Coppin Gap (AMG 023900).

North of the De Grey River, the Yarrie Belt is mainly fine- to medium-grained amphibolite (*AWba*) after tholeiitic basalt. The amphibolites are hornblende–plagioclase–quartz rocks with extensive alteration (metamorphic retrogression) to actinolite–epidote–carbonate–sericite assemblages. Minor ultramafic schists (*AWut*) and large serpentinite bodies (*AWus*) are also present.

North of Yarrie Mining Village (AMG 167224), the Yarrie Belt is intruded by a granodiorite (*AgMr*) that yielded a Sensitive High-Resolution Ion Microprobe (SHRIMP) U–Pb zircon age of 3438 ± 4 Ma (Nelson, 1998; Table 1).

Overall, the metamorphic grade of the Yarrie Belt is marginally higher than the middle to upper greenschist facies assemblages in Warrawoona Group rocks of the Marble Bar Belt in the southwest corner of MUCCAN. An exception is the presence of low amphibolite facies assemblages in rocks adjacent to the intrusive plutons of the Mount Edgar Granitoid Complex described earlier (see **Mount Ada Basalt**, **Apex Basalt**). Hence, the higher metamorphic grade of the greenstone remnants in the Yarrie Belt is probably due to the proximity and volume of the adjacent granitoid rocks.

The relationship between units of the Yarrie Belt and the formalized stratigraphy of the Warrawoona Group rocks in the Marble Bar Belt is unclear. However, it should be noted that gold and base-metal mineralization at the Bamboo Mining Centre (AMG 095834) in the Marble Bar Belt, and at the Battler (AMG 065042) and Friendly Stranger (AMG 069033) mines in the Yarrie Belt are hosted by similarly altered ultramafic rocks.

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

Scattered through some components of the large granitoid complexes are single, groups, and linear trains of mafic and ultramafic xenoliths, pendants, and metamorphosed remnants of early dykes that cannot directly be related to the main greenstone belts. In most cases, these rocks lie within xenolith-rich, foliated and gneissic granitoid rocks (*AgMx, AgWx, AgEchx, AgEcox*). Hickman (1983) postulated that some of these rocks could represent root zones of eroded greenstone belts whereas others formed in the contact zones of plutons. On MUCCAN, such zones are located in the Warrawagine Granitoid Complex west and east of the abandoned Du Valles Well (AMG 361129) north of the De Grey River, and between the abandoned Wattle (AMG 911988) and Old House wells (AMG 985020) in the Muccan Granitoid Complex.

Mafic and ultramafic rocks include amphibolite, banded amphibolite, and hornblende–plagioclase schist (*Aba*), metapyroxenite (*Aux*), serpentinized peridotite (*Aus*), tremolite–serpentine–chlorite–(talc) schist (*Aut*), and carbonate–tremolite–chlorite–talc schist (*Auc*). Metamorphic assemblages in the amphibolite rocks indicate middle to upper amphibolite facies, which is higher than the metamorphic facies in the greenstone belts. Xenoliths of banded amphibolite east of Du Valles Well (AMG 361129) contain a pyroxene–hornblende–plagioclase–quartz assemblage. However, such assemblages also show retrograde metamorphism with the prograde minerals being extensively replaced by actinolite, epidote, chlorite, and carbonate.

In the Wattle Well area (AMG 911988), ultramafic rocks form a series of prominent hills and ridges rising out of the flat granite surface. These are mainly tremolite–serpentine–chlorite–talc rocks (*Aut*) with some serpentinized peridotite dykes (*Aus*). Amphibolite is a minor component in this area.

Mafic and ultramafic intrusive rocks in greenstone belts (*AaGpd, AaGx, AaGus, AaWu, AaT*)

The Warrawoona Group in the Marble Bar Belt is intruded by three large mafic–ultramafic bodies; the Strutton, Nobb Well, and Gap Intrusions (Appendix 1).

The Strutton Intrusion (*AaT*) is largely mafic and consists of metagabbro with minor metapyroxenite and serpentinized peridotite components at the base. Unlike the apparently conformable ultramafic Gap and Nobb Well Intrusions in the Apex Basalt, the mafic Strutton Intrusion is a discordant body obliquely cutting the Duffer Formation and the overlying Apex Basalt (see Appendix 1).

The small ultramafic Nobb Well Intrusion (*AaWu*) comprises a serpentine–tremolite–chlorite–talc–chromite assemblage, probably after a peridotite, although no primary textures are preserved. There are small chromite pods near the basal contact (Baxter, 1978; Appendix 1).

The Gap Intrusion is the largest body and has a faulted upper contact. It is a layered body with a serpentinized dunite cumulate (*AaGpd*) at the base and metapyroxenite (*AaGx*) at the top. This is well exposed west of Gap Bore (AMG 955845). The bulk of the body is a serpentinized peridotite (*AaGus*; Appendix 1).

All three bodies are discordantly cut by plutons belonging to the Mount Edgar Granitoid Complex; the Gap and Strutton Intrusions by the Coppin Gap Granodiorite (3314 ± 13 Ma; Table 1), and the Nobb Well Intrusion by the Mullugunya Granodiorite. The mafic–ultramafic intrusions post-date the Duffer Formation (3471 ± 5 Ma; Table 1) and all have undergone greenschist facies metamorphism.

Granitoid complexes

Granitoid rocks are a major component on MUCCAN and occupy over 56% of the map sheet. Recent geochronological work using the SHRIMP U–Pb zircon dating method (Nelson, 1998) has shown that the age of crystallization for the zirçons, and presumably the age of emplacement of the plutons, has a timespan of c. 230 Ma, from c. 3470 Ma for the granodiorite gneiss (*AgMm*) to c. 3244 Ma for the porphyritic and seriate monzogranite (*AgMwo*). Although both of these ages come from the Muccan Granitoid Complex, the other two complexes on MUCCAN are expected to have similar age ranges. The current data show that the c. 3313 Ma age cluster is common to all three complexes (Nelson, 1998), whereas age clusters around c. 3440 and c. 3300 Ma are common to both the Mount Edgar (Williams and Collins, 1990) and Muccan Granitoid Complexes (Nelson, 1998).

Geochronological data obtained from samples collected on MUCCAN are summarized in Table 1.

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

The intrusive margins of the Warrawagine Granitoid Complex (*AgW*) are concealed mostly beneath the unconformably overlying Gorge Creek and Fortescue Groups, and Eel Creek Formation. An exception is west of the Y2/3 iron-ore pit (YARRIE; AMG 172189) where a grey, medium-grained granodiorite intrudes amphibolite of the Yarrie Belt.

Granitoid rocks of the Warrawagine Granitoid Complex resemble many of those in the western part of the Muccan Granitoid Complex. The magnetic signatures of a zone comprising poorly exposed mafic and ultramafic xenolith-rich, foliated and gneissic granitoids (*AgWx*) reflect a change from a west-southwesterly trend in the Du Valles Well area (AMG 361129) to a south-southeasterly trend in the Sheep Camp Well area (AMG 327085) over a 6 km distance (GSWA, 1997). The northern boundary of this high magnetic zone is the Du Valles Fault, a strike-slip fault that has an apparent 4–5 km dextral displacement (north block east). The xenolith-rich granitoids (*AgWx*) in this area contain distinctive dykes of spotted metapyroxenite (*Aux*). The pyroxene is replaced by large poikiloblastic tremolite.

A small area of mixed, well-foliated to gneissic granitoid rocks and pegmatite (*AgWm*) lies 4 km southeast of Du Valles Well. The granitoid rocks are mainly biotite- and hornblende-bearing granodiorite and tonalite. These intrude older, more mafic components that consist of banded amphibolite and tonalitic gneiss. The latter is intruded by a leucocratic, pegmatite-rich gneissic granitoid.

The best exposures of the Warrawagine Granitoid Complex lie south of the Port Hedland – Woodie Woodie road. They are mainly massive to weakly foliated, pink–grey, coarse- to medium-grained, biotite-bearing monzogranite and syenogranite (*AgWc*). Grey–white granodiorite in the Kennedy Gap area and pink syenogranite northeast of Chinaman Springs are included in this unit. A pink, medium-grained monzogranite to syenogranite east-northeast of 17 Mile Well (AMG 363873) contains disseminated molybdenite and weak copper mineralization. Minor muscovite and biotite (partially altered to chlorite) are present.

Seriate and porphyritic, pink–grey biotite monzogranite and syenogranite (*AgWp*) occupy a small pluton east of Sue Well (AMG 290955). A similar larger body lies southwest of Chintabul Dam Well (AMG 380970). Fluorite was identified in thin section from samples collected in this area.

Mount Edgar Granitoid Complex (*AgE, AgEmu, AgEml, AgEco, AgEcox, AgEch, AgEchx*)

The Mount Edgar Granitoid Complex (*AgE*) on MUCCAN is well exposed, unlike the Muccan and Warrawagine Granitoid Complexes. Parts of four coalescing, bulbous-shaped plutons, the Munganbrina Monzogranite, Mullugunya Granodiorite, Coppin Gap Granodiorite, and Chimingadji Trondjhemite, were identified in the sheet area (Fig. 4). The contact between the plutons and the supracrustal rocks of the Warrawoona Group is sharply discordant. The adjacent supracrustal rocks have been recrystallized (a hornfelsic contact metamorphism) up to 1000 m from the contact. The contact zone is intruded by sparse, thin pegmatite and granitoid dykes. Quartz–feldspar–dacite and rhyodacite porphyry (*Apd*), which has intruded the Euro Basalt near Coppin Gap, is interpreted to be derived from the Coppin Gap Granodiorite.

The plutons on MUCCAN are amongst the youngest of the Mount Edgar Granitoid Complex (Williams and Collins, 1990). Their general geological features and detailed petrographic and geochemical characteristics have been described by Collins (1983, 1989, 1993) and Collins and Gray (1990). The latter authors referred to the complex as the Mount Edgar Batholith. A separate petrographic and geochemical study of the Mount Edgar Granitoid Complex is in Davy and Lewis (1986).

Munganbrina Monzogranite (AgEmu)

The oldest component of the Mount Edgar Granitoid Complex on MUCCAN is the Munganbrina Monzogranite (Munganbrina Suite; Collins, 1983, 1993). Although restricted to the southern boundary area south of the old Marble Bar – Bamboo Mining Centre road and to a small outcrop in the southwest corner, the Munganbrina Monzogranite is the largest unit recognized within the Mount Edgar Granitoid Complex (Collins, 1983; Fig. 3).

The Munganbrina Monzogranite consists mainly of banded, seriate to porphyritic, medium-grained monzogranite with scattered, large, pink K-feldspar phenocrysts, although a wide range of rocks from trondjhemite to syenogranite are also recorded (Collins, 1983). In contrast to adjoining plutons, pegmatite dykes are common. The distinct banding in the rocks is believed to be primary and due to alternating layers of biotite- and plagioclase-rich horizons (Collins, 1983). The northern margin of the Munganbrina Monzogranite is intruded by the Coppin Gap Granodiorite.

Mullugunya Granodiorite (AgEml)

The Mullugunya Granodiorite (Collins, 1983) outcrops southeast of Nobb Well on the southern margin of MUCCAN (AMG 080760; Fig. 3). It is faulted against the Chimingadgi Trondjhemite on MUCCAN, but on the adjacent MOUNT EDGAR sheet it is intruded by the trondjhemite (Collins, 1983). The granodiorite intrudes a xenolith-rich, foliated granitoid (*AgEcox*) to the northwest, which is a marginal zone of the Coppin Gap Granodiorite.

Although more mafic in composition, the Mullugunya Granodiorite is similar in many respects to the Coppin Gap Granodiorite. It is a weakly foliated, medium-grained, biotite- and hornblende-bearing granodiorite where biotite is commonly altered to chlorite, but hornblende forms individual crystals or small mafic clots scattered throughout the rock. The granodiorite lacks poikilitic K-feldspar grains characteristic of the Coppin Gap Granodiorite.

Coppin Gap Granodiorite (AgEco, AgEcox)

The bulk of the Mount Edgar Granitoid Complex on MUCCAN is made up of the Coppin Gap Granodiorite (*AgEco*; Fig. 3). The granodiorite contains several relatively homogeneous, mafic to more felsic units that have strongly discordant contacts with supracrustal rocks of the Warrawoona Group up to the Apex Basalt. The Coppin Gap Granodiorite contains massive to seriate, pink and grey, medium-grained granodiorite, which is more felsic in the northern parts due to increased quartz and K-feldspar. There are fine-grained biotite flakes in both the groundmass and poikilitically enclosed within the K-feldspar. Compositionally, the granodiorite straddles the trondjhemite boundary between tonalite and granodiorite (Collins, 1983).

A zone rich in mafic and ultramafic xenoliths (*AgEcox*), including large xenoliths of hornblende–plagioclase schist (*AWoh*) and felsic rocks from the Duffer Formation (*AWd*), extends southeast from Andy Creek (AMG 035800) to the southern boundary of the map sheet.

A small separate pluton, similar in composition to the Coppin Gap Granodiorite but weakly foliated, is centred on the Bamboo Mining Centre airstrip. This pluton is enclosed within the Duffer Formation (Fig. 3).

Chimingadgi Trondjhemite (AgEch, AgEchx)

The Chimingadgi Trondjhemite (*AgEch*) is an elliptical pluton on the southern boundary of MUCCAN around Zulu Well (AMG 155757; Fig. 3). It is the northernmost of a series of late plutons lying along the eastern margin of the Mount Edgar Granitoid Complex (Collins, 1983). It intrudes the Euro Basalt and the older, weakly foliated Munganbrina Monzogranite, and is unconformably overlain by the basal Fortescue Group.

The Chimingadji Trondjhemite consists of whitish-grey, massive, medium-grained trondjhemite characterized by a high proportion of plagioclase and quartz and preserved igneous textures. Biotite is the only ferromagnesian mineral; K-feldspar is minor or absent. Geochemical analyses have confirmed the trondjhemite composition of the rock, which has high Na_2O (4.2–5.0%) and a high Na_2O/CaO ratio (Collins, 1983).

A mafic, xenolith-rich, amphibole-bearing hybrid granitoid, mainly tonalite (*AgEchx*), lies 2 km east-southeast of Zulu Well (AMG 170760). This area includes large mafic pendants that are probably Euro Basalt.

Quartz–feldspar–dacite and rhyodacite porphyry (*Apd*)

Several subconcordant, lenticular to tabular bodies and dykes of a felsic porphyritic rock intrude the Euro Basalt just south and southwest of Coppin Gap. These bodies can be traced over a distance of 4 km where they intrude pillowed high-Mg basalt, serpentinized peridotite, and talc–chlorite schist. The porphyritic and fine-grained bodies are probably apoptheses of the nearby Coppin Gap Granodiorite, which lies about 1 km to the south (Jones, 1990).

The bodies are cream to bluish-grey, fine-grained to porphyritic rocks with a quartz–sericite–plagioclase–epidote assemblage. Opaque minerals, chlorite, and K-feldspar are accessory. The rocks are altered and metamorphosed dacite and rhyodacite. They have brecciated and silicified contact zones that contain mafic and ultramafic hornfelsic rocks with diopside–hornblende–tremolite assemblages. The felsic bodies also contain multiple-phase stockworks of quartz–carbonate veins with, and without, chlorite, K-feldspar, and biotite. These veins carry chalcopyrite, molybdenite, pyrite, pyrrhotite, rare sphalerite, and scheelite (Baxter, 1978; Marston, 1979; Jones, 1990).

Muccan Granitoid Complex (*Agw, Agwm, Agwx, Agwr, Agwc, Agwf, Agwb, Agwwo*)

The straight-sided margins of the Muccan Granitoid Complex (*AgM*) imply a strong structural control contributed to the shape of this complex. Along its northeastern boundary, the complex is unconformably overlain by the basal Gorge Creek Group. The eastern boundary between the Muccan Granitoid Complex and the mafic and ultramafic rocks of the Yarrie Belt is a partly faulted, intrusional contact. Although the southern margin of the complex is intrusive into mafic and ultramafic rocks, it has also been extensively sheared by the westerly trending South Muccan Shear Zone (Zegers, 1996; Fig. 4). The granitoid component of the faulted Kennedy Gap Inlier is also part of the complex (Fig. 3).

The granitoid rocks that intrude mafic and ultramafic rocks along the southern and eastern margins as far north as Surface Well (AMG 055021), are xenolith-rich, foliated and gneissic granitoids (*AgMx*). A zone of similar rocks, which extends 14 km westwards from Surface Well towards Wattle Well (AMG 911988), contains large tremolite–serpentine–chlorite–talc bodies and small patches of amphibolite. This zone, which is not adjacent to a greenstone belt, represents the eroded keel of an older greenstone belt (Hickman, 1983). The xenolith-rich granitoids (*AgMx*) comprise mixed granodiorite, tonalite, and minor quartz diorite. Hornblende is more common in these rocks than elsewhere in the complex and is probably derived from the assimilation of mafic material. The xenolith-rich granitoids are not adjacent to the Nimingarra Iron Formation, which forms the northeast boundary of the Muccan Granitoid Complex. This absence adds further credence to the unconformable nature of this contact.

Away from the greenstone belt margins, the xenolith-rich granitoid unit (*AgMx*) merges with mixed fine- to coarse-grained, foliated granitoid rocks and gneiss, including banded gneiss and migmatite (*AgMm*). Granodiorite makes up the bulk of the banded gneiss and migmatite unit (*AgMm*), although the composition ranges from monzogranite to tonalite. Biotite is the main mafic mineral. Pegmatites of various ages and younger, medium-grained monzogranite obliquely cut the foliated granitoids. The banded gneiss and migmatite are the oldest components of the Muccan Granitoid Complex (Table 1).

The granitoid component of the Kennedy Gap Inlier consists of grey–white, foliated, biotite- and hornblende-bearing, medium-grained tonalite and granodiorite (*AgMr*). A SHRIMP U–Pb zircon age of 3438 ± 4 Ma from the granodiorite (Nelson 1998; Table 1) is similar in age to a foliated monzogranite (3443 ± 6 Ma) collected from the Sunrise West iron-ore pit, beneath the unconformably overlying Nimingarra Iron Formation. This locality lies 4.5 km north of the northern boundary of MUCCAN on COORAGOORA (Dawes et al., 1995).

Plutons of weakly foliated, pink–grey and cream, medium- to coarse-grained monzogranite and syenogranite (*AgMc*) lie north of the De Grey River. Samples collected from 2 km southeast of Don Well (AMG 958257) yielded a SHRIMP U–Pb zircon age of 3313 ± 3 Ma (Nelson 1998; Table 1).

A number of small plutons of cream to white–grey, fine- to medium-grained, magnetite-rich monzogranite (*AgMb*) are exposed in the Yundinna Creek area (AMG 886050). These rocks yielded a SHRIMP U–Pb zircon age of 3303 ± 2 Ma (Nelson, 1998; Table 1).

An unusual, fine-grained, leucocratic, muscovite-bearing granophyre (*AgMf*) lies 2.5 km east of Gap Well (AMG 999257). The only other granophyric-textured rocks on MUCCAN formed large xenoliths within a thick dolerite dyke at Black Hill.

Wolline Monzogranite (AgMwo)

The Muccan Granitoid Complex contains several intrusive stocks that are distinctly younger than the c. 3313 and c. 3303 Ma weakly foliated monzogranites and syenogranites previously described. These younger granitoid stocks are considered to be parts of a pluton, named the Wolline Monzogranite (Appendix 1), and are dated at c. 3244–3252 Ma (Nelson, 1998). A fine-grained monzogranite dyke that intrudes a c. 3313 Ma monzogranite southeast of Don Well (AMG 958256) may belong to the Wolline Monzogranite.

The Wolline Monzogranite is a pink–grey, porphyritic to seriate, medium- to coarse-grained monzogranite. Where K-feldspar is the principal mineral, the rocks approach a syenogranite composition. Phenocrysts are commonly poikilitic K-feldspar, including microcline. Biotite, replaced in places by chlorite, is the only ferromagnesian mineral.

Gorge Creek Group

Historically, the name ‘Gorge Creek’ applied to epiclastic rocks and BIF in the area around, and between, the Yarrie Homestead (AMG 086114) and headwaters of the Strelley River (‘Gorge Creek Formation’; Noldart and Wyatt, 1962). This succession was renamed the Gorge Creek Group, then expanded to include mafic volcanic units (Hickman and Lipple, 1975), and subsequently extended to include similar lithologies in the west Pilbara (Hickman, 1983). The diagnostic link between the west and east Pilbara was the presence of similar thick units of BIF and chert. These units were called the Cleaverville Formation in the west Pilbara (Ryan and Kriewaldt, 1964), a name later applied to similar rocks in the east Pilbara (Hickman, 1983).

Due to the excellent exposure of the Gorge Creek Group succession on MUCCAN and the confirmation of its newly described structural and stratigraphic relationships (Dawes et al., 1995), a revised stratigraphy can be presented (Appendix 1). Recent work on NORTH SHAW and TAMBOURAH show that the Gorge Creek Group disconformably overlies the c. 3240 Ma Strelley succession (Van Kranendonk, 1997).

Nimingarra Iron Formation (*AGn, AGna*)

The name Nimingarra Iron Formation was introduced to replace the Cleaverville Formation (Hickman, 1983; Podmore, 1990; see Appendix 1) in the northeastern part of the Pilbara Craton. A correlation with the Cleaverville Formation in the west Pilbara is still not proven and until precise geochronology is used to either validate or refute this correlation, a local stratigraphic name is preferred. The use of the term iron formation is justified by the overall high Fe content (>30% in the BIF). The Nimingarra Iron Formation hosts a number of openpit iron-ore mines; the abandoned Shay Gap East pit (AMG 990300), the currently operating Y2/3 pit (AMG 190180), and the Shay Gap West, Sunrise Hill, and Nimingarra pits on the adjacent COORAGOORA sheet (see **Economic geology** below).

The Nimingarra Iron Formation (*AGn*) consists of BIF, jaspilite (banded hematite and red jasper), banded and ferruginous chert, black (pyritiferous) shale, and mudstone. The shales are up to 40 m thick and form prominent marker horizons in the Shay Gap area (Podmore, 1990). The succession is 400–1000 m thick.

Dawes et al. (1994, 1995) showed that the BIF in the Shay Gap region, previously thought to be intruded by the underlying granitoid rocks (Hickman, 1983; Hickman et al., 1983; Podmore, 1990), unconformably overlies the granitoids. The present study has confirmed this relationship. The basal granitoid-clast-bearing, cobble to pebble conglomerate, sandstone, siltstone, and shale unit (*AGna*) described in Dawes et al. (1995) outcrops discontinuously along the base of the Nimingarra Iron Formation over both the Muccan and Warrawagine Granitoid Complexes. This unit varies in thickness from less than 5 m to several hundred metres. The absence of basal epiclastic rocks corresponds to sheared and tectonized contacts. In some areas, the granitoid rocks are tectonically interleaved with the BIF and chert.

A good exposure of the basal epiclastic unit (*AGna*) outcrops east of the Friendly Stranger mine (AMG 084020) where it unconformably overlies ultramafic volcanic rocks of the unassigned Warrawoona Group. The same unconformity outcrops further south where basal conglomerate and sandstone of the Nimingarra Iron Formation unconformably overlie the Euro Basalt on the southern side of the Coppin Gap Syncline. The basal conglomerate in this region contains distinctive clasts of fuchsitic quartzite. These clasts are identical to fuchsitic quartzite horizons that lie in the underlying Euro Basalt of the Warrawoona Group.

The basal metasandstones (*AGna*) are medium to coarse grained with subangular to subrounded quartz grains set in a fine-grained, recrystallized groundmass. Minor K-feldspar (microcline) and plagioclase grains are also present.

Cundaline Formation (*AGu*)

The newly named Cundaline Formation (Appendix 1) disconformably overlies the Nimingarra Iron Formation in the Shay Gap – Cundaline Gap area. This unit is also situated northwest of Cattle Gorge (AMG 128266), in a tight syncline northeast of Leo Bore (AMG 155105), and southeast of the Yarrie microwave tower (AMG 095045). The succession in this area is about 800 m thick.

The succession comprises mixed thin- to thick-bedded, red–brown weathered, grey–green shale, siltstone, sandstone, immature pebbly sandstone, pebble conglomerate, and wacke. The wackes are commonly quartz and lithic wackes; the lithic clasts comprise mainly chert, jasper, and minor devitrified felsic volcanic rock. Feldspar is absent. Detrital biotite and muscovite are minor and opaque minerals, including pyrite, are accessory. Minor intercalated high-Mg basalts are in the succession east of Shay Gap. Thick, coarse-grained units commonly show graded bedding and the clasts indicate a supracrustal source, probably the underlying Nimingarra Iron Formation.

East of Coppin Gap (AMG 030860), a polymictic pebble to cobble conglomerate unconformably overlies the Nimingarra Iron Formation (Horwitz, 1987). The clasts are mainly chert, banded chert, jaspilite, and BIF derived from the underlying Nimingarra Iron Formation. The Cundaline Formation is discontinuous in this area and, in places, the overlying Coonieena Basalt rests unconformably on the Nimingarra Iron Formation.

Coonieena Basalt (*AGo*)

The newly named Coonieena Basalt* (Appendix 1) disconformably overlies the Cundaline Formation between Coonieena Creek and Cattle Gorge. In the Coppin Gap Syncline area (Fig. 3), the Coonieena Basalt unconformably overlies the Nimingarra Iron and Cundaline Formations (AMG 040860). Further east, the Coonieena Basalt is unconformably overlain by the basal Fortescue Group.

The Coonieena Basalt consists of massive and pillowed tholeiitic basalt, silicified basaltic andesite, and minor high-Mg basalt. Pillow structures in the 1500 m succession east of Shay Gap consistently show way-up to the northeast. Basaltic hyaloclastite and pillow breccia are noted in this area. Mafic pisolitic tuffs formed in the upper parts of the succession north of Cattle Gorge.

Seven kilometres east of Coppin Gap (AMG 061867), pillowed tholeiitic basalts are overlain by a thick, pale-grey, talc–quartz rock with scattered vesicles, which is interpreted to be a high-Mg basalt. In earlier publications, this unusual rock was included in the Mount Roe Basalt (Hickman et al., 1983; Nijman et al., 1998).

The tholeiitic basalt is an intergranular-textured, clinopyroxene–plagioclase rock. Chlorite and epidote alteration is variable together with minor carbonate. Quartz is an accessory mineral. Large square patches of chlorite and carbonate are probably after orthopyroxene.

The top of the Coonieena Basalt in the Shay Gap townsite and Cattle Well area is intruded by the layered mafic Shay Intrusion.

Metadolerite intrusions (*AGd*)

There are medium- to coarse-grained dolerite intrusions in the Nimingarra Iron Formation, Cundaline Formation, and Coonieena Basalt. The intrusions are mostly sills and are concentrated in the Cundaline Formation. This concentration suggests they may be subvolcanic intrusions related to the overlying Coonieena Basalt.

The dolerite comprises strongly saussuritized plagioclase and unaltered clinopyroxene. Tremolite–chlorite patches have pseudomorphed orthopyroxene. The dolerite is characterized by many intersertal, granophyric quartz–feldspar patches and minor quartz.

A highly altered dolerite dyke intrudes sheared Nimingarra Iron Formation north of the Y2/3 iron-ore pit.

* Coonieena Basalt is incorrectly spelt 'Cooneeina Basalt' in the reference on the printed map.

Relict textures, preserved mainly by chlorite, suggest this dyke was a pyroxene-rich rock with a high-Mg composition.

De Grey Group

A thick succession (about 4000 m) of fine- to coarse-grained epiclastic rocks, carbonate, and felsic pyroclastic and reworked tuffaceous rocks disconformably overlies the Coonieena Basalt on the northern margin of MUCCAN. Hickman (1983) assigned these rocks to the Lalla Rookh Sandstone, a former component of the Gorge Creek Group. Horwitz and Guj (1986) and Horwitz (1987, 1990) postulated a regional unconformity between the BIF and chert unit (called Cleaverville or Paddy Market Formation at that time), the overlying mafic volcanic rocks (Honeyeater Basalt), and the epiclastic rocks (Lalla Rookh Sandstone). They argued for the exclusion of these rocks from the Gorge Creek Group. They also correlated the epiclastic rocks (Lalla Rookh Sandstone) with the Whim Creek Group in the west Pilbara. Hickman (1990) reassigned the upper clastic formations of the Gorge Creek Group, the Mosquito Creek Formation and the Lalla Rookh Sandstone, to the newly defined De Grey Group.

Recent mapping on MUCCAN and the adjoining COORAGOORA map sheet (Williams, in prep.) recognized two new formations: the Cattle Well Formation and the overlying Cooragoora Formation. These formations are equivalent to, and replace, the previously used term Lalla Rookh Sandstone (Hickman, 1983) in this area.

Cattle Well Formation (*ADa*)

The newly named Cattle Well Formation (Appendix 1) is exposed south of Cattle Well (AMG 100280) and 2.5 km north-northwest of Cattle Gorge (AMG 132305), where it is unconformably overlain by the Neoproterozoic Eel Creek Formation. The relationship between the Cattle Well Formation and the underlying Coonieena Basalt is unclear since the contact is masked by the sill-like, mafic Shay Intrusion. However, the regional distribution of the two formations supports a disconformity.

The Cattle Well Formation is poorly exposed. Bedding trends are marked by low rubble-covered strike ridges, which are composed of buff, grey and brown, thinly bedded, medium- to coarse-grained sandstone, feldspathic sandstone, and lithic and feldspathic wacke. Muscovite is an accessory mineral. The sandstone and wacke are interbedded with buff, cream and brown micaceous siltstone and shale. Some thin-bedded, grey–white, dolomitic carbonate and calcareous shale formed in the lower part of the formation.

Middle to upper parts of the Cattle Well Formation contain abundant felsic volcaniclastic material. Bedded blue–grey dacite tuff, welded tuff, blue–black chert, possibly a rhyodacite tuff, and resedimented tuffaceous sandstone and siltstone are interbedded with the epiclastic component. Lithic and crystal-lithic tuffs are present; the dacite tuff carries abundant shards, many of which are devitrified volcanic glass. The welded tuff consists of a quartzofeldspathic groundmass set with small angular fragments of quartz, plagioclase, microcline, biotite, and muscovite. There are also fragments of devitrified felsic glass with highly sutured outlines. Nelson (in prep.) dated a dacite tuff from the Cattle Well Formation at 3048 ± 19 Ma, which represents a maximum possible age for the deposition of a detrital component within the tuff (Table 1).

The Cattle Well Formation is an epiclastic succession deposited in a shallow-marine basin with a coeval, felsic volcanic component.

Cooragoora Formation (*ADo*)

The Coorogoora Formation (Williams, in prep.a) is restricted to a small area north of Cattle Well (AMG 100305) where it conformably overlies the Cattle Well Formation. It comprises resistant red–brown to purple–red, coarse- to medium-grained sandstone, feldspathic sandstone, and pebble to cobble conglomerate. These are interbedded with red–brown to dark-red shale, siltstone, and grey–brown, feldspathic and lithic wacke.

Cobbles and pebbles in the conglomerate are mainly chert, banded chert, jasper, and BIF with minor shale and quartzite. Most of the clasts are derived from the underlying and nearby outcropping Nimingarra Iron Formation. The Elephant Rock Fault (Fig. 4), which truncates the Nimingarra Iron and Cooragoora Formations, was probably active during deposition of the Cooragoora Formation.

The epiclastic rocks of the Cooragoora Formation are interpreted as fluvial deposits. The high incidence of feldspar — microcline and plagioclase, in the Cattle Well and Cooragoora Formations points to a granitoid provenance.

Shay Intrusion (*AaYn, AaYo*)

The layered mafic Shay Intrusion (Appendix 1) intrudes the contact between the Coonieena Basalt of the Gorge Creek Group and the Cattle Well Formation of the De Grey Group. The intrusion is a 500 m thick sill that is at least 10 km long. The sill is cut by the Elephant Rock Fault to the southeast.

The Shay Intrusion was first described by Hickman et al. (1983). A thick norite body (*AaYn*) was identified and contained large orthopyroxene prisms largely replaced by serpentine, set in a matrix of saussuritized plagioclase and interstitial clinopyroxene. Most of the sill is fairly altered with the primary minerals commonly replaced, or partly replaced, by epidote, chlorite, sericite/clay, carbonate, prehnite, and zeolites. Quartz is a minor component. The gabbronorite, norite, and thin, basal ultramafic pyroxenite layer, now a tremolite–chlorite rock, lie southwest of the intrusion. Gabbro, quartz gabbro, epidotized quartz gabbro, and an unusual granophyric-rich gabbro or diorite (*AaYo*) overlie the norite. The primary clinopyroxene–amphibole–plagioclase–quartz assemblage is strongly altered to epidote, chlorite, sericite, and carbonate. The patchy granophyric-rich matrix together with the overall high quartz content of the gabbroic rocks suggests there may be some contamination from the adjacent Cattle Well Formation.

Minor felsic intrusive rocks (*Apa, Ape, Apff*)

Dykes of aegirine-bearing sodic porphyry (*Apa*) intruded the Muccan Granitoid Complex 7 km north of the Yarrie Homestead (AMG 078182; Hickman et al., 1983), and the Cattle Well Formation 1 km south of Cattle Well (AMG 106276). These distinctive leucocratic, porphyritic rocks are packed with phenocrysts of feldspar and green aegirine–augite set in a fine-grained matrix of quartz, sodic and potassic feldspar, and small laths of aegirine–augite.

Several distinctive northerly trending, fine-grained to porphyritic felsic dykes of rhyolite to dacite composition (*Ape*) intruded the Warrawagine Granitoid Complex around the Chintabul Dam (AMG 390000) and 17 Mile Well areas (AMG 317940). The dykes, which can be traced over a distance of at least 10 km, are broadly arcuate but on a local scale have a sinuous outcrop pattern. The matrix of the dykes shows either a spherulitic or a micropoikilitic (snowflake) texture. Some polycrystalline quartz phenocrysts, which resemble amygdales, have anhedral, embayed margins with spherulitic-textured coronas. The felsic dykes are cut by hornblende-phyric dykes (*Ɇph*).

East-northeasterly trending, fluorite-bearing, quartz–feldspar porphyry dykes (*Apff*) intruded the Chimangadgi Trondjhemite northwest of Zulu Well (AMG 140766), and the Warrawagine Granitoid Complex northwest of 17 Mile Well (AMG 305901). The dyke north of Zulu Well consists of euhedral quartz and K-feldspar (?sanidine) phenocrysts set in a coarsely spherulitic-textured groundmass. There is fluorite in thin cross-cutting veins or in joints and cleavage planes in the altered K-feldspar.

The dykes to the northwest of 17 Mile Well consist of several large, lenticular porphyry bodies up to 200 m wide and 1 km long. The porphyry bodies comprise two phases: an older, coarse-grained, quartz–perthite–plagioclase porphyry with large vugs of dark-blue to purple fluorite; and a younger, fine-grained porphyry with phenocrysts (mainly quartz) set in a rhyodacite matrix (Hickman, 1976, 1983; Hickman et al., 1983). Chemical analyses show that the porphyries are potash rich (Hickman, 1976). The fluorite-bearing porphyritic dykes (*Apff*) are older than the spherulitic-textured felsic dykes (*Ape*).

Fortescue Group

Late Archaean Fortescue Group rocks of the Hamersley Basin (Trendall, 1990a,b) are confined to the broad southeasterly plunging Oakover Syncline (Fig. 3). Here, the stratigraphy comprises a mixed assemblage of mafic and felsic volcanic and sedimentary rocks, and is subdivided into the Mount Roe Basalt and the Hardey, Kylena, Tumbiana, Maddina, and Jeerinah Formations. The Fortescue Group was deposited between c. 2772 and c. 2687 Ma (Arndt et al., 1991; Trendall et al., 1998). All rocks in this succession are weakly metamorphosed to prehnite–pumpellyite facies (Smith et al., 1982).

A revised and updated lithostratigraphy, based on the previously published Fortescue Group stratigraphy for YARRIE (Hickman et al., 1983) and the recent work of Thorne and Trendall (in prep.), was used on MUCCAN. The relationships between the earlier and current lithostratigraphic tabulations and the sequence stratigraphic model proposed by Blake (1993) are shown in Figure 5.

Black Range Dolerite Suite (*AFdb*)

Several large north-northeasterly trending, medium- to coarse-grained dolerite dykes that intruded the Muccan and Mount Edgar Granitoid Complexes have been assigned to the Black Range Dolerite Suite (Lewis et al., 1975; Hickman, 1983).

The largest dyke, which passes through Black Hill (AMG 883259), is up to 200 m wide and is the northerly extension of the Black Range dykes originally described from MARBLE BAR (1:250 000; Lewis et al., 1975). At Black Hill, the coarse-grained dolerite consists of a subophitic intergrowth of randomly oriented plagioclase laths and anhedral augite crystals. Large scattered orthopyroxene crystals show pervasive alteration to chlorite. The dolerite has interacted strongly with the adjoining granitoid rocks producing a distinct chilled margin in the dolerite, a hybrid zone, and a remelted granitoid zone similar to that described by Lewis et al. (1975). Large granitoid xenoliths show pervasive granophyric textures, which are a product of the remelting process.

Smaller dykes, commonly less than 50 m wide, intruded the Coppin Gap Granodiorite of the Mount Edgar Granitoid Complex and the overlying Warrawoona Group up to the level of the Apex Basalt. The petrography of these dykes and their relationship to the surrounding granitoids is similar to the dolerite at Black Hill.

Recently, Wingate (1997) obtained an age of 2772 ± 2 Ma on a dyke from the Black Range Suite using SHRIMP U–Pb baddeleyite geochronology. This age supports earlier proposals (Lewis et al., 1975; Hickman, 1983) that the Black Range Suite is probably a feeder dyke system for the basal Mount Roe Basalt of the Fortescue Group, which is dated at c. 2767 Ma (Arndt et al., 1991).

Mount Roe Basalt (*AFr, AFra, AFrs*)

Outcrops of the Mount Roe Basalt (*AFr*; Kriewaldt, 1964) can be traced almost continuously along the southwestern, western, and northeastern margins of the Oakover Syncline. The unit unconformably overlies the Chimingadgi Trondjhemite, components of the

YARRIE Hickman et al. (1983)	MUCCAN Williams (this publication)	Sequence stratigraphy Blake (1993)		
Lewin Shale *(Ꝑfl)*	Jeerinah Formation *(AFj)*	Marra Mamba Supersequence package		Chichester Range Megasequence
Maddina Basalt *(Ꝑfm)*	Maddina Formation *(AFm)*	Maddina sequence package	Mount Jope Supersequence	
Kuruna Siltstone *(Ꝑfs)*	Kuruna Member *(AFmk)*			
Nymerina Basalt *(Ꝑfn)*	Maddina Formation *(AFm)*			
Tumbiana Formation *(Ꝑft)*	Tumbiana Formation *(AFt)*	Tumbiana sequence		
Meentheena Carbonate Member *(Ꝑftc)*	Meentheena Carbonate Member *(AFtc)*			
Mingah Tuff Member *(Ꝑftt)*	Mingah Tuff Member *(AFtt)*			
Kylena Basalt *(Ꝑfk)*	Kylena Formation *(AFk)*	Kylena sequence		
Hardey Sandstone *(Ꝑfh)*	Hardey Formation *(AFh)*	Hardey sequence package	Nullagine Supersequence	
Bamboo Creek Porphyry *(Ꝑp)*	Bamboo Creek Member *(AFhb)*			
Mount Roe Basalt *(Ꝑfr)*	Mount Roe Basalt *(AFr)*	Mount Roe sequence		

IRW157 15.02.99

Figure 5. Fortescue group correlation chart: a historical comparison

Warrawoona and Gorge Creek Groups, and the Muccan and Warrawagine Granitoid Complexes.

The Mount Roe Basalt is up to 700 m thick on MUCCAN, but is absent from the keel area of the Oakover Syncline, northeast of the Friendly Stranger mine (AMG 090052). At this point, the overlying Hardey Formation onlaps the Gorge Creek Group. This suggests there was a basement high in this area during deposition. There is also evidence to suggest faults were active during extrusion of the basalts (Kriewaldt, 1964; Hickman, 1983; Trendall, 1990b; Blake, 1993). The Mount Roe Basalt consists mainly of subaerially extruded, amygdaloidal, porphyritic or glomeroporphyritic, massive basalt and basaltic andesite. Restricted areas of pillow lava showing carbonate alteration are also present in Miningarra Creek (AMG 190756).

Coarse-grained basaltic agglomerate and blue–grey tuffaceous rocks (*AFra*) with a distinctive mottled weathered appearance lie at the base of the formation on the western side of the Oakover Syncline (south and east of Surface Well; AMG 050005), and continue along the northeastern margin of the syncline between the Jarman and 17 Mile Well areas (AMG 185971 and AMG 385832). A basalt–dacite breccia also forms part of the unit and consists of large angular fragments of pale-blue–grey altered dacite enclosed in dark-grey–green vesicular basalt. The origin of these rocks is unclear, although there is some evidence for the explosive mixing of dacitic and basaltic lavas.

A small exposure of polymictic conglomerate grading to fine-grained sandstone (*AFrs*) underlies the Mount Roe Basalt north-northwest of the Bamboo Mining Centre (AMG 065876). The clasts consist of chert, banded chert, quartzite, and vein quartz derived from the underlying Gorge Creek Group. These fluvial rocks occupy a small palaeovalley eroded from the underlying Coonieena Basalt.

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

The Hardey Formation (*AFh*; Thorne et al., 1991; originally named Hardey Sandstone by MacLeod et al., 1963) is a major component of the Fortescue Group on MUCCAN. It disconformably overlies the Mount Roe Basalt and unconformably onlaps the Nimingarra Iron and Cundaline Formations northeast of the Friendly Stranger mine (AMG 093050). The thickness of the formation ranges from greater than 1500 m east of Thomas Well (AMG 058980), to about 100 m in the southeast corner of MUCCAN.

On MUCCAN, the Hardey Formation consists of five rock assemblages, one of which, the Bamboo Creek Member, has been formally named (Thorne and Trendall, in prep.). The lowermost unit comprises polymictic, matrix-supported, pebble to boulder conglomerate, wacke, sandstone, and siltstone (*AFhc*). This unit formed on the western side of the Oakover Syncline and discontinuously outcrops along the valley of the Bamboo Creek, south of Thomas Well (AMG 047979). Clasts in the conglomerate include chert, BIF, quartzite, various granitoid rocks, and metabasalt from the older Archaean basement, as well as vesicular and amygdaloidal basalt from the underlying Mount Roe Basalt. There is a maximum thickness of 300 m in the area 4 km south of Thomas Well.

The upper contact of the basal coarse-grained unit (*AFhc*) is commonly intruded by feldspar porphyry from the overlying Bamboo Creek Member (*AFhb*). Further south on Miningarra Creek (AMG 200766), fragments of siltstone and sandstone were incorporated in the base of the porphyry to produce a rock resembling a peperite. This suggests the porphyry, whether as a flow or intrusion, was emplaced into wet sediments (McPhie et al., 1993). The basal coarse-grained unit (*AFhc*) is absent from the northeastern side of the Oakover Syncline where felsic lavas and pyroclastic deposits disconformably overlie the Mount Roe Basalt.

The contact between the Bamboo Creek Member and the disconformably overlying epiclastic unit of medium to very coarse grained feldspathic sandstone, pebbly sandstone, and conglomerate (*AFha*) is marked by a thin-bedded, matrix-supported conglomerate in places. In this conglomerate, the pebbles and cobbles are almost exclusively porphyry derived from the underlying Bamboo Creek Member. In some places (e.g. near Green Hole; AMG 172814), the conglomerate passes abruptly upwards into thinly bedded sandstone, siltstone, shale, and mudstone. In other areas (e.g. near Helen Well; AMG 261877), it is difficult to distinguish the overlying arkose and feldspathic sandstone from the underlying porphyry. Such rocks are probably grus, the fragmental products of in situ granular disintegration of the underlying porphyry.

The sandstone unit (*AFha*) is thickest in the northwestern and western parts of the Oakover Syncline where it is more than 1000 m thick and lenses out to the southeast. It commonly consists of coarse-grained sandstone, pebbly sandstone, and conglomerate. Feldspar is a major component of the sandstone. These rocks are fluvial with palaeocurrents directed mainly towards the east-southeast (Blake, 1984). Some fine-grained sandstone, siltstone, and shale towards the top of the unit contain a tuffaceous component.

The sandstone unit (*AFha*) is disconformably overlain by interbedded tuffaceous sandstone, siltstone, shale, and some epiclastic sandstone and conglomerate (*AFhu*). A direct pyroclastic input into the latter unit (*AFhu*) is indicated by felsic tuffs with local accretionary lapilli beds. Some thin, white, dolomitic horizons outcrop with tuffaceous siltstone and shale near the top of this unit. The top unit (*AFhu*) is thickest in the northwestern and western parts of the Oakover Syncline, and ranges from about 700 m thick in the northwest, to less than 100 m thick south of 17 Mile Well (AMG 337835) in the southeast. The top unit (*AFhu*) sits disconformably on the Bamboo Creek Member and was deposited in a lacustrine environment with some minor fluvial input (Blake, 1984).

Bamboo Creek Member (*AFhb*)

The newly named Bamboo Creek Member (Thorne and Trendall, in prep.) is a felsic porphyry complex. Previously called the Bamboo Creek Porphyry, it was considered to be a large intrusive acid sill in the Hardey Formation (Hardey Sandstone; Noldart and Wyatt, 1962; Hickman et al., 1983). However, recent studies showed that the unit consists of a pile of porphyritic lavas and pyroclastic deposits enlarged by extensive comagmatic, synvolcanic, porphyritic sills and dykes, all with a composition ranging from rhyolite to dacite (Blake, 1984, 1993; Thorne and Trendall, in prep.).

The Bamboo Creek Member, which commonly lies between the basal coarse-grained sandstone and conglomerate (*AFhc*) and the higher mixed sandstone (*AFha*) units of the Hardey Formation, is a major unit on the southwestern side of the Oakover Syncline. The unit reaches its maximum thickness east of the Bamboo Mining Centre (AMG 120840). This unit consists of thick, shallow-level sills of brown-weathered quartz and quartz–feldspar porphyry with some micropoikilitic-textured groundmass. Some of the porphyries in Miningarra Creek (AMG 220767) are flow banded. A rhyolitic quartz porphyry southwest of Green Hole (AMG 168802) yielded a SHRIMP U–Pb zircon age of 2756 ± 8 Ma (Arndt et al., 1991; Table 1).

Although the Bamboo Creek Member is absent from the northern end of the Oakover Syncline, it is present on the northeastern limb where it has a maximum thickness of about 500 m in the Helen Well area (AMG 300860). The member is commonly less than 200 m thick along the northeast limb. In this area, the member consists of porphyritic, amygdaloidal, massive, fine-grained rhyolite and dacite flows mixed with a high proportion of tuff and accretionary lapilli. In summary, the Bamboo Creek Member may represent the eroded remnants of a large felsic volcanic edifice.

Hornblende monzogranite and granodiorite (*Agh*)

A composite pluton of medium-grained, hypidiomorphic, granular hornblende granodiorite and fine-grained hornblende monzogranite covering about 4.5 km^2, is exposed near 8 Mile Soak Dam (AMG 026788) where it intrudes the Coppin Gap Granodiorite. This hornblende granodiorite has yielded a SHRIMP U–Pb zircon age of 2757 ± 7 Ma (the same age as the porphyry of the Bamboo Creek Member, Table 1). Therefore, the pluton is coeval with the Hardey Formation, although not included within it. A suite of hornblende-bearing monzogranite, granodiorite, and monzonite dykes and plutons (*Pgh*), which has intruded units as high as the Tumbiana Formation, is petrographically similar to the hornblende monzogranite and granodiorite (*Agh*). The former units (*Pgh*) are younger than the latter units (*Agh*) and are discussed below.

Kylena Formation (*AFk, AFka, AFkc*)

The Kylena Formation (Kojan and Hickman, 1998; previously called Kylena Basalt by Kriewaldt and Ryan, 1967) ranges in thickness from 400 to 1300 m on MUCCAN. Although field observations suggest that the formation is conformable on the underlying Hardey Formation, the abrupt change from the fluvio-lacustrine sedimentary deposits to subaerial mafic to felsic extrusive rocks favours a disconformable, or non-depositional unconformable, contact between the two formations. This contact is extensively faulted on the southwestern side of the Oakover Syncline.

The Kylena Formation (*AFk*) consists mainly of dark-grey to grey–green, massive, amygdaloidal basalt and basaltic andesite. These are intercalated with increasing amounts of pale-coloured, blue–grey, fine-grained andesite and possible andesitic dacite in upper levels. An upward increase in the intermediate and felsic content of the formation was detected from the potassium and thorium gamma-ray spectrometric images (Mackey, 1997c).

Individual flows are up to 10 m thick and have strongly amygdaloidal flow tops showing irregular brecciation and criss-cross quartz veining. Some larger flows are columnar jointed. Amygdales contain agate (banded chalcedony), quartz, chlorite, or carbonate.

The basalts commonly have an intersertal or intergranular texture and consist mainly of clinopyroxene and partly altered plagioclase. Some large chlorite patches pseudomorph orthopyroxene. Some carbonate alteration was noted, including calcite veining. Minor sericite, epidote, chlorite, and tremolite are secondary.

A thick, cliff-forming, brown-weathered agglomerate (*AFka*) is prominent towards the base of the formation in the northwest part of the Oakover Syncline, southwest of Jarman Well (between AMG 188940 and AMG 127875). This coarse pyroclastic unit represents the site of an explosive vent. Southwest of Jarman Well, the agglomerate is underlain by a thin, lenticular, white carbonate unit (*AFkc*). This commonly laminated carbonate is extensively replaced by silica (blue chert) and microbial laminations. Some poorly formed, low-profile, cumulate stromatolite forms are preserved. Ripple marks have been noted on the top surface of the carbonate unit.

Tumbiana Formation (*AFt*)

The Tumbiana Formation (Hickman and Lipple, 1975) consists of two members; the lower Mingah Tuff Member (*AFtt*), and the Meentheena Carbonate Member (*AFtc*; Lipple 1975). The two members combine to give a total thickness of about 400 m, although west of Miningarra Creek (AMG 190880) the succession may exceed 500 m. In most areas, the Mingah Tuff Member is the thicker unit. Field observations support a disconformity between the Mingah Tuff Member and the underlying Kylena Formation. The depositional environment varies from subaerial for the Kylena Formation, to shallow coastal marine or lacustrine, intertidal, and restricted subaerial conditions for the Tumbiana Formation.

Mingah Tuff Member (*AFtt*)

The Mingah Tuff Member (Lipple, 1975) consists of pyroclastic material, resedimented volcaniclastic rocks, and volcanogenic sedimentary rocks. Thin- to medium-bedded pisolitic tuff, including accretionary lapilli tuff, is common. The accretionary lapilli range in size from 2 to 10 mm. These bedded deposits show normal and reverse grading. The beds are up to 1 m thick and interlayered with blue–grey, crystal, lithic and vitric airfall tuff and grey–green tuffaceous sandstone and siltstone. The tuffaceous siltstone locally carries pyrite, particularly northwest of Miningarra Creek. The high accretionary lapilli tuff content of the member is indicative of phreatomagmatic eruptions (McPhie et al., 1993).

Although some thin carbonate beds outcrop in the Mingah Tuff Member, the first thick (>1 m) carbonate unit is considered to be the basal unit of the conformably overlying Meentheena Carbonate Member. Fine-grained basalt flows are irregularly interspersed within the member. Palaeocurrent directions in cross-bedded tuffaceous sandstone indicate that currents flowed mainly from the northeast.

Meentheena Carbonate Member (*AFtc*)

The Meentheena Carbonate Member (Lipple, 1975) is characterized by banded, dark-grey dolomitic carbonate and limestone beds that contain scattered oncolites and stromatolites in bioherms and biostromes. Commonly cliff-forming, the carbonate beds are interbedded with red–brown to green–grey tuffaceous shale and siltstone, and minor thin-bedded lapilli tuff beds. Calcareous sandstone and siltstone, edgewise-carbonate conglomerate, and oolitic beds are also present. Large pyrite cubes are common in shale and siltstone south of 17 Mile Well (AMG 366781).

The Meentheena Carbonate Member is the favoured horizon for several extensive medium-grained dolerite sills and associated feeder dykes (*Ad*). The member is conformably overlain by the Maddina Formation.

A wide range of stromatolite forms are recognized in the Meentheena Carbonate Member. The stromatolites formed as single, large domal bioherms up to 1 m in diameter, or small (centimetre scale) biohermal mounds of branching columns, or thin tabular biostromes. Cauliflower-shaped bioherms of branching stromatolites are distinctive in form. The distribution of stromatolite buildups is random within individual beds. The morphology of stromatolites in the Meentheena Carbonate Member was described by Packer (1990), who also interpreted the depositional environment to be sublittoral to supralittoral. Other references to stromatolites in the Meentheena Carbonate Member are in Grey (1981, 1984) and Walter (1983).

Maddina Formation (*AFm*)

The 600 m thick Maddina Formation (Kojan and Hickman, 1998; previously called Maddina Basalt by MacLeod and de la Hunty, 1966) occupies the core of the

Oakover Syncline in the southeast corner of MUCCAN. The formation is disconformably overlain by the Jeerinah Formation in the Lance Bore area (AMG 260805).

In earlier mapping of YARRIE (Hickman et al., 1983), the area now assigned to the Maddina Formation was divided between the older Nymerina Basalt and the overlying Maddina Basalt. The two basalt formations are separated by the Kuruna Siltstone. However, following recent reappraisals of the Fortescue Group, the term Nymerina Basalt was discontinued and all basaltic rocks above the Tumbiana Formation were grouped into the Maddina Formation (Thorne and Tyler, 1997; Thorne and Trendall, in prep.). The reason behind this decision lay in the discontinuous outcrop of the Kuruna Siltstone, which, when absent, makes it impossible to distinguish the Maddina Basalt from the underlying Nymerina Basalt.

On MUCCAN, the Maddina Formation consists of thick, massive, amygdaloidal basalt flows similar to those in the lower parts of the Kylena Formation. Several large amygdales, ranging from oval to streaked in shape, carry quartz, agate (banded chalcedony), chlorite, calcite, epidote, and uncommon sulfide beds. Traces of chalcopyrite and malachite in quartz veins embedded in flow tops outcrop south-southeast of 17 Mile Well (AMG 372777). Calcite and epidote veins cut some of the flows. The frequency of amygdales increases upwards and flow tops are recognized by brecciation, quartz veining, and scoriaceous surfaces. Petrographically, the basalts resemble those described from the underlying Kylena Formation.

Kuruna Member (AFmk)

A distinctive horizon of siliceous vitric tuff, pisolitic lapilli tuff, tuffaceous sandstone, siltstone, and shale lies near the top of the Maddina Formation, east and southeast of Lance Bore (AMG 240826). The unit is 20–30 m thick and interbedded between basalt flows of the Maddina Formation. The unit is correlated with the Kuruna Member (Thorne and Tyler, 1997), which was previously called the Kuruna Siltstone (MacLeod and de la Hunty, 1966). Hickman et al. (1983) recorded disseminated galena in sheared siltstone of the Kuruna Member, 1 km north of Lance Bore.

Jeerinah Formation (*AFj*)

A small, complexly faulted basin around Lance Bore (AMG 240826) contains a succession of epiclastic, volcaniclastic, and minor pyroclastic rocks intruded by medium- to coarse-grained dolerite. The succession, which disconformably overlies the Maddina Formation, is correlated with the Jeerinah Formation (MacLeod et al., 1963). These rocks were previously mapped as Lewin Shale on YARRIE (Hickman et al., 1983), a term now superceded and replaced by the Jeerinah Formation (Hickman, 1983; Williams, 1989).

Scattered outcrops and complex faulting in the area make it difficult to estimate the thickness of the formation. However, local steep dips suggest that over 300 m is present northwest of Lance Bore. The succession consists of a basal brown tuffaceous siltstone, khaki–brown lapilli tuff, and siliceous vitric and crystal lithic tuffs. These are overlain by flaggy brown siltstone, brown to yellow shale, red–brown wacke, thin-bedded, quartz-pebble conglomerate, and blue chert. Blue–grey, ripple-marked quartz sandstone is present 1.5 km north-northwest of Lance Bore.

Mafic intrusive rocks (*Ad*)

Scattered medium- to coarse-grained, subophitic- to ophitic-textured dolerite and granular-textured gabbro dykes (*Ad*) intrude the Muccan and Warrawagine Granitoid Complexes and the Coppin Gap Granodiorite. In some instances, the mafic dykes can be traced into the supracrustal rocks of the Warrawoona Group. Most of the dykes are linear, short with continuous exposure over less than 2 km, commonly northerly or east-northeasterly trending, and, in many cases, show alteration commensurate with very low grade metamorphism.

Two transgressive medium- to coarse-grained dolerite sills intrude the Tumbiana Formation. A third dolerite intruded the overlying Maddina and Jeerinah Formations in the vicinity of Lance Bore. The dolerite sills in the Tumbiana Formation may be subvolcanic intrusions related to the basaltic rocks of the overlying Maddina Formation. If this is the case, the ring-shaped dolerite intrusion that cuts the Maddina and Jeerinah Formations is a younger unit.

Structure

Hickman (1983) and Hickman et al. (1983) recognized five main deformation episodes in the eastern part of the Pilbara Craton. Several of these episodes are recognized on MUCCAN. The earliest event, D_1, includes complex, isoclinal folding of earlier greenstone and granitoid material accompanied by granitoid intrusions and the development of banded gneiss, migmatite, and early schistosity (S_1). This structural event is recorded in the xenolith-bearing granitoid unit (*AgMx*), which lies in the southern half of the Muccan Granitoid Complex, and in the eastern and northeastern parts of the Warrawagine Granitoid Complex (see simplified geology sketch map, MUCCAN map sheet).

The second and main deformation episode, D_2, is directly related to the tectonic emplacement of diapiric granitoid domes (Hickman, 1983; Collins, 1989; van Kranendonk, 1997). Deformation is associated with a regional schistosity (S_2) and greenschist to amphibolite facies metamorphism. The spatial relationship between the granitoid domes and surrounding tightly folded, faulted, curvilinear synclinoria of greenstone or supracrustal rocks typical of the east Pilbara region resulted from the D_2 event (Figs 3 and 4). This was not a single event but the product of multiple pulses of granitoid material, most of which were emplaced within pre-existing granitoid complexes.

The response in the adjoining greenstone belts to this diapiric and inflationary pressure was initially one of uplift with steepening dips and the development of listric growth faults around the rising domes. Continued inflation saw the formation of intense, discrete shear zones subparallel to bedding with strike-slip movements. These are roughly parallel to the edge of the domes; for example, the Bamboo Creek Shear Zone (Fig. 4; Zegers, 1996). With the continued upward growth of the domes, erosion of the greenstones commenced, which, in many cases, eventually unroofed the granitoid cores to the domes. This material was deposited in the adjoining deepening synclinal areas.

On MUCCAN, the Gorge Creek Group is an example of the late, unconformably bounded epiclastic and volcanic successions. These successions became tightly folded in some areas — for example, the Coppin Gap Syncline (Fig. 3) — or were subject to strong strike-slip faulting as the rocks tried to accommodate the continued strong compressive deformation associated with the continually expanding granitoid domes. The sinistral Elephant Rock Fault and complementary dextral Kennedy Gap Fault are examples of this space accommodation problem (Fig. 4).

The early D_2 doming of the c. 3440 Ma granitoid complexes (>3440 Ma) was complete before intrusion of the strongly discordant Coppin Gap Granodiorite (c. 3314 Ma; Williams and Collins, 1990), Mullugunya Granodiorite, and Chimingadji Trondjhemite in the Mount Edgar Granitoid Complex (Collins, 1983). Similar c. 3313 Ma ages were obtained from the adjacent Muccan and Warrawagine Granitoid complexes (Nelson, 1998; Table 1).

The Coppin Gap Syncline contains rocks of the Gorge Creek Group unconformably overlying Warrawoona Group rocks, which occupy a pre-existing, but now sheared out, synclinorium. The Coppin Gap Syncline is a reinforcement of the earlier structure and was formed by the continual uplift and doming of the granitoid complexes. This relationship contrasts with the faulting and folding of the Gorge Creek Group in the Shay Gap Belt, which is structurally unrelated to earlier sheared synclines in the Warrawoona Group of the Yarrie Belt deformed prior to c. 3440 Ma.

The Shay Gap Belt was affected by the continued growth of the Muccan and Warrawagine Granitoid Complexes (post c. 3240 Ma), particularly in the Eel Creek – Yarrie area. The tight Leo Syncline in the Gorge Creek Group rocks can be traced, disjointedly, northward from east of the Yarrie microwave tower (AMG 085057), to west of the Yarrie iron mine (AMG 190180) where it is faulted out along the sinistral, strike-slip Elephant Rock Fault (Fig. 4). This fault is complementary to the large, dextral strike-slip Kennedy Gap Fault to the east (Fig. 4). These faults form the boundaries of a north-directed pop-up wedge, or strike-slip flower structure, which has been squeezed out from between the Muccan and Warrawagine Granitoid Complexes by east-west directed compression. The Leo Syncline plunges north and south of the late Callawa Fault, a sinistral strike-slip fault. The southerly plunging Leo Syncline is unconformably overlain by the late Archaean Fortescue Group.

The complex structures in the Yarrie iron mine area (AMG 190180), adjacent to the Kennedy Gap Fault, are described by Waters (1998). Five distinct fold sets are recorded; some fold sets may be a result of soft-sediment deformation. The earliest fold sets are isoclinal and superimposed by northerly plunging mesoscopic folds whose axial surfaces dip to the east and west. Both of these early fold sets have been refolded by upright, northerly plunging open folds. The whole sequence at the Yarrie iron mine dips moderately to the north and east, off the Warrawagine Granitoid Complex. There was tectonic interleaving of the basal Nimingarra Iron Formation with the unconformably underlying granitoid rocks.

Away from the Eel Creek, Cattle Gorge, and Yarrie iron mine areas, the Gorge Creek Group and the disconformably overlying De Grey Group form a northeast to northerly dipping succession. South of the Yarrie iron mine, the Gorge Creek Group and underlying granitoid rocks together with the Elephant Rock and Kennedy Gap Faults are cut by two east-northeasterly trending strike-slip faults; the sinistral Callawa Fault to the north, and the dextral Du Valles Fault to the south. These faults are marked by quartz-filled shear zones and form the margins of a large block of Gorge Creek Group that was transported about 5 km to the east. These faults are the product of north-south compression and die out to the west within the Muccan Granitoid Complex.

The late Archaean Fortescue Group occupies the large open, southeasterly plunging Oakover Syncline, a D_5 structure (Hickman et al., 1983; Fig. 4). The Oakover Syncline is superimposed on the older greenstone belts, including the Gorge Creek and Warrawoona Groups, which occupied a pre-existing synclinoria between the Muccan, Warrawagine, and Mount Edgar Granitoid Complexes. The Oakover Syncline is intersected by several steeply dipping block faults, which commonly resolve into a northwest (315°) set and a younger northerly (350°) set. The latter has a consistent small dextral offset. The structures, represented by the Elephant Rock and Kennedy Gap Faults (Fig. 4), may have continued south beneath the Fortescue Group unconformity. Reactivation of these earlier structures could account for some of the faulting in the younger Oakover Syncline.

Proterozoic rocks

Felsic and mafelsic intrusive rocks

An unusual suite of felsic to mafelsic granitoid and porphyritic rocks outcrop in several widely scattered small plutons, less than 1 km^2 in area, in numerous porphyritic dykes and sporadic sills. In many cases, the dykes can be traced into the small granitoid plutons. These rocks are widespread in the southern half of MUCCAN, but are less common in the north. The small plutons were previously described as either hornblende adamellite (Lewis and Davy, 1981; Hickman, 1983; Hickman et al., 1983), or quartz monzonite and monzonite (Rock and Barley, 1988). Similarly, the porphyritic dykes were referred to as hornblende porphyries (Maitland, 1905; Finucane, 1936; Noldart and Wyatt, 1962; Hickman, 1983), trachyandesites (Hickman, 1978; Barley, 1980; Lewis and Davy, 1981;

Hickman et al., 1983), calc-alkaline lamprophyres, and, in some specific instances, spessartite (Rock and Barley, 1988).

Rock and Barley (1988) assigned a Proterozoic age to these intrusions, which occur over a large area of the east Pilbara in a north-northwesterly trending belt about 140 km long and 25 km wide (Hickman, 1983). The trend of the suite cuts across major fold structures in the Fortescue and Hamersley Groups of the east Pilbara.

Hornblende monzogranite and granodiorite (*Ꝑgh*)

Small plutons of pinkish-green to grey–green hornblende monzogranite and granodiorite intrude the Apex Basalt south-southwest of the Bamboo Creek Mining Centre (AMG 095801 and AMG 091781), and the Euro Basalt south-southeast of the Bamboo Creek Mining Centre (AMG 107799 and AMG 122779) and east of Seven Oaks (AMG 160790). Some of these plutons intrude the Chimingadgi Trondjhemite (AMG 145774 and AMG 170765). All these intrusions appear to be closely related to swarms of porphyritic trachyandesite dykes that outcrop in the same area.

A slightly larger pluton of hornblende granodiorite intrudes the Bamboo Creek Member, 1.6 km south of Thomas Well (AMG 052962). A cluster of eight small plutons of hornblende monzogranite and granodiorite intrude the Mingah Tuff Member in an area west of Helen Well and centered around AMG 170890. The plutons in this area are characterized by contact aureoles, which attain hornblende hornfels facies. Several sills of porphyritic hornblende andesite and scattered trachyandesite dykes are associated with these plutons.

The granitoid rocks are commonly fine to medium grained with hypidiomorphic- to allotriomorphic-granular-textured assemblages of plagioclase (oligoclase–andesine), K-feldspar, green to light-brown pleochroic hornblende, and quartz. The K-feldspar is commonly perthitic and some of the plagioclase shows oscillatory zoning. Some hornblendes have clinopyroxene cores. Hornblende is partly altered to chlorite and plagioclase is commonly saussuritized.

Trachyandesite and lamprophyre dykes (*Ꝑph*)

Several porphyritic trachyandesite dykes lie in the southern half of MUCCAN where they are concentrated in the Chimingadji Trondjhemite and adjacent Mullugunyah Granodiorite. They have intruded the Warrawoona Group rocks, particularly in the area adjacent to the Chimingadji Trondjhemite, the Muccan Granitoid Complex south of latitude 20°45'S, and the lower formations of the Fortescue Group west of longitude 120°20'E. In the lower formations of the Fortescue Group, the dykes are closely associated with a cluster of hornblende monzogranite plutons that intrude the Mingah Tuff Member. There are few dykes in the Warrawagine Granitoid Complex. A brecciated trachyandesite plug intrudes unassigned Warrawoona Group south of the Yarrie mining village (AMG 170190). A similar body intrudes the Cundaline Formation southwest of the Yarrie mining village (AMG 125186).

An unusual feature of all these dykes is the common sinuous outcrop pattern created where they intrude granitoid rocks. Most are also arcuate on a regional scale, although they tend to be straighter in supracrustal rocks. There are four main dyke sets: approximately 315°, 360°, 040°, and 080°.

These dykes were originally described as hornblende porphyries and trachyandesites (Lewis and Davy, 1981; Hickman, 1983; Hickman et al., 1983), although Rock and Barley (1988) proposed that, on compositional and textural grounds, these rocks should be called calc-alkaline lamprophyres. Data collected during this study suggest some dykes are lamprophyres but, as shown by Lewis and Davy (1981), the chemistry of the rocks ranges from rhyolite to andesite. Individually, a dyke is either a spessartite (a calc-alkaline lamprophyre with idiomorphic-textured phenocrysts of hornblende and plagioclase) or a trachyandesite (a trachytic-textured, hornblende-phyric rock of andesitic composition).

Most of the dykes are distinctively pinkish to pinkish-grey–green. Mafic phenocrysts are dominantly green, acicular or platy hornblende with minor biotite and clinopyroxene. Plagioclase is the dominant phenocryst in some of the dykes, but K-feldspar and quartz are also phenocrystic. The diagnostic feature, in all cases, is the large number of idiomorphic phenocrysts. The hornblende is partly altered to chlorite, carbonate, and epidote whereas plagioclase and K-feldspar are commonly altered or saussuritized. Two types of groundmass are distinguished: a swirling, trachytic-textured groundmass of acicular hornblende and microlaths of feldspar; and a more granular, micropoikilitic-textured groundmass of dominantly K-feldspar, some quartz, and disseminated opaque minerals. The trachytic-textured groundmass is common in dykes intruding the Coppin Gap Granodiorite.

Tarcunyah Group

Mainly shallow-dipping, epiclastic sedimentary and minor tuffaceous volcanic rocks unconformably overlie the Archaean granite–greenstone terrain in northeastern MUCCAN. These volcanic rocks are lithologically and structurally similar to the Neoproterozoic Tarcunyah Group (Williams and Trendall, 1998b) and represent a possible westward extension of this group. First described in the mid-1990s, the Tarcunyah Group is now considered to be a northwest extension of the Officer Basin (Bagas et al., 1995; Perincek, 1996; Stevens and Grey, 1997; Williams and Trendall, 1998a,b,c; Williams and Bagas, in prep.).

Eel Creek Formation (*Ꝑue, Ꝑueh, Ꝑueq*)

The Eel Creek Formation (*Ꝑue*; Hickman et al., 1983) occupies about 3% of MUCCAN and is an unmetamorphosed, epiclastic sedimentary succession over 500 m thick with a minor tuffaceous volcanic component.

The formation overlies, with angular unconformity, rocks belonging to the Warrawoona Group, the Warrawagine Granitoid Complex, and the Gorge Creek and De Grey Groups. The succession is shallow dipping and occupies the area north of Cattle Gorge (AMG 135305), where the rocks are easterly dipping, to the Moxam Well area (AMG 355195), where the rocks are northerly dipping. The formation is unconformably overlain by the Permian Paterson Formation in this area. Along the northern margin, it is unconformably overlain by the Jurassic–Cretaceous Callawa Formation. The Eel Creek Formation is extensively intruded by fine- to coarse-grained dolerite sills and dykes.

The basal unit of the Eel Creek Formation is a discontinuous, hematite-clast-rich conglomerate (*ⱣUeh*) up to 12 m thick (Waters, 1998). The main exposures are between Cattle Gorge and 3 km north-northwest of Cabbage Tree Well (AMG 152261, AMG 187236, AMG 215214, and AMG 270220). The Y10 iron-ore openpit mine is located in this hematite-clast conglomerate (AMG 215214).

The hematite-clast conglomerate is overlain, and, in places, overlapped by, the main succession of the Eel Creek Formation. This consists of variably coloured shale, mudstone, and siltstone. Southeast of Reid Bore (AMG 195257), grey–green shale rests directly on steeply dipping Nimingarra Iron Formation, which may have formed a basement high. Alternatively, there was probably a hiatus in deposition with erosion of the conglomerate before deposition of the overlying shales and mudstones.

The basal shale and siltstone of the Eel Creek Formation contain a number of subaqueous, resedimented pyroclastic layers that are now bedded, devitrified rhyolite and dacite tuffs; for example, in the Cattle Gorge Bore area (AMG 143283) and in the Moxam Well area (AMG 352187).

The Eel Creek Formation is an upward-coarsening, shallow-water marine succession. The upper units consist of fine- to coarse-grained sandstone, white quartz sandstone, and brown or grey micaceous siltstone (*ⱣUeq*). Siltstone intraclasts are common in some of the sandstones. Thinly bedded sandstones show symmetrical and asymmetrical ripple marks, synaeresis cracks, and rib and furrow structures. Palaeocurrent evidence indicates flow to the north. There are halite pseudomorphs in red–brown, fine-grained sandstone northeast of Reid Bore (AMG 211292 and AMG 223263). Sparse glauconite was identified in siltstone east of the Y10 iron mine (AMG 257218).

Mafic intrusive rocks (*Ɽde*)

A suite of fine- to coarse-grained dolerite sills and feeder dykes is prominent in the Eel Creek Formation. Some fine-grained dolerites contain scattered amygdales, which indicate shallow emplacement. The dolerite has a subophitic texture with randomly oriented plagioclase laths and interstitial clinopyroxene, minor hornblende, and sparse olivine. Patchy myrmekitic intergrowths of K-feldspar and quartz are characteristic of the coarse-grained sills. Plagioclase is partly saussuritized. Some clinopyroxene is bordered by brown hornblende whereas green hornblende is interstitial. Both hornblendes are locally replaced by chlorite. Baddeleyite, visible in thin sections, is also present.

The dolerite intrusions have baked the surrounding shale and siltstone. In most cases, this has produced a blue–black contact hornfels.

Structure

The Neoproterozoic Eel Creek Formation occupies the southwestern part of a basin, which extends northeast beneath Phanerozoic rocks (Fig. 3). Overall, the Eel Creek Formation is a shallow, easterly to northerly dipping succession (Fig. 4). The bedding dip steepens towards the unconformable contact with the Archaean rocks, a steepening that is accredited mainly to primary dips that formed on deeply eroded bedrock, particularly the Nimingarra Iron Formation. The succession is gently folded about an open, shallow northeasterly plunging syncline northwest of Cabbage Tree Well (AMG 238272). Several nearby vertical faults are probably reactivated basement faults.

There are asymmetric northerly plunging folds at irregular intervals in the basal hematitic conglomerate; for example, west of Cabbage Tree Well (AMG 262235). These asymmetric folds have near-vertical to overturned western limbs and shallow east-dipping limbs with moderately east-dipping axial planes. The folds, some on a mesoscopic scale (metres), form right-handed en echelon sets. The steep to vertical western limbs commonly have vertical slickensides on the top surface of the hematite conglomerate. This surface is crossed by randomly spaced kinks or flexures trending mainly 300° and 325° northwest of Cabbage Tree Well. These show similar asymmetry to the larger folds with axial planes dipping to the east and northeast. The large folds are concentric and axial planar cleavage is absent. Some of the overlying shale and siltstone units show a faint, spaced cleavage trending about 320°. These asymmetric folds are not in the western part of the basin.

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

A number of dolerite dykes (*d*), age unknown, are scattered throughout MUCCAN. Some are well exposed, or weathered to clay, or show up as strong, linear magnetic anomalies. The magnetic anomalies are particularly evident in the large granitoid complexes.

Thin, linear but commonly short (about 1 km), fine-grained dolerite dykes are scattered irregularly throughout the granitoid complexes and Warrawoona Group. Most of these dykes are assigned to two main sets: an east-northeasterly to northeasterly trending set (Mundine Well

Suite; Hickman, 1983); and a west-northwesterly to northwesterly trending set (Round Hummock Suite; Hickman, 1983). Recently, Wingate (1997) obtained a 755 ± 3 Ma age from east-northeasterly trending dykes using SHRIMP U–Pb baddeleyite geochronology. A third set comprising larger dolerite dykes (>5 km), which have a bouldery surface expression and a sinuous outcrop pattern, trend northwards.

Large quartz veins comprising massive or faintly banded cryptocrystalline quartz (*q*) occupy major fault zones, such as the Du Valles Fault. In other areas, granitoid rocks are cut by thin, intersecting quartz veins that occupy joints and shear zones. Most quartz veins on MUCCAN trend northwest to north-northwest and some carry base-metal mineralization (copper and lead; see **Economic geology**).

The Coonieena Basalt contains several iron-rich, gossanous, quartz-filled shear zones (*qgo*) west and east of Cattle Well (AMG 061280 and AMG 124290).

Palaeozoic rocks

Permian rocks

Permian fluvioglacial rocks are located in several localities along the northern margin of MUCCAN between Shay Gap (AMG 010280) and Moxam Well (AMG 353193). The rocks are not well exposed and, in a number of instances, their presence is inferred from overlying Quaternary boulder beds. These distinctive mixed colluvial and eluvial deposits (*Qcp*) together with exposed Permian rocks, indicate the position and trend of narrow palaeoglacial valleys that have been incised into the Gorge Creek and De Grey Groups, and Eel Creek Formation (Fig. 3). Shay Gap (AMG 010280) is interpreted to have a glacial origin.

Permian fluvioglacial rocks are exposed north and east of Shay Gap. In this area, they occupy a narrow glacial valley that can be traced from the overlying scattered exotic boulders and cobbles of the mixed alluvial and eluvial unit (*Qcp*) to 8 km east of Shay Gap towards an unnamed gap, 2 km southeast of Cattle Well. Permian rocks on MUCCAN are marginal to the Canning Basin, which is the main depocentre of Permian rocks in the region. The edge of the Canning Basin lies about 15 km east of Moxam Well on WARRAWAGINE (Williams, in prep.b).

Paterson Formation (*Pa*)

The Paterson Formation (Traves et al., 1956; Towner and Gibson, 1980) is the sole Permian stratigraphic unit on MUCCAN. Poor outcrop makes it difficult to estimate the thickness of the unit. Over 250 m of this unit has been recorded from drillholes on WARRAWAGINE (Hickman et al., 1983). The Paterson Formation is part of depositional Sequence Pz5 (Middleton, 1990) and, from correlation with equivalent rocks in the Carnarvon Basin, has a lower Sakmarian–Asselian age (Mory and Backhouse, 1997).

The basal unit is a pebble- to boulder-bearing diamictite. In the Shay Gap area, granitoid boulders up to 2 m in diameter are embedded in the clay–silt portion of the mixed alluvial and eluvial unit (*Qcp*). There are similar boulders up to 8 km east of Shay Gap. The granitoid boulders can be matched to similar lithologies in the Muccan Granitoid Complex, which lies southwest of Shay Gap. Quartzite boulders are striated and faceted.

The largest exposure of Paterson Formation lies north-northeast of the Y10 iron mine (AMG 260265). In this area, interbedded sandstone, siltstone, shale, and conglomerate overlie the diamictite. The conglomerate occupies channels cut into the adjacent sedimentary rocks and there are small tabular cross-beds in the sandstone. The shale and siltstone are silicified and banded in places. Hickman et al. (1983) interpreted some of the banded rocks to be varves. A silicified siltstone outcrop on Salt Well Creek (AMG 316271) features multicoloured Liesegang bands. The basal diamictite of the Paterson Formation on MUCCAN is possibly a tillite whereas the overlying fine- to coarse-grained sandstone, siltstone, shale, and conglomerate are fluvioglacial deposits.

The Paterson Formation dips gently to the northeast. A low-angle unconformity is present between the Paterson Formation and the overlying Mesozoic Callawa Formation.

Mesozoic rocks

Jurassic–Cretaceous rocks

Callawa Formation (*JKc*)

Outliers of the Jurassic–Cretaceous Callawa Formation are restricted to the area north of latitude 20°36'S and east of longitude 120°07'E, but the most extensive outcrops are located in the headwaters of the Eel and Salt creeks. Remnants of a once continuous cover of Callawa Formation unconformably onlap the Nimingarra Iron Formation and unconformably overlie the Eel Creek and Paterson Formations. The Callawa Formation is a cliff-forming unit that occupies a series of rugged buttes, mesas, and small tablelands that rise over 50 m above the surrounding countryside. The thickness of the formation has been estimated to be about 100 m (Hickman et al., 1983).

The age of the Callawa Formation, as determined from plant fossils by White (1961), is considered to be Late Jurassic – Early Cretaceous. The Callawa Formation falls within depositional Sequence Mz4 (Middleton, 1990) and is now considered to be part of the Lambert Shelf (Fig. 3), a marginal shelf in the Westralian Superbasin (Hocking et al., 1994). Hence, the Mesozoic succession on MUCCAN is a thin onlap of sedimentary rocks onto a Precambrian basement and is not part of the structurally controlled Canning Basin succession, which lies to the east.

The Callawa Formation consists of a lower and an upper part. It is described and discussed in detail by a number of workers (Traves et al., 1956; Veevers and Wells, 1961; Towner and Gibson, 1983; Hickman et al., 1983;

Middleton, 1990). The lower part is exposed in the headwaters of the Eel, Salt Well, and Coonieena creeks. The base of the lower unit is commonly marked by a thin cobble to boulder conglomerate that, in places, contains recycled, faceted, and polished quartzite clasts derived from the underlying Paterson Formation. The conglomerate is overlain by white claystone, very fine to very coarse grained sandstone, pebbly sandstone, and conglomerate. A very ferruginous silty sandstone packed with plant fossils lies close to the base of the succession, 5 km north of Cabbage Tree Well (AMG 281266). The plant fossils, mainly stems, are completely replaced by iron oxide. This unit may have originally been a swamp deposit. Towards the top of the lower unit, several beds up to 2 m thick of mottled, red–white, bioturbated, clayey sandstone carry many trace fossils. Most of the fossils are burrows at right angles to the bedding, up to 12 cm long. The depositional environment for this unit was either lacustrine or intertidal shallow marine. Sandstone in the lower unit is locally cross-bedded with a wide range of palaeocurrent directions. Ripple marks and synaeresis cracks are present in fine-grained sandstone in places.

The upper part of the Callawa Formation, which onlaps the Nimingarra Iron Formation and forms caps on the mesas and buttes, consists of thick beds of matrix-supported, pebble to boulder conglomerate separated by massive or cross-bedded, medium- to coarse-grained sandstone and pebbly sandstone. Minor intercalations of white claystone carry plant fossils (Traves et al., 1956; Veevers and Wells, 1961). The conglomerate occurs as both tabular sheets and channel fills incised in the underlying sandstone. Some conglomerate beds are graded. Clasts consist of subangular to subrounded chert, jasper, BIF, vein quartz, quartzite, and minor granitoid rocks. Trough cross-beds measured in the sandstone show a persistent, northwest- to north-directed palaeocurrent.

Although the Callawa Formation is described as a fluvial deposit* (Hickman et al., 1983) with the provenance for the coarse epiclastic rocks lying to the south in the Pilbara Craton, the lower part, recognized in this study, indicates that the fluvial environment only became fully established in the upper part of the formation. The lower part is indicative of a mixed regime of interfingering lacustrine or near-shore marine to littoral environments, encroached upon by advancing, high-energy fluvial deposition. It may be correlative with part of the Jarlemai Siltstone, a marine unit recorded from water boreholes on COORAGOORA, north of MUCCAN (Leech, 1979; Hickman et al., 1983).

Cainozoic rocks

Cainozoic rocks cover nearly half of MUCCAN and are particularly common on the granitoid complexes. Superficial material includes consolidated alluvial, colluvial, and residual deposits and Quaternary unconsolidated alluvial, colluvial, eluvial, and eolian deposits.

* The 'fluvialglacial' description recorded on the accompanying 1:100 000 map sheet is incorrect and should read 'fluvial deposit'.

Residual calcrete (*Czrk*) overlies, and is derived from, altered carbonate-rich ultramafic rocks near the Friendly Stranger gold mine (AMG 065031). The calcrete forms sheets, encrustations, and joint-fills within carbonate–tremolite–chlorite rocks and is associated with minor magnesite. The calcrete is either massive or nodular and, where it is replaced by silica, forms rough vuggy surfaces. The poorly sheeted calcrete also occupies old gold-bearing drainage lines.

Patchy, dissected and partly silicified valley calcrete (*Czak*; Butt et al., 1977) lies along tributaries and the lower reaches of Eel Creek (e.g. AMG 123130), in the upper reaches of Ngarrin Creek (e.g. AMG 350862), and at Yundinna (AMG 883991) and Monitor wells (AMG 083181). The calcrete is a massive to nodular, locally cavernous, grey–white limestone. The upper surface is commonly replaced by opaline and chalcedonic silica, particularly on low mesa-form outcrops. The silicified surface consists of blue, black, or cream opaline and chalcedonic silica. Where the calcrete is less eroded and subdued in outcrop, the carbonate is less silicified and more friable.

A small patch of grey silcrete (*Czrz*) caps a low hill 3 km northwest of Chintabul Well. The unit is a remnant of a once more extensive sheet in this area and comprises angular quartz grains set in a siliceous cement.

Ferruginous duricrust (*Czrf*), which includes some laterite, is restricted to a few outcrops on the northern margin of MUCCAN where it overlies the Callawa Formation. Although some of the outcrops are rubbly and mixed with wind-blown sand, massive, nodular, and pisolitic forms have been identified. The unit weathers to form ironstone pebbles in the overlying sand.

Several types of dissected, consolidated, iron-rich colluvial and alluvial deposits are specifically associated with the erosion of the Nimingarra Iron Formation. These include dissected, old scree and iron-rich canga deposits (*Czcf*) that fringe the Nimingarra Iron Formation, 5 km west of Kimberley Gap (AMG 123160). The iron-rich canga deposits (*Czcf*) consist of an iron-cemented apron of subangular clasts of chert, jaspilite, and BIF.

Silica- and iron-cemented, alluvial channel deposits (*Czaz*) consist of subangular to subrounded clasts of chert, jaspilite, and BIF. These deposits are south and west of the Yarrie Y2/3 iron mine (AMG 150123 and AMG 100155) in dissected and elevated tongues and lobate-shaped channel fills, which extend outwards from the Nimingarra Iron Formation. Clast size diminishes rapidly downstream and away from Nimingarra Iron Formation ridges. The unit forms low mesas that extend across the basement rocks.

Pisolitic ferruginous channel deposits (*Czap*) form another category of consolidated alluvial valley fills. These consist of limonite, goethite, and hematite pisolites and are, in most cases, low-grade iron-ore deposits. Plant fossils have been recorded from this unit (Hickman et al., 1983). The pisolitic ferruginous channel deposits (*Czap*) indicate a more sluggish drainage system than the system that deposited the consolidated channel-deposit conglomerates (*Czaz*). Hickman et al. (1983) tentatively correlated the former unit (*Czap*) with the Poondano Formation (McWhae et al., 1958), which was originally described from the Port Hedland area. The age of the pisolitic ferruginous channel deposits is possibly late Eocene to Oligocene (Blockley, 1990).

Dissected, consolidated colluvium (*Czc*) is located adjacent to the Hardey and Callawa Formations. It consists of poorly stratified clay, silt, sand, and thin-bedded pebbly sand and gravel with a clay or silica cement. Similar units form mounds on the granitoid rocks. These may be distal correlatives to the consolidated alluvial channel (*Czaz*) and iron-rich canga (*Czcf*) deposits. The consolidated colluvium unit (*Czc*) is not specifically related to drainage lines.

Consolidated, poorly stratified clay, silt, and sand (*Czaa*) formed along the banks of creeks that flow north into the De Grey River.

South of the De Grey River, consolidated alluvial deposits are coarser grained. They consist of carbonate- and clay-cemented, poorly stratified gravel, sand, and silt deposits (*Czag*). This unit, which overlies granitoid rocks, is identified away from the active drainage lines by a surface lag-deposit of coarse gravel. The gravel is composed of chert, basalt, and porphyry derived from supracrustal rocks to the south. The consolidated alluvial deposits (*Czag*) probably include older outwash fan deposits.

Quaternary deposits

On MUCCAN, Quaternary deposits consist of eolian, residual, alluvial, and colluvial deposits together with sheetwash and lacustrine deposits.

Fine- to medium-grained eolian sand (*Qs*) comprising iron-stained quartz grains occupies the northeast corner of the map sheet. This area is an undulating sandplain with a few widely scattered, westerly trending, longitudinal (seif) and chain dunes and forms part of the southwest margin of the Great Sandy Desert. Flat sheets of red–brown, medium-grained quartz sand (*Qsg*) lie north and northeast of Muccan Homestead. The variable grain size and coarser grained components of these sands suggests that they constitute a mixture of eolian and eluvial sand. The latter is derived from weathering of underlying granitoid rocks.

Medium- to coarse-grained quartz and feldspar sand with scattered quartz pebbles and granite fragments (*Qrg*) overlies, or is adjacent to, the main granitoid areas; for example, between Yundinna and Kookenyia creeks, and between the Miningarra and Ngarrin creek systems (AMG 340910). Although the unit is mainly eluvial, there is some reworking of the finer components by wind action.

Recent colluvium (*Qc*), in the form of scree and talus, is common in hilly areas underlain by the Gorge Creek, De Grey, and Fortescue Groups, and the Eel Creek Formation. The unit also covers broad outwash fans that are a feature of the contact between the Nimingarra Iron Formation and the subdued granitoid complex landsurface. Other colluvial units consist of quartz-pebble-covered scree slopes adjacent to large quartz veins (*Qcq*) and a mixed colluvial and eluvial deposit of scattered pebbles, cobbles, and boulders embedded in unconsolidated clay, silt, and silty sand (*Qcp*). The latter deposit is derived from the weathered fluvioglacial Paterson Formation. Some of the quartzite boulders and cobbles show glacial striations and faceting.

Broad valleys containing low-gradient sheetwash deposits (*Qw*) lie north of Moxam Well (AMG 360240) and northeast of Cattle Gorge Bore (AMG 160300). The sheetwash deposits lack distinct drainage lines. Similar low-gradient sheetwash deposits (*Qwg*) overlie the Muccan and Warrawagine Granitoid Complexes. The incipient claypans in the sheetwash unit (*Qwg*) locally carry a veneer of white quartz pebbles, as well as weathered granitoid rock fragments.

The drainage system on MUCCAN includes a wide range of alluvial units. The fluvial unit (*Qaa*) consists of unconsolidated silt, sand, and gravel in creeks and rivers where the channel fill, overbank, and floodplain deposits have not been distinguished. Unconsolidated sand, silt, and gravel (*Qaas*) was mapped in the channels of the De Grey River and larger tributaries. The surface of the channels may be as much as 15 m below the top of the overbank deposits and adjacent floodplains. Gravel and sand in banks and point bars within the channels may be up to 7 m high. The overbank deposits (*Qao*) consist of clay, silt, and silty sand. Shallow channels on this surface are filled by clay, silt, or sand.

Broad areas of the floodplain are commonly characterized by several, commonly small, circular, elongate, or irregular-shaped claypans (*Qaoc*). These claypans contain clay, silt, and silty sand locally with a quartz pebble or gravel veneer. In places, this claypan unit is cut by narrow, vegetation-lined, anastomosing channels 1–2 m deep. Larger claypans (*Qac*) are up to 3 km long and greater than 500 m wide. They commonly have a clay surface although some have a scattered quartz-pebble or rock-fragment veneer.

Some linear clay and silt deposits on the floodplains (*Qaob*) contain swelling-clay deposits, also called gilgai or crabhole. Such deposits occupy abandoned drainage courses or anabranches. Swelling-clay deposits were also located in a broad valley 3.5 km east of Cattle Gorge Bore (AMG 180280). The swelling-clay deposits (*Qaob*) in this area overlie weathered shales and dolerite of the Eel Creek Formation.

A distinctive pebble- and cobble-veneered sand and silt deposit (*Qag*) lies east of Miningarra Creek. This narrow, wedge-shaped deposit can be traced southwards to where Miningarra Creek issues from a gorge incised in Fortescue Group rocks (AMG 243910). The unit is considered to be a high-energy, alluvial-fan deposit and overlies older, consolidated alluvial deposits (*Czag*) believed to be of a similar origin.

Away from the major floodplains, lacustrine deposits form large, bare claypans (*Qlc*) and vegetated, gilgaisurfaced claypans (*Qlb*). The former claypans (*Qlc*) overlie granitoid rocks and are partly rimmed by low lunette dunes: the latter claypans (*Qlb*) formed in the Moxam Well area (AMG 350210) where they overlie the Eel Creek and Paterson Formations. These claypans are terminal pans for a broad sheetwash area (*Qw*). A mixed eolian and lacustrine unit (*Qls*) consists of several small claypans separated by mounds and small dunes of silt and sand. Examples of this unit are situated west of Wolline Well (AMG 930960).

Economic geology

The historic Bamboo (Creek) Gold Mining Centre, discovered around 1890 (Maitland, 1904), and the recently opened Yarrie Y2/3 (1993) and Y10 (1996) openpit iron-ore mines (Waters, 1998) are the largest mines on MUCCAN. Although both are currently operating, the Bamboo Creek mine was placed under care and maintenance in January 1996 pending resolution of gold recovery problems (Gonnella, 1997, 1998). Surface mining for alluvial gold using metal detectors was in progress in 1996 in the Friendly Stranger and Nuggety Gully areas.

Abandoned iron-ore pits are located at Shay Gap East (AMG 990300) and Hematite Hill (AMG 007283; Podmore, 1990); several abandoned, alluvial openpit and underground gold workings lie from Nuggety Gully (AMG 062857), through the main Bamboo Creek Mining Centre, to Strattons alluvial workings (AMG 185756), a total distance of 16 km. Over the last 30 years, a number of potential iron-ore and gold-bearing prospects have been outlined and lead, copper, zinc, molybdenum, chromium, nickel, manganese, and gemstone occurrences recorded.

Exploration company data, submitted to GSWA since 1961, are held in the WAMEX open-file system at the GSWA library. The information covering MUCCAN is summarized in Appendix 2. Six monthly updated data on mines and mineral deposits in Western Australia are held in the MINEDEX database (Townsend et al., 1996).

Gold

Total gold production from the Bamboo Mining Centre recorded between 1890 and 1995 is 7049.037 kg. This includes 47.966 kg of dollied and alluvial gold. The mined gold was obtained from 801 194.73 t of ore at an average grade of 8.6 g/t. Over 60% of gold production from the Bamboo Mining Centre has been produced since 1986.

The gold mines at the Bamboo Mining Centre lie within the Bamboo Creek Shear Zone. There is gold mineralization within the komatiitic boudins in structurally controlled, 1–3 m wide, laminated quartz–carbonate–sulfide veins (Zegers, 1996). The veins are bordered by wide alteration zones containing chlorite, magnesite, dolomite, quartz, and fuchsite. The gold is sited as free gold in microbrecciated zones within the quartz–magnesite–sulfide lode. It is closely associated with galena, tetrahedrite, and tourmaline and less commonly with pyrite, sphalerite, and gersdorffite (Zegers, 1996).

Several workers have attempted to date gold mineralization at the Bamboo Mining Centre using galena to obtain a Pb–Pb model age (Richards, 1983; Thorpe et al., 1992a; Zegers, 1996). Three samples, collected from the Kitchener and Mount Prophecy – Perseverance mines, gave Pb–Pb model ages within error of 3400 ± 4 Ma (Zegers, 1996). This agrees with earlier work from Thorpe et al. (1992a; see Table 1). Further information on the Bamboo Mining Centre is in Finucane (1936), Hickman (1983), and Hickman et al. (1983).

Gold mineralization at the Friendly Stranger (AMG 069033) and Battler (AMG 065042) mines has many similarities to mineralization at the Bamboo Mining Centre. Although recent gold production has come from metal detecting of alluvial deposits in the vicinity of the Friendly Stranger mine, earlier records show that in 1921 the mine produced 1.681 kg of gold. Gold is associated with chalcopyrite and malachite at the Battler mine; malachite-stained quartz veins are situated 400 m northeast of the Friendly Stranger mine. Further observations from this area are described in Hickman et al. (1983) and in item 5685, WAMEX open-file report listed in Appendix 2.

Iron ore

In late 1993, BHP Iron Ore commenced openpit iron-ore mining at the Yarrie Y2/3 bedrock deposit (AMG 190180). Published resources for the Y2/3 deposit in 1993 were 65 Mt at 64.7% Fe, 0.034% P, 4.95% SiO_2, and 1.38% Al_2O_3 (Waters, 1998). In 1995, proven reserves amounted to 34 Mt at 64.9% Fe (Wilkinson, 1998). Production since 1993 was about 5 Mt per annum. The iron-ore mineralization, structure, and ore genesis of the Yarrie Y2/3 deposit is discussed by Waters (1998).

A second openpit mine was started at Y10 (AMG 215214; formerly known as the Kennedy Gap prospect) in 1996. This mine exploits a bedded hematite conglomerate at the base of the Neoproterozoic Eel Creek Formation and has resources of 23.6 Mt. The hematite conglomerate contains ore grades of 61.2% Fe, 0.090% P, 6.5% SiO_2, and 3.0% Al_2O_3 (Waters, 1998). Apart from the Y10 deposit, all iron-ore deposits and prospects on MUCCAN are associated with the Nimingarra Iron Formation (Appendix 1).

Copper

A low grade, large tonnage copper–molybdenum deposit is outlined 1.5 km southwest (AMG 991873) of Coppin Gap (Marston, 1979; Barley, 1982; Jones, 1990). Ore reserves are estimated to be 102 Mt of 0.152% Cu and 0.105% Mo (Jones, 1990). The deposit lies within a multiple-phase stockwork of quartz–carbonate veins that carry up to 2% chalcopyrite, molybdenite, pyrite, pyrrhotite, rare sphalerite, and scheelite. The stockwork is best developed in the silicified contact zone of an intrusive dacite–rhyolite porphyry (Marston, 1979). Hickman et al. (1983) recorded several other minor copper occurrences in quartz veins within ultramafic rocks. These include secondary copper mineralization around the Battler gold mine and quartz veins 3.5 km southwest of Du Valles Well (AMG 330110).

A further seven copper occurrences were located during the current mapping program. These include secondary copper mineralization northwest of Kittys Well (AMG 927917 and AMG 932922). Here, the mineralization occurs in a large, northeasterly trending quartz vein that occupies a large fault within the Muccan Granitoid Complex. A small, northeasterly trending quartz vein in the Warrawagine Granitoid Complex (AMG 372044) also carries secondary copper mineralization. Further south and east of 17 Mile Well (AMG 363873), the Warrawagine Granitoid Complex contains a pink, leucocratic, muscovite-bearing monzogranite that carries secondary copper minerals on joint planes together with disseminated molybdenite grains. A malachite-bearing quartz vein was located in the faulted contact between the Warrawagine Granitoid Complex and Mount Roe Basalt, south-southeast of 17 Mile Well (AMG 358835). A similar gossanous, northwesterly trending quartz vein outcropping south of 17 Mile Well (AMG 337836) contain chalcopyrite, pyrite, galena, and malachite. Here, the quartz vein cuts the unconformity between the Warrawagine Granitoid Complex and overlying Mount Roe Basalt.

Silicified flow tops in the Maddina Formation south-southeast of 17 Mile Well (AMG 372777) contain disseminated chalcopyrite and malachite.

Silver, lead, and zinc

Silver is a byproduct of gold mining at the Bamboo Mining Centre. Records show that up to the end of 1996, total silver production amounted to 648.246 kg. Hickman et al. (1983) recorded several auriferous and cupriferous quartz veins in the Coppin Gap and Battler gold mine areas that assayed low silver values.

Lead mineralization, in the form of galena, was located in, and described from, quartz veins in the Apex Basalt (AMG 003855) and about 800 m north of Lance Bore (AMG 240826) in sheared Kuruna Member (Davy and Hickman, 1983; Hickman et al., 1983). Galena collected from a quartz vein south of Coppin Gap (AMG 003855) yielded a Pb–Pb model age of 3336 ± 1 Ma (Richards, 1983; Table 1). Galena is present in the gold lodes in the Bamboo Mining Centre (Zegers, 1996; see Table 1). During the present study, fresh galena and copper mineralization was located in a quartz vein south of 17 Mile Well (AMG 337836).

Hickman et al. (1983) recorded 2.56% Zn from the Battler gold mine. Minor sphalerite is present in the Coppin Gap copper–molybdenum prospect (AMG 991873; Jones, 1990) and is abundant in some parts of the Bamboo Mining Centre, particularly in the Mount Prophecy – Perseverence area (AMG 095834; Zegers, 1996).

Chromium, nickel, and molybdenum

Baxter (1978) and Hickman et al. (1983) recorded a chromite-bearing, serpentinized peridotite 7 km south of the Bamboo Mining Centre. The ultramafic body, named the Nobb Well Intrusion (AMG 085766; Appendix 1), is 2.8 km long and up to 600 m wide. It carries small chromite pods towards the base and disseminated chromite crystals up to 2 mm in diameter throughout the body. The chromite pods assay up to 3.15% Cr and 0.18% Ni.

In 1969, Woodsreef Mines encountered disseminated gersdorffite in the Bamboo Mining Centre. The concealed body lies between the Mount Prophecy and Prince Charles gold mines at a depth of 150–200 m (AMG 095834). The orebody formed in silicified and brecciated, carbonate-rich ultramafic rock. The best intersection averaged 1.69% Ni over 5.09 m (Marston, 1984; see also item 6043, WAMEX open-file report, Appendix 2).

Molybdenite is commonly associated with copper mineralization. A large, low-grade copper–molybdenum deposit (102 Mt at 0.105% Mo, 0.152% Cu) was outlined 1.5 km southwest of Coppin Gap (AMG 991873; Jones, 1990). During the current mapping, disseminated molybdenite grains and associated weak secondary copper mineralization were located in a pink, leucocratic, muscovite-bearing monzogranite of the Warrawagine Granitoid Complex, east of 17 Mile Well (AMG 363873).

Other minerals

Some small pits and costeans have intersected a thin-bedded seam (>30 cm) of pyrolusite (manganese oxide) northeast of 6 Mile Well (AMG 140055). This possible syngenetic deposit lies in basal shales of the Hardey Formation, close to the unconformity with the underlying Nimingarra Iron Formation. This manganese occurrence was briefly described by de la Hunty (1963). Nodules and seams of manganese oxide coat fractures and joints in Permian siltstone north of Shay Gap (AMG 017302).

A silicified, Leisegang-banded (purple to mauve bands) siltstone of Permian age was prospected for ornamental stone on Salt Creek (AMG 316271).

Gravel pits and quarries for road metal are at irregular intervals along all main graded roads on MUCCAN. Most material was obtained from unconsolidated or semi-consolidated Cainozoic gravel deposits.

Graded waste from the iron-ore deposits was used to make the ballast for the Yarrie – Port Hedland railway line.

References

ARNDT, N. T., NELSON, D. R., COMPSTON, W., TRENDALL, A. F., and THORNE, A. M., 1991, The age of the Fortescue Group, Hamersley Basin, Western Australia, from ion microprobe zircon U–Pb results: Australian Journal of Earth Sciences, v. 38, p. 261–281.

ASHWAL, L. D., 1991, Two cratons and an orogen: IGCP Project 280, Department of Geology, University of Witwatersrand, Johannesburg, Excursion guidebook and review articles for a field workshop through selected Terranes of Swaziland, South Africa and Zimbabwe, p. 130–131.

BAGAS, L., GREY, K., and WILLIAMS, I. R., 1995, Reappraisal of the Paterson Orogen and Savory Basin: Western Australia Geological Survey, Annual Review 1994–95, p. 58–63.

BARLEY, M. E., 1980, Evolution of Archaean calc-alkaline volcanics: University of Western Australia, Nedlands, PhD thesis (unpublished), 169p.

BARLEY, M. E., 1982, Porphyry-style mineralization associated with early Archaean calc-alkaline igneous activity, Eastern Pilbara, Western Australia: Economic Geology, v. 77, p. 1230–1235.

BAXTER, J. L., 1978, Molybdenum, tungsten, vanadium and chromium in Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 11, 140p.

BEARD, J. S., 1970, The natural regions of the deserts of Western Australia: Journal of Ecology, v. 57, p. 677–711.

BEARD, J. S., 1975, The vegetation of the Pilbara area: Vegetation Survey of Western Australia, 1:1 000 000 Vegetation Series, Explanatory Notes to Sheet 5: Perth, University of Western Australia Press, 120p.

BLAKE, T. S., 1984, The lower Fortescue Group of the northern Pilbara Craton — stratigraphy and palaeogeography, *in* Archaean and Proterozoic basins of the Pilbara — Evolution and Mineralization Potential *edited by* J. R. MUHLING, D. I. GROVES, and T. S. BLAKE: University of Western Australia, Geology Department and University Extension, Publication, no. 9, p. 123–143.

BLAKE, T. S., 1993, Late Archaean crustal extension, sedimentary basin formation, flood basalt volcanism and continental rifting. The Nullagine and Mount Jope Supersequences, Western Australia: Precambrian Research, v. 60, p. 185–241.

BLAZEY, E. L., RAYNER, J. M., and NYE, P. B., 1938, Geophysical report on the Bamboo Creek area, Pilbara Goldfield: Aerial Geological and Geophysical Survey of Northern Australia, Report Western Australia 39, 6p.

BLOCKLEY, J. G., 1990, Iron Ore, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 679–692.

BUTT, C. R. M., HORWITZ, R. C., and MANN, A. W., 1977, Uranium occurrences in calcrete and associated sediments in Western Australia: Australia CSIRO, Division of Mineralogy, Minerals Research Laboratories, Report FP16, 67p.

CAMPANA, B., HUGHES, F. E., BURNES, W. G., WHITCHER, I. G., and MUCENIEKAS, E., 1964, Discovery of the Hamersley iron deposits (Duck Creek — Mt Pyrton — Mt Turner areas): Australasian Institute of Mining and Metallurgy, Proceedings, no. 210, p. 1–30.

COLLINS, W. J., 1983, Geological evolution of an Archaean batholith: La Trobe University, PhD thesis (unpublished), 315p.

COLLINS, W. J., 1989, Polydiapirism of the Archaean Mount Edgar Batholith, Pilbara Craton, Western Australia: Precambrian Research, v. 43, p. 41–62.

COLLINS, W. J., 1993, Melting of Archaean sialic crust under high $a\mathrm{H_2O}$ conditions: genesis of 3300 Ma Na-rich granitoids in the Mount Edgar Batholith, Pilbara Block, Western Australia: Precambrian Research, v. 60, p. 151–174.

COLLINS, W. J., and GRAY, C. M., 1990, Rb–Sr isotopic systematics of an early Archaean granite–gneiss terrain: the Mount Edgar Batholith, Pilbara Block, Western Australia: Australian Journal of Earth Sciences, v. 37, p. 9–32.

DAVY, R., and HICKMAN, A. H., 1983, Statistical assessment for prospecting purposes of the trace-element composition of caprock ironstones in the northeast Pilbara: Western Australia Geological Survey, Record 1982/10, 49p.

DAVY, R., and LEWIS, J. D., 1986, The Mount Edgar Batholith, Pilbara area, Western Australia — Geochemistry and petrography: Western Australia Geological Survey, Report 17, 44p.

DAWES, P. R., SMITHIES, R. H., CENTROFONTI, J., and PODMORE, D. C., 1994, Unconformable contact relationships between the Muccan and Warrawagine batholiths and the Archaean Gorge Creek Group in the Yarrie mine area, northeast Pilbara: Western Australia Geological Survey, Record 1994/3, 23p.

DAWES, P. R., SMITHIES, R. H., CENTROFONTI, J., and PODMORE, D. C., 1995, Sunrise Hill unconformity: a newly discovered regional hiatus between Archaean granites and greenstones in the northeastern Pilbara Craton: Australian Journal of Earth Sciences, v. 42, p. 635–639.

de la HUNTY, L. E., 1963, The geology of the manganese deposits of Western Australia: Western Australia Geological Survey, Bulletin 116, 122p.

de LAETER, J. R., and MARTYN, J. E., 1986, Age of molybdenum–copper mineralization at Coppin Gap, Western Australia: Australian Journal of Earth Sciences, v. 33, p. 65–77.

DI MARCO, M. J., and LOWE, D. R., 1989, Stratigraphy and sedimentology of an early Archaean felsic volcanic sequence, eastern Pilbara Block, Western Australia, with special reference to the Duffer Formation and implications for crustal evolution: Precambrian Research, v. 44, p. 147–169.

FINUCANE, K. J., 1936, Bamboo Creek Mining Centre (Pilbara Goldfield): Aerial Geological and Geophysical Survey of Northern Australia, Report Western Australia 9, 23p.

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA, 1997, Muccan, W.A. Sheet 2956: Western Australia Geological Survey, 1:100 000 Total Magnetic Intensity Image.

GONNELLA, P., (editor), 1997, Australian Gold Annual 1997: Perth, Western Australia, Resource Information Unit, 256p.

GONNELLA, P., (editor), 1998, Register of Australian Mining 1997/98: Perth, Western Australia, Resource Information Unit, 652p.

GREY, K., 1981, A new stromatolite form from the Tumbiana Formation (2.6–2.7 b.y.), Nullagine 1:250 000 sheet: Western Australia Geological Survey, Palaeontology Report 35/81 (unpublished), 2p.

GREY, K., 1984, Field studies of Precambrian stromatolites from the Nabberu Basin and Eastern Pilbara: Western Australia Geological Survey, Palaeontology Report 79/84 (unpublished), 18p.

GRIFFIN, T. J., 1990, North Pilbara granite–greenstone terrane, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 128–158.

HICKMAN, A. H., 1976, Fluorite porphyry at Ngarrin Creek, Yarrie: Western Australia Geological Survey, Record 1976/3, 4p.

HICKMAN, A. H., 1977, New and revised definitions of rock units in the Warrawoona Group, Pilbara Block: Western Australia Geological Survey, Annual Report 1976, p. 53.

HICKMAN, A. H., 1978, Nullagine, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 22p.

HICKMAN, A. H., 1983, Geology of the Pilbara Block and its environs: Western Australia Geological Survey, Bulletin 127, 268p.

HICKMAN, A. H., 1990, Geology of the Pilbara Craton, *in* Third International Archaean Symposium, Perth, 1990. Excursion guidebook no. 5: Pilbara and Hamersley Basin *edited by* S. E. HO, J. E. GLOVER, J. S. MYERS, and J. R. MUHLING: University of Western Australia, Geology Department and University Extension, Publication, no. 21, p. 2–13.

HICKMAN, A. H., CHIN, R. J., and GIBSON, D. L., 1983, Yarrie, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 33p.

HICKMAN, A. H., and LIPPLE, S. L., 1975, Explanatory notes on the Marble Bar 1:250 000 geological sheet, Western Australia: Western Australia Geological Survey, Record 1974/20, 90p.

HOCKING, R. M., MORY, A. J., and WILLIAMS, I. R., 1994, An atlas of Neoproterozoic and Phanerozoic basins of Western Australia, *in* The sedimentary basins of Western Australia *edited by* P. C. and R. R. PURCELL: Petroleum Exploration Society of Australia, Symposium, Perth, 1994, Proceedings, p. 21–43.

HORWITZ, R. C., 1987, The unconformity in the Kelly Belt, east Pilbara Craton: Royal Society of Western Australia, Journal, v. 70, p. 49–53.

HORWITZ, R. C., 1990, The Archaean unconformity at Shay Gap, northeastern Pilbara Craton, *in* The Archaean: Terrains, processes and metallogeny *edited by* J. E. GLOVER and S. E. HO: University of Western Australia, Geology Department and University Extension, Publication, no. 22, p. 51–57.

HORWITZ, R. C., and GUJ, P., 1986, Re-accredition of the Whim Creek Group: Australia CSIRO, Division of Mineralogy and Geochemistry, Research Review 1985, p. 6–7.

JONES, C. B., 1990, Coppin Gap copper–molybdenum prospect, *in* Geology of the mineral deposits of Australia and Papua New Guinea, Volume 1 *edited by* F. E. HUGHES: Australasian Institute of Mining and Metallurgy, Melbourne, Monograph 14, p. 141–144.

JUTSON, J. T., 1950, The physiography (geomorphology) of Western Australia: Western Australia Geological Survey, Bulletin 95, (3rd edition of Bulletin 61).

KOJAN, C. J., and HICKMAN, A. H., 1998, Late Archaean volcanism in the Kylena and Maddina Formations, Fortescue Group, west Pilbara: Western Australia Geological Survey, Annual Review 1997–98, p. 43–53.

KRAPEZ, B., 1993, Sequence stratigraphy of the Archaean supracrustal belts of the Pilbara Block, Western Australia: Precambrian Research, v. 60, p. 1–45.

KRAPEZ, B., and BARLEY, M. E., 1987, Archaean strike-slip faulting and related ensialic basins — evidence from the Pilbara Block: Australia Geological Magazine, v. 124, p. 555–567.

KRIEWALDT, M., 1964, The Fortescue Group of the Roebourne region, North-West Division: Western Australia Geological Survey, Annual Report 1963, p. 30–34.

KRIEWALDT, M., and RYAN, G. R., 1967, Pyramid, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series, 39p.

LEECH, R. E. J., 1979, Geology and groundwater resources of the southwestern Canning Basin, Western Australia: Western Australia Geological Survey, Record 1979/9, 89p.

LEWIS, J. D., and DAVY, R., 1981, Felsic dykes of the Mount Edgar Batholith: Western Australia Geological Survey, Annual Report 1980, p. 103–108.

LEWIS, J. D., ROSMAN, K. R. J., and de LAETER, J. R., 1975, The age and metamorphic effects of the Black Range dolerite dyke: Western Australia Geological Survey, Annual Report 1974, p. 80–88.

LIPPLE, S. L., 1975, Definitions of new and revised stratigraphic units of the eastern Pilbara region: Western Australia Geological Survey, Annual Report 1974, p. 58–63.

MACKEY, T. E., 1997a, Total magnetic intensity (reduced to the pole) with northeast illumination colour pixel-image map of Nullagine/Yarrie, W.A. (1:250 000 scale): Australian Geological Survey Organisation.

MACKEY, T. E., 1997b, First vertical derivative of total magnetic intensity (reduced to the pole) greyscale pixel-image map of Nullagine/Yarrie, W.A. (1:250 000 scale): Australian Geological Survey Organisation.

MACKEY, T. E., 1997c, Airborne gamma-ray spectrometry colour composite pixel-image map of Nullagine/Yarrie, W.A. (1:250 000 scale): Australian Geological Survey Organisation.

MacLEOD, W. N., and de la HUNTY, L. E., 1966, Roy Hill, W.A. (1st edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 27p.

MacLEOD, W. N., de la HUNTY, L. E., JONES, W. R., and HALLIGAN, R., 1963, A preliminary report on the Hamersley Iron province, North-West Division: Western Australia Geological Survey, Annual Report 1962, p. 44–54.

MAITLAND, A. G., 1904, Preliminary report on the geological features and mineral resources of the Pilbara Goldfield: Western Australia Geological Survey, Bulletin 15, 118p.

MAITLAND, A. G., 1905, Further report on the geological features and mineral resources of the Pilbara Goldfield: Western Australia Geological Survey, Bulletin 20, 127p.

MAITLAND, A. G., 1906, Third report on the geological features and mineral resources of the Pilbara Goldfield: Western Australia Geological Survey, Bulletin 23, 92p.

MARSTON, R. J., 1979, Copper mineralization in Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 13, p. 73.

MARSTON, R. J., 1984, Nickel mineralization in Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 14, p. 217.

McPHIE, J., DOYLE, M., and ALLEN, R., 1993, Volcanic textures — a guide to the interpretation of textures in volcanic rocks: Centre for Ore Deposit and Exploration Studies, University of Tasmania, 189p.

McWHAE, J. R. H., PLAYFORD, P. E., LINDER, A. W., GLENISTER, B. F., and BALME, B. E., 1958, The stratigraphy of Western Australia: Geological Society of Australia, Journal, v. 4, pt 2, p. 1–162.

MIDDLETON, M. F., 1990, Canning Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 425–457.

MORY, A. J., and BACKHOUSE, J., 1997, Permian stratigraphy and palynology of the Carnarvon Basin, Western Australia: Western Australia Geological Survey, Report 51, 41p.

NELSON, D. R., 1998, Compilation of SHRIMP U–Pb zircon geochronology data, 1997: Western Australia Geological Survey, Record 1998/2, 242 p.

NELSON, D. R., in prep., Compilation of SHRIMP U–Pb zircon geochronology data, 1998: Western Australia Geological Survey, Record 1999/2.

NIJMAN, W., WILLIGERS, B. A. J., and KRIKKE, A., 1998, Tensile and compressive growth structures: Relationships between sedimentation, deformation and granite intrusion in the Archaean Coppin Gap Greenstone Belt, eastern Pilbara, Western Australia: Precambrian Research, v. 88, p. 83–108.

NOLDART, A. J., and WYATT, J. D., 1962, The geology of portion of the Pilbara Goldfield covering the Marble Bar and Nullagine 4–mile map sheets: Western Australia Geological Survey, Bulletin 115, 119p.

PACKER, B. M., 1990, Palaeontology, sedimentology, and stable isotope geochemistry of selected formations in the 2.8 Ga old Fortescue Group: University of California, Los Angeles, PhD thesis (unpublished), 187p.

PERINCEK, D., 1996, The age of Neoproterozoic–Palaeozoic sediments within the Officer Basin of the Centralian Superbasin can be constrained by major sequence-bounding unconformities: APPEA Journal, v. 36, pt 1, p. 350–368.

PINK, B. N., 1992, Western Australia Year Book, no. 29: Australian Bureau of Statistics, Perth Office, p. 3.1–3.15.

PODMORE, D. C., 1990, Shay Gap – Sunrise Hill and Nimingarra iron ore deposits, *in* Geology of the mineral deposits of Australia and Papua New Guinea, Volume 1 *edited by* F. E. HUGHES: Australasian Institute of Mining and Metallurgy, Melbourne, Monograph 14, p. 137–140.

RICHARDS, J. R.,1983, Lead isotopes as indicators of old stable craton in Western Australia: Geochemical Journal, v. 17, p. 247–255.

RICHARDS, J. R., FLETCHER, I. R., and BLOCKLEY, J. G., 1981, Pilbara galenas: precise isotopic assay of the oldest Australian leads; model ages and growth-curve implications: Mineralium Deposita, v. 16, p. 7–30.

ROCK, N. M. S., and BARLEY, M. E., 1988, Calc-alkaline lamprophyres from the Pilbara Block, Western Australia: Royal Society of Western Australia, Journal, v. 71, p. 7–13.

RYAN, G. R., and KRIEWALDT, M. J. B., 1964, Facies changes in the Archaean of the West Pilbara Goldfield: Western Australia Geological Survey, Annual Report 1963, p. 28–30.

SMITH, R. E., PERDRIX, J. L., and PARKS, T. C., 1982, Burial metamorphism in the Hamersley Basin, Western Australia: Journal of Petrology, v. 23, p. 75–102.

STEVENS, M. K., and GREY, K., 1997, Skates Hills Formation and Tarcunyah Group, Officer Basin — carbonate cycles, stratigraphic position, and hydrocarbon prospectivity: Western Australia Geological Survey, Annual Review 1996–97, p. 55–60.

THORNE, A. M., and TRENDALL, A. F., in prep., The geology of the Fortescue Group, Hamersley Basin, Western Australia: Western Australia Geological Survey, Bulletin 144.

THORNE, A. M., and TYLER, I. M., 1997, Mount Bruce, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 28p.

THORNE, A. M., TYLER, I. M., and HUNTER, W. M., 1991, Turee Creek, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 29p.

THORPE, R. I., HICKMAN, A. H., DAVIS, D. W., MORTENSEN, J. K., and TRENDALL, A. F., 1992a, Constraints to models for Archaean lead evolution from precise zircon U–Pb geochronology for the Marble Bar region, Pilbara Craton, Western Australia, *in* The Archaean: Terrains, processes and metallogeny *edited by* J. E. GLOVER and S. E. HO: University of Western Australia, Geology Department and University Extension, Publication, no. 22, p. 395–406.

THORPE, R. I., HICKMAN, A. H., DAVIS, D. W., MORTENSEN, J. K., and TRENDALL, A. F., 1992b, U–Pb zircon geochronology of Archaean felsic units in the Marble Bar region, Pilbara Craton: Precambrian Research, v. 56, p. 169–189.

TOWNER, R. R., and GIBSON, D. L., 1980, Geology of Late Carboniferous and younger rocks of the onshore western Canning Basin, Western Australia: Australia BMR, Record 1980/30 (unpublished), 67p.

TOWNER, R. R., and GIBSON, D. L., 1983, Geology of the onshore Canning Basin, Western Australia: Australia BMR, Bulletin 215, 51p.

TOWNSEND, D. B., PRESTON, W. A., and COOPER, R. W., 1996, Mineral resources and locations, Western Australia: Digital dataset from MINEDEX: Western Australia Geological Survey, Record 1996/13, 19p.

TRAVES, D. M., CASEY, J. N., and WELLS, A. T., 1956, The geology of the southwestern Canning Basin, Western Australia: Australia BMR, Report 29, 74p.

TRENDALL, A. F., 1990a, Pilbara Craton, Introduction, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 128.

TRENDALL, A. F., 1990b, Hamersley Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 163–189.

TRENDALL, A. F., NELSON, D. R., de LAETER, J. R., and HASSER, S. W., 1998, Precise zircon U–Pb ages from the Marra Mamba Iron Formation and Wittenoom Formation, Hamersley Group, Western Australia: Australian Journal of Earth Sciences, v. 45, no. 1, p. 137–142.

VAN KRANDENDONK, M. J., 1997, Results of field mapping 1994–1996, in the North Shaw and Tambourah 1:100 000 sheet areas, eastern Pilbara Craton, northwestern Australia: Australian Geological Survey Organisation, Record 1997/23, 44p.

VEEVERS, J. J., and WELLS, A. T., 1961, The geology of the Canning Basin, Western Australia: Australia BMR, Bulletin 60, 323p.

WALTER, M. R., 1983, Archaean stromatolites: evidence of the Earth's earliest Benthos, Chapter 8, *in* Earth's earliest Biosphere: its origin and evolution *edited by* J. W. SCHOPE: Princeton University Press, Princeton, New Jersey, p. 187–213.

WATERS, P. J., 1998, Geology of the Y2/3 and Y10 iron-ore deposits Yarrie, Western Australia, *in* Geology of Australian and Papua New Guinean mineral deposits *edited by* D. A. BERKMAN and D. H. MacKENZIE: Australasian Institute of Mining and Metallurgy, Melbourne, Monograph 22, p. 371–374.

WELLS, A. T., 1959, Yarrie — 4–mile Geological Series: Australia BMR, Explanatory Notes SF/51-1, 15p.

WHITE, M. E., 1961, Appendix 6 — Plant fossils from the Canning Basin, Western Australia, *in* The geology of the Canning Basin, Western Australia *edited by* J. J. VEEVERS and A. T. WELLS: Australian BMR, Bulletin 60, p. 291–320.

WILKINSON, D., (editor), 1998, The Australian Mines Handbook 1997/1998 edition: Perth, Western Australia, Louthean Publishing Pty Ltd and Minmet Australia Pty Ltd, 616p.

WILLIAMS, I. R., 1989, Balfour Downs, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 38p.

WILLIAMS, I. R., in prep.a, Geology of the Cooragoora 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Explanatory Notes.

WILLIAMS, I. R., in prep.b, Geology of the Warrawagine 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Explanatory Notes.

WILLIAMS, I. R., and BAGAS, I., in prep., Geology of the Throssell 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes.

WILLIAMS, I. R., and TRENDALL, A. F., 1998a, Geology of the Isabella 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 24p.

WILLIAMS, I. R., and TRENDALL, A. F., 1998b, Geology of the Braeside 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 39p.

WILLIAMS, I. R., and TRENDALL, A. F., 1998c, Geology of the Pearana 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 33p.

WILLIAMS, I. S., and COLLINS, W. J., 1990, Granite–greenstone terranes in the Pilbara Block, Australia, as coeval volcano-plutonic complexes: evidence from U–Pb zircon dating of the Mount Edgar Batholith: Earth and Planetary Science Letters, v. 97, p. 41–53.

WINGATE, M. T. D., 1997, Testing Precambrian continental reconstructions using ion microprobe U–Pb baddeleyite geochronology and palaeomagnetism of mafic igneous rocks: Australian National University, Canberra, PhD thesis (unpublished), 236p.

ZEGERS, T. E., 1996, Structural, kinematics and metallogenic evolution of selected domains of the Pilbara granitoid–greenstone terrain: implications for mid-Archaean tectonic regimes: University of Utrecht, Utrecht, PhD thesis (unpublished), 208p.

Appendix 1

Definitions of new and revised stratigraphic and plutonic names

Name	*Derivation of name*	*Type area*	*Distribution, thickness & lithology*	*Relationships and age (Ma)*	*Remarks*
Strutton Intrusion	Strutton Creek AMG 938825	1.6 km north of No 2 Well AMG 940820	Lies between AMG 940820 and AMG 876840. Dimensions: ~6500 m long with maximum thickness of ~500 m. Metagabbro, minor metapyroxenite, and serpentinized peridotite (*AaT*)	Discordant body, intrudes Duffer Formation and overlying Apex Basalt; intruded by Coppin Gap Granodiorite. Age: c. 3471 – c. 3314 Ma	–
Nobb Well Intrusion	Nobb Well (abandoned) AMG 060764	2.5 km east of Nobb Well AMG 085767	Lies between AMG 085765 and AMG 084792. Dimensions: ~2500 m long with maximum thickness of ~600 m. Coarse-grained, serpentinized peridotite, minor metapyroxenite (*AaWu*)	Concordant body along contact between Duffer Formation and overlying Apex Basalt; intruded by Mullugunya Granodiorite. Age: c. 3471 – 3300 Ma	Contains chromite prospect (Baxter, 1978)
Gap Intrusion	Gap Bore AMG 968847	1.8 km southwest of Gap Bore AMG 953840	Lies between AMG 955842 and AMG 879847. Dimensions: 8000 m long with maximum thickness of ~1000 m. Serpentinized peridotite (*AaGus*), serpentinized dunite (*AaGpd*), metapyroxenite (*AaGx*)	Concordant body within the Apex Basalt; intruded by Coppin Gap Granodiorite. Age: c. 3471 – 3314 Ma	–
Wolline Monzogranite	Wolline Well AMG 941960	1.6 km north of Wolline Well AMG 944977	Pluton north, west, and southwest of Wolline Well; second pluton southwest of Near Home Well. Pink–grey, medium- to coarse-grained, porphyritic to seriate monzogranite and syenogranite (*AgMwo*)	Youngest plutons in the Muccan Granitoid Complex. Age: c. 3244 – 3252 Ma (see Table 1)	Shown as unnamed porphyritic adamellite on YARRIE (1:250 000) (Hickman et al., 1983)
Nimingarra Iron Formation	Nimingarra Homestead (abandoned) AMG 035293 (COONGAN)	(a) Cattle Gorge AMG 117260 (b) Coppin Gap AMG 001880	Distributed across MUCCAN, PARDOO, COORAGOORA, and DE GREY 1:100 000 sheets. Between 400 and 1000 m thick. BIF, jaspilite, banded and ferruginous chert (*AGn*); basal conglomerate, sandstone, and shale, (*AGna*), metamorphosed	Lies unconformably on the Muccan and Warrawagine Granitoid Complexes and Warrawoona Group; unconformably overlain by Cundaline Formation (in part), Coonieena Basalt, Fortescue Group, and Eel Creek Formation. Age: contains detrital zircon populations of c. 3362, c. 3403, c. 3415, c. 3430, c. 3438, and 3458 Ma in basal quartzite	Belongs to Gorge Creek Group; previously mapped as Cleaverville Formation (Hickman, 1983); synonymy 'Paddy Market Formation'
Cundaline Formation	Cundaline Gap AMG 089220	(a) Railway cutting 2 km east of Shay Gap AMG 037280 (b) 3 km east of Coppin Gap AMG 030880	Distributed across MUCCAN and COORAGOORA 1:100 000 sheets. Maximum thickness about 1000 m. Shale, siltstone, lithic wacke, sandstone, and pebble conglomerate, local polymictic, matrix-supported conglomerate, metamorphosed (*AGu*)	Disconformably to unconformably overlies Nimingarra Iron Formation; unconformably overlain by Coonieena Basalt, Fortescue Group, and Eel Creek Formation. Age; <c. 3244, contains detrital zircon populations of c. 3398, c. 3434 Ma, and c. 3455 Ma	Belongs to Gorge Creek Group; previously included in Cleaverville Formation (Hickman, 1983)

Coonieena Basalt	Coonieena Creek AMG 019280	3.5 km southwest of Cattle Gorge AMG 107242	Distributed across MUCCAN and COORAGOORA 1:100 000 sheets. Maximum thickness about 1500 m. Pillowed and massive basalt, hyaloclastic breccia, silicified basaltic andesite, metamorphosed (*AGo*)	Unconformable on Cundaline Formation and Nimingarra Iron Formation east of Coppin Gap; upper contact intruded by Shay Intrusion, disconformably overlain by Cattle Well Formation, unconformably overlain by Fortescue Group and Eel Creek Formation. Age: < c. 3244 Ma	Belongs to Gorge Creek Group; previously mapped as Honeyeater Basalt (Hickman, 1983)
Cattle Well Formation	Cattle Well AMG 104287	(a) 1.5 km west of Cattle Well AMG 089287 (b) 1.5 km south of Cattle Well AMG 105272	Distributed across MUCCAN and COORAGOORA 1:100 000 sheets. Maximum thickness about 2500 m. Interbedded dacite tuff, welded tuff, and tuffaceous siltstone and shale; thin bedded sandstone, siltstone, wacke, conglomerate, and carbonate rocks, metamorphosed (*ADa*)	Disconformable on Coonieena Basalt, base intruded by Shay Intrusion; unconformably overlain by Eel Creek Formation. Age: Resedimented dacite tuffs give maximum age of c. 3048 Ma for deposition	Belongs to De Grey Group; previously mapped as Lalla Rookh Sandstone (Hickman, 1983)
Shay Intrusion	Shay Townsite (abandoned) AMG 044305	Along power line track to Yarrie iron-ore mine AMG 113256	Lies between AMG 042301 and AMG 116254 on MUCCAN. Dimensions: >9000 m long with maximum thickness of 500 m. Epidotized quartz gabbro, gabbronorite, pyroxenite; weakly metamorphosed (*AaYo*, *AaYn*)	Intrudes contact between Coonieena Basalt and overlying Cattle Well Formation. Age: <3048 Ma	Unnamed gabbronorite sill on YARRIE (1:250 000) (Hickman et al., 1983)

Appendix 2

Company data on GSWA WAMEX open file for MUCCAN

GSWA WAMEX item number[(a)]	*Duration*	*Title*	*Company*
1942	1961–1967	Nimingarra iron-ore – manganese exploration	Kakiuchi and Company, Kokan Mining Company
7084	1962–1963	Roebourne iron exploration	Mt Goldsworthy Mining Associates
6062	1967–1977	Pilbara regional exploration	Australian Anglo American
1922	1968–1973	Coongan Belt – West Stirling – Talga Talga nickel–copper exploration	Pacminex
942	1969–1973	Coppin Gap copper–molybdenum exploration	Australian Anglo American
3279	1970–1973	Yarrie nickel–copper, copper–molybdenum exploration	Australian Anglo American, Charter Mining Corporation, Kitchener Mining, Woodsreef Mines
972	1971–1972	Little de Grey copper–molybdenum exploration	Mogul Mining
6043	1971–1986	Bamboo Creek nickel–gold exploration	Bamboo Creek Gold Mines, CRA Exploration, CRA Services, Forrest Gold, Haoma North West, Kitchener Mining, Woodsreef Mines
3317	1974–1975	Murphy Well copper–zinc exploration	Esso Exploration Australia
5572	1974–1989	Nuggety Gully copper–molybdenum–gold exploration	Amax Iron Ore Corporation, City Resources, Esso Australia
2412	1978–1978	Yarrie bauxite reconnaissance	CSR Exploration
1601	1978–1981	Warrawagine diamond exploration	Australian Selection, Seltrust Mining Corporation
1039	1979–1980	Bamboo Creek diamond–uranium exploration	CRA Exploration
1326	1979–1980	Little de Grey base-metals exploration	Broken Hill Company
1307	1981-1981	Jarman Well gold exploration	CRA Exploration
1328	1981–1981	Shay Gap base-metals exploration	Pennzoil of Australia
1830	1981–1982	Nobb Well chromite exploration	Metals Exploration
2457	1981–1982	Muccan–Yukerakine copper–molybdenum–tungsten exploration	Duval Mining Australia
2230	1981–1985	Surface Well gold–diamond exploration	Indian Ocean Gold
2345	1982–1984	Bamboo Creek gold exploration Company	Carpentaria Exploration
6242	1983–1990	Bamboo Creek gold exploration	Kitchener Mining
2449	1984–1986	Nobb Well platinum exploration	Hunter Resources
4235	1984–1990	Kimberley Gap diamond exploration	Auridiam, Mr R. Baxter-Brown
4236	1984-1990	Bamboo Creek gold exploration	Mr M. G. Creasy, Mr B. V. De Vincentiis, Zenith Mining
3225	1986–1987	Cundaline Gap iron-ore exploration	BHP Minerals
4017	1986–1989	Cattle Gorge gold exploration	CRA Exploration
5362	1986–1989	Nuggety Gully gold exploration	Mr A. J. Dwyer
4099	1987–1989	Helen Well gold exploration	Mr M. G. Creasy

Appendix 2 (continued)

GSWA WAMEX item number [(a)]	*Duration*	*Title*	*Company*
6476	1987–1992	Bamboo Creek gold exploration	Vince Roberts and Associates
4044	1988–1989	Shay gold–uranium exploration	CRA Exploration
5880	1988–1991	Bamboo diamond exploration	Randolph Resources
6516	1988–1992	Bamboo diamond exploration	Randolph Resources
6604	1988–1992	Yarrie iron exploration	BHP Minerals
7210	1988–1993	Bamboo diamond exploration	Alkane Exploration, Randolph Resources
4616	1989–1990	Greenhole West gold exploration	Mr M. G. Creasy
5685	1989–1991	Bamboo Creek gold exploration	Mr M. G. Creasy
7067	1991–1993	Bamboo Creek gold exploration	Elazac
7351	1992–1993	Gap Well gold–base-metals exploration	BHP Minerals
8169	1992–1995	Panorama East gold–base-metals exploration	Sipa Resources
8728	1992–1996	Coppin Gap gold–base-metals exploration	Sipa Resources
7260	1993–1993	Marble Bar gold–base-metals exploration	Poseidon Exploration
8420	1993–1995	Yarrie diamond exploration	Rudall Resources
8666	1993–1996	Nullagine gold–copper–diamond exploration	Alkane Exploration, Navan Mines, Normandy Exploration
8667	1993–1996	Coongan gold exploration	Compass Resources

NOTE: (a) Information available from GSWA Library, Mineral House

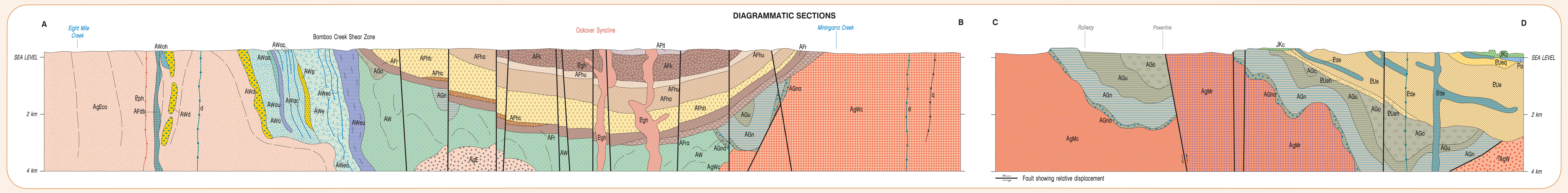
AUSTRALIA 1:100 000 GEOLOGICAL SERIES

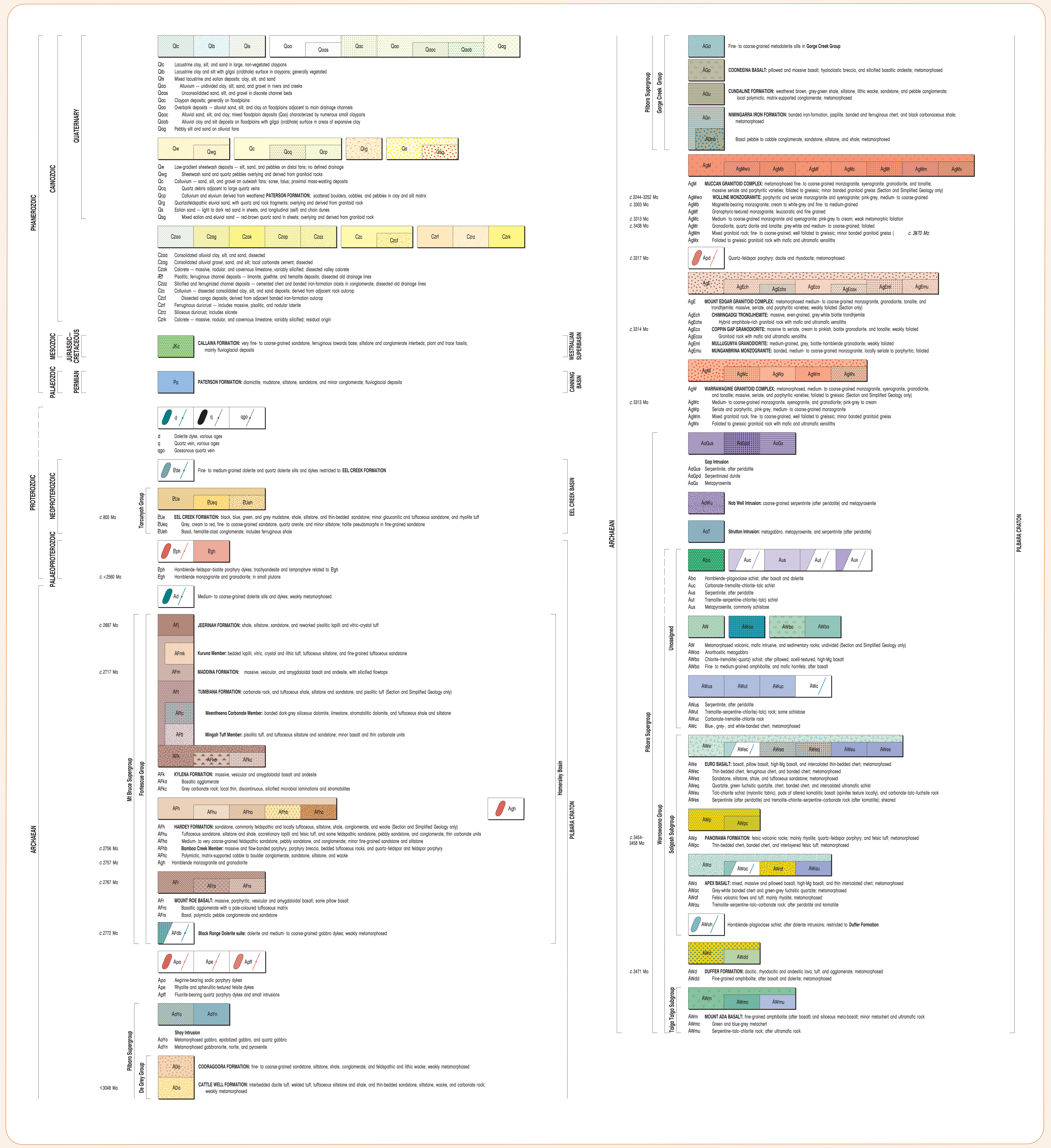
MUCCAN

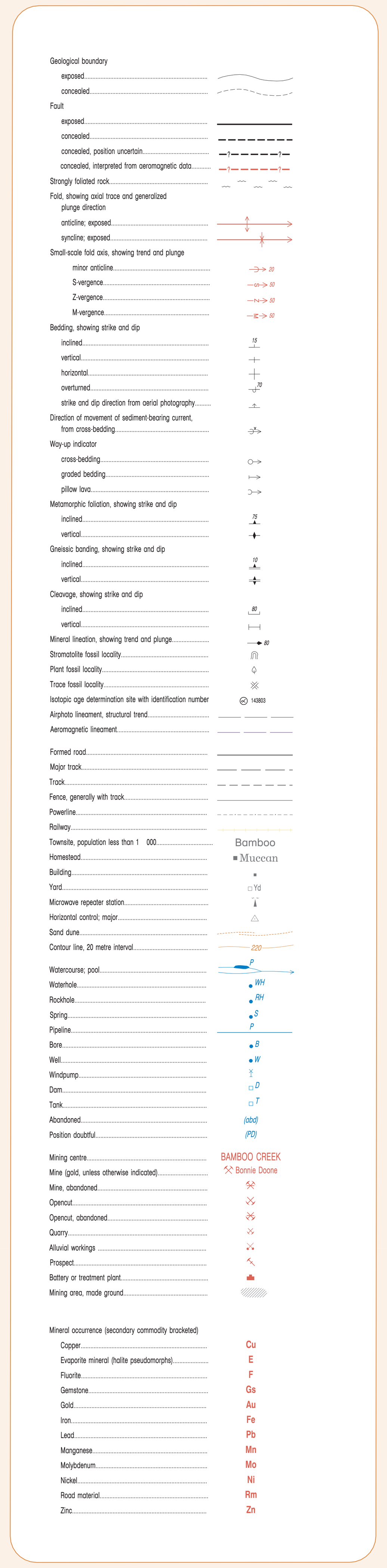
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 2956

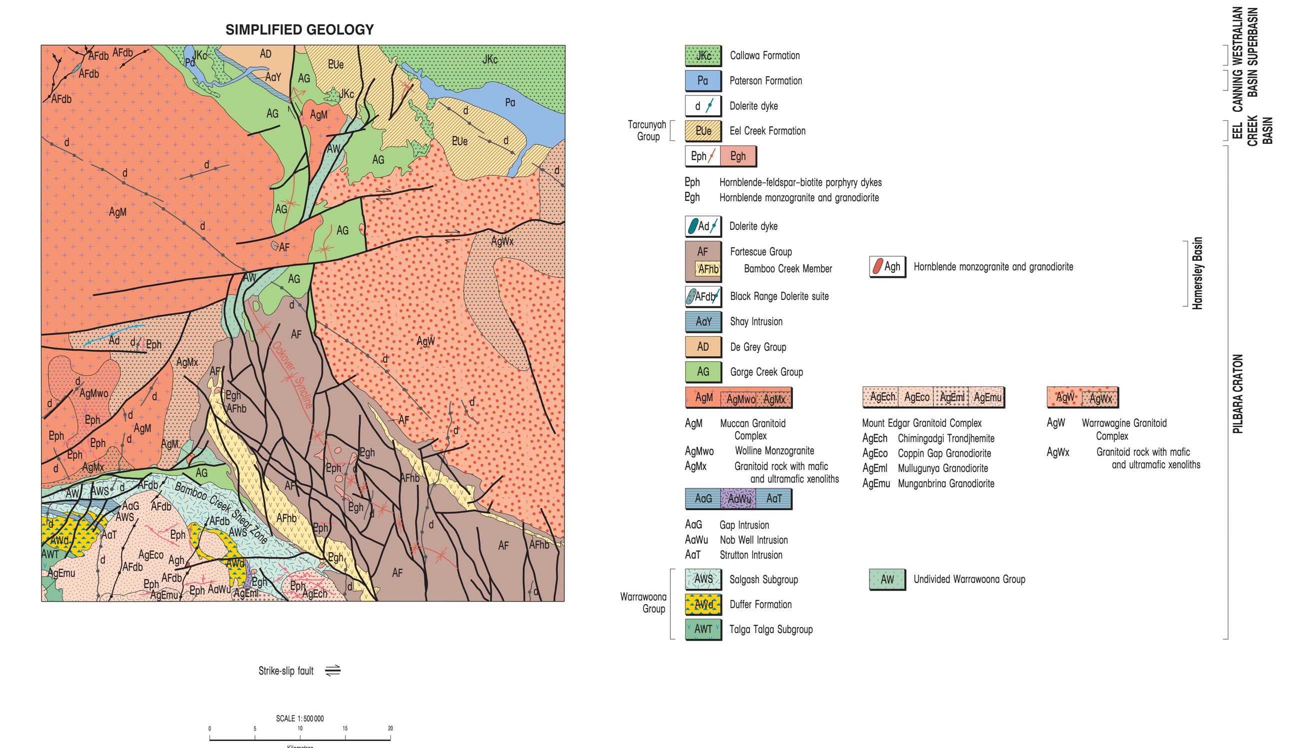
DIAGRAMMATIC SECTIONS

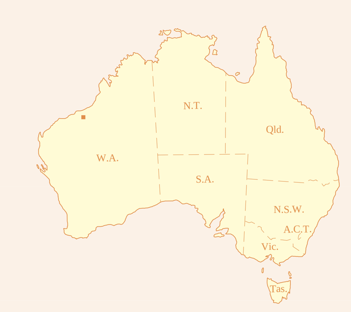


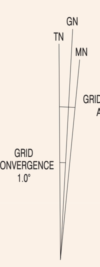




SIMPLIFIED GEOLOGY

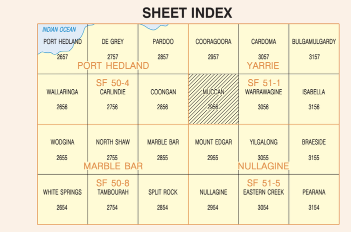






True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 1998 and moves easterly by about 0.1° in 3 years.

SHEET INDEX



1:100 000 maps shown in black

1:250 000 maps shown in brown

Department of Industry and Resources

CLIVE BROWN, M.L.A.
MINISTER FOR STATE DEVELOPMENT

JIM LIMERICK
DIRECTOR GENERAL

Geological Survey of Western Australia

TIM GRIFFIN
DIRECTOR

NGA

PRODUCT OF THE NATIONAL GEOSCIENCE AGREEMENT

SCALE 1:100 000

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

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

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

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

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

Geology by I. R. Williams 1996

Edited by C. Strong, N. Tetlaw, and G. Loan

Cartography by D. Ladbrook and K. Greenberg

Topography from the Department of Land Administration Sheet SF 51–1, 2956, with modifications from geological field survey

Published by the Geological Survey of Western Australia. Copies available from the Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, WA, 6004. Phone (08) 9222 3459, Fax (08) 9222 3444

This map is also available in digital form

Printed by the Land Information Centre, Bathurst, New South Wales

The recommended reference for this map is:
WILLIAMS, I. R., 1998, Muccan, W.A. Sheet 2956: Western Australia Geological Survey, 1:100 000 Geological Series.

MUCCAN

SHEET 2956

FIRST EDITION 1998
Version 1.1 — May 2003