EXPLANATORY NOTES

Department of
Industry and Resources

YARRIE
1:250 000 SHEET
WESTERN AUSTRALIA
THIRD EDITION

1:250 000 GEOLOGICAL SERIES

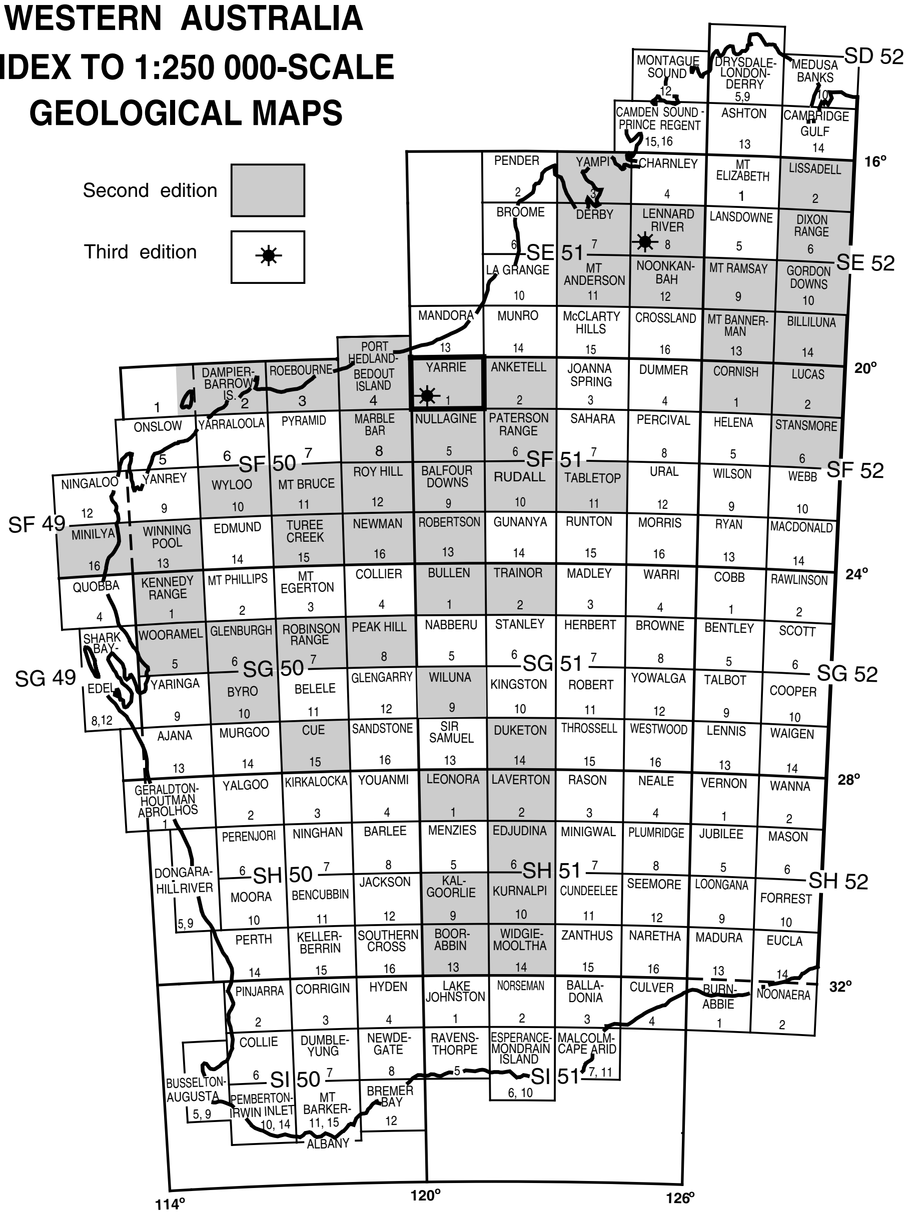
SHEET SF 51-1 INTERNATIONAL INDEX

Geological Survey of Western Australia

WESTERN AUSTRALIA
INDEX TO 1:250 000-SCALE GEOLOGICAL MAPS

Second edition

Third edition



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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
1:250 000 GEOLOGICAL SERIES — EXPLANATORY NOTES

YARRIE

WESTERN AUSTRALIA

THIRD EDITION

SHEET SF 51-1 INTERNATIONAL INDEX

by

I. R. WILLIAMS

Perth, Western Australia 2003

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by I. R. Williams

INTRODUCTION

The YARRIE* 1:250 000 geological map sheet (SF 51-1), bounded by latitudes 20°S and 21°S and longitudes 120°E and 121°30'E, straddles the boundary between the northeastern margin of the Pilbara Region and the southwestern part of the Great Sandy Desert Region on Figure 1 (Beard, 1975). YARRIE falls within the Marble Bar District of the Pilbara Mineral Field and derives its name from the Yarrie pastoral lease, which lies along a section of the De Grey River. Other occupied pastoral leases on YARRIE are Muccan on the western margin, and Warrawagine, in the south-central parts, which covers the area where the Nullagine and Oakover rivers combine to form the De Grey River. Portions of two other pastoral leases encroach on the northwestern (Pardoo Station) and northern (Wallal Station) margins of YARRIE. All pastoral leases on YARRIE are beef-cattle stations.

An aboriginal pastoral lease, Callawa (north of Warrawagine Station), and an aboriginal community, Myijimaya (37 km east of Warrawagine Homestead), both on the edge of the Great Sandy Desert, were unoccupied in 2002. Most of the Great Sandy Desert region is vacant crown land.

Apart from homesteads, the only other occupied settlements on YARRIE are Yarrie Village and the Bamboo Creek Mining Centre. The former is the service centre for BHP Billiton Iron Ore operations in the Yarrie and Nimingarra areas. The latter comprises a gold-treatment plant (Elazac Process) operated by Haoma Mining NL that in 2002 was milling and processing high-grade material collected from a number of localities in the East Pilbara.

The southwestern quarter of YARRIE is well serviced with graded roads (Fig. 2). The original Port Hedland – Woodie Woodie road crosses the southwestern and south-central parts of the sheet. However, with the opening of the new, sealed Ripon Hills road, which connects Marble Bar directly to the Woodie Woodie – Telfer road junction on BRAESIDE, the original Port Hedland – Woodie Woodie road is now maintained by the East Pilbara shire only as far as Warrawagine Homestead. The road southeast of the homestead has been downgraded to a station track.

The original Port Hedland – Woodie Woodie road is linked to the Great Northern Highway north of YARRIE via the Muccan – Shay Gap – Boreline road. This road is used as a shortcut for vehicles from the Marble Bar district travelling to Broome and beyond. The abandoned (1993) Shay Gap townsite, now bypassed by the Muccan–Boreline road, is linked by sealed road between the Boreline road and Nimingarra mines turnoff, and graded road to the Pardoo Roadhouse on the Great Northern Highway to the northwest on PARDOO. A graded road

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

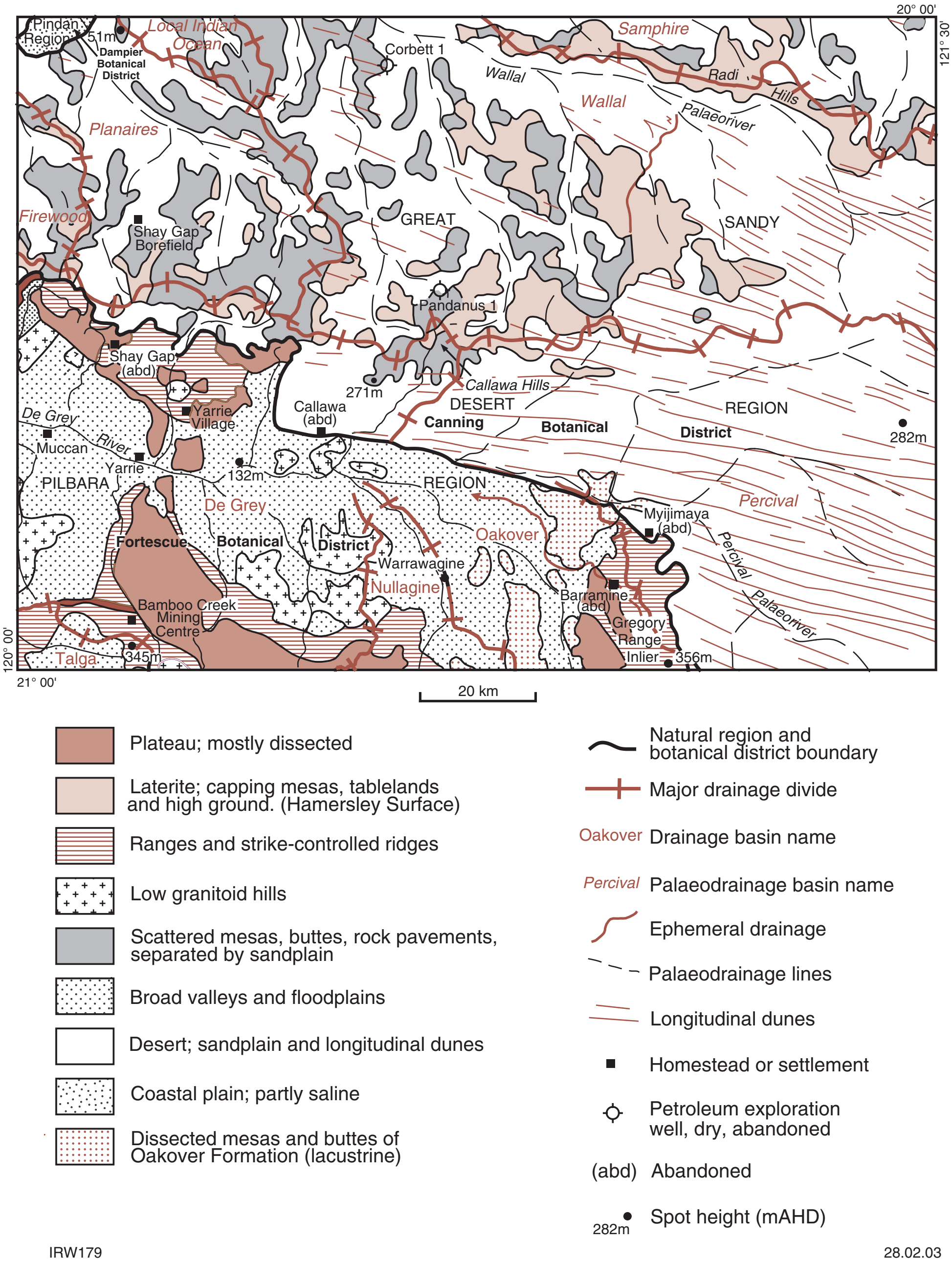


Figure 1. Natural regions, botanical districts, physiography, and drainage map of YARRIE

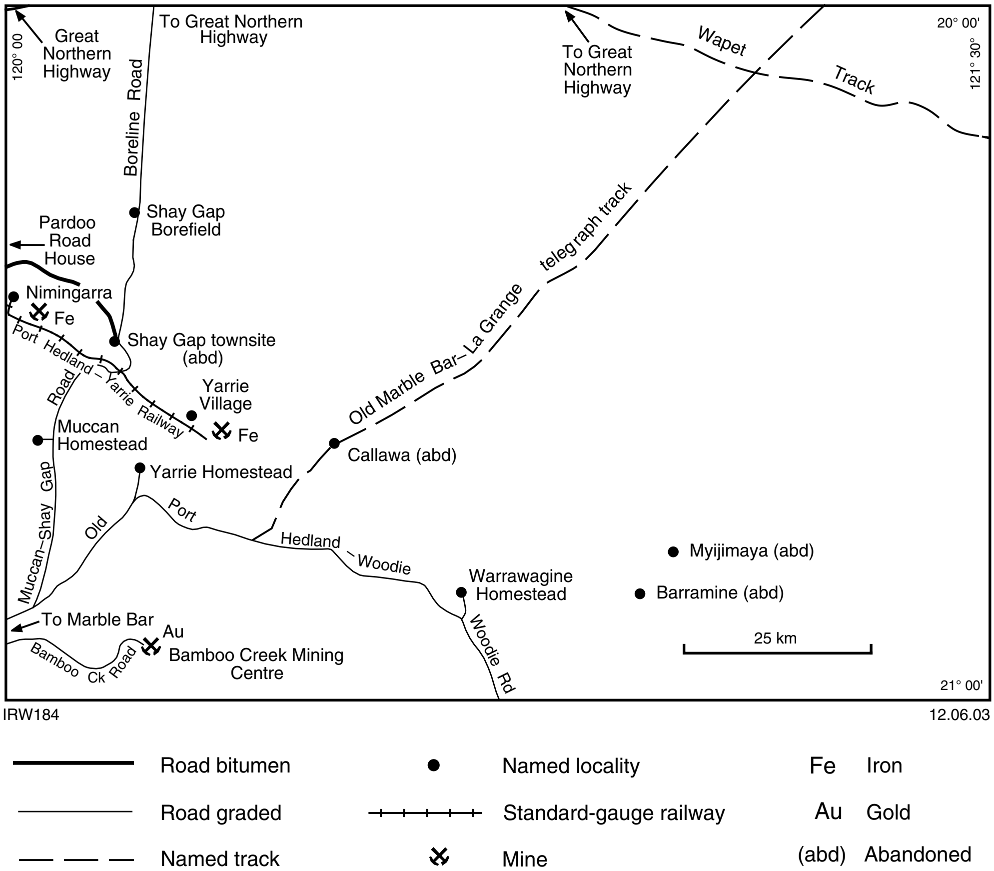


Figure 2. Locality map for Yarrie

also links the Bamboo Creek Mining Centre westwards to the original Port Hedland – Woodie Woodie road.

Numerous roads and tracks give access to abandoned and operating iron ore openpits in the Nimingarra, Shay Gap, and Yarrie districts. A good graded road links the Yarrie Village and nearby working iron ore openpits, Yarrie Y2/Y3 and Y10, to the Muccan–Boreline road near Shay Gap. All of these roads and tracks are privately maintained by BHP and have restricted access. BHP also operates a standard gauge railway that transports crushed and beneficiated iron ore from Yarrie and Nimingarra, 200 km west to Finucane Island at Port Hedland for export.

Station tracks on Muccan, Yarrie, and Warrawagine permit reasonable access to the southwestern and south-central parts of Yarrie. However, the remainder of the sheet, which is mostly occupied by the Great Sandy Desert, is only sparsely serviced by tracks. Although some seismic lines and mineral exploration tracks have been constructed over the last three decades in the Great Sandy Desert Region north and east of Warrawagine, most have fallen into disrepair and are now difficult to follow. The heavy sand and scrubby conditions in this region make off-road work arduous. A rough sandy track follows the abandoned Marble Bar – La Grange telegraph line northeast from Callawa Homestead. In the northeast corner of Yarrie this track crosses an east-southeasterly trending track, originally a West Australian

Petroleum Pty Ltd (WAPET) exploration track, that links the Great Northern Highway near Wallal Homestead (on MANDORA) to aboriginal communities in the Great Sandy Desert.

The Shay Gap Bore Field supplies potable water via a 42 km pipeline southeast to the Yarrie iron mines and village.

PREVIOUS AND CURRENT INVESTIGATIONS

Bibliographies published in Traves et al. (1956), explanatory notes for the YARRIE 4-mile Geological Series (Wells, 1959) and YARRIE 1:250 000 Geological Series (Hickman et al., 1983), Hickman (1983), and recent 1:100 000-scale explanatory notes for ISABELLA (Williams and Trendall, 1998a), MUCCAN (Williams, 1999a), COORAGOORA (Williams, 2000), and WARRAWAGINE (Williams, 2001) give detailed coverage of previous geological investigations on YARRIE.

In summary, such previous investigations on YARRIE fall into four main periods. The first period, from 1861 to 1890, covers the exploration (Gregory and Gregory, 1884; Feeken et al., 1970) and pastoral settlement of the district (Hardie, 1988); geological observations are sparse.

The second period, from 1890 to 1952, covers the early, mainly reconnaissance geological mapping (Smith 1898; Maitland, 1906, 1908, 1919; Blatchford, 1913; Clapp, 1925; Reeves, 1951), and the discovery and more detailed mapping of mineral prospects (gold, copper) (Maitland, 1904; Blatchford, 1925; Finucane, 1938). It also included the first regional reappraisals of the geological history of the region (Maitland, 1919; Clarke, 1923), and the first preliminary geophysical surveys (Blazey et al., 1938).

The third period, from 1952 to the early 1990s, saw a renewed interest in the mineral potential of the region. Several systematic regional mapping programs, based on 1:48 000- and 1:80 000-scale black and white aerial photography and later enhanced by colour Landsat TM imagery, were carried out. These lithostratigraphic mapping episodes on YARRIE were published in reports (Traves et al., 1956), explanatory notes and maps (Wells, 1959; Hickman et al., 1983), and bulletins (Veevers and Wells, 1961; Hickman, 1983; Towner and Gibson, 1983). Additional detailed mapping of the Neoarchaean Fortescue Group, in the southwestern part of YARRIE, was also undertaken during this period using a model-driven, sequence-stratigraphic approach (Blake, 1984, 1990, 1993; Krapez, 1993).

This third period also saw the introduction and application of Pb–Pb isotopic, Rb–Sr whole-rock, conventional zircon U–Pb, and early SHRIMP* U–Pb zircon dating techniques (Richards, 1983; de Laeter and Martyn, 1986; Williams and Collins, 1990; Arndt et al., 1991; Thorpe et al., 1992a,b). The first specific geochemical surveys (Davy and Hickman, 1983; Glikson et al.,1986, 1991) and local and regional geophysical surveys were also undertaken during this period. Such surveys included seismic refraction (in the Oakover Valley – Mount Cecelia area, Sentinel Mining, 1967), preliminary regional gravity (Bouguer anomaly, BMR[†], 1979); total magnetic intensity (TMI) contours (AGSO[‡], 1993a), and radiometric total count contours (AGSO, 1993b) maps for YARRIE. Subsurface data were obtained from stratigraphic, hydrogeological, mineral, and petroleum drilling (Sentinel Mining, 1967; Leech, 1979a,b); and numerous company reports held in the WAMEX and WAPEX open-file system, MPR[§] Library). Large-scale iron ore and gold mining also took place during this period (Podmore, 1990).

* SHRIMP: sensitive high-resolution ion microprobe
† BMR: Bureau of Mineral Resources
‡ AGSO: Australian Geological Survey Organisation, now Geoscience Australia (GA)
§ MPR: Department of Mineral and Petroleum Resources, now Department of Industry and Resources (DoIR)

The fourth period, from the 1990s onwards, is characterized by a renewed interest in the Precambrian component of YARRIE. This detailed reassessment has been aided by new 1:25 000-scale colour photography, current remote-sensing technologies, and detailed geophysical surveys conducted under the auspices of the National Geoscience Mapping Accord (NGMA) North Pilbara Project. New airborne magnetic (Mackey, 1997a,b; Mackey and Richardson, 1997), and gamma-ray spectrometry programs (Mackey, 1997c) were conducted over the southwest corner of YARRIE. The data from the latter survey are included in a 1:500 000-scale map of the Pilbara Region (Milligan et al., 1999). A summary and a 1:1.5 million-scale atlas of all the geophysical data and Landsat-5-Tm (Glikson, 1997; Macias, 1998) data gathered for the NGMA project can be found in Blewett et al. (2000).

New field data, collected during this fourth period by the GSWA and published in the 1:100 000-scale map series of ISABELLA (Williams and Trendall, 1996), MUCCAN (Williams, 1998), COORAGOORA (Williams, 1999b) and WARRAWAGINE (Williams, 1999c), have been incorporated in the third edition YARRIE.

The increased precision of isotopic dating, provided by SHRIMP U–Pb zircon geochronology (Nelson, 1996, 1998, 1999, 2000) of samples collected during the 1:100 000-scale mapping projects, has aided and greatly enhanced understanding of the geological history of the region.

CLIMATE, VEGETATION, AND PHYSIOGRAPHY

The YARRIE climate is characteristically arid merging to semi-arid–tropical on the northern margin towards the northwest coast of Western Australia (Beard, 1975). Most rain falls between January and March and is the product of scattered thunderstorms associated with monsoonal troughs, and south-tracking, decaying, tropical cyclones. Light to moderate rains may also fall in the late autumn and early winter months (May–June). This precipitation generally comes from the northwest Australian cloudband weather systems (Tapp and Barrell, 1984). The mean annual rainfall varies from around 250 mm in the Great Sandy Desert to over 300 mm in the ranges in the southwest corner of YARRIE. Rainfall on YARRIE is characteristically unreliable and highly variable at any particular time of the year. The evaporation rate is high, generally greater than 4000 mm per annum. Except for the cyclone season (December–April) humidity is low, although it noticeably increases northwards towards the coast. Summers are very hot with a mean maximum temperature in the low forties and winters are mild with mean minimum temperatures around 12°–13°C (Sturman and Tapper, 1996).

Apart from a very small area in the northwestern corner that is assigned to the Dampier Botanical District of the Northern Botanical Province, YARRIE falls within the Eremean Botanical Province (Beard, 1975). The small, botanically distinct area in the northwest corner corresponds to the Pindan region (Fig. 1). It is characterized by a three-tiered community of trees, shrubs, and spinifex represented mainly by *Triodia pungens* and scattered *Bauhinia cunninghamii*, *Eucalyptus zygophylla*, and various *Acacia* species. These last commonly form thickets. Low-lying areas contain claypans and saline marshes with samphire (*Arthrocnemum benthamii*) and scattered clumps of tea-tree (*Melaleuca* sp.) marking the edge of the sandplain country (Burbidge, 1944; Beard, 1975).

The Eremean Botanical Province on YARRIE is unevenly divided between the Canning Botanical District, which corresponds to the Great Sandy Desert Region, and the Fortescue Botanical District, which corresponds to the Pilbara Natural Region (Fig. 1).

Although three separate floristic assemblages can be distinguished in the Canning Botanical District on YARRIE (Beard, 1975), the dominant vegetation is a shrub steppe characterized by *Acacia* species, particularly *Acacia pachycarpa*, *Grevillea* species, and various smaller shrubs with a thick ground layer of soft spinifex (*Triodia pungens*). This is the typical sandplain cover and extends into the interdunal areas of the longitudinal dunefields in the southeast part of YARRIE. The spinifex-covered dunes carry scattered desert bloodwood (*Corymbia dichromophloia*; Hill and Johnson, 1995). Deep sandplain on the northern margin of YARRIE that is restricted to the Wallal Palaeodrainage Basin (Fig. 1), carries a tree steppe of desert walnut (*Owenia reticulata*), *Gardenia keartlandii*, and *Erythrophloeum chlorostachys*. The ground cover consists of soft spinifex (*Triodia pungens*) and feathertop spinifex (*Plectrachne schinzii*). Scattered sandstone mesas, buttes, and stony rises throughout the Great Sandy Desert are thinly vegetated with soft spinifex (*Triodix pungens*), scattered *Acacia* shrubs, and occasional stunted *Eucalyptus papuana* (forma) trees (Beard, 1975). The Percival Palaeoriver, east of the Isabella Range (Fig. 1) carries thick patches of mixed wattle (*Acacia* species) and tea-tree (*Melaleuca* species) scrub (Beard, 1975).

The Fortescue Botanical District that corresponds to the Pilbara Natural Region encompasses a wide floral range (Beard, 1975; Mitchell and Wilcox, 1994). Vegetation regimes are closely connected to the topography, underlying rock type, depth of superficial cover, and soil type. Vegetation regimes on YARRIE include shrub, tree and grass steppes, tree and grass (grassland) savannas, and riverain woodlands (Beard, 1975). The most widespread vegetation regime is the shrub steppe. It covers plains, rocky granitoid hills, and dissected plateau regions in the southwestern parts of YARRIE. Similar vegetation is also found in the dissected plateau and rocky hills of the Gregory Range Inlier east of the Oakover River (Fig. 1). The shrub steppe is distinguished by scattered kanji (*Acacia inaequilatera*; Mitchell and Wilcox, 1994), and a groundcover of soft spinifex (*Triodia pungens*). *Grevillea* and *Hakea* species, and a variety of smaller *Acacia* species, are also endemic in these areas. In the Gregory Range Inlier the soft spinifex ground cover is shared with buck spinifex (*Triodia wiseana*). Very scattered snappy gums (*Eucalyptus brevifolia*) are found on the rocky hills of the Gregory Range Inlier.

The tree steppe is found on the abrupt ranges and jumbled hills that correspond to the greenstone belts in the southwestern parts of YARRIE. This is typified by scattered snappy gum (*Eucalyptus brevifolia*) and a ground cover of both soft spinifex (*Triodia pungens*) and buck spinifex (*Triodia brizoides*). Scattered *Acacia, Grevillea*, and *Hakea* species are also present.

The tree and grass savannahs are restricted to the flood plains adjacent to the De Grey, Nullagine, and Oakover rivers. Downstream from Yarrie Homestead, a tree savannah of coolabah (*Eucalyptus microtheca*) up to 8 km wide covers floodplains adjacent to the De Grey River. In contrast, upstream from Yarrie Homestead and particularly surrounding the confluence of the Oakover and Nullagine rivers, extensive grasslands of Roebourne Plains grass (*Eragrostis xerophila*), neverfail (*Eragrostis setifolia*), and other annual and perennial grasses overlie ‘swelling clay’ or ‘gilgai’ country. Introduced buffel grass (*Cenchrus ciliaris*) is common along the banks of many incised creeks and gullies in the gilgai country. Sclerophyll riverain woodlands of coolabah (*Eucalyptus microtheca*) grow along disused anabranches and plants north of the Oakover River on Warrawagine Station. Narrow riverain woodlands of *Eucalyptus camaldulensis* (river red gum), and *Melaleuca leucodendron* (paperbarks) fringe the De Grey, Nullagine, and Oakover rivers, as well as some of their larger tributaries on YARRIE (Beard, 1975).

The physiographic divisions shown in Figure 1 are based on Jutson (1950), Hickman (1983), Beard (1975), and Williams (1999a, 2000, 2001). The smallest area occupied by a physiographic division on YARRIE, the Pindan Region, lies in the northwest corner. This region is part of the Mandora Coastal Plain (Beard, 1975) that parallels the Eighty Mile Beach to the north. This low-lying plain is less than 20 m AHD (Australian Height Datum), and contains saline marshes and claypans.

The next largest physiographic division is the Pilbara Natural Region (Beard, 1975), which covers the southwestern part of YARRIE. This division is further subdivided into physiographic units and includes dissected plateau, range and strike-controlled ridges, low granitoid hills, and broad valleys with associated floodplains (Fig. 1). An additional and singularly distinctive unit of the Pilbara Region on YARRIE is the low dissected plateau, mesa, and butte topography developed on, and restricted to, the Cainozoic Oakover Formation. This unit is confined to the Oakover River valley (Williams, 2001; Fig. 1). On YARRIE, maximum elevation is attained in the range and strike-controlled ridge unit as shown by the Isabella Range (356 m AHD) to the southeast. Greatest relief (around 190 m) exists between the De Grey River and the abrupt, scarp-lined ranges in the Yarrie and Coppin Gap areas.

The Great Sandy Desert (Beard, 1975) is the most widespread physiographic division on YARRIE. The division is split between mostly dune-free sandplain in the western, northwestern, northern, and northeastern parts of the sheet, and longitudinal (seif) and chain dune-covered sandplain (Crowe, 1975) in the central, eastern, and southeastern parts. The longitudinal dunes trend between 300° in the northwestern and eastern parts and around 270° in the central parts. Dune spacing varies from about 300 m east of the Isabella Range to over several kilometres in the central and northwestern areas. Individual dunes may be up to 30 km long and, in the southeastern and eastern parts, average 13 m high. The western, central, and northern parts of the Great Sandy Desert on YARRIE contain numerous scattered sandstone mesas, buttes, and rock pavements. This region is also overlain in places, particularly along drainage divides and on high ground, by laterite and ferruginous gravel (Fig. 1). Some of this ferruginous material may be remnants of the old Hamersley Surface (Campana et al., 1964).

The Pilbara Region on YARRIE is an area of active, although ephemeral, drainage. The region is occupied by parts of the Oakover, Nullagine, De Grey, and Talga drainage basins. In contrast, the Great Sandy Desert hosts a series of palaeodrainage basins that originally flowed north to the Indian Ocean or west to join the currently active Oakover and De Grey rivers. The Indian Ocean-directed basins are, from west to east, the Firewood (Williams, 2000), Plainaires (Williams, 2000), Wallal (van de Graaff et al., 1977), and Samphire palaeodrainage basins. The Percival Palaeodrainage Basin, which hosts the Percival Palaeoriver (van de Graaff et al., 1977), lies to the south of the Wallal Palaeodrainage Basin. This palaeoriver can be traced for over 800 km east-southeasterly and easterly across the Canning Basin (Myers and Hocking, 1998) and is probably an ancestral extension of the present-day De Grey River.

REGIONAL GEOLOGICAL SETTING

YARRIE is located along the northeast margin of the Pilbara Craton (Fig. 3). The sheet covers components of four major tectonic units — the Archaean Pilbara Craton (Trendall, 1990a, 1995), Proterozoic Paterson Orogen (Williams and Myers, 1990) including the Eel Creek Embayment (this publication), the Phanerozoic Canning Basin (Middleton, 1990), and the Mesozoic Northern Carnarvon Basin (Hocking et al., 1994) (Fig. 4). These units occupy roughly 25%, 3%, 57%, and 15% of the total surface area of YARRIE, respectively. Geophysical (TMI and gravity) and drillhole data show that the Phanerozoic basins are floored in the west by the Archaean Pilbara Craton (approximately 66% by area) and in the east by the Proterozoic Paterson Orogen (approximately 33% by area).

The regional geological setting for YARRIE is given in Figure 3, the major structural elements in Figures 4, 5, and 6a–f, and a regional TMI image in Figure 7. The stratigraphy and major

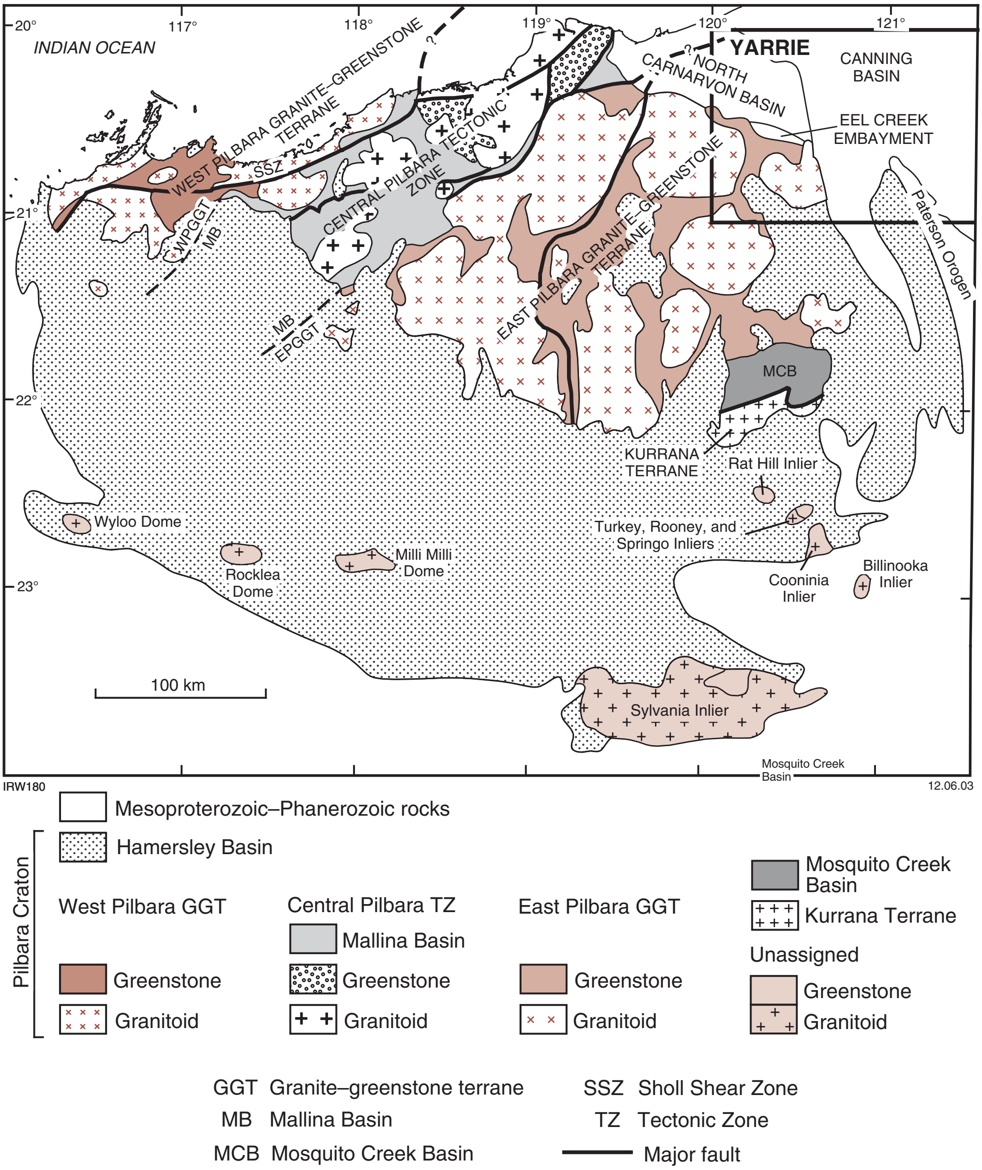


Figure 3. Regional geological setting of YARRIE

structures on YARRIE are shown on the interpretative bedrock geological map on the YARRIE 1:250 000 sheet (Williams, 2002), and the geological history for YARRIE is summarized in Table 1.

The Archaean rocks of the Pilbara Craton can be divided into two components — the pre-2800 Ma granite–greenstone terranes of the north Pilbara (Van Kranendonk et al., 2001, 2002; cf. North Pilbara granite–greenstone terrane, Griffin, 1990) and the unconformably overlying volcano-sedimentary Mount Bruce Supergroup of the c. 2800–2400 Ma Hamersley Basin (Trendall, 1990b) (Fig. 5).

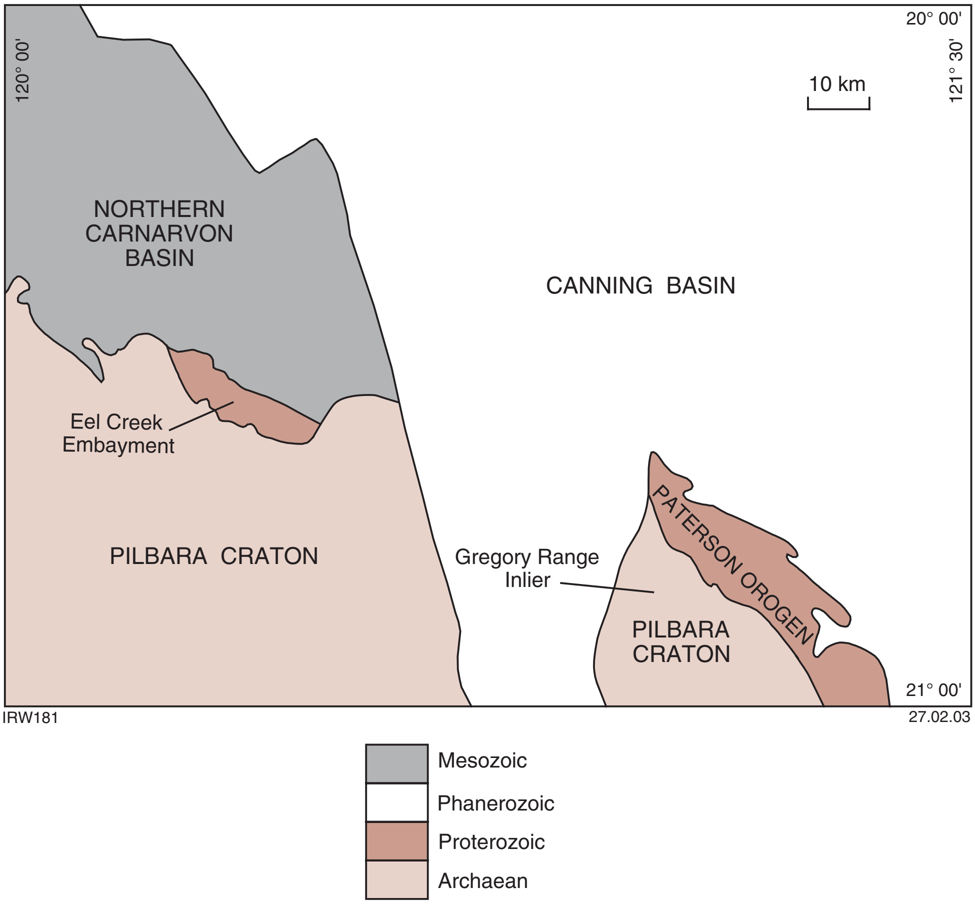


Figure 4. Major tectonic units on YARRIE

Recent studies of the pre-2800 Ma part of the Pilbara Craton in the northern Pilbara have established five lithotectonic elements that have, from northwest to southeast, been designated the West Pilbara Granite–Greenstone Terrane (WPGGT), the Central Pilbara Tectonic Zone, the East Pilbara Granite–Greenstone Terrane (EPGGT), the Mosquito Creek Basin, and the Kurrana Terrane (Hickman, 2001; Hickman and Smithies, 2001; Van Kranendonk et al., 2001, 2002). The granite–greenstone regions, exposed in the southwest corner of YARRIE, are part of the East Pilbara Granite–Greenstone Terrane (Fig. 5). The EPGGT on YARRIE consists of the exposed southwestern part of the Warrawagine Granitoid Complex (c. 3655–3242 Ma; Nelson, 1998, 1999; Williams, 1999a, 2001), the eastern third of the Muccan Granitoid Complex (c. 3470–3244 Ma; Nelson, 1996, 1998; Williams, 1999a), and the northern tip of the Mount Edgar Granitoid Complex (c. 3460–2830 Ma; Nelson, 2000; Williams and Collins, 1990; Williams, 1999a). These granitoid–gneiss complexes intrude, or are in tectonic contact with, belts of tightly folded and mainly steep-dipping volcanic and sedimentary rocks of the Pilbara Supergroup (Hickman, 1983). This layered greenstone succession is metamorphosed to upper greenschist facies and may reach lower amphibolite (hornblende-hornfels facies) in contact aureoles adjacent to intrusive granitoids. Lithostratigraphically, these volcano-sedimentary rocks have been assigned to the Talga Talga and Salgash Subgroups of the Warrawoona Group (c. 3490–

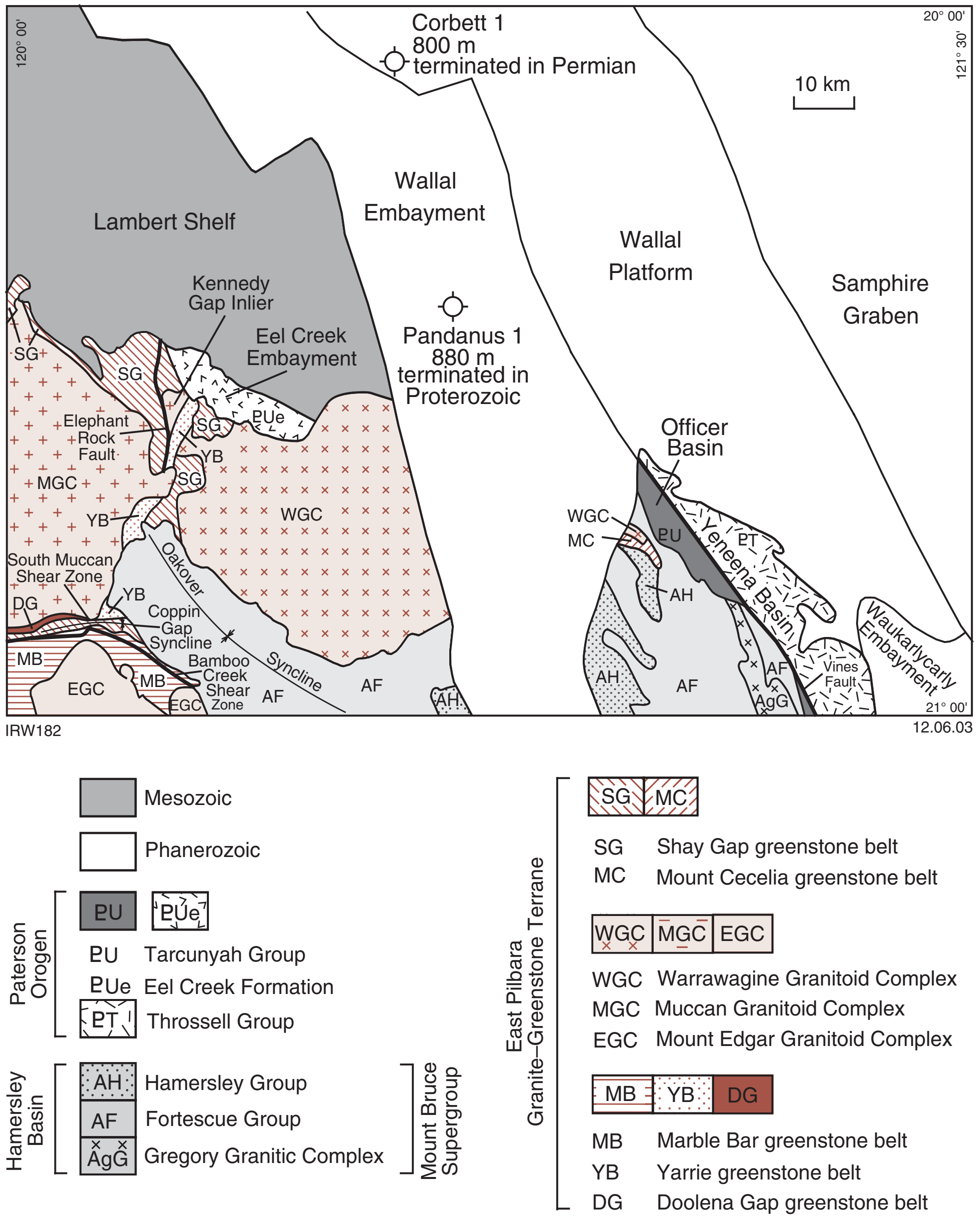


Figure 5. Lithotectonic subdivisions on YARRIE

3310 Ma; Williams, 1999a, 2001; Van Kranendonk et al., 2001). Regionally, the successions on YARRIE are part of the Marble Bar, Dooleena Gap, and Yarrie greenstone belts (Figs 5 and 6a).

The Gorge Creek Group (<3235 Ma; Williams, 1999a; Van Kranendonk, 2000) unconformably overlies the Warrawoona Group and the Warrawagine and Muccan Granitoid Complexes (Dawes et al., 1995a,b; Williams, 1999a) in the Yarrie–Nimingarra area. Rocks of the Gorge Creek Group are also exposed in the Coppin Gap Syncline (Williams, 1999a).

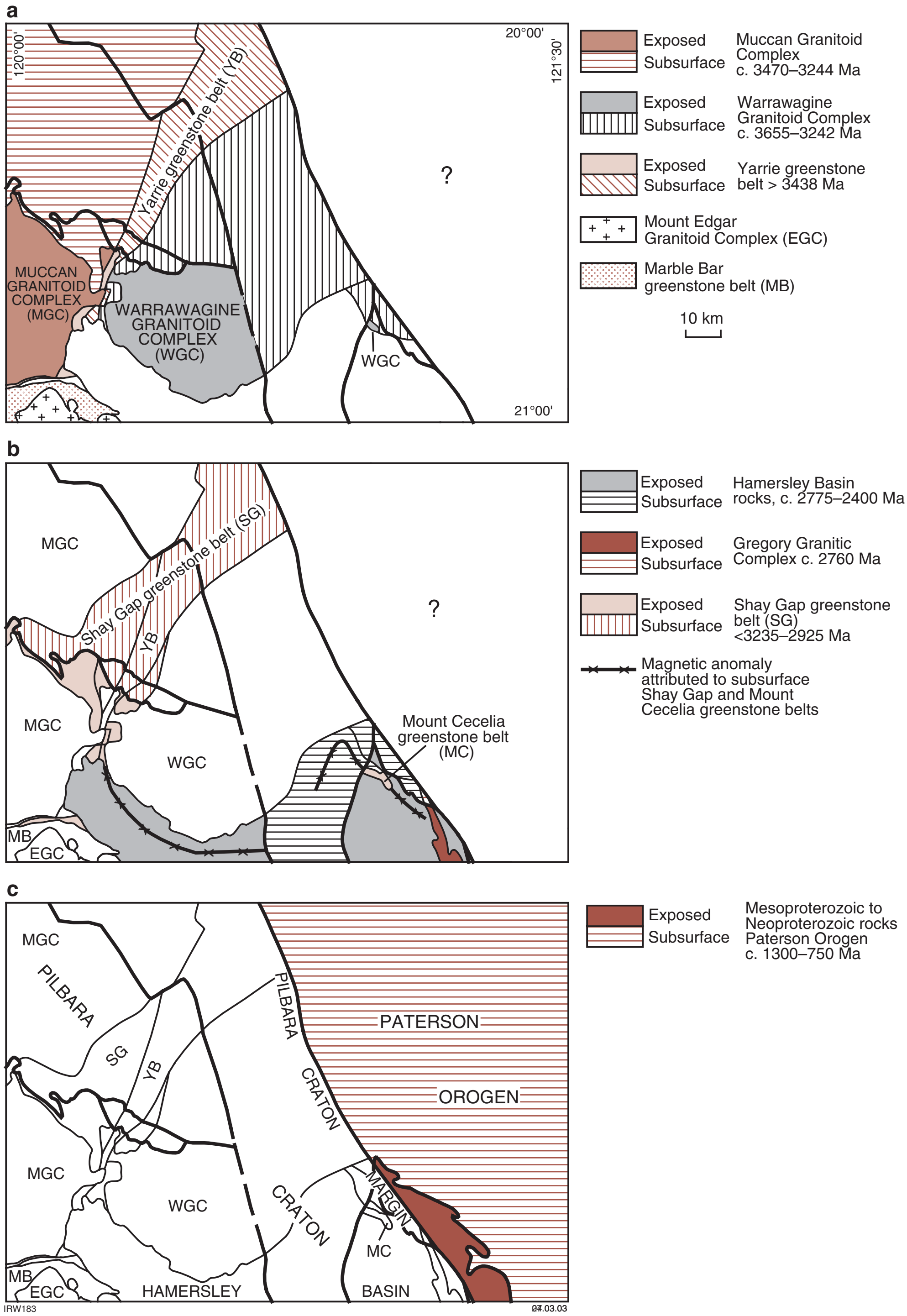
The Gorge Creek Group, together with rocks from the younger and disconformably overlying De Grey Group (<3048 Ma; Nelson, 1999), constitutes the Shay Gap greenstone belt (Williams, 1999a) (Fig. 5). A small inlier of the Gorge Creek Group, the Mount Cecelia greenstone belt, is exposed at the northern end of the Gregory Range Inlier (Fig. 5). Total magnetic intesity data suggest that this isolated exposure may be linked, beneath the Fortescue Group and Permian rocks, to the Shay Gap greenstone belt that lies 75 km to the west (Figs 6b and 7).

The Neoarchaean Fortescue Group (c. 2775–2629 Ma; Nelson et al., 1999), together with the disconformably overlying Carawine Dolomite (c. 2541 Ma, Pb–Pb; Jahn and Simonson, 1995) of the Hamersley Group and closely associated Palaeoproterozoic Pinjin Chert Breccia (Williams and Trendall, 1998b), are exposed in the Oakover Syncline (Hickman, 1983; Blake, 1993; Williams, 1999a) and Gregory Range Inlier (Williams and Trendall, 1998a; Williams, 2001). These two regions lie along the southern boundary of YARRIE (Fig. 5). They also constitute the northeasternmost exposures of Fortescue Group and Hamersley Group rocks in the Hamersley Basin (Figs 5 and 6b). The two areas are linked beneath a shallow cover of Lower Permian rocks in the Nullagine and Oakover river valleys (see cross section YARRIE 1:100 000 sheet, Williams, 2002) (Figs 5, 6b and e). The Oakover Syncline is part of the Northeast Pilbara Sub-basin, one of four Fortescue Group sub-basins (Blake, 1984; Thorne and Blake, 1990; Thorne and Trendall, 2001).

Exposures of Proterozoic rocks on YARRIE are limited to the northwest-trending Paterson Orogen that lies east and northeast of the Gregory Range Inlier (Williams and Trendall, 1998a) and to a portion of the Eel Creek Embayment sandwiched between the Pilbara Craton and overlying Mesozoic rocks of the Northern Carnarvon Basin (Westralian Superbasin) in the central west (Williams, 1999a, 2000) (Figs 5,6c and d). The Paterson Orogen (Williams and Myers, 1990), on YARRIE, comprises two tectonostratigraphic components — the Mesoproterozoic–Neoproterozoic Yeneena Supergroup of the Yeneena Basin (Williams and Bagas, 1999; Bagas et al., 1999), and the Neoproterozoic Tarcunyah Group of the Officer Basin (Williams and Bagas, 1999; Bagas et al., 1999) (Figs 5,6c and d). The paucity of precise geochronological data leaves a degree of uncertainty as to the age relationships between the Tarcunyah Group and Yeneena Supergroup. The Yeneena Supergroup comprises the Throssell Group (c. 1250–900 Ma; Hickman and Bagas, 1999) and, on Yarrie, the subsurface Lamil Group (Williams and Trendall, 1998a; c. 1070–678 Ma; Bagas, 2000). However, the exact stratigraphic–structural relationships between the Lamil and Throssell Groups are still uncertain (Bagas, 2000). The Lamil Group is postulated, from exploration drillhole data, to underlie Permian rocks in the southeast corner of YARRIE (Williams and Trendall, 1998a). The Throssell Group, which lies to the west of the Lamil Group, is separated from the younger Tarcunyah Group (<800 Ma) by the dextral transpressional Vines Fault (Williams and Trendall, 1998a). The Vines Fault may also mark the tectonic boundary or sutured eastern margin of the Pilbara Craton (Fig. 5).

The Neoproterozoic Tarcunyah Group unconformably overlies the Gregory Granitic Complex and Fortescue Group rocks of the Pilbara Craton on YARRIE (Williams and Trendall, 1998a). The Eel Creek Formation, which occupies the Eel Creek Embayment in the central western part of YARRIE, is postulated to be coeval with, and a western extension of, the Tarcunyah Group rocks (Williams, 1999a, 2000). The Eel Creek Embayment is interpreted to be a shallow-water embayment that extends westwards from the northwest-trending Officer Basin (Williams and Bagas, 1999; Figs 5 and 6d).

The Phanerozoic Canning Basin occupies most of the eastern half of YARRIE (Fig. 4). The Canning Basin is a long-lived, multiple-phase, pericratonic basin with a complex structural


a
120°00'
20°00'
121°30'
21°00'
Yarrie greenstone belt (YB)
MUCCAN GRANITOID COMPLEX (MGC)
WARRAWAGINE GRANITOID COMPLEX (WGC)
WGC
?
Exposed
Subsurface
Muccan Granitoid Complex c. 3470–3244 Ma
Warrawagine Granitoid Complex c. 3655–3242 Ma
Yarrie greenstone belt > 3438 Ma
Mount Edgar Granitoid Complex (EGC)
Marble Bar greenstone belt (MB)
10 km
b
MGC
Shay Gap greenstone belt (SG)
YB
WGC
MB
EGC
?
Mount Cecelia greenstone belt (MC)
Hamersley Basin rocks, c. 2775–2400 Ma
Gregory Granitic Complex c. 2760 Ma
Shay Gap greenstone belt (SG) <3235–2925 Ma
Magnetic anomaly attributed to subsurface Shay Gap and Mount Cecelia greenstone belts
c
MGC
PILBARA
SG
YB
WGC
MB
EGC
HAMERSLEY
PILBARA
CRATON
CRATON
MARGIN
MC
BASIN
PATERSON
OROGEN
Mesoproterozoic to Neoproterozoic rocks Paterson Orogen c. 1300–750 Ma
IRW183

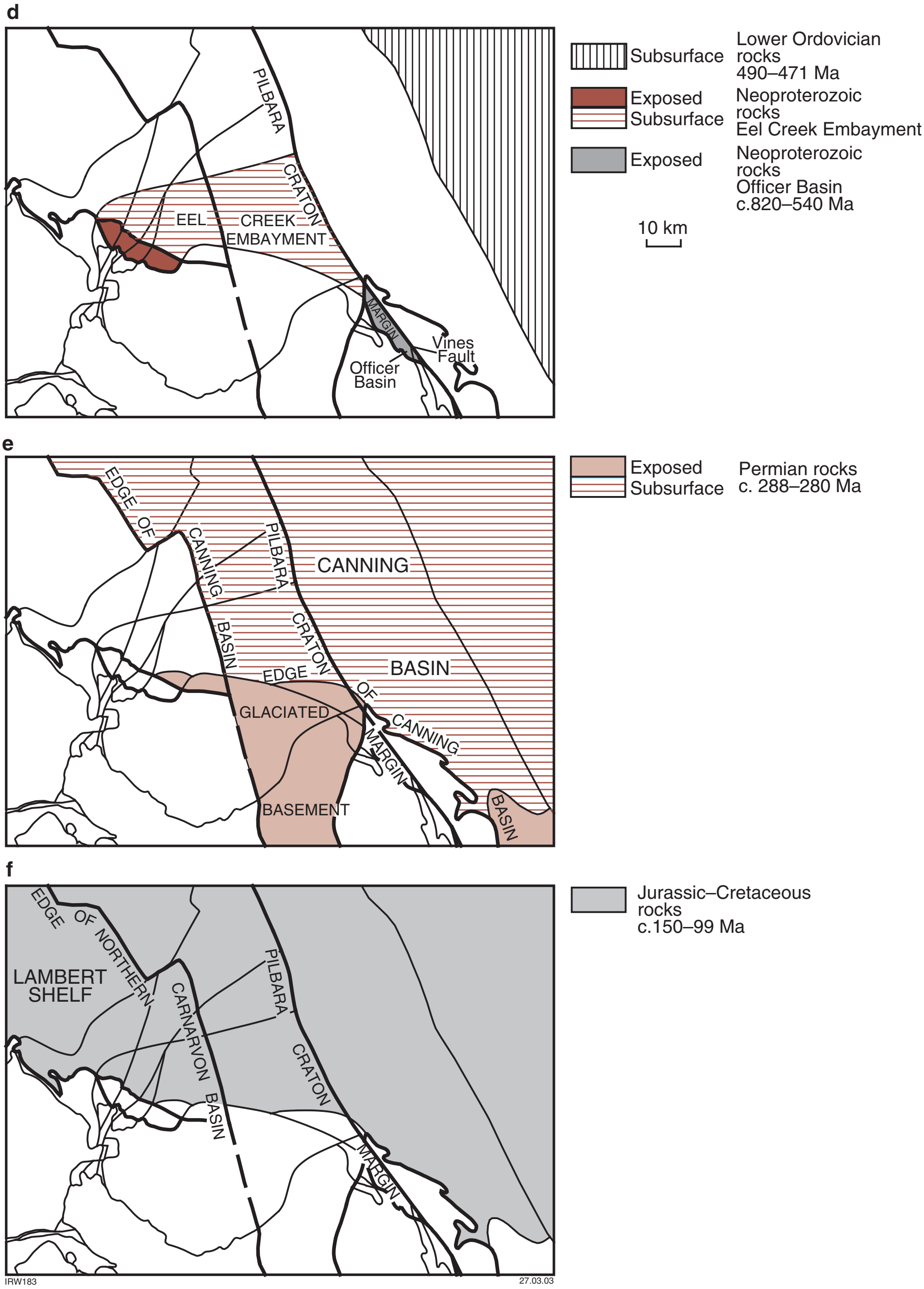


Figure 6. Interpretative subsurface geology based on total magnetic intensity (TMI) image and stratigraphic drilling data for YARRIE; presented in chronological sequence: a) Archaean (c. 3655–3242 Ma); b) Archaean–Palaeoproterozoic (c. 3235–2400 Ma); c) Mesoproterozoic–Neoproterozoic (c. 1300–750 Ma); d) Neoproterozoic – lower Palaeozoic (c. 820–471 Ma); e) upper Palaeozoic (c. 288–280 Ma); and f) Mesozoic (c. 150–99 Ma)

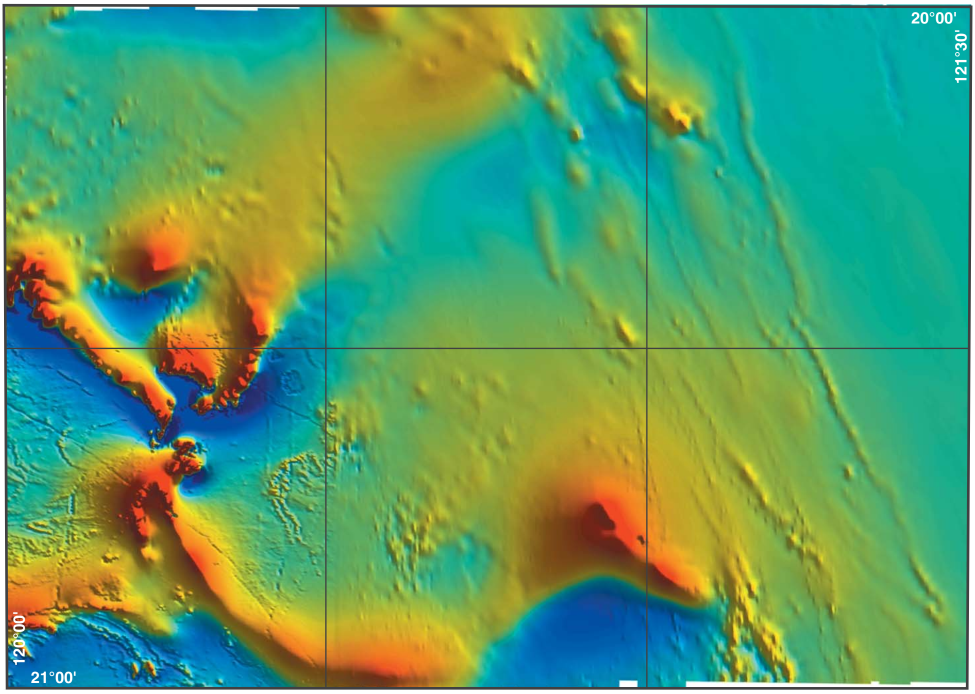


Figure 7. Total magnetic intensity (TMI) image for YARRIE

history (Kennard et al., 1994). Sedimentation commenced in the Early Ordovician and was initiated by extension and rapid subsidence connected with the development of northwest-trending half-grabens (Romine et al., 1994). Units of this early sedimentation are probably preserved at depth in the Samphire Graben on the eastern margin of YARRIE (Towner and Gibson, 1983; Fig. 5).

The Lower Permian fluvioglacial Paterson Formation is the most widespread sedimentary unit of the Canning Basin on YARRIE, but is concealed beneath Mesozoic and Cainozoic units in most areas.

Tectonic elements of the Canning Basin on YARRIE include parts of the Samphire Graben, Wallal Platform, and Waukarlycarly Embayment that overlie a Paterson Orogen basement (Figs 5 and 6e). In contrast, the Wallal and Carawine Embayments overlie a Pilbara Craton basement (Hocking et al., 1994; Figs 5 and 6e). The newly named Carawine Embayment (this publication) is primarily interpreted as a glacial or ice-erosional feature carved in Pilbara Craton basement beneath a north-moving ice sheet (Playford, 2001).

The northwestern part of YARRIE is covered with a thin veneer of Mesozoic rocks overlying Pilbara Craton basement. This corresponds to the Lambert Shelf tectonic unit of the Northern Carnarvon Basin, a component of the Westralian Superbasin (Hocking et al., 1994; Figs 4 and 5). However, younger units of the Mesozoic succession (the Callawa and Parda Formations) also extend eastwards from the Lambert Shelf to disconformably or unconformably overlie the Lower Permian Paterson Formation of the Canning Basin succession (Fig. 6f).

Table 1. Summary of the geological history of YARRIE

Age (Ma)	*Geological events*
c. 3655–3576	Formation of older crust in EPGGT[a]; felsic plutonism, tonalite, granodiorite; Warrawagine Granitoid Complex
<3576	Deformation and metamorphism produced banded tonalite gneiss; preserved as xenoliths and remnants in foliated plutons of the Warrawagine Granitoid Complex
c. 3471–3320	Cyclic eruption and deposition of subaqueous ultramafic, mafic, and felsic volcanic and sedimentary rocks (greenstones) of the Warrawoona Group with concomitant mafic and ultramafic sills constitute the Marble Bar and Yarrie greenstone belts: intruded by synvolcanic tonalite–trondhjemite–granodiorite (TTG) sills and plutons (>3438 Ma); Warrawagine and Muccan Granitoid Complexes; progressive deformation accompanied by greenschist facies regional metamorphism; D_1
c. 3315–3300	Widespread intrusive felsic plutonism; monzogranite, granodiorite, tonalite, trondhjemite and syenogranite; major period of inflation in the Muccan, Warrawagine and Mount Edgar Granitoid Complexes; hornblende-hornfels contact metamorphism
<3300	Uplift and erosion; progressive unroofing of granitoid complexes with removal of greenstone belt cover; D_2
c. 3252–3242	Renewed felsic plutonism: monzogranite, granodiorite and tonalite plutons in the Muccan, Mount Edgar, and Warrawagine Granitoid Complexes; D_3
<3235	Deposition of Gorge Creek Group; epiclastic, chemical, and mafic volcanic deposition under shallow- to moderate-depth marine shelf or basin conditions; Shay Gap greenstone belt and Coppin Gap Syncline; intermittent deformation, uplift and erosion producing local unconformities; low greenschist-facies metamorphism; D_4
<3048	Deposition of epiclastic and volcaniclastic De Grey Group; Shay Gap greenstone belt; initially under shallow-marine shelf conditions; stromatolites; later under prograding high-energy fluvial conditions; moderate deformation with very low grade metamorphism; uplift and erosion; D_5
?c. 2925	Emplacement of the mafic layered Shay Intrusion along the disconformable contact between the Gorge Creek and De Grey Groups; uplift and erosion
c. 2775–2763	Extensional faulting; intrusion of Black Range Dolerite Suite (c. 2772 Ma); deposition of Mount Roe Basalt, basal Fortescue Group of the Hamersley Basin on eroded and weathered EPGGT; mild tectonism and erosion
c. 2764–2756	Deposition of epiclastic and volcaniclastic Hardey Formation; alkali felsic volcanism and subvolcanic sills in the Bamboo Creek and Koongaling Volcanic Members; consanguineous genesis and emplacement of subvolcanic, alkaline (A_2-type) Gregory Granitic Complex in the Gregory Range Inlier; the active extensional regime may have led to (?)rifting along the eastern margin of the EPGGT; erosion
c. 2741	Fissure eruption of mostly subaerial basalts and andesite, local stromatolitic carbonate and volcaniclastic lacustrine deposits of the Kylena Formation
c. 2719	Deposition of coastal, near-shore marine and lacustrine volcaniclastic and volcanogenic sedimentary rocks of the Mingah Tuff Member and overlying carbonate (stromatolitic), epiclastic, and volcaniclastic Meentheena Carbonate Member of the Tumbiana Formation
c. 2717	Fissure eruption and deposition of basalts and minor volcaniclastic rocks of the Maddina Formation; hiatus
c. 2684	Deposition of nearshore epiclastic, chemical, and volcaniclastic sedimentary rocks of the Jeerinah Formation; top of Fortescue Group; felsic intrusive and intermediate/ mafic pyroclastic volcanic and volcaniclastic rocks prominent in the Gregory Range Inlier; erosion
c. 2741–2629	Intrusion of consanguineous mafic sills throughout the Fortescue Group
c. 2541	Deposition of shallow-water shelf Carawine Dolomite, Hamersley Group

Table 1. (continued)

Age (Ma)	*Geological events*
c. 2775–2500	Fortescue and Hamersley Groups broadly folded and faulted by continual greenstone basement sag between granitoid complexes in the southwest of YARRIE; (?)extensional rift faulting (listric faults) in the east; very low grade greenschist-facies metamorphism; D_6
<2400	Uplift, erosion, and karstification of Carawine Dolomite; deposition of (Palaeoproterozoic)Pinjian Chert Breccia
<1800	Intrusion of numerous hornblende-phyric trachyandesite (lamprophyric) dykes and hornblende-rich monzogranite to microsyenite plutons; in EPGGT and Fortescue Group
c. 1290	Maximum possible age for deposition of sedimentary Throssell Group in the (Mesoproterozoic) strike-slip Yeneena Basin; a component of the Paterson Orogen, lying east of the EPGGT and probably part or marginal to North Australian Craton
c. 1070–678 Ma (Mesoproterozoic to Neoproterozoic)	Deposition of slightly younger sedimentary Lamil Group in Yeneena Basin
c. 1200—820 (Mesoproterozoic to Neoproterozoic)	Miles Orogeny (Proterozoic $D_{3–4}$), strong west to southwest directed transpressional deformation; sinistral strike-slip movement recorded in Fortescue and Hamersley Group rocks along margin of Pilbara Craton; low to moderate greenschist-facies metamorphism; uplift of Gregory Granitic Complex (c. 1226–1194 Ma) along steep reverse faults; transpressional regime attributed to collision of the North Australian Craton with the West Australian Craton; “Rodinia” development (Pangea C); uplift and erosion
<820 (Neoproterozoic)	Deposition of the sedimentary Tarcunyah Group in the northwest extension of the Officer Basin; unconformable on, and sourced from, the Fortescue and Hamersley Group rocks of the Hamersley Basin component of the Pilbara Craton on YARRIE; included in Paterson Orogen: deposition of epiclastic and volcaniclastic Eel Creek Formation; unconformable and sourced from the EPGGT of the Pilbara Craton; deposited in an embayment extending west from the northwest-trending Officer Basin; intruded by thick dolerite sills
c. 775 (Neoproterozoic)	East-northeasterly to northeasterly trending mafic dykes in EPGGT; Mundine Well Suite
c. 540 (Neoproterozoic)	Paterson Orogeny (Proterozoic D_6) reactivated west- to southwest-directed folds and transpressional faults, moderate to recumbent folds in Tarcunyah Group; the dextral strike-slip and steep reverse Vines Fault separates the older Throssell Group from the Tarcunyah Group; Paterson Orogen; mild folding and brittle faulting in Eel Creek Formation; Paterson Orogeny attributed to intracratonic deformation associated with the breakup of ‘Rodinia’; uplift and erosion
c. 490–471[(b)] (Lower Ordovician)	Developing Canning Basin (multiple-phase pericratonic basin); extensional regime producing half-grabens in northeast YARRIE, deposition of marine shales, interpreted to be subsurface in Samphire Graben; uplift and erosion
c. 288–280	Non-marine and glacial marine Grant Group (no surface exposure on YARRIE) deposited in Wallal Embayment, on the Wallal Platform, and in the Samphire Graben; fluvioglacial Paterson Formation restricted to eroded palaeoglacial valleys and embayments on the Pilbara Craton, e.g. Carawine Embayment, and to the Waukarlycarly Embayment and adjacent Wallal Platform on Paterson Orogen basement; the Pilbara Craton subjected to strong erosion under ice-cap conditions; post-glacial fluvial and shallow-water marine Poole Sandstone deposited in the Samphire Graben; uplift and erosion
189.6–154.1 (Jurassic)	Deposition of continental to shallow-marine Wallal Sandstone on the Lambert Shelf situated over EPGGT basement, and the Canning Basin; shallow-marine transression of Jarlemai siltstone deposited on Lambert Shelf and Canning Basin; uplift and erosion

Table 1. (continued)

Age (Ma)	*Geological events*
150.7–120.5 (Jurassic–Cretaceous)	Deposition of fluvial Callawa Formation on the Lambert Shelf, sourced from EPGGT and Hamersley Basin rocks, and Canning Basin, sourced from Hamersley Basin and Paterson Orogen rocks
120.5–98.9 (Cretaceous)	Transgression of shallow-marine Parda Formation deposited on Lambert Shelf and Canning Basin followed by fluvial deltaic Frezier Sandstone deposition in the Canning Basin; uplift and prolonged erosion
c. 95–20 (Late Cretaceous–Miocene)	Development of inland drainage systems, e.g. Percival and Wallal Palaeorivers; extensive duricrusted surfaces formed, widespread ferricrete (laterite), and silcrete; development of Hamersley Surface; moist temperate–tropical climate becomes increasingly dry towards the Pliocene
5–2 (Pliocene)	Increasing desiccation associated with continental climate deposition of lacustrine carbonate Oakover Formation; pedogenic calcrete development
<1 (Pleistocene–Holocene)	Continuing aridity, interspersed with wet and humid periods; palaeodrainage systems dried out; major unconsolidated dunefields of the Great Sandy Desert developed; erosion of older weathered surfaces in periods of higher rainfall; erosion has become the dominant process in recent times; active seismic events in southwest corner of YARRIE

NOTES: (a) East Pilbara Granite–Greenstone Terrane
(b) Veevers (2000)

ARCHAEAN ROCKS

PILBARA CRATON

Recent geological investigations (Williams, 1999a, 2000, 2001) have shown that YARRIE straddles a north-northwesterly trending tectonic contact between the Archaean Pilbara Craton (Trendall, 1995; Van Kranendonk et al., 2002) and the oldest elements of the Proterozoic Paterson Orogen (Williams and Myers, 1990; Myers et al., 1996; Bagas, 2000). Geophysical data, as well as exploration and stratigraphic drilling information associated with the search for minerals, oil, and water, show that Archaean basement underlies the western two-thirds of YARRIE, whereas the remaining eastern one-third of the map sheet is underlain by Proterozoic basement (Fig. 6c). However, exposed Archaean Pilbara Craton is restricted to the southwest quarter and to the Gregory Range Inlier in the southeast quarter of YARRIE. Apart from a small area of unconformably overlying Neoproterozoic Eel Creek Formation north of Yarrie iron mines, over half of the area of the Pilbara Craton on YARRIE is covered by a thin veneer of Phanerozoic sedimentary rocks. These are the Mesozoic rocks of the Northern Carnarvon Basin in the northwest quarter of YARRIE, and the Permian fluvioglacial rocks of the Canning Basin and Oakover–Nullagine river valley area in the central-south areas (Figs 4,5,6e and f).

The Pilbara Craton has two major components; an assemblage of pre-2800 Ma granite–greenstone terranes and the unconformably overlying Mount Bruce Supergroup of the Hamersley Basin (Trendall, 1990b). Elements of both are exposed on YARRIE. Of the five pre-2800 Ma terranes (Van Kranendonk, 2001, 2002), only the oldest, and the original nucleus of the Pilbara Craton, the East Pilbara Granite–Greenstone Terrane (EPGGT), is present on YARRIE (Figs 5,6a and b).

Pilbara Supergroup

Exposures of Pilbara Supergroup rocks in the EPGGT are almost entirely restricted to the southwest quarter of YARRIE. The Pilbara Supergroup is unconformably overlain by the Neoarchaean Mount Bruce Supergroup of the Hamersley Basin. The latter occupies the Oakover Syncline along the southern margin and the Gregory Range Inlier in the southeast quarter of YARRIE (Fig. 4). To the north and northeast, the Pilbara Supergroup exposure is delimited by the unconformably overlying Neoproterozoic Eel Creek Formation and Phanerozoic rocks of the Northern Carnarvon and Canning Basins (Fig. 5).

The broad, dichotomic composition of the EPGGT, comprising ovoid granitoid–gneiss complexes surrounded by metamorphosed, tightly folded, moderately to steeply dipping, curvilinear, volcano-sedimentary rock successions or greenstone belts, is also found on YARRIE. Portions of the Mount Edgar, Muccan, and Warrawagine Granitoid Complexes intrude, or are in tectonic contact with, the Marble Bar and Yarrie greenstone belts (Williams, 1999a). Younger greenstones in the Shay Gap greenstone belt and in the core of the Coppin Gap Syncline unconformably overlie Warrawoona Group rocks of the Marble Bar and Yarrie greenstone belts and the Muccan and Warrawagine Granitoid Complexes (Dawes et al., 1995a,b; Williams, 1999a). The granitoid complexes on YARRIE contain components that range in age from c. 3655 to c. 3241 Ma, whereas the greenstone belts range from c. 3471 to less than 3048 Ma (Tables 2 and 3).

All the greenstone belts of the Pilbara Craton have been collectively assigned to the Pilbara Supergroup (Hickman, 1983). In the EPGGT, the Pilbara Supergroup now comprises the Coonterunah (c. 3.5–3.50 Ga), Warrawoona (c. 3.49–3.31 Ga), Sulphur Springs (c. 3.26–3.24 Ga), Gorge Creek (c. 3.24–2.94 Ga), and De Grey (c. 2.94 Ga) Groups (Van Kranendonk, 2000; Van Kranendonk et al., 2002). Lithostratigraphic components of the Warrawoona, Gorge Creek, and De Grey Groups have been identified on YARRIE (Williams, 1999a).

Warrawoona Group

On YARRIE, Warrawoona Group rocks (Lipple, 1975) are restricted to the Marble Bar greenstone belt (Hickman and Lipple, 1975, 1978), lying between the Mount Edgar and Muccan Granitoid Complexes, and the Yarrie greenstone belt (Williams, 1999a) that separates the Muccan Granitoid Complex from the Warrawagine Granitoid Complex (Fig. 5). Recently, it was shown that the Doolena Gap greenstone belt extends onto YARRIE from the adjoining COONGAN 1:100 000 sheet along the southern margin of the Muccan Granitoid Complex (Van Kranendonk et al., 2001).

On the YARRIE 1:250 000 sheet (Williams, 2002), the Warrawoona Group is described in terms of the lithostratigraphic subdivisions previously published by Hickman (1983, 1990) and adapted for the already published MUCCAN 1:100 000 sheet. This format recognizes two subgroups of mainly basaltic and ultramafic rocks in the Warrawoona Group: the older Talga Talga Subgroup, and the younger Salgash Subgroup. The subgroups are separated by the felsic Duffer Formation (Hickman, 1983).

Recently, several detailed reviews of this lithostratigraphic scheme in Warrawoona Group rocks adjacent to YARRIE have been undertaken (Van Kranendonk et al., 2001, 2002; Bagas and Van Kranendonk, in prep.). New proposals include the division of the Warrawoona Group into three subgroups, the Talga Talga (oldest), Salgash, and Kelly Subgroups, the inclusion of the Duffer Formation with the Talga Talga Subgroup, and the removal of the

Table 2. Summary of SHRIMP and conventional U–Pb zircon geochronological data for YARRIE

Age (Ma)	Lithology, formation	MGA Coordinates Easting	MGA Coordinates Northing	Sample no.
3655 ± 6				
3637 ± 12	Zircon populations from banded tonalite gneiss; a xenolith in the Warrawagine Granitoid Complex	246936	7696862	142870[3]
3595 ± 4				
3576 ± 6				
3471 ± 5[1]	Metadacite; Duffer Formation, Warrawoona Group	205737	7682362	100512[5]
3470 ± 4	Banded gneiss; Muccan Granitoid Complex	199237	7694962	142828[4]
3458 ± 2[1]	Metarhyolite; Panorama Formation; Warrawoona Group	199837	7686762	100511[6]
3454 ± 1[1]	Metarhyolite; Panorama Formation; Warrawoona Group	206237	7684262	94770[5]
3445 ± 2	Metarhyolite; Panorama Formation; Warrawoona Group	196297	7686301	unknown[7]
3443 ± 6	Granodiorite; Muccan Granitoid Complex	191037	7736262	124755[10]
3438 ± 4	Granodiorite, Muccan Granitoid Complex	216837	7722562	143807[4]
3410 ± 7	Banded tonalite gneiss; Warrawagine Granitoid Complex	246936	7696862	142870[3]
3403 ± 10[2]	Quartzite; Nimingarra Iron Formation; Gorge Creek Group	208236	7702562	143995[4]
3395 ± 15[2]	Quartzite; Cundaline Formation; Gorge Creek Group	205636	7726662	143996[4]
3362 ± 13[2]	Quartzite; Nimingarra Iron Formation. Gorge Creek Group	197037	7688162	143994[4]
3314 ± 13	Granodiorite; Coppin Gap Granodiorite; Mount Edgar Granitoid Complex	196837	7677862	LTU5577[8]
3313 ± 6	Monzogranite; Warrawagine Granitoid Complex	231337	7699662	143809[4]
3313 ± 3	Monzogranite; Muccan Granitoid Complex	195939	7725862	143803[4]
3303 ± 2	Monzogranite; Muccan Granitoid Complex	188737	7705162	143806[4]
3303 ± 5	Granodiorite; Warrawagine Granitoid Complex	250836	7687662	142871[3]
3252 ± 3	Monzogranite; Muccan Granitoid Complex	191636	7718762	143805[4]
3244 ± 3	Monzogranite; Wolline Monzogranite; Muccan Granitoid Complex	199537	7697862	143810[4]
3244 ± 3	Granodiorite; Warrawagine Granitoid Complex	246936	7696662	142869[3]
3242 ± 4	Granodiorite; Warrawagine Granitoid Complex	242536	7695162	142874[3]
3048 ± 19[2]	Dacite tuff; Cattle Well Formation; De Grey Group	209027	7628862	142867[3]
2758 ± 4	Quartz–feldspar porphyry dyke; intruding Warrawagine Granite Complex	241837	7710062	142875[3]
2757 ± 7	Granodiorite (?xenocrysts); intruding Mount Edgar Granitoid Complex	202580	7678820	142825[4]
2756 ± 8	Rhyolite porphyry; Bamboo Creek Member; Hardey Formation	216937	7680362	94761[9]

NOTES:
1. Conventional zircon U–Pb dating
2. Maximum depositional age of volcaniclastic rock
3. Nelson (1999)
4. Nelson (1998)
5. Thorpe et al. (1992a,b)
6. Thorpe, R. I., (written comm., 1991)
7. Van Kranendonk et al. (2001) (samples collected by J. Wybrans and W. Nijman, unpublished data)
8. Williams and Collins (1990)
9. Arndt et al. (1991)
10. Nelson (1996)

Euro Basalt from the Salgash Subgroup and its placement in the newly defined Kelly Subgroup (Bagas, 2003).

The Warrawoona Group in the Marble Bar greenstone belt on YARRIE comprises the Mount Ada Basalt, Duffer Formation, Apex Basalt, Panorama Formation, and Euro Basalt together with three layered bodies, the Strutton, Nob Well, and Gap Intrusions. The mafic and ultramafic rocks of the Yarrie greenstone belt are similar to the mafic–ultramafic rocks of the Apex and Euro Basalts in the Marble Bar greenstone belt that lies to the south of the Coppin Gap Syncline (Fig. 5), although the rocks of the Yarrie greenstone belt have a higher metamorphic grade.

Table 3. Additional geochronological data for YARRIE

Age (Ma)	*Lithology, formation*	*Method*	*MGA coordinates* *Easting*	*Northing*	*Sample no.*
3430					Pb455[1]
3416	Galena, in quartz veins within	Pb–Pb isotopic	209737	7683562	Pb455[2]
3414 ± 40	the Bamboo Creek Shear Zone	model age			PP1[3]
3412 ± 40					K1[3]
3376 ± 10					PP2[3]
3336 ± 1	Galena in quartz vein, Apex Basalt; Warrawoona Group		200437	7685662	42193[1,4]
3317 ± 1	Rhyolitic quartz–feldspar porphyry intrudes Euro Basalt	Conventional titanite U–Pb	199237	7687462	103279[5]
3234 ± 117	Dacite porphyry intrudes Euro Basalt	Rb–Sr whole	199237	7687462	various[6]
3204 ± 45	Granodiorite, Coppin Gap Granodiorite; Mount Edgar Granitoid Complex	rock isochron	various localities in Coppin Gap Granodiorite		LTU Nos[7] 5570, 5571, 5573, 5574, 5575, 5578
1598 ± 32	Granodiorite; intruding Mount Edgar	K–Ar hornblende	202580	7678820	142825[8]
1730 ± 9	Granitoid Complex	$^{46}Ar/^{39}Ar$ hornblende	202580	7678820	142825[9]

NOTES:
1. Richards (1983)
2. Thorpe et al. (1992a)
3. Zegers (1996)
4. Davy and Hickman (1983)
5. Thorpe, R. I. (written comm., 1992)
6. de Laeter and Martyn (1986)
7. Collins and Gray (1990)
8. Nelson (2002)
9. Nelson (in prep.)

The lithostratigraphy of the Warrawoona Group is summarized in Table 4.

Mount Ada Basalt (AWm, AWmc, AWmu)

The Mount Ada Basalt (Hickman, 1977; Williams, 1999a) is restricted to the southwest corner of YARRIE, south of Eight Mile Creek, where it dips steeply to the north-northeast. The formation comprises mainly blue-grey to dark green-grey, fine-grained, actinolite-rich metabasalt (*AWm*) that is characterized by fine-grained amphibolite adjacent to the Coppin Gap Granodiorite. Some thin-bedded, blue-grey to green-grey metachert (*AWmc*) and serpentine–talc–chlorite rock (*AWmu*) are exposed 2 km west of the abandoned 3 Mile Well.

The east-southeasterly trending metabasalts are discordantly intruded by the Coppin Gap Granodiorite (c. 3314 Ma; Williams and Collins, 1990) to the east and by the Munganbrina Monzogranite in the southwest corner. Both granitoid–basalt contacts are marked by cross-cutting pegmatite and aplite dykes, and a distinct increase in metamorphic grade from greenschist to upper greenschist – lower amphibole facies (?hornblende hornfels), attributed to contact metamorphism (Williams, 1999a).

The Mount Ada Basalt is the oldest component of the greenstone belts on YARRIE. Recent studies have shown that the upper part of this basalt pile is interlayered with the overlying Duffer Formation (McNaughton et al., 1993; Van Kranendonk et al., 2001). An interlayered felsic lapilli tuff, from the basal part of the Mount Ada Basalt west of YARRIE yielded an age of 3469 ± 3 Ma (Nelson, 1999, p. 160–162; GSWA Sample 185001), and the overlying Duffer Formation on YARRIE was been dated at 3471 ± 5 Ma (Thorpe et al., 1992a,b).

Table 4. Archaean lithostratigraphy of the Pilbara Supergroup, on YARRIE

Group	*Formation*	*Thickness (m)*	*Lithology and relationships*
De Grey	Cooragoora Formation	~2 000	Sandstone, polymictic conglomerate, siltstone, carbonaceous shale
	Cattle Well Formation	~2 500	Sandstone, siltstone, shale, wacke, carbonate, stromatolitic, carbonate, chert, resedimented volcaniclastic rocks, dacitic, lithic, and crystal-lithic tuffaceous rocks Age 3048 ± 19 Ma (maximum age of deposition)
~ ~ ~ *disconformity to low-angle unconformity* ~ ~ ~			
Gorge Creek	Coonieena Basalt	~1 500	Pillowed and massive tholeiitic basalt, basaltic andesite, high-Mg basalt, mafic pisolitic tuff
~ ~ ~ *local unconformity* ~ ~ ~			
	Cundaline Formation	0–1 000	Shale, siltstone, sandstone, lithic wacke, pebble conglomerate
~ ~ ~ *local unconformity* ~ ~ ~			
	Nimingarra Iron Formation	400–1 000	BIF, jaspilite, banded chert, chert, basal conglomerate, sandstone, shale
~ ~ ~ *angular unconformity* ~ ~ ~			
Warrawoona	Euro Basalt	~3 000	Pillowed and massive tholeiitic and high-Mg basalt, peridotitic komatiite, serpentinized peridotite, banded chert, fuchsitic quartzite, minor pelitic rocks
~ ~ ~ *disconformity* ~ ~ ~			
	Panorama Formation	≤800	Flow-banded, fine-grained and porphyritic rhyolite, banded chert, black chert (hydrothermal veins). Age 3454 ± 1 Ma; 3458 ± 2 Ma
	Apex Basalt	~2 000	Pillowed, massive and amygdaloidal basalt and ocelli high-Mg basalt, some basaltic komatiite, thin chert
~ ~ ~ *disconformity* ~ ~ ~			
	Duffer Formation	~3 500	Fine-grained to porphyritic dacitic volcanic rocks, agglomerate tuff. Age 3471 ± 5 Ma
	Mount Ada Basalt	~2 000	Massive tholeiitic basalt, minor serpentinite, chert

Isotopic data from MARBLE BAR 1:100 000 sheet summarized by Van Kranendonk et al. (2002) confirm an overlap in the age range of the two formations.

Duffer Formation (AWd, AWda)

North to north-northeasterly dipping Duffer Formation (Lipple, 1975; Williams, 1999a) overlies Mount Ada Basalt west of No. 2 Well along the southwest margin of YARRIE. A second smaller exposure rims and extends south from a small ovoid, intrusive apophysis, the 'Aerodrome Pluton' (Williams and Hickman, 2000) of the Coppin Gap Granodiorite, 6 km southwest of the Bamboo Creek Mining Centre. In both areas the Duffer Formation is truncated and contact metamorphosed by the Coppin Gap Granodiorite.

The Duffer Formation consists of metamorphosed dacite, rhyodacite, and rhyolite lava, tuff, and agglomerate (*AWd*) with subordinate fine-grained amphibolite units after basalt and dolerite (*AWda*) towards the base of the succession in the southwest exposures. The latter may be related to the underlying Mount Ada Basalt or to overlying basalts of the Salgash Subgroup.

The dacite, rhyodacite, and andesite lavas are mostly light-grey weathering, blue-grey, fine-grained, and porphyritic varieties (Hickman, 1983). Plagioclase is the dominant phenocryst mineral. Crystal tuffs with lithic fragments, agglomerate, poorly bedded volcaniclastic breccia, and turbiditic tuff-breccia have been recorded. Plagioclase, together with quartz, is the principal mineral. Brownish-green biotite, green hornblende, epidote, and chlorite are abundant, sericite, K-feldspar (microcline), and carbonate are minor constituents. DiMarco and Lowe (1989) carried out sedimentological studies on the Duffer Formation that indicated subaqueous volcaniclastic aprons flanking volcanic centres.

A porphyritic metadacite collected from near the Bamboo Creek airstrip yielded a conventional method zircon U–Pb age of 3471 ± 5 Ma (Thorpe et al., 1992a,b; see Table 2).

Mafic dykes (AW(oh))

A characteristic feature of the Duffer Formation is the number of cross-cutting dykes of hornblende–plagioclase schist (*AW(oh)*), presumably metamorphosed dolerite dykes. These are particularly common around the Aerodrome Pluton, which they predate. These dykes cut the Duffer Formation at a high angle but do not seem to penetrate the overlying Apex Basalt. They have been interpreted to be possible feeder dykes for the overlying and younger Apex Basalt (Williams, 1999a).

Apex Basalt (AWa, AWau, AWac, AWaf)

The Apex Basalt (Hickman, 1977; Williams, 1999a) is exposed in a continuous, arcuate, steeply dipping to overturned, north- and east-younging belt over 25 km long in the southwest corner of YARRIE, where it disconformably overlies the Duffer Formation. The Towers Formation that separates the Duffer Formation from the Apex Basalt on adjacent MARBLE BAR (Hickman, 1977, 1983) is absent on YARRIE. The Apex Basalt is discordantly intruded and contact metamorphosed by the Coppin Gap and Mullugunya Granodiorites of the Mount Edgar Granitoid Complex (Williams, 1999a).

The Apex Basalt is predominantly pillowed tholeiitic and high-Mg metabasalt (*AWa*) with some massive flows. The pillowed tholeiitic basalts are fine grained or amygdaloidal with the amygdales filled with quartz, chalcedony or carbonate. These rocks are commonly actinolite–plagioclase–quartz assemblages with minor chlorite and epidote. All pillowed basalts record a consistent younging to the north and east. The high-Mg basalts commonly have ocelli texture (Ashwal, 1991) and consist of tremolite–chlorite and minor quartz assemblages. Some rocks appear to be komatiitic basalts exhibiting tremolite replacement of pyroxene spinifex textures. Thin tabular bands of tremolite–serpentine–talc–carbonate rock (*AWau*) are probably komatiitic lavas.

The Apex Basalt contains a number of interlayered, thin (1–5 m) beds of blue chert, grey and black chert, black and white banded chert, and red and white ferruginous chert (*AWac*). Thin, epiclastic, green (fuchsitic) quartzite is interlayered with the metabasalts. Near Five Mile Hill, a cream-white, fine-grained metarhyolite unit (*AWaf*) lies near the base of the Apex Basalt, 2 km southwest of Gap Bore.

Regional metamorphism for the Apex Basalt is low grade except adjacent to the Coppin Gap and Mullugunya Granodiorites (*AGEml*), where it reaches upper greenschist – low amphibolite facies (?hornblende hornfels).

The Apex Basalt is intruded by the chromite-bearing layered ultramafic Nobb Well Intrusion (*AaWu*) at the southern end of the belt, the large layered ultramafic Gap Intrusion (*AaGx*, *AaGus*) on the western margin of YARRIE, and the discordant layered mafic ultramafic Strutton Intrusion (*AaT*), also near the western margin of the map sheet (Williams, 1999a).

Panorama Formation (AWp, AWpc)

The Panorama Formation (Lipple, 1975) is restricted to the southwest corner of YARRIE (Williams, 1999). Recent studies (Nijman et al., 1999) have confirmed that the Panorama Formation emerges from the South Muccan Shear Zone (SMSZ) (Zegers, 1996; Fig. 5) on the western margin of YARRIE. The formation reaches a maximum thickness of around 800 m south of Kittys Gap, but rapidly thins to less than 100 m east of the Coppin Gap road. Farther southeast, the formation becomes a series of discontinuous units separating the Apex Basalt from the overlying Euro Basalt.

The felsic volcanic rocks are partly silicified, fine-grained to porphyritic rhyolite flows and tuffaceous rocks (*AWp*). Phenocrysts are quartz and altered K- and Na-feldspar. South and southeast of Kittys Gap the felsic volcanic rocks are capped by thin-bedded, buff, cream, and white chert, banded chert, and interlayered felsic tuffs (*AWpc*). The felsic tuffs form upward-fining sequences and exhibit cross-bedding that indicates way-up to the north. Biogenic laminations, and some small stromatolites have recently been recognized in some of the cherty horizons (Nijman et al., 1999). Discordant black chert veins and dykes, together with silicified breccias, point to hydrothermal fluid activity in these upper units that is attributed to the felsic volcanism (Nijman et al., 1999; Van Kranendonk et al., 2001).

Two samples from these lenticular bodies have yielded U–Pb zircon ages of 3454 ± 1 and 3458 ± 2 Ma (Thorpe et al., 1992a,b). A 3445 ± 2 Ma age has recently been obtained from felsic volcanic rocks of the Panorama Formation south of Kittys Gap (Van Kranendonk et al., 2001).

Euro Basalt (AWe, AWec, AWea, AWesq, AWeu, AWes)

The Euro Basalt (Hickman 1977; Williams, 1999a) is exposed in an arcuate belt that extends from west of Kittys Gap, where it is unconformably overlain by the Nimingarra Iron Formation of the Gorge Creek Group, to a point 25 km to the southeast, where it is intruded by the Chimingadji Trondhjemite. The Euro Basalt disconformably overlies the Panorama

Formation, or where this is absent, the Apex Basalt. Along the northeast margin it is unconformably overlain by the Neoarchaean Fortescue Group (Williams, 1999a).

Until recently, the Euro Basalt was interpreted to be the uppermost formation of the Salgash Subgroup of the Warrawoona Group as shown on the accompanying YARRIE 1:250 000 sheet (Hickman 1983; Williams, 2002). Recent revision of the Warrawoona Group now places the Euro Basalt at the base of the newly defined Kelly Subgroup of the Warrawoona Group (Bagas, 2003).

The Euro Basalt consists predominantly of pillowed to massive tholeiitic and high-Mg basalts intercalated with thin-bedded coloured and banded cherts (*AWe*). Steeply dipping but well-preserved pillows consistently indicate way-up to the north and east (Williams, 1999a; Williams and Hickman, 2000). The Euro Basalt on YARRIE is about 2000 m thick, significantly less than the thickness of the Euro Basalt elsewhere; for example, up to 9.4 km thick in the Panorama greenstone belt on the NORTH SHAW 1:100 000 sheet (Van Kranendonk, 2000). The Euro Basalt is lithologically similar to the underlying Apex Basalt on YARRIE, with the exception that the Euro Basalt has a marginally higher proportion of ultramafic and metasedimentary rocks.

Metamorphosed tholeiitic basalts consist of actinolite–plagioclase(–chlorite–quartz) assemblages, whereas metamorphosed high-Mg basalts, which commonly have ocelli texture, consist of tremolite–chlorite(–quartz–carbonate) assemblages. Subordinate komatiitic basalt is characterized by pyroxene (commonly amphibole pseudomorphed) spinifex texture.

The Euro Basalt is host to the slightly oblique-trending Bamboo Creek Shear Zone (BCSZ), (Zegers, 1996; Fig. 5). The shear zone comprises talc–chlorite mylonite schist enclosing undeformed pods or boudins of carbonate- and silica-altered spinifex-textured (after olivine) komatiite (*AWeu*). Westwards from Coppin Gap Creek the shear zone contains serpentinite and sheared tremolite–chlorite–serpentine–carbonate rocks after peridotite and komatiite (*AWes*).

The Euro Basalt south and southwest of the BCSZ contains intercalated metamorphosed, thin-bedded, black and white banded, ferruginous and coloured cherts (*AWec*). South of the Bamboo Creek Mining Centre, and west of the BCSZ, a 150 m-thick unit of metamorphosed, thin-bedded sandstone, tuffaceous sandstone, siltstone, and shale (*AWea*) is obliquely truncated, at a low angle, by the BCSZ. The Euro Basalt, north and east of the BCSZ, contains a higher proportion of chemical and epiclastic rocks. Interbedded fuchsitic quartzite, grey quartzite, banded chert, and ultramafic schist (*AWesq*) immediately overlie the ultramafic mylonitic schists of the BCSZ in the Bamboo Creek Mining Centre area.

The BCSZ, just west of Coppin Gap, is intruded by a fine-grained quartz–feldspar porphyry (*Apd*) that is dated at 3317 ± 1 Ma (Thorpe, R. I., 1992, written comm.; see Table 3). The BCSZ also hosts a number of gold mines (see **Economic geology**). Lead–lead isotopic dating of galena, associated with the gold mineralization, has yielded a c. 3400 Ma model age (Richards, 1983; Thorpe et al., 1992a; Zegers, 1996; see Table 3).

Unassigned Warrawoona Group (AW(uc), AW(ut), AW(us), AW(oa), AW(ba), AW(bo))

Unassigned units of the Warrawoona Group are restricted to the Yarrie greenstone belt. This belt is discontinuously exposed in the southwest corner of YARRIE (Williams, 1999a), and extends for 38 km in a north-northeasterly direction from east of Coppin Gap to the Kennedy Gap area. The Yarrie greenstone belt is truncated by the South Muccan Shear

Zone (SMSZ), (Zegers, 1996) at the southern end and is unconformably overlain by the Gorge Creek Group and Neoproterozoic Eel Creek Formation at the northern end (Williams, 1999a). The belt separates the Muccan Granitoid Complex in the west from the Warrawagine Granitoid Complex to the east.

Although the layered succession comprising the Yarrie greenstone belt has not been formalized, the schistose mafic and ultramafic assemblage resembles lithologies found and described from the Warrawoona Group rocks in the Marble Bar greenstone belt. The Yarrie greenstone belt is marked by an overall higher metamorphic grade that reaches lower amphibolite facies. The higher grade is attributed to the proximity and intrusion of granitoid rocks from the Muccan and Warrawagine Granitoid Complexes. Granodiorite, quartz diorite, and tonalite from the Muccan Granitoid Complex (*AgMgt*) intrude the Yarrie greenstone belt north of the Yarrie Village. A tonalite has yielded a SHRIMP U–Pb zircon age of 3438 ± 4 Ma (Nelson, 1998, p. 84–8, GSWA Sample 143807; see Table 2). This would suggest that the mafic and ultramafic rocks in the northern part of the Yarrie greenstone belt are older than the Euro basalt and may be equivalent to the Apex Basalt.

Lithologies in the northern part of the Yarrie greenstone belt include fine- to medium-grained amphibolites and mafic hornfels (*AW*(*ba*)) with hornblende–plagioclase–quartz assemblages. In places, these show metamorphic retrogression to actinolite–epidote–carbonate–sericite assemblages. Minor ultramafic schists with tremolite–serpentine–chlorite(–talc) assemblages (*AW(ut)*), and large serpentinite bodies (*AW(us)*), are also present.

South of the De Grey River, the Yarrie greenstone belt comprises mostly schistose high-Mg basalt with ocelli texture and pillow structures. These are chlorite–tremolite(–quartz) assemblages (*AW*(*bo*)). They are interlayered with carbonate–tremolite–chlorite rocks (*AW*(*uc*)), tremolite–serpentine–chlorite(–talc) schist (*AW*(*ut*)) and thin-bedded banded chert. These rocks are host to gold and copper mineralization at the Battler and Friendly Stranger mines (see **Economic geology**). The host rocks for the gold mineralization share many mineralogical and lithological characteristics with the Euro Basalt that hosts the gold mineralization in the Bamboo Creek Mining Centre area, 20 km to the south. An anorthositic metagabbro (*AW*(*oa*)) intrudes the Yarrie greenstone belt 3 km northeast of Coppin Gap.

Between the southern margin of the Muccan Granitoid Complex and the Gorge Creek Group rocks in the Coppin Gap Syncline (Williams, 1999a) there is a thin succession of mafic and ultramafic schists and amphibolites entrapped within the SMSZ. These were initially assigned to the Yarrie greenstone belt (Williams, 1999a; Fig. 5). More recent work has reassigned these fine-grained amphibolites (*AW*(*ba*)), serpentinite (*AW(us)*), and ultramafic schists (*AW*(*ut*), *AW*(*uc*)) to the Doolena Gap greenstone belt (Van Kranendonk et al., 2001; Fig. 5).

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

Scattered through some units of the large granitoid complexes are numerous mafic and ultramafic xenoliths, rafts, and pendants. Such bodies may be found singly or in clusters. Some xenoliths form linear chains interpreted as disrupted, metamorphosed, and deformed mafic dykes. The diagnostic character of all these mafic and ultramafic bodies is that they cannot be directly related to the main greenstone belts. The bulk of this material is found in xenolith-rich, foliated and gneissic granitoid rocks (*AgEchx*, *AgEcox*, *AgMnx*, *AgWnx*).

Extensive zones of disrupted mafic and ultramafic material, particularly north of Wolline Well in the Muccan Granitoid Complex, and south and southwest of Callawa Homestead in the Warrawagine Granitoid Complex, may represent root zones of eroded greenstone belts (Hickman, 1983). Other xenolith-rich zones are related to contact zones of intrusive plutons (Williams, 1999a).

Xenolith lithologies include hornblende–plagioclase schist after basalt and dolerite (*Aba*), carbonate–tremolite–chlorite–talc schist (*Auc*), serpentinite after peridotite (*Aus*), tremolite–serpentine–chlorite(–talc) schist (*Aut*), and metapyroxenite (*Aux*).

Mafic and ultramafic intrusions in the Marble Bar greenstone belt (AaT, AaWu, AaGus, AaGx)

The Warrawoona Group in the Marble Bar greenstone belt is intruded by three large layered bodies: the Strutton, Nobb Well, and Gap Intrusions (Williams, 1999a).

The Strutton Intrusion (*AaT*), which lies 1.5 km north of No. 2 Well, is a discordant, mainly mafic body obliquely cutting the Duffer Formation and overlying Apex Basalt. It comprises metagabbro overlying metapyroxenite and a thin serpentinized peridotite at the base (southern side).

The Nobb Well Intrusion (*AaWu*) lies 3 km northeast of Nobb Well and appears to be a conformable ultramafic body lying between the Duffer Formation and overlying Apex Basalt. This intrusion consists of a serpentine–tremolite–chlorite–talc–chromite assemblage after peridotite. The eastern side of the body is pyroxenitic. Small chromite pods have been located near the basal contact on the western side of the body (Baxter, 1978).

The Gap Intrusion lies 1.5 km west of Gap Well and is a large ultramafic body that can be traced over 8 km to the western boundary of YARRIE. The intrusion is a slightly discordant body within the Apex Basalt; the upper contact is faulted. The Gap Intrusion consists of a metapyroxenite (*AaGx*) on the northern side overlying a thick serpentinized peridotite (*AaGus*). On the western edge of YARRIE, the basal peridotite merges with a serpentinized dunite cumulate.

The Gap and Strutton Intrusions are discordantly cut by the Coppin Gap Granodiorite (3314 ± 13 Ma; Table 2), and the Nobb Well Intrusion by the Mullugunya Granodiorite (Williams, 1999a). All intrusions post-date the Duffer Formation (3471 ± 5 Ma; Table 2), and all have undergone greenschist-facies metamorphism.

Granitoid complexes

Granitoid complexes are the major component of the East Pilbara Granite–Greenstone Terrane on YARRIE, occupying around 80% by area. The remaining 20% is divided equally between the older Marble Bar, Doolena Gap, and Yarrie greenstone belts, and younger Shay Gap greenstone belt. The last belt unconformably overlies the Muccan and Warrawagine Granitoid Complexes and the older Marble Bar and Yarrie greenstone belts. The Marble Bar greenstone belt contains felsic volcanic rocks coeval with plutons in the granitoid complexes.

The morphology and lithotectonic relationships between the domical granitoid complexes and encompassing greenstone belts have been widely discussed in the literature (Hickman, 1983, 1984; Williams and Collins, 1990; Buick et al., 1995; Dawes et al., 1995a,b; Van Kranendonk, 1998; Barley and Pickard, 1999; Van Kranendonk et al., 2001, 2002). In general, earlier, more sodic tonalite, trondhjemite and granodiorite (TTG) components were emplaced as sheeted sill complexes in and beneath the Warrawoona Group rocks.

Granitoid plutons of age similar to that of the Duffer Formation (c. 3471 ± Ma; see Table 2) and Panorama Formation (c. 3458 Ma–3445 Ma; see Table 2) are found in the Muccan Granitoid Complex on YARRIE. Older granitoid components tend to be preserved more towards the margins of the complexes, pushed up and out towards the margins by successively younger and more potassic plutons emplaced in the cores of the complexes (Van Kranendonk et al., 2001, 2002). Geochronological data for the granitoid complexes are summarized in Table 2.

Parts of three granitoid complexes are exposed on YARRIE: the northern tip of the Mount Edgar Granitoid Complex, the eastern quarter of the Muccan Granitoid Complex, and the exposed southwestern half of the Warrawagine Granitoid Complex. A review of exploration and water drilling data, together with TMI imaging on the COORAGOORA and WARRAWAGINE 1:100 000 sheets (Williams, 2000, 2001), shows that the Muccan and Warrawagine Granitoid Complexes extend a considerable distance north and east from known exposures beneath the Gorge Creek Group, Eel Creek Formation, and Phanerozoic rocks of the Northern Carnarvon and Canning Basins (see Fig. 5).

Warrawagine Granitoid Complex (AgWtg, AgWmp, AgWmc, AgWgn, AgWnx)

The Warrawagine Granitoid Complex is exposed in the southwest quarter of YARRIE. The exposure is delimited in the west by an intrusive relationship with the Yarrie greenstone belt (Warrawoona Group) and unconformable contacts with the Shay Gap greenstone belt (Gorge Creek Group) and Fortescue Group. The arcuate southern margin is defined by the unconformably overlying Fortescue Group, the eastern margin by the fluvioglacial Paterson Formation of the Canning Basin, and the northern margin by a series of unconformities between the granitoids and overlying Gorge Creek Group, the Neoproterozoic Eel Creek Formation, and Mesozoic rocks of the Northern Carnarvon Basin. A small inlier of medium-grained monzogranite, just north of Mount Cecelia on the northern end of the Gregory Range Inlier, has been assigned to the Warrawagine Granitoid Complex.

The Warrawagine Granitoid Complex comprises a number of discrete younger plutons (*AgWtg*, *AgWmp*, *AgWmc*) hosted by poorly outcropping, older, mixed foliated to gneissic granitoid rocks (*AgWgn*) and associated xenolith-rich, foliated to gneissic granitoids (*AgWnx*). The latter may represent the root zones of older greenstone belts (Hickman, 1983). The xenolith-rich granitoids are common southwest and south of Callawa Homestead in a belt that runs parallel to the De Grey River, and in the 6 Mile Well area. The oldest dated material obtained from the Warrawagine Granitoid Complex, and incidentally the oldest zircon age determined so far for early protoliths in the Pilbara granitoid complexes using the SHRIMP U–Pb zircon method, comes from a xenolith of banded tonalite gneiss that is hosted by the mixed granitoid unit (*AgWgn*). The sample was collected from 4.1 km west-northwest of 6 Mile Well (Warrawagine) (Williams, 2001). It yielded xenocrystic zircon populations of ages c. 3655, c. 3637, c. 3595, and c. 3576 Ma (Nelson, 1999). The c. 3655–3576 Ma age range is attributed to different precursor components within the composite banded gneiss (Nelson, 1999, p. 129–132, GSWA Sample 142870).

Petrographically, most granitoids in the mixed granitoid unit (*AgWgn*) and xenolith-rich unit (*AgWnx*) are orthogneiss or have a gneissic or strongly foliated fabric. They are all recrystallized and deformed with incipient to prominent mineral segregation. The foliation is emphasized by the strong mica (generally biotite) orientation. The granitoids are pre- or synkinematic bodies that have been subjected to regional prograde metamorphism under upper greenschist- or lower amphibolite-facies conditions. Most rocks show later retrograde, lower greenschist-facies recrystallization. Biotite is the main ferromagnesian mineral with hornblende appearing in granitoids associated with the xenolith-rich zones. The mixed granitoids (*AgWgn*, *AgWnx*) include tonalite, trondhjemite, granodiorite, and monzogranite precursors. Discrete later plutons indicate that the mixed foliated and gneissic granitoids are older than c. 3313 Ma.

The mixed granitoid unit (*AgWgn*), from which the old xenocrystic zircons were obtained, is intruded by a porphyritic oligoclase–biotite granodiorite dyke (not shown on map). This dark-grey granodiorite consists of large (up to 20 mm) widely spaced microcline phenocrysts and coarse oligoclase set in a fine-grained groundmass. SHRIMP U–Pb zircon dating yielded an age of 3244 ± 3 Ma for the dyke (Nelson, 1999, p. 126–128, GSWA Sample 142869), which is the same age as the Wolline Monzogranite of the Muccan Granitoid Complex to the west (Williams, 1999a).

Pinkish grey, medium- to coarse-grained foliated monzogranite and granodiorite (*AgWmc*) occupies the southwest part of the Warrawagine Granitoid Complex. Although generally even grained, some seriate and porphyritic syenogranite phases are also present. A biotite monzogranite 2.2 km west of Narrana Well was dated at 3313 ± 6 Ma (Nelson, 1998, p. 87–89, GSWA Sample 143809).

A small pluton of pinkish grey, seriate to porphyritic biotite–oligoclase monzogranite and granodiorite (*AgWmp*), characterized by large scattered tors, is exposed in the vicinity of Granite Well (Williams, 2001). This granodiorite has been dated at 3303 ± 5 Ma (Nelson, 1999), an age shared with other plutons in the adjoining Muccan and Mount Edgar Granitoid Complexes.

A distinct, speckled greenish grey and white, coarse-grained hornblende–oligoclase tonalite and granodiorite (*AgWtg*) lies northwest of 10 Mile Well (Williams, 2001). The pluton has yielded a 3242 ± 4 Ma age (Nelson, 1999, p. 136–139, GSWA Sample 142874), which is within error of the c. 3244 Ma porphyritic granodiorite dyke that lies 5 km to the northeast in the 6 Mile Well (Warrawagine) area (Nelson, 1999, p. 126–128, GSWA Sample 142869).

Muccan Granitoid Complex (AgMmt, AgMmy, AgMmc, AgMgt, AgMgn, AgMnx, AgMwo)

The eastern third of the Muccan Granitoid Complex extends onto YARRIE from the southwest margin of the map. The complex is bordered to the south by the South Muccan Shear Zone (SMSZ; Zegers, 1996) that transects the Doolena Gap greenstone belt (Van Kranendonk et al., 2001); to the east-southeast by the Yarrie greenstone belt and unconformably overlying Fortescue Group; and to the northeast by the unconformably overlying Gorge Creek Group (Shay Gap greenstone belt; Dawes et al., 1995a,b; Williams, 1999a). North of Shay Gap and the Nimingarra iron mines area, a thin cover of Mesozoic sedimentary rocks of the Northern Carnarvon Basin overlies an extensive area of granitoid rocks that have been tentatively assigned to the Muccan Granitoid Complex (Williams, 2000). An inlier of the Muccan Granitoid Complex, the Kennedy Gap Inlier, is exposed just west of Yarrie Village. This inlier is faulted against, or intrudes, the Yarrie greenstone belt and is unconformably overlain by the Gorge Creek Group and Neoproterozoic Eel Creek Formation.

The granitoids at the largely intrusive but locally tectonically modified southern and east-southeastern margins between the Muccan Granitoid Complex and the Doolena Gap and Yarrie greenstone belt are xenolith-rich, strongly foliated, gneissic granitoid and gneiss (*AgMnx*). These pass gradationally to the mixed fine- to coarse-grained, strongly foliated and gneissic granitoids with banded gneiss and migmatite components (*AgMgn*). Although many of the xenolith-rich granitoids are amphibole-rich, most granitoids distant from the intrusive contacts with the greenstone belts have biotite as the dominant ferromagnesian mineral. A zone of xenolith-rich granitoids, including large rafts or pendants of tremolite–serpentine–chlorite–talc rock (*Aut*), serpentinite (*Aus*), and amphibolite (*Aba*), extends 14 km west of Surface Well. This zone, which is distant from known greenstone belts, may possibly represent the eroded keel of an older greenstone belt (cf. Hickman, 1983). The xenolith-rich, gneissic granitoids (*AgMnx*) are absent adjacent to the Gorge Creek Group contact with the Muccan Granitoid Complex to the northeast. This reinforces the unconformable relationship already observed between the granitoids and overlying Shay Gap greenstone belt (Dawes et al., 1995a,b; Williams, 1999a).

The mixed granitoid, migmatite, and banded gneiss unit (*AgMgn*) is mainly tonalitic, granodioritic, and monzogranitic in composition with lesser trondhjemitic and syenogranitic components. Pegmatites of various ages are common in some areas. Heterogeneous granodiorite gneiss, 2.5 km south-southwest of Fred Well, yielded a SHRIMP U–Pb zircon age of 3470 ± 4 Ma (Nelson, 1998, p. 81–83, GSWA Sample 142828; Williams and Hickman, 2000). The mixed granitoid unit (*AgMgn*) is widespread south of the De Grey River, where it is intruded by a number of discrete younger plutons and felsic dykes ranging in age from c. 3313 to c. 3244 Ma.

Included within the mixed granitoids (*AgMgn*) are more homogeneous, older foliated plutons north of the De Grey River. A foliated, medium-grained biotite granodiorite, collected from beneath the unconformable Nimingarra Iron Formation of the Gorge Creek Group at the Sunrise Hill West 4 iron ore pit, gave a SHRIMP U–Pb zircon age of 3443 ± 6 Ma (Nelson, 1996, p. 153–155, GSWA Sample 124755; Williams and Hickman, 2000). A similar age of 3438 ± 4 Ma was obtained from a foliated grey-white, medium-grained biotite–hornblende granodiorite (*AgMgt*) 3.5 km north of the Yarrie Village.

Scattered outcrops of weakly foliated, pink-grey to cream, medium- to coarse-grained monzogranite (*AgMmc*) lie north of the De Grey River. Dykes of similar material have been recognized cutting the mixed granitoids (*AgMgn*) south of the De Grey River. A sample collected 2 km southeast of Don Well (GSWA 143803) yielded a SHRIMP U–Pb age of 3313 ± 3 Ma (Williams and Hickman, 2000; Table 2). A xenocrystic zircon population in this sample had a c. 3434 Ma age (Nelson, 1998, p. 139–141, GSWA Sample 143803).

A fine-grained, leucocratic, muscovite-bearing, granophyric monzogranite (*AgMmy*) 2.5 km east of Gap Well is unconformably overlain by the Gorge Creek Group.

Magnetite-bearing biotite monzogranite (*AgMmt*) forms a number of small plutons in the mixed granitoid unit (*AgMgn*) around Yundinna Creek on the western margin of YARRIE. The rock, which is cream to whitish-grey and fine to medium grained, yielded a SHRIMP U–Pb zircon age of 3303 ± 2 Ma (Nelson, 1998, p. 145–147, GSWA Sample 143806; Table 2).

Wolline Monzogranite (AgMwo)

The Wolline Monzogranite (Williams, 1999a) is located in the vicinity of Wolline Well, where a porphyritic biotite monzogranite has yielded a SHRIMP U–Pb zircon age of 3244 ± 3 Ma (Nelson, 1998, p. 108–110, GSWA Sample 143810; Williams, 1999a; Williams and Hickman, 2000; Table 2). A slightly older date of 3252 ± 3 Ma was obtained from a seriate biotite monzogranite sampled 2.6 km west-southwest of Near Home Well on the northern side of the De Grey River (Nelson, 1998, p. 142–144, GSWA Sample 143805; Williams, 1999a; Table 2). This suite of younger intrusive plutons is distal from the intrusive margins of the Muccan Granitoid Complex with the adjacent greenstone belts.

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

Unlike the widely scattered exposures of the Muccan and Warrawagine Granitoid Complexes, the Mount Edgar Granitoid Complex is well exposed along the southern margin of the southwest quarter of YARRIE. In contrast also to the sparse preliminary data available for the Muccan and Warrawagine Granitoid Complexes (Hickman et al., 1983; Williams, 1999a), there is a wealth of petrogenetic, geochemical, and geochronological data available for the Mount Edgar Granitoid Complex (Collins, 1983, 1989, 1993; Davy and Lewis, 1986; Collins and Gray, 1990; Williams and Collins, 1990).

Portions of four named plutons, the Munganbrina Monzogranite, Mullugunyah Granodiorite, Coppin Gap Granodiorite, and Chimingadgi Trondhjemite, constitute the Mount Edgar Granitoid Complex on YARRIE (Collins, 1983, 1993; Williams, 1999a). All have sharply discordant intrusive contacts with the Warrawoona Group rocks of the Marble Bar greenstone belt. These rocks have been strongly recrystallized (contact metamorphosed) up to 1000 m from the granitoid contact. The Chimingadgi Trondhjemite is unconformably overlain by the Neoarchaean Fortescue Group. All four plutons belong to the younger, and less deformed intrusions of the Mount Edgar Granitoid Complex.

Munganbrina Monzogranite (AgEmu)

The Munganbrina Monzogranite (Williams, 1999a; cf. Munganbrina Suite of Collins, 1983, 1993) is restricted to the southern boundary of YARRIE. It consists mainly of banded, seriate to porphyritic medium-grained monzogranite with scattered, pink K-feldspar phenocrysts. Pegmatite dykes are common. The faint but distinct banding in the rocks is postulated to be primary and due to alternating layers of biotite- and plagioclase-rich horizons (Collins, 1983).

Although Collins (1993) stated that the Munganbrina Monzogranite is the oldest pluton in this part of the Mount Edgar Complex, and variably deformed, the contact relationship with the adjacent Coppin Gap Granodiorite to the north is unclear. Recent geochronology on similar rocks farther south on the MOUNT EDGAR 1:100 000 sheet show that some foliated components of the Munganbrina Suite (Collins, 1993) are as young as c. 3241 ± 3 Ma (Nelson, 2000, p. 181–183, GSWA Sample 142983; Williams and Bagas, in prep.). The pluton intrudes the Mount Ada Basalt in the extreme southwest corner of YARRIE.

Mullugunya Granodiorite (AgEml)

The Mullugunya Granodiorite (Collins, 1983) is exposed southeast of Nobb Well on the southern boundary of YARRIE. It is a weakly foliated, medium-grained, biotite- and hornblende-bearing granodiorite. Although somewhat similar to the adjacent Coppin Gap Granodiorite (*AgEco*) to the northwest, it lacks poikilitic K-feldspar grains characteristic of the Coppin Gap Granodiorite. It also appears to intrude the xenolith-rich zone (*AgEcox*) that envelops the Coppin Gap Granodiorite east of Nobb Well.

The Mullugunya Granodiorite intrudes the Duffer Formation, Apex Basalt, and possibly the Euro Basalt. It is faulted against the Chimingadgi Trondhjemite to the east, although on the adjacent MOUNT EDGAR 1:100 000 sheet it is intruded by the trondhjemite (Collins, 1983).

Coppin Gap Granodiorite (AgEco, AgEcox)

The Coppin Gap Granodiorite (Williams, 1999a; cf. Coppin Gap Suite of Collins, 1983, 1993) constitutes the major part of the Mount Edgar Granitoid Complex on YARRIE. It is a bulbous, roughly triangular-shaped pluton that intrudes the Warrawoona Group succession up to the level of the Apex Basalt. It is composed of homogeneous, non-foliated, massive to seriate, pink and grey, medium-grained granodiorite and tonalite. The quartz and K-feldspar contents increase northwards across the pluton.

Zones rich in mafic and ultramafic xenoliths (*AgEcox*), including large rafts of hornblende–plagioclase schist (*AW(oh)*) and felsic rocks of the Duffer Formation (*AWd*), extend southeast from the Andy Creek area to the southern boundary of YARRIE. A similar zone is also found in the southwest corner of YARRIE where the Coppin Gap Granodiorite intrudes the Mount Ada Basalt. A discrete small elliptical pluton, informally called the Aerodrome Pluton (Williams and Hickman, 2000) intrudes the Duffer Formation around the Bamboo Creek Mining Centre airstrip. Petrographically the pluton is the same as the nearby Coppin Gap Granodiorite.

The Coppin Gap Granodiorite was dated at 3314 ± 13 Ma (Williams and Collins, 1990; Table 2).

Chimingadgi Trondhjemite (AgEch, AgEchx)

The Chimingadgi Trondhjemite (Williams, 1999a; cf. Chimingadgi Suite of Collins, 1983, 1993) is an elliptical pluton on the eastern margin of the Mount Edgar Granitoid Complex. It intrudes the Apex and Euro Basalts and the weakly foliated Mullugunya Granodiorite, and extends southwards onto the adjacent MOUNT EDGAR 1:100 00 sheet.

The Chimingadgi Trondhjemite is a whitish-grey, massive, non-foliated, medium-grained trondhjemite characterized by high plagioclase and quartz contents, and lesser biotite. K-feldspar is very minor or absent. A mafic xenolith-rich amphibole-bearing hybrid granitoid, mainly tonalite (*AgEchx*), lies 2 km east-southeast of Zulu Well, and is characterized by large xenoliths of Euro or Apex Basalt.

Quartz–feldspar dacite and rhyodacite porphyry (Apd)

Subconcordant lenticular or tabular bodies and dykes of fine-grained to porphyritic dacite and rhyodacite (*Apd*) intrude mafic and ultramafic rocks of the Euro Basalt and the Bamboo Creek Shear Zone immediately south and southwest of Coppin Gap. Such bodies can be traced over a distance of 4 km and are host to multiple-phase stockworks of quartz–carbonate veins with or without chlorite, K-feldspar, and biotite, that carry chalcopyrite, molybdenite, pyrite, pyrrhotite, scheelite, and rare sphalerite (Baxter, 1978; Marston, 1979; Jones, 1990; see **Economic geology** section).

The felsic bodies are cream to bluish-grey, fine-grained to porphyritic rocks with a quartz–sericite–plagioclase–epidote(–K-feldspar) assemblage.

A rhyodacite porphyry body has been dated using the conventional titanite (sphene) U–Pb method (Thorpe, R. I., 1992, written comm.; see Table 3). This yielded an age of 3317 ± 1 Ma that was interpreted to date a hydrothermal event subsequent to magmatic emplacement. However, the intrusions are postulated to be magmatically related to the nearby c. 3314 Ma Coppin Gap Granodiorite.

Gorge Creek Group

The Gorge Creek Group (Hickman and Lipple, 1975; Hickman, 1983) is a widespread, but as yet directly undated group that on YARRIE comprises the Nimingarra Iron Formation, the metasedimentary Cundaline Formation, and Coonieena Basalt (Williams, 1999a). The group is exposed in the Coppin Gap Syncline, south of the Muccan Granitoid Complex, and in the Shay Gap greenstone belt east and northeast of the Muccan Granitoid Complex and northwest of the Warrawagine Granitoid Complex (Williams, 1999a; 2000). An isolated exposure of banded iron-formation (BIF) and chert at Mount Cecelia, 73 km east-southeast of the Yarrie iron mine, is correlated with the Gorge Creek Group. This correlation is supported by the regional TMI image map (AGSO, 1993b; Fig. 6) that shows an almost continuous magnetic high (produced by the BIF) between these areas.

Recent detailed mapping has shown that the Gorge Creek Group on YARRIE unconformably overlies the Warrawoona Group in the Marble Bar and Yarrie greenstone belts, and the Muccan and Warrawagine Granitoid Complexes (Dawes et al., 1995a,b; Williams, 1999a, 2000). The Gorge Creek Group is, in turn, disconformably overlain by the De Grey Group north and east of Shay Gap. The Group is also unconformably overlain by the Neoproterozoic Eel Creek Formation and the Mesozoic Callawa Formation north of the Shay Gap greenstone belt, and by the Neoarchaean Fortescue Group at the eastern end of the Coppin Gap Syncline (Williams, 1999a, 2000).

The age of the Gorge Creek Group on YARRIE is constrained only by detrital zircon populations extracted from the basal epiclastic rocks of the Nimingarra Iron Formation and from the disconformably overlying Cattle Well Formation of the De Grey Group. This indicates an age bracket of c. 3362 to 3048 Ma. On the NORTH SHAW 1:100 000 sheet the Gorge Creek Group is younger than the Sulphur Springs Group (c. 3235 Ma; Van Kranendonk, 2000; Buick et al., 2002; Van Kranendonk et al., 2002). However, the Cattle Well Formation may be considerably younger.

Nimingarra Iron Formation (AGn, AGna)

The Nimingarra Iron Formation (Williams, 1999a) is the basal, and also the dominant formation of the Gorge Creek Group on YARRIE. It has a strong magnetic expression (Fig. 6) that enables the unit to be traced beneath younger shallow cover, such as the unconformable Fortescue Group and Phanerozoic rocks of the Northern Carnarvon and Canning Basins. Apart from Mount Cecelia at the northern end of the Gregory Range Inlier, exposures of the Nimingarra Iron Formation are limited to the Coppin Gap Syncline and Shay Gap greenstone belt (Fig. 4) in the southwest quarter of YARRIE (Williams, 1999a, 2000, 2001).

The Nimingarra Iron Formation comprises BIF, jaspilite (banded hematite and red jasper) banded and ferruginous chert, black (pyritiferous) shale, and mudstone. The shale units can be up to 40 m thick, and in the Shay Gap area form prominent marker horizons (Podmore, 1990). The basal part of the Nimingarra Iron Formation is marked by discontinuous lenses of metamorphosed granitoid-clast-bearing cobble to pebble conglomerate, quartz sandstone, siltstone, and shale (*AGna*; Williams, 1999a, 2000). This epiclastic unit can be up to 200 m thick. Where the conglomerate is absent, faulted contacts between the BIF and the underlying older granitoids and greenstones have been found. Tectonic interleaving of the basal Nimingarra Iron Formation and underlying granitoids has also been observed in the Shay Gap and Yarrie areas (Williams, 1999a, 2000). Recent studies (Dawes et al., 1995a,b; Williams, 1999a, 2000) of the basal Nimingarra Iron Formation have confirmed an unconformable relationship between these rocks and the underlying Muccan and Warrawagine Granitoid Complexes and the Warrawoona Group rocks of the Marble Bar and Yarrie greenstone belts.

The Nimingarra Iron Formation is host to a number of small to moderate-sized openpit iron ore mines spread over a distance of 41 km from Yarrie iron mine in the east to Nimingarra on the western edge of YARRIE (see **Economic geology**).

Cundaline Formation (AGu)

The Cundaline Formation (Williams, 1999a) is exposed in a number of localities in the Shay Gap greenstone belt where it disconformably overlies the Nimingarra Iron Formation. The main exposures lie along the northern edge of the ridge between Shay Gap and Cundaline Gap, 4 km north of the Yarrie iron mine along Eel Creek, and in a tight syncline 3.5 km northeast of Leo Bore. It is also exposed in the core of the Coppin Gap Syncline, 3 km east of Coppin Gap, where it lies unconformably on the Nimingarra Iron Formation, and on the western side of Mount Cecelia, where it is faulted against the Nimingarra Iron Formation.

In the Shay Gap greenstone belt, the formation consists of interbedded, thin- to thick-bedded, red-brown weathered, grey-green shale, siltstone, sandstone, immature pebbly sandstone, pebble conglomerate, quartz and lithic wacke. The thick, coarser grained wackes have graded beds with way-up to the northeast.

East of Coppin Gap, the Cundaline Formation consists of thick, quartz sandstone on the northern limb of the syncline and pebble to large cobble, polymictic conglomerate in the core and southern limb. The clasts in the conglomerate are mostly chert, banded chert, jaspilite, and BIF derived from the underlying Nimingarra Iron Formation. This points to an erosional unconformity between the Cundaline and Nimingarra Iron Formations.

West of Mount Cecelia, the Cundaline Formation comprises ferruginous, purple to brown-weathering pelitic and psammitic schists (Williams, 2001).

Coonieena Basalt (AGo)

The Coonieena Basalt (Williams, 1999a) is well exposed in the Shay Gap greenstone belt between Coonieena Creek and the Elephant Rock Fault where it is displaced northwards (Williams, 1999a). Further outcrops lie north of Cattle Gorge where it is bordered to the east by the unconformably overlying Neoproterozoic Eel Creek Formation. The basalt disconformably overlies the Cundaline Formation in these areas. Farther south, at the eastern end of the Coppin Gap Syncline, the Coonieena Basalt unconformably overlies the Cundaline and Nimingarra Iron Formations. The basalt, in turn, is unconformably overlain by the Mount Roe Basalt of the Fortescue Group in this region.

The Coonieena Basalt comprises massive and pillowed tholeiitic basalt, silicified basaltic andesite, and minor high–Mg basalt. Basaltic hyaloclastite and pillow breccia are associated with the pillow basalts. Mafic pisolitic tuffaceous rocks are found in the upper parts of the formation north of Cattle Gorge. A thick, pale-grey, talc–quartz rock with scattered vesicles, interpreted to be a high-Mg basalt, overlies pillowed tholeiitic basalts in the Coppin Gap Syncline (Williams, 1999a). The tholeiitic basalt is an intergranular-textured clinopyroxene–plagioclase(–quartz) rock with chlorite, epidote and carbonate alteration indicative of very low grade metamorphism. Ocelli textures are found in the high-Mg basalt.

Metadolerite intrusions (AGd)

A number of weakly metamorphosed fine- to coarse-grained dolerite intrusions (Williams, 1999a), mainly sills, are found in the Cundaline Formation, and to a lesser extent in the underlying Nimingarra Iron Formation and overlying Coonieena Basalt. The dolerite consists of strongly saussuritized plagioclase and unaltered clinopyroxene. Patchy tremolite–chlorite have pseudomorphed orthopyroxene crystals. The dolerite is characterized by interstitial, granophyric quartz–feldspar patches and minor quartz.

A highly altered dolerite dyke, with relict spinifex-like textures preserved by chlorite and suggestive of a pyroxene-rich high-Mg composition, intrudes the Nimingarra Iron Formation on the northern margin of the Y2/Y3 iron ore pit. An unusual ultramafic dyke with a serpentine–clinopyroxene–talc assemblage, and thin chlorite–quartz dykes after fine-grained dolerite, intrude the Nimingarra Iron Formation in the Shay Gap 7 iron ore openpit, east of Sunrise Hill.

These mafic and ultramafic intrusions are considered to be subvolcanic intrusions related to the overlying Coonieena Basalt (Williams, 1999a, 2000).

De Grey Group

On YARRIE, the De Grey Group (Hickman, 1990) is a thick, weakly metamorphosed epiclastic and volcaniclastic succession comprising two newly defined formations — the lower Cattle Well Formation and the overlying Cooragoora Formation, which locally replace the former Lalla Rookh Sandstone (Hickman, 1983).

The De Grey Group is part of the Shay Gap greenstone belt. Although representing a thick succession (approximately 4000 m), exposures are restricted to a small area extending east from the Muccan–Boreline road to just east of the Elephant Rock Fault (Fig. 5). The group disconformably overlies the Gorge Creek Group to the south. Most of this contact is masked by the emplacement of the mafic Shay Intrusion along the disconformity. The De Grey Group is in turn unconformably overlain by the Neoproterozoic Eel Creek Formation 2 km northwest of Cattle Gorge Bore.

Cattle Well Formation (ADa)

The Cattle Well Formation (Williams, 1999a) is a poorly exposed unit roughly centred around Cattle Well. Scattered outcrops also lie northwest of Cattle Gorge Bore.

The lower part of the formation is a mixed unit comprising buff, grey, and brown, thinly bedded, medium- to coarse-grained sandstone, feldspathic sandstone, and lithic and feldspathic wacke. The rocks are interbedded in places with buff, cream, and brown micaceous siltstone and shale. Thin-bedded, grey-white dolomitic carbonate and calcareous shale lie towards the base of the formation (Williams, 1999a).

The middle and upper parts of the Cattle Well Formation contain abundant layers of felsic tuffaceous and volcaniclastic material. Bedded blue-grey dacitic tuff, welded tuff and resedimented tuffaceous sandstone, siltstone, wacke, and chert are interbedded with the previously described epiclastic component. Some dacitic tuffs carry abundant shards of devitrified volcanic glass.

A gently north-dipping mesa, 5 km north of Cattle Pool, is capped by blue and white chert and chert breccia that overlie interbedded maroon and pink calcareous mudstone, shale, and blue-grey resedimented felsic tuff horizons. The chert and chert breccia are considered to be silicified carbonate rocks that include some possible evaporite horizons. The chert contains poorly preserved, silicified stromatolites that are weakly columnar up to 10 cm high and 5 cm wide (Williams, 2000). The stromatolites are associated with uncommon laminated rocks that consist of thin, rhythmic pancake-like layers of alternate grey and white chert. These rocks closely resemble structures exhibited by the dubiofossil *Eozoon canadense* Dawson 1864 (Hoffman, 1971; Williams, 2000).

A resedimented, dacitic, tuffaceous sandstone from west of Cattle Well contains six detrital zircon population groups ranging from 3566 ± 3 to 3048 ± 19 Ma (Nelson, 1999, p. 122–125, GSWA Sample 142867; see Table 2), indicating that the formation was deposited after 3048 Ma.

The Cattle Well Formation is a mixed epiclastic and volcaniclastic succession deposited in a shallow-marine basin or shelf (Williams, 1999a).

Cooragoora Formation (ADo)

The Cooragoora Formation (Williams, 2000) conformably overlies the Cattle Well Formation north of Cattle Well, where it is exposed in a number of parallel strike ridges.

This well-exposed formation consists of red to red-brown, medium- to coarse-grained sandstone, pebbly sandstone, lithic wacke, and matrix-supported, polymictic conglomerate. The valleys between the strike ridges are commonly occupied by micaceous siltstone and shale, including grey-black carbonaceous shale locally carrying finely disseminated pyrite (Weir, 1990). Cream to white quartz sandstone is found in the upper parts of the formation.

The poorly sorted conglomerate contains cobbles and pebbles of white vein quartz, coloured cherts, banded black and white chert, jasper, and siliceous BIF. The cherts and BIF are similar to those found in the underlying Nimingarra Iron Formation. The conglomerates appear to occupy channels. This, coupled with the irregular shapes and poor sorting of the clasts, suggests that they are fanglomerates deposited under high-energy conditions (Williams, 2000). The sandstones exhibit trough cross-bedding and both upward-fining and upward-coarsening sequences.

The Cooragoora Formation resembles a high-energy, fluvial–deltaic deposit prograding into a shallow-marine or lacustrine basin.

Shay Intrusion (AaYo, AaYn)

The layered mafic Shay Intrusion (Williams, 1999a) intrudes the disconformable contact between the Coonieena Basalt of the Gorge Creek Group and the overlying Cattle Well Formation of the De Grey Group. The intrusion is around 500 m thick and can be traced in a northwesterly direction for over 12 km from the Elephant Rock Fault to a point 2 km northwest of the abandoned Shay Gap Townsite.

The Shay Intrusion consists of a thick norite and gabbronorite layer (*AaYn*) marked by a thin basal pyroxenite on the southwest margin. This layer is overlain to the northeast by assemblages variously identified as gabbro, quartz gabbro, epidotized quartz gabbro, granophyric gabbro and diorite (*AaYo*) (Hickman et al., 1983; Williams, 1999a).

The norite–gabbronorite layer (*AaYn*) exhibits large orthopyroxene crystals, now largely serpentine, set in a groundmass of saussuritized plagioclase and interstitial clinopyroxene. Partial or complete replacement of the primary minerals by epidote, chlorite, sericite/clay, carbonate, prehnite, and zeolites is common. The basal pyroxenite is now largely a tremolite–chlorite rock.

The overlying gabbro and quartz gabbro layers (*AaYo*) have a primary mineral assemblage of clinopyroxene, amphibole, plagioclase, and quartz. These rocks are also strongly altered to epidote, chlorite, sericite, and carbonate. The patchy, granophyric-rich gabbros may indicate contamination from the adjacent quartz-rich Cattle Well Formation (Williams, 1999a).

Minor felsic intrusive rocks (Apa, Ape, Apff)

A variety of felsic dyke rocks are found in the granitoid complexes that are much younger than the host granitoid. Aegirine-bearing sodic porphyry dykes (*Apa*) intrude the Muccan Granitoid Complex 7 km north of Yarrie Homestead, and the Cattle Well Formation 1 km south of Cattle Well. These distinctive, leucocratic porphyritic dyke rocks are packed with sodic feldspar and green, aegirine–augite phenocrysts set in a fine-grained matrix of quartz, sodic and K-feldspar, and small laths of aegirine–augite.

Fine-grained to porphyritic felsic dykes of rhyolite to dacite composition (*Ape*) intrude the Warrawagine Granitoid Complex in the Chintabul Dam, 17 Mile Well, and 6 Mile Well areas. These dykes can be traced over considerable distances (around 10 km), but on a local scale can be sinuous or discontinuous in outcrop pattern. Most phenocrysts are quartz, whereas the matrix may be either spherulitic or micropoikilitic (snowflake) textured. Some polycrystalline quartz phenocrysts resemble amygdales. These felsic dykes are cut by the later hornblende-phyric trachyandesite dykes (*Eph*).

A third suite of felsic dykes trend east-northeasterly across the Chimingadgi Trondhjemite northwest of Zulu Well, and the Warrawagine Granitoid Complex in the 17 Mile and 10 Mile Well areas. These dykes are fluorite-bearing, quartz–feldspar porphyry dykes (*Apff*) where the euhedral quartz and K-feldspar (?sanidine) phenocrysts are set in a coarsely spherulitic-textured groundmass. The fluorite is found in thin cross-cutting veins or in joints and cleavage planes in the feldspars. Several large, lenticular bodies, up to 200 m wide and 1 km long, lie 5 km northwest of 17 Mile Well. These porphyry bodies comprise two phases. The older phase is a coarse-grained, quartz–perthite–plagioclase porphyry with large vugs of dark-blue to purple fluorite, whereas the younger phase is a porphyry with phenocrysts of quartz set in a fine-grained rhyodacite matrix (Hickman, 1976, 1983; Hickman et al., 1983). Other smaller bodies lie northwest of 10 Mile Well.

Structure and evolution of the EPGGT on Yarrie

A number of comprehensive reviews and conceptual viewpoints on the structural evolution of the East Pilbara Granite–Greenstone Terrane (EPGGT) have been published over the last twenty years following the pioneering work of Bickle et al. (1980) and Hickman (1983, 1984). Such publications include those of Bickle et al. (1985), Krapez (1993), Zegers et al. (1996), Barley (1997), Collins et al. (1998), Nijman et al. (1999), White et al. (2001), Blewett (2002), and Van Kranendonk et al. (2001, 2002). Previously published accounts of the structure of the EPGGT on Yarrie are recorded in Hickman et al. (1983) and Williams (1999a, 2000, 2001).

The regional setting of Yarrie in relation to the EPGGT is given in Figure 3 and a summary of the geological history is presented in Table 1.

As already described, the portion of the EPGGT exposed on Yarrie comprises parts of the Warrawagine, Muccan, and Mount Edgar Granitoid Complexes. These have intrusive, faulted or tectonized intrusive contacts with the adjacent greenstones of the Marble Bar, Yarrie, and Doolena Gap greenstone belts that contain Warrawoona Group supracrustal rocks. In addition, a fourth greenstone belt, the Shay Gap greenstone belt, comprising the Gorge Creek and De Grey Groups, unconformably overlies both the older greenstone belts and granitoid complexes (Dawes et al., 1995a,b; Williams, 1999a; see Fig. 5). Such granitoid–greenstone belt relationships are observed throughout the EPGGT. The granitoid complexes on YARRIE are the result of multiple intrusive phases spanning at least 228 m.y. from c. 3470 to c. 3242 Ma.

Evidence for ancient crust

Several geochronology samples collected from the granitoid complexes and adjacent greenstone belts on YARRIE yielded inherited and detrital zircons indicative of ancient sialic crust in the EPGGT. This crust was later exposed during uplift, erosion, and deposition in basins of the Pilbara Supergroup. A large xenolith of banded biotite tonalite gneiss (3410 ± 7 Ma; Nelson, 1999) from the 6 Mile Well (Warrawagine) area in the Warrawagine Granitoid Complex, yielded xenocrystic zircon populations of c. 3655, c. 3637, c. 3595, and c. 3576 Ma (Table 2). This is the oldest material so far dated on YARRIE (Nelson, 1999, p. 129–132, GSWA Sample 142870; Williams, 2001). A heterogeneous granodiorite gneiss (3470 ± 4 Ma, Nelson, 1998, p. 81–83, GSWA Sample 142828) from the Muccan Granitoid Complex, collected 2.3 km southwest of Fred Well, yielded inherited zircons dated at c. 3575, c. 3538, and c. 3506 Ma (Nelson, 1998, p. 83, GSWA Sample 142828; Williams, 1999a).

Old detrital zircon populations have been obtained from basal quartzites in the Nimingarra Iron Formation of the Gorge Creek Group near Kittys Gap and Friendly Stranger mine (Williams, 1999a; see Table 2). These yielded detrital zircons with ages clustered around c. 3595 and c. 3560 Ma (Nelson, 1998, p. 73–80, GSWA Samples 143994, 143995). A volcaniclastic sandstone of 3048 ± 19 Ma maximum age of deposition (Nelson, 1999, p. 122–125, GSWA Sample 142867; Table 2), collected from the Cattle Well Formation of the De Grey Group, has yielded similar detrital zircon ages of c. 3583 and c. 3567 Ma.

D_1 events

The earliest recognized structures connected with the evolution of the granite–greenstone terranes on YARRIE are assigned to the D_1 event. These structures span a period from c. 3490 to c. 3410 Ma (Van Kranendonk et al., 2001, 2002).

The Muccan and Warrawagine Granitoid Complexes on YARRIE carry zones of banded and migmatite gneiss associated with strongly foliated and gneissic granitoids (*AgMgn*, *AgWgn*) and xenolith-rich foliated and gneissic granitoids (*AgMnx*, *AgWnx*). Both the gneiss–migmatite and mafic xenoliths show multiphase deformation, including tight isoclinal folds and rootless intrafolial folds, together with amphibolite-facies metamorphism. These are assigned to the D_1 deformation event (Hickman, 1983, 1984; Van Kranendonk et al., 2001, 2002).

On YARRIE, mixed granitoid–gneiss components (c. 3470–3438 Ma) can be found adjacent to greenstone belts, such as in the Muccan Granitoid Complex where these rocks show intrusive and tectonized intrusive relationships with the Doolena Gap and Yarrie greenstone belts. The granitoid–gneiss components can also be remote from greenstone belts, such as in the 6 Mile Well area and Callawa Homestead – Du Valles Well area of the Warrawagine Granitoid Complex, and the Wattle Well – Old House Well area in the Muccan Granitoid Complex. These xenolith-rich granitoid–gneiss zones are postulated to be the root zones of older greenstone belts (Hickman, 1983).

The intrusive contacts between the greenstone belts and the granitoid–gneiss component of the Muccan Granitoid Complex are very steep. In the case of the Doolena Gap greenstone belt the granitoid–greenstone contact is, in places, overturned towards the north. Along both the Doolena Gap and Yarrie greenstone belts there is a shared single foliation extending from the granitoid across the intrusive boundary into the greenstone belts. This foliation becomes weaker away from the granitoid contact, together with a decline in metamorphic grade in the greenstone belts.

The thick succession of the Marble Bar greenstone belt (approximately 15 km) on YARRIE typically displays a single moderate- to steep-dipping foliation throughout except for bedding-parallel high-strain zones, such as the Bamboo Creek Shear Zone (BCSZ) (Zegers, 1996). These contain multiple overprinted foliations (Blewett, 2002).

The Muccan Granitoid Complex contains foliated and gneissic plutons, some with partial melting migmatitic phases, that give ages comparable with those of the felsic volcanic components in the Marble Bar Belt. The Duffer Formation (c. 3471 Ma; Thorpe et al., 1992a,b) is the same age as the granodiorite gneiss dated near Fred Well (c. 3470 Ma; Nelson, 1998, p. 81–83, GSWA Sample 142828). The Panorama Formation, dated between c. 3458 and c. 3445 Ma on YARRIE (Thorpe, written comm., 1991; Thorpe et al., 1992a,b; Van Kranendonk et al., 2001), is similar to the foliated biotite granodiorite pluton at Sunrise Hill West 4 openpit (c. 3443 Ma; Nelson, 1996, p. 153–155, GSWA Sample 124755), and the tonalite–granodiorite pluton northwest of Yarrie village (c. 3438 Ma; Nelson, 1998, p. 84–86, GSWA Sample 143807). The felsic volcanic component of the greenstone belts has been postulated to be coeval and consanguineous with the emplacement of sheeted TTG intrusions in the form of subvolcanic sills and plutons (Thorpe et al., 1992a,b; Barley and Pickard, 1999; Van Kranendonk et al., 2001, 2002). The upper part of the felsic volcanic Panorama Formation is now known to be widely distributed across the EPGGT. This suggests that crustal coherence was probably established by c. 3430 Ma (Van Kranendonk et al., 2001, 2002).

Synvolcanic, listric, normal growth faults involving the Panorama Formation on the western side of the younger, intrusive Coppin Gap Granodiorite of the Mount Edgar Granitoid Complex have been investigated and discussed in detail by Nijman et al. (1999).

All the above events are included with the D_1 structures (Hickman, 1983, 1984; c. 3490–3410 Ma; Van Kranendonk et al., 2001, 2002). The D_1 event is, in effect, an evolving tectono-magmatic episode that includes all structures generated prior to c. 3410 Ma (Van Kranendonk et al., 2002) on YARRIE.

D_2 events

Previous investigations attributed the development of the EPGGT signature morphology, represented by the large ovoid granitoid domes flanked by arcuate and linear, generally synclinal greenstone belts, to the tectonic emplacement of rising diapiric granitoid bodies coupled to the gravitational sinking of the adjacent, denser greenstone belts. These tectono-magmatic events were assigned to D_2 (Hickman, 1983, 1984; Collins,1989). New data, collected from recent investigations elsewhere in the EPGGT, favour magmatic diapirism as a major process in granitoid dome emplacement (Van Kranendonk et al., 2002). This model connects the magmatic diapirism to solid-state remobilization of older granitoids and greenstones (Collins et al., 1998; Van Kranendonk and Collins, in press). The younger (<3315 Ma) granitoids that form the bulk of the granitoid domes were derived from partial melting of the older granitoids (Bickle et al., 1989; Collins, 1993). The doming process was set in motion by the long-term (~200 m.y.), voluminous (≤18 km thick) volcanic outpourings of the greenstones that culminated in the 5–8 km-thick Euro Basalt

(Van Kranendonk et al., 2002). This event was postulated to trigger the increasing gravitational instability that subsequently resulted in partial convective overturn in which granitoid melts migrated upwards concomitant with the sinking of the denser greenstone upper crust. Peak periods of granitoid emplacement during this time on YARRIE are between the periods c. 3470–3430 Ma and c. 3315–3300 Ma (Williams, 1999a, 2001).

Recent studies in the central-southern parts of the EPGGT have linked the D_2 tectono-magmatic events more precisely to tilting, uplift, and development of the unconformity between the volcanic Wyman Formation (c. 3325–3320 Ma) and Budjan Creek Formation (c. 3308 Ma) (Bagas, 2003; Bagas and Van Kranendonk, in prep.). The latter units are absent on YARRIE. However, the age span of these two formations corresponds to the emplacement of large volumes of sometimes bulbous granitoids (c. 3315–3300 Ma; Nelson, 1998, p. 87–89, GSWA Sample 143809; p. 139–141, GSWA Sample 143803; p. 145–147, GSWA Sample 143806), ranging in composition from tonalite to monzogranite within, or marginal to, the earlier granitoid complexes (>3470–3410 Ma; Nelson, 1998; Collins et al., 1998; Van Kranendonk et al., 2002, in press).

These plutons include the Coppin Gap Granodiorite (3314 ± 13 Ma; Williams and Collins, 1990), Mullugunya Granodiorite, and Chimingadgi Trondhjemite of the Mount Edgar Granitoid Complex. They discordantly intrude the Marble Bar greenstone belt up to the level of the Apex Basalt. The greenstones adjacent to these plutons are strongly contact metamorphosed to lower amphibolite (hornblende-hornfels) facies. Small lens-shaped porphyritic rhyolite bodies and dykes intrude the Euro Basalt near Coppin Gap. These are dated at c. 3317 Ma (Thorpe, R. I., 1992, written comm.) and are probably apophyses of the nearby Coppin Gap Granodiorite (Jones, 1990; Williams, 1999a). All these bodies post-date the single, moderate- to steep-dipping foliation attributed to D_1, in the Marble Bar greenstone belt.

Similar large plutons, but distant from the established margins of the granitoid complexes, are found around Don Well (c. 3313 Ma; Nelson, 1998, p. 139–141, GSWA Sample 143803) in the Muccan Granitoid Complex. Likewise, in the Warrawagine Granitoid Complex similar plutons have been located in the Narrana Well (c. 3313 Ma; Nelson, 1998, p. 87–89, GSWA Sample 143809) and Granite Well areas (c. 3303 Ma; Nelson, 1999, p. 133–135, GSWA Sample 142871). All these plutons are syn- to late kinematic intrusions of the D_2 tectono-magmatic event.

The D_2 event points to additional or renewal of multiple pulses of granitoid material that were focused on the pre-existing, older complexes. The inflationary pressure of the additional magma on the previously emplaced older granitoids initiated or reactivated faults and bedding-plane shears in the overlying cover rocks.

The increasing-volume problem between the enlarging granitoid complexes is exemplified by the steeply dipping, long-lived South Muccan Shear Zone (Zegers, 1996) along the southern margin of the Muccan Granitoid Complex that seems to have eliminated almost the entire Warrawoona Group (>10 000 m) from the northern side of the Coppin Gap Syncline (Williams, 1999a).

Another outcome of the D_2 structural event is the first evidence for the unroofing of the granitoid domes, for example the Budjan Creek Formation (Bagas and Van Kranendonk, in prep.). Eroded granitic material began to contribute epiclastic material to the continually evolving greenstone depositories adjacent to the rising granitoid complexes. This is illustrated by the gradually increasing epiclastic content (quartzite, sandstone, conglomerate) of the successively younger greenstone belts.

D_3 events

The felsic volcanism of the Kangaroo Caves Formation of the Sulphur Springs Group and coeval Strelley Granite in the central parts of the EPGGT have been assigned to the D_3 structural event where synvolcanic growth faults have been identified (c. 3240 Ma; Van Kranendonk, 2000; Van Kranendonk et al., 2001, 2002). On YARRIE, plutons of similar age are found in the cores of the Muccan and Warrawagine Granitoid Complexes well away from the older intrusive margins of the complexes. The porphyritic Wolline Monzogranite (c. 3250–3244 Ma; Nelson, 1998, p. 108–110, GSWA Sample 143810), exposed north of Wolline Well and southwest of Near Home Well in the Muccan Granitoid Complex, is coeval with this event. Similarly, a porphyritic granodiorite dyke (c. 3244 Ma; Nelson, 1999, p. 126–128, GSWA Sample 142869) near 6 Mile Well and a hornblende–oligoclase granodiorite pluton (c. 3242 Ma; Nelson, 1999, p. 136–139, GSWA Sample 142874) northwest of 10 Mile Well have been identified in the Warrawagine Granitoid Complex.

Although the Gorge Creek Group has not yet been directly dated, it is shown to be younger than the c. 3235 Ma Sulphur Springs Group in the central parts of the EPGGT (Van Kranendonk, 2000; Van Kranendonk et al., 2001, in press). Deposition of the basal Nimingarra Iron Formation took place during a pause in tectonic activity in the later stages or at the completion of the D_3 event (cf. Van Kranendonk et al., 2002). On YARRIE, the Gorge Creek Group unconformably overlies Warrawoona Group rocks, the youngest in this area being the Euro Basalt (c. 3325 Ma), and the Muccan and Warrawagine Granitoid Complexes (Dawes et al., 1995a,b; Williams, 1999a, 2000).

Detrital zircon populations (minimum age 3362 ± 13 Ma) in the basal quartzites of the Nimingarra Iron Formation, which unconformably overlies the granitoid complexes and Warrawoona Group, have not, as yet, yielded zircons indicative of the D_2 (c. 3315–3300 Ma) or D_3 (c. 3252–3240 Ma) tectono–magmatic tectonic events. This suggests that plutons of this age had not yet been exposed to erosion. The bulk of the detrital zircon population in the basal quartzites of the Gorge Creek Group range from c. 3490 to 3360 Ma, with peaks around the Panorama Formation age (c. 3458–3430 Ma; Nelson, 1998, p. 69–80, GSWA Samples, 143996, 143995, 143996). A few zircons point to pre-Coonterunah Group (Buick et al., 1995; Van Kranendonk, 2000) ancient Archaean crust (maximum age 3596 Ma).

Local unconformities are recognized throughout the Gorge Creek Group between the component Nimingarra Iron Formation, Cundaline Formation, and Coonieena Basalt. Such activity implies continuing magmatic activity at depth resulting in further uplift and erosion during the waning stages of D_3.

South of the Muccan Granitoid Complex, the Gorge Creek Group is folded by the Coppin Gap Syncline (Williams, 1999a), a tight, asymmetric syncline with a vertical to overturned northern limb plunging steeply to the east. The Gorge Creek Group unconformably overlies the Warrawoona Group in this region. The Warrawoona Group, in turn, occupies a pre-existing but now sheared-out synclinorium between the Muccan and Mount Edgar Granitoid Complexes (a D_1–D_2 structure). The Coppin Gap Syncline is a reinforcement of the previous structures and points to the continual or episodic uplift and expansion of the granitoid complexes. Detailed structural studies in the area have identified extensional west-block-down listric normal growth faulting and complex compressional (D_3) structures in the Gorge Creek Group (Nijman et al., 1999).

D_4 events

Tight to moderate folding of the Gorge Creek Group on YARRIE is a D_4 tectono-magmatic event poorly constrained between c. 2950 and 3048 Ma. North of the Muccan Granitoid

Complex the Gorge Creek Group occupies the broad, east-southeasterly moderately plunging Shay Syncline (Williams, 2000). In this region, the Gorge Creek Group unconformably overlies the Muccan Granitoid Complex. Some tectonic interleaving has been recorded at this contact (Dawes et al., 1995b). Unlike the Coppin Gap Syncline, there is no evidence to support a pre-existing synclinal keel of older greenstones beneath the unconformity. This supposition is supported by 3D magnetic and gravity studies carried out on banded iron-formations in the Pilbara Craton that showed that there was only a shallow structure in this area (Wellman, 2000). The core of the Shay Syncline is occupied by the disconformably overlying De Grey Group (maximum age of deposition c. 3048 Ma; Nelson, 1999, p. 122–125, GSWA Sample 142867).

Waters (1998) recognized five distinct fold sets locally in the Nimingarra Iron Formation in the Yarrie iron mine area. The earliest folds may be soft sediment deformation. Early isoclinal and superimposed, north-plunging, mesoscopic folds are refolded by northerly plunging open folds. The whole sequence at the Yarrie iron mine dips moderately north away from the Warrawagine Granitoid Complex. These fold sets are attributed to the D_4 event.

The Gorge Creek Group between the Muccan and Warrawagine Granitoid Complexes is folded into tight, north- and south-plunging synclines (Williams, 1999a). This region, together with the Shay Syncline, is part of the Shay Gap greenstone belt.

It is speculative to consider whether the outpouring of the widespread Coonieena Basalt at the top of the Gorge Creek Group on YARRIE and its equivalent, the Honeyeater Basalt in the central parts of the EPGGT, triggered or increased processes (e.g. convective overturn) similar to that envisaged for the consequences of the outpouring of the thick Euro Basalt in the D_2 tectonic-magmatic event (Van Kranendonk et al., 2001, 2002).

D_5 events

One dramatic outcome of the slow, continually expanding Muccan and Warrawagine Granitoid Complexes is the strong east–west compressional zone that developed between them in the De Grey River area east of Yarrie Homestead. A number of north-trending faults that post-dated the D_4 folding developed in the region, and these are attributed to D_5. These include the sinistral strike-slip Elephant Rock Fault (Williams, 1999a), and the more easterly complementary dextral strike-slip Kennedy Gap Fault (Williams, 1999a). These faults mark the boundaries of a north-directed pop-up wedge or strike-slip flower structure that forms the Cattle Gorge part of the Nimingarra Iron Formation. The southern extensions of these faults run beneath the unconformably overlying Neoarchaean Fortescue Group. Similar faults in the Fortescue Group suggest continual reactivation of these fault systems.

The Elephant Rock Fault may also initially have been a listric growth fault for the De Grey Group. The epiclastic Cooragoora Formation becomes coarser grained against the fault where polymictic conglomerates contain clasts derived from the Gorge Creek Group, particularly clasts of jaspilite, chert, and BIF from the Nimingarra Iron Formation. These north-trending fault zones may be similar in age to the Lalla Rookh – Western Shaw structural corridor formed around 2940 Ma (Van Kranendonk and Collins, 1998; Van Kranendonk et al., 2001, 2002).

Such northerly trending faults are intersected south of the Yarrie iron mine and along the De Grey River by two large east-northeasterly trending strike-slip faults. These are the sinistral Callawa Fault and the dextral Du Valles Fault (Williams, 1999a). The Du Valles Fault can be traced over 75 km across the Warrawagine Granitoid Complex and into the

Muccan Granitoid Complex. The faults are marked by quartz-filled shear zones occupying ridges up to 80 m high southwest and south of Callawa Homestead. These complementary faults are marginal to a large block of Nimingarra Iron Formation that has a relative displacement of 5 km to the east (Williams, 1999a).

It is conjectured that this north–south compression may be part of the c. 2920–2850 Ma event that caused shortening across the Mosquito Creek Basin more than 100 km to the south (Van Kranendonk et al., 2001).

Mount Bruce Supergroup

The northeasternmost parts of the Neoarchaean to Palaeoproterozoic Hamersley Basin (Trendall, 1990b) extend into the southern part of YARRIE. The Hamersley Basin, the depositional basin for the Mount Bruce Supergroup (Trendall, 1979; 1990), is located in two structural settings: the Oakover Syncline (Hickman, 1983; Blake, 1993; Williams, 1999a), and the Gregory Range Inlier (Williams and Trendall, 1998a,b; Williams, 2001). These two areas are linked subsurface beneath Permian rocks in the Oakover–Nullagine river valleys (Williams, 2001).

The Mount Bruce Supergroup is represented on YARRIE by the Neoarchaean Fortescue Group (c. 2772–2629 Ma; Arndt et al., 1991; Nelson et al., 1999; Wingate, 1999), and the disconformably overlying Neoarchaean Carawine Dolomite (c. 2541 Ma; Jahn and Simonson, 1995) of the Hamersley Group. The Carawine Dolomite is unconformably overlain by the Palaeoproterozoic Pinjian Chert Breccia (Noldart and Wyatt, 1962; Williams and Trendall, 1998b), which is interpreted to be a residual, karst-related deposit.

Gregory Granitic Complex (AgGyf, AgGyy, AgGyr)

The Gregory Granitic Complex (Hickman, 1978; Hickman et al., 1983; Williams and Trendall, 1998a,b,c) is exposed along the eastern side of the Gregory Range Inlier (Fig. 3) on the southern boundary of YARRIE. The complex occupies the core of a faulted, north-northwesterly plunging anticlinal structure.

Although the Gregory Granitic Complex is not well exposed on YARRIE, three distinct lithologies have been identified in low-profile, rubble-covered outcrops between sand dunes.

Fine- to coarse-grained syenogranite (*AgGyf*) exposures lie 25–30 km south-southeast of the abandoned Myijimaya Community. The syenogranite comprises mainly coarse perthite and microcline with lesser Na-plagioclase, quartz, and biotite. Magnetite is an abundant accessory mineral. The syenogranite is heterogeneously deformed with a weak pervasive foliation and very low grade metamorphism. The rocks are also cataclastically deformed. Many thin granulation zones of recrystallized quartz can pass to wide zones of tectonically reduced grainsize resulting in a granite gneiss.

Granophyre (*AgGyy*) is the major component of the Gregory Granitic Complex on YARRIE. Although it underlies the Koongaling Volcanic Member of the Hardey Formation, the contact relationship is obscured by sand. Observations made elsewhere suggest tectonic or gradational contacts (Williams and Trendall, 1998b).

The granophyre consists of widespread coarse-grained granophyric intergrowth of quartz and alkali feldspar. Microcline, perthite, quartz, biotite, and lesser amphibole (both hornblende and hastingsite) are the main minerals between the granophyric patches. The granophyre has a weak cataclastic foliation.

Several small plutons of porphyritic, coarse-grained syenogranite (*AgGyr*) intrude the basal rhyolite of the Koongaling Volcanic Member 21 km south-southeast of Myijimaya (Williams and Trendall, 1998a). The syenogranite contains large ovoid-shaped phenocrysts and glomerocrysts of perthite and microcline set in a matrix of quartz, alkali feldspar, and biotite. The rocks show low-grade metamorphic recrystallization and cataclastic deformation.

Recent studies (Williams and Trendall, 1998b,c) confirm that the Gregory Granitic Complex, a complicated mixture of plutonic and hypabyssal rocks, is the same age as the overlying Koongaling Volcanic Member of the Hardey Formation in this area. Chemical, petrographic, and geochronological data indicate a consanguineous relationship between the two units. SHRIMP U–Pb zircon dates show that the felsic volcanic rocks of the Koongaling Volcanic Member and plutonic rocks of the Gregory Granitic Complex all fall within the c. 2764–2757 Ma range (Arndt et al., 1991; Nelson, 1996, 1999). Such data support the proposal by Trendall (1990b, 1991) that the Gregory Granitic Complex represents the plutonic and hypabyssal components underlying the volcanoes from which the Koongaling Volcanic Member had erupted.

Current data show that the igneous suite is alkaline, both petrologically and chemically. The rocks are also silicic (SiO_2 range 70–77%) and potassic (K_2O range 4.9–5.9%). They belong to the A-type felsic igneous rock category (Eby, 1992). Emplacement took place in an anorogenic setting under extensional conditions.

The surface exposure of deep crustal rocks of the Gregory Granitic Complex is attributed to uplift along a series of steep reverse faults. These successively thrusted deep-crustal material up and southwestwards onto the overlying comagmatic volcanic rocks. The genesis of the thrusting is related to collisional tectonics (probably continent–continent) along the northeast margin of the Pilbara Craton in late Mesoproterozoic times (Myers, 1993; Hickman et al., 1994; Myers et al., 1996; Hickman and Bagas, 1998). Reactivation of these faults took place during the Neoproterozoic Paterson Orogeny (Hickman et al., 1994; Bagas and Smithies, 1998).

Fortescue Group

The Fortescue Group (MacLeod et al., 1963) on YARRIE is a mixed assemblage of mafic and felsic volcanic, volcaniclastic, epiclastic, and biogenic chemical rocks. The Fortescue Group succession in the Oakover Syncline to the west differs in some details from the succession exposed in the Gregory Range Inlier to the east. The Fortescue Group in the Gregory Range Inlier lacks the basal Mount Roe Basalt. Instead, the basal Koongaling Volcanic Member of the Hardey Formation overlies, and is genetically related to, the underlying Gregory Granite Complex (Hickman, 1983; Williams and Trendall, 1998b). The epiclastic component of the Hardey Formation is assigned to the Warroo Hill Member. The only other major difference between the two areas is the addition of the Baramine Volcanic Member and Isabella Member to the Jeerinah Formation in the Gregory Range Inlier. The Fortescue Group on YARRIE has a maximum thickness of about 5200 m.

The relationships between earlier (Hickman et al., 1983) and current lithostratigraphic terminology, and the sequence stratigraphic model proposed by Blake (1990, 1993), are shown in Figure 8. The regional stratigraphy and tectonic evolution of the Fortescue Group has been reviewed by Blake (1993), and Thorne and Trendall (2001).

Black Range Dolerite Suite (AFdb)

Several large, north-northeasterly trending medium- to coarse-grained dolerite and gabbro dykes intrude the Muccan and Mount Edgar Granitoid Complexes, and marginal

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

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Figure 8. Fortescue Group stratigraphic correlation chart; a historical comparison for YARRIE

Warrawoona and Gorge Creek Groups. They are absent from the Warrawagine Granitoid Complex.

The coarse-grained dolerite consists of subophitic intergrowth of randomly oriented plagioclase laths and anhedral augite crystals. Large orthopyroxene crystals are pervasively altered to chlorite. The dolerite has reacted strongly in places with the host granitoid rocks producing hybrid zones of remelted granitoid rock typified by granophyric textures.

These dykes have been assigned to the Black Range Dolerite Suite (Lewis et al., 1975; Hickman, 1983). SHRIMP U–Pb baddeleyite geochronology has obtained an age of 2772 ± 2 Ma from this suite (Wingate, 1999). The Black Range Suite is probably part of the feeder dyke system for the basal Mount Roe Basalt of the Fortescue Group, which is dated at around 2775–2763 Ma (Nelson et al., 1999).

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

The Mount Roe Basalt (Kriewaldt, 1964; Thorne and Trendall, 2001) is restricted to the Oakover Syncline exposures of the Fortescue Group on YARRIE. It can be traced almost continuously around the margins of the Oakover Syncline except in the keel at the northwest end of the syncline near the Yarrie microwave repeater station, where it is overlapped by the Hardey Formation. The Mount Roe Basalt is unconformable on the Warrawagine and Muccan Granitoid Complexes, the Chimingadgi Trondhjemite of the Mount Edgar Granitoid Complex, and on the Warrawoona and Gorge Creek Groups. The formation is up to 700 m thick in the western parts of the syncline but gradually decreases to less than 500 m in the eastern parts.

The Mount Roe Basalt consists mainly of subaerially extruded amygdaloidal, vesicular, porphyritic, or glomeroporphyritic, massive to well-jointed, black, grey, and green-grey basalt and basaltic andesite. Amygdales are mostly filled with calcite or chlorite, or with both. Basaltic pillow lavas have been recorded from Miningarra Creek (Williams, 1999a) on the southern margin of YARRIE. The proportion of the pillowed basalts increases eastwards and is particularly well developed at localities 5.5 km south-southwest and 4 km south of Granite Well.

South and east of Surface Well on the western side of the Oakover Syncline, and along the northeastern margin between Jarman Well and 17 Mile Well, a thick coarse-grained agglomerate and blue-grey tuffaceous rock (*AFra*) with a distinctive mottled weathered surface constitutes the basal unit of the Mount Roe Basalt. An additional component of this unit is a basalt–dacite breccia comprising a pale blue-grey dacite enclosed within a dark grey-green vesicular basalt. Such a unit suggests explosive lava mixing of dacite and basalt flows.

A small exposure of coarse- to fine-grained sandstone and polymictic conglomerate with clasts of chert, banded chert, quartzite, and vein chert (*AFrs*) underlies the basalt 5 km northwest of the Bamboo Creek Mining Centre. These fluvial deposits occupy a small palaeovalley, eroded in the underlying Coonieena Basalt, that controlled the initial outpourings of the basalt flows.

A dark-grey siliceous limestone and dolomite bed (*AFrk*) lies 600 m north of the Five Mile Hill microwave repeater station. Similar thin carbonate beds (1–2 m) are interlayered at several levels within the Mount Roe Basalt.

Hardey Formation, Oakover Syncline area (AFh, AFhc, AFhb, AFha, AFhu)

The Hardey Formation (Thorne et al., 1991) is a major epiclastic unit on YARRIE with considerable input of felsic volcanic and volcaniclastic material in the Gregory Range Inlier and east of the Bamboo Creek Mining Centre areas in the Oakover Syncline. The formalized members and other lithologic units of the Hardey Formation in the Gregory Range Inlier are described separately from the assemblages found in the Oakover Syncline. However, the lithostratigraphic equivalence of the two assemblages is strongly supported by geochronology, geochemical, and petrographic data (Thorne et al., 1991; Williams and Trendall, 1998a,b,c; Williams, 2001; Thorne and Trendall, 2001).

The Hardey Formation in the Oakover Syncline consists of five rock assemblages including the formalized felsic volcanic Bamboo Creek Member. The Hardey Formation disconformably overlies the Mount Roe Basalt and unconformably overlies the older Gorge Creek and Warrawoona Groups near the Yarrie microwave repeater station. The thickness of the Hardey Formation in the Oakover Syncline on YARRIE varies considerably from 1500 m in the core of the syncline near Thomas Well to less than 150 m south of 15 Mile Well.

The discontinuous basal unit of the Hardey Formation (*AFhc*) consists of polymictic matrix-supported pebble, cobble, and boulder conglomerate, wacke, sandstone, and siltstone. The unit is well exposed along the western side of the Oakover Syncline south of Thomas Well and along the northern boundary southwest of Granite Well. The latter exposure is a broad upward-fining conglomerate to siltstone succession. Conglomerate clasts include chert, BIF, and quartzites from the Gorge Creek Group, granitoid rocks from the older granitoid complexes, and amygdaloidal and vesicular basalt from the Mount Roe Basalt.

Bamboo Creek Member (*AFhb*)

The Bamboo Creek Member (Thorne and Trendall, 2001), generally considered to be a porphyry sill in the Hardey Formation (Hardey Sandstone of Noldart and Wyatt, 1962;

Hickman et al., 1983), has been shown to be a felsic volcanic succession of porphyritic rhyolite to dacite lavas and pyroclastic deposits, enlarged by the addition of comagmatic and synvolcanic porphyritic sills and dykes (Blake, 1984, 1993; Williams, 1999a, 2001; Thorne and Trendall, 2001).

The Bamboo Creek Member disconformably overlies the lower clastic unit (*AFhc*) and, where this is absent, the Mount Roe Basalt. Along Bamboo Creek some porphyry units intrude the lower basal clastic rocks (*AFhc*). On Miningarra Creek a peperite, attributed to intrusion into wet mud, has been recorded from the base of the Bamboo Creek Member (Williams, 1999a).

This member is laterally discontinuous. It is thickest east of the Bamboo Creek Mining Centre (~900 m) on the southwestern limb of the Oakover Syncline and south of Granite Well on the northern limb of the syncline. It is absent from the keel of the syncline where it is overlapped by the overlying, thick epiclastic mixed sandstone unit (*AFha*).

The Bamboo Creek Member consists of porphyritic, amygdaloidal, massive, fine-grained and flow-banded rhyolite, rhyodacite, and dacite flows admixed with crystal, lithic, and vitric tuffs, accretionary lapilli tuffs and welded tuffs. Near Five Mile Hill lapilli tuff contains accretionary lapilli up to 14 mm in size. Nearby amygdaloidal rhyolites contain quartz- and agate-filled amygdales (Williams, 2001). A porphyritic rhyolite from the Bamboo Creek Member yielded a U–Pb zircon age of 2756 ± 8 Ma (Arndt et al., 1991; see Table 2).

A quartz–feldspar porphyry dyke with spherulitic texture (*Aph*), dated at 2758 ± 4 Ma (Nelson, 1999, p. 140–143, GSWA Sample 142875; see Table 2), intrudes the Warrawagine Granitoid Complex 4.2 km north of Simpson Well. This age is similar to that of the Gregory Granitic Complex and the nearby Bamboo Creek Member of the Hardey Formation. Identical porphyry dykes, decribed from the Mount Edgar Granitoid Complex, are now interpreted to be feeder dykes for the Bamboo Creek Member (Williams and Bagas, in prep.).

In summary, the Bamboo Creek Member appears to be an eroded remnant of a large felsic volcanic edifice. It is coeval, and petrographically and chemically similar to the Koongaling Volcanic Member of the Hardey Formation in the Gregory Range Inlier (Williams, 2001; Thorne and Trendall, 2001).

The Bamboo Creek Member in the Oakover Syncline is disconformably overlain by an unnamed epiclastic unit (*AFha*) of medium- to very coarse grained feldspathic sandstone, pebbly sandstone, and conglomerate. Clasts in a thin conglomerate at the base of the sandstone unit (*AFha*) are almost exclusively porphyry suggesting derivation from the underlying Bamboo Creek Member. Near Helen Well, it is difficult to distinguish the overlying arkosic sandstone and conglomerate from the underlying porphyry unit. Such rocks are probably grus, the fragmental products of granular disintegration in situ of the underlying porphyritic felsic rocks. Both observations point to erosion before the deposition of the sandstone unit (*AFha*).

The sandstone unit (*AFha*), which fines upwards, is a spatially discontinuous fluvial unit (Blake, 1984) that is well developed on the western side and in the keel of the Oakover Syncline, where it is over 1000 m thick. It is overlapped to the southeast by a younger, mixed epiclastic–volcaniclastic unit (*AFhu*) west of 17 Mile Well, on the northern side of the Oakover Syncline.

The unnamed mixed epiclastic and volcaniclastic unit (*AFhu*) of the Hardey Formation comprises interbedded tuffaceous sandstone, siltstone, and shale with local felsic accretionary lapilli tuff beds. Thin sandstone and some conglomerate beds lie throughout the unit, whereas thin, white dolomitic horizons are found towards the top. The mixed epiclastic and volcaniclastic unit (*AFhu*) is thickest in the keel of the Oakover Syncline southwest of 6 Mile Well on Yarrie Station where it is up to 700 m thick. It gradually thins to the southeast where it disconformably overlies the Bamboo Creek Member. This unit also lenses out 6 km southwest of Granite Well beneath the Kylena Basalt.

The mixed epiclastic and volcaniclastic unit (*AFhu*) is postulated to be a lacustrine deposit with minor fluvial and distal volcanic input (Blake, 1984).

Hardey Formation, Gregory Range Inlier (AFhl, AFhim, AFhos)

Koongaling Volcanic Member (*AFhi, AFhim*)

The Hardey Formation in the Gregory Range Inlier on YARRIE is dominated by the basal Koongaling Volcanic Member (Hickman, 1978; Williams and Trendall, 1998a; Thorne and Trendall, 2001). The Koongaling Volcanic Member is exposed in a number of fault-bounded northwesterly plunging anticlines and is particularly well exposed in the Isabella Range. The nature of the basal contact with the underlying Gregory Granitic Complex is difficult to determine on YARRIE owing to poor exposure. Observations recorded on BRAESIDE to the south suggest a gradational contact with the granophyre (*AgGyy*). Although thickness is difficult to estimate because of repetition from steep reverse faulting, it is probably around 2000 m (Williams and Trendall, 1998a).

The Koongaling Volcanic Member (*AFhi*) is mainly a dark-grey or brown, porphyritic rhyolite, rhyodacite and dacite with few discernible flow structures. Phenocrysts are K-feldspar and quartz, mostly less than 5 mm across. On weathered surfaces, a near-vertical penetrative foliation parallel to the delimiting faults is evident.

On the eastern side of the Gregory Granitic Complex, 30 km southeast of Myijimaya, strongly deformed felsic volcanic rocks of the Koongaling Volcanic Member include metarhyolite, metadacite, and quartz–feldspar–mica schist (*AFhim*). The foliation is marked by biotite and white mica. Poikiloblastic garnet is seen in thin section.

Warroo Hill Member (*AFhos*)

The easternmost exposures of the Hardey Formation in the Gregory Range Inlier comprise low-grade mica-rich pelitic and psammitic schist and semischist of the Warroo Hill Member (Williams and Trendall, 1998b). These quartz- and mica-rich metasedimentary rocks overlie the Koongaling Volcanic Member. They may represent distal metamorphosed sandstone and siltstone equivalents of the feldspathic sandstone and conglomerate unit (*AFha*) of the Hardey Formation in the Oakover Syncline to the west.

Kylena Formation (AFk, AFka, AFkc)

The Kylena Formation (Kojan and Hickman, 1998; previously called Kylena Basalt by Kriewaldt and Ryan, 1967) is a widespread, predominantly mafic volcanic unit in both the Oakover Syncline and Gregory Range Inlier areas. The Kylena Formation disconformably overlies the upper mixed epiclastic–volcaniclastic unit (*AFhu*) and Bamboo Creek Member (*AFhb*) in the Oakover Syncline, and unconformably overlies the Koongaling Volcanic Member and unassigned Hardey Formation 5 km south-southeast of Snell Well in the Gregory Range Inlier.

In the Oakover Syncline, the Kylena Formation consists mainly of dark-grey to grey-green, massive, amygdaloidal and vesicular basalt, and basaltic andesite. These pass upwards into increasing amounts of pale-coloured, blue-grey, fine-grained andesite and possibly andesitic dacite. This change to more acidic rocks can be detected on the potassium and thorium gamma-ray spectrometric images (Mackey, 1997c).

The Kylena Formation is up to 1300 m thick in the Oakover Syncline (Williams, 2001). Some thick flows exhibit columnar jointing. The individual basalt flows are up to 10 m thick, and are marked by strongly amygdaloidal flow tops with irregular brecciation and criss-cross quartz veining indicative of subaerial extrusion. Amygdales are filled with quartz, agate (banded chalcedony), chlorite, and carbonate. The basalts have interstitial or intergranular texture and consist of clinopyroxene and partly altered plagioclase. Minor orthopyroxene is pseudomorphed by large patches of chlorite. Tremolite, chlorite, epidote, and minor sericite are secondary. Calcite veining is common in some flows.

A thick, cliff-forming, brown-weathered basaltic agglomerate (*AFka*) is prominent in the lower part of the Kylena Formation southwest of Jarman Well. In places, the basaltic agglomerate is underlain by a thin, lenticular, white carbonate (*AFkc*). Silica (blue chert) has extensively replaced microbial laminations in the carbonate. Some poorly preserved, low-profile cumulate stromatolites have been recorded (Williams, 1999a). Farther east, similar stromatolite-bearing, grey-white, cliff-forming carbonate and associated calcareous siltstone can be traced over a distance of 8 km southwest of Granite Well. The overlying siltstone has directional ripple marks that consistently indicate current movement from north to south. These deposits are probably lacustrine (Williams, 2001).

The Kylena Formation in the Gregory Range Inlier is exposed in a number of north-plunging anticlines bounded by steep reverse faults that make thickness estimates difficult (~1000 m; Williams and Trendall, 1998a). The Kylena Formation here consists predominantly of subaerial, massive, aphanitic to amygdaloidal, dark-green, well-jointed basalt flows. Individual flows are up to 20 m thick and have well-developed flow tops. These are recognized by bleached and silicified zones with criss-cross quartz veins and irregularly brecciated basalt. Amygdales increase upwards in individual flows and are filled with quartz, chlorite, and/or carbonate. In thin section the basalts are more altered than those found in the Oakover Syncline. Primary pyroxene and plagioclase are almost entirely altered to a fine-grained felted mass of secondary amphibole and are set in a matrix of albite, quartz, and epidote. A spaced cleavage is evident in some weathered exposures.

Tumbiana Formation (AFt)

The Tumbiana Formation (Lipple, 1975) is a laterally persistent mixture of carbonate, epiclastic, volcaniclastic, and mafic volcanic units that appears to conformably overlie the Kylena Formation. In the Oakover Syncline the formation is divided into the lower Mingah Tuff Member and the overlying Meentheena Carbonate Member. The total thickness reaches some 400 m. However, this twofold subdivision has not been recognized in the Gregory Range Inlier, where the thickness of the Tumbiana Formation is reduced to less than 200 m, and the spatial distribution of the formation is structurally complicated.

The Tumbiana Formation in the Gregory Range Inlier has a high carbonate content and a number of stromatolite forms have been recognized (Williams and Trendall, 1998a). The carbonates include well-stratified, pale to dark-grey and buff-weathered carbonate, alternating with thin, darker shaley carbonates, red-brown weathering to dark-grey dolomite and pale-grey limestone. The carbonates are interbedded with discontinuous units of shale, sandstone, pisolitic tuff, and thin amygdaloidal basalt flows. Numerous stromatolites in some carbonate horizons give reliable way-up directions in steep-dipping (~75°) Tumbiana Formation, as for example 6 km west of Snell Well.

Mingah Tuff Member (*AFtt*)

The Mingah Tuff Member (Lipple, 1975) is the lower and dominant member of the Tumbiana Formation in the Oakover Syncline on YARRIE. It consists of resedimented volcaniclastic, volcanogenic sedimentary, and pyroclastic units. Distinctive thin- to medium-bedded pisolitic tuff, including accretionary lapilli tuff beds, are common. Accretionary lapilli range from 2 to 10 mm in size. Bedded deposits show both normal and reverse grading. Pisolitic beds are up to 1 m thick and interlayered with blue-grey, vitric, crystal and lithic airfall tuff, and grey-green tuffaceous siltstone and sandstone. The high accretionary lapilli tuff content is attributed to frequent phreatomagmatic eruptions (cf. McPhie et al., 1993). Most of the lapilli beds have been reworked under subaqueous conditions.

Some carbonate beds lie towards the top of the formation. The tuffaceous sandstone and siltstone is ripple-marked and cross-bedded. Thin basalt flows are interspersed through the member in the western part of the Oakover Syncline on YARRIE.

Meentheena Carbonate Member (*AFtc*)

The Meentheena Carbonate Member (Lipple, 1975) is distinguished by the high proportion of dark-grey carbonate. The conformable base of the Meentheena Carbonate Member on the Mingah Tuff Member is taken as the first thick (>1 m) carbonate unit. Regionally, the boundary is gradational.

The carbonates are banded, dark-grey, dolomitic carbonate and limestone that contain numerous stromatolites in bioherms and biostromes, and scattered oncolites. The morphology and depositional environment of the stromatolites in the Meentheena Carbonate Member have been studied by Grey (1981, 1984), Walter (1983), Packer (1990), Buick (1992), Awramik and Buchheim (1997), and Thorne and Trendall (2001).

The carbonates are commonly cliff-forming. They are interbedded with red-brown to green-grey tuffaceous shale, siltstone, and minor thin-bedded lapilli tuff beds. Calcareous siltstone and sandstone, edgewise-carbonate conglomerate, and oolitic beds have also been recorded.

Several thick dolerite sills (*Ad*) intrude the Meentheena Carbonate Member, mostly along shale–siltstone horizons.

Traditionally, the Tumbiana Formation has been considered to be a near-shore shelf facies deposit adjacent to areas of phreatomagmatic volcanic activity (Thorne and Trendall, 2001). However, recent studies suggest depositional environment may have been lacustrine and fluvial with coeval volcanic activity (Awramik and Buchheim, 1997).

Maddina Formation (AFm)

The Maddina Formation (Kojan and Hickman, 1998; previously mapped as Maddina Basalt by MacLeod and de la Hunty, 1966) is widespread in the Oakover Syncline and Gregory Range Inlier (Williams, 1999a, 2001). In both areas it conformably overlies the Tumbiana Formation. The Maddina Formation occupies the core of the Oakover Syncline on YARRIE, where it is up to 1000 m thick (Williams, 2001), and is present in a number of fault slices in the Gregory Range Inlier, where it is at least 700 m thick (Williams and Trendall, 1998a).

In both areas, the Maddina Formation consists of thick, massive, amygdaloidal and vesicular basalt and andesite. Amygdales are filled with quartz, agate (banded chalcedony including carnelian), chlorite, calcite, and epidote. Up to 30 stacked basalt flows are recorded from the Gregory Range Inlier (Williams and Trendall, 1998a). Each flow has a distinctive silicified flow top marked by brecciation (scoriaceous), common amygdales, and criss-cross quartz veining.

Kuruna Member (*AFmk*)

The Kuruna Member (Thorne and Tyler, 1997; previously mapped as Kuruna Siltstone by MacLeod and de la Hunty, 1966) forms a distinctive horizon of siliceous vitric tuff, pisolitic lapilli tuff, tuffaceous sandstone, siltstone, and shale in the top one-third of the Maddina Formation. A discontinuous unit, it can be traced over several kilometres in the Lance Bore area in the central part of the Oakover Syncline and at the eastern end of the syncline west and north of Pinjian Pool (Williams, 1999a, 2001). The member is also an important marker horizon in the Maddina Formation of the Gregory Range Inlier, where it is about 70 m thick. Here it is a greyish-green, fine-grained, finely stratified felsic tuffaceous siltstone with rare sandstone. Accretionary lapilli bands are also present (Williams and Trendall, 1998a).

Jeerinah Formation (AFj)

Small areas of Jeerinah Formation (MacLeod et al., 1963; originally mapped as Lewin Shale by de la Hunty, 1964; Hickman et al., 1983 on YARRIE) are preserved in the Oakover Syncline (Williams, 1999, 2001) around Lance Bore and west and north of Pinjian Pool, where it disconformably overlies the Maddina Formation.

The Jeerinah Formation around Lance Bore occupies a small basin and is about 300 m thick. It consists of a mixed volcaniclastic and epiclastic succession of brown tuffaceous siltstone, khaki-brown lapilli tuff, vitric and crystal tuffs together with flaggy brown siltstone, shale, red-brown wacke, quartz pebble conglomerate, and blue chert (Williams, 1999a). Farther east, on the northern limb of the Oakover Syncline near Pinjian Pool, the lower part of the Jeerinah Formation comprises red-brown sandstone, siltstone, and shale, coloured and banded chert and yellow dolomite and sandy dolomite. Scattered goethite–limonite nodules after pyrite–marcasite weather from the shale horizons. This succession is at least 350 m thick (Williams, 2001),

The Jeerinah Formation in the Gregory Range Inlier is distinguished by the addition of two locally thick igneous members; the lower mafic volcanic Baramine Volcanic Member (*AFjv*), and the upper felsic igneous (?sill) Isabella Member (*AFji*). In other respects the lithologies in the Jeerinah Formation are similar to the epiclastic–chemical succession west of the Pinjian Pool in the Oakover Syncline. The succession in the Gregory Range Inlier consists of white-weathering shale, siltstone, mudstone, and sandstone together with cream to grey chert and thin-bedded dolomite up to 100 m thick beneath the Baramine Volcanic Member. Similar rocks separate the Baramine Volcanic Member from the Isabella Member. The sedimentary succession above the Isabella Member is characterized by banded and multicoloured chert, brown and cream siltstone and sandstone, silicified shale and thin bedded dolomite. The formation reaches 700 m in thickness.

Baramine Volcanic Member (*AFjv*)

The Baramine Volcanic Member (Hickman et al., 1983; Williams and Trendall, 1998a) is conformably contained within the lower part of the Jeerinah Formation and Gregory Range Inlier. It is up to 400 m thick and comprises dark-brown to dark-grey weathering, pyroclastic and volcaniclastic and volcanic rocks. These rocks are well jointed and weather in a karst-like fashion due to the high carbonate alteration of the volcanic rocks.

Specifically, the Baramine Volcanic Member consists of a mixture of bedded vitric, lithic and crystal tuffs, minor accretionary lapilli tuff interlayered with bedded fine to very coarse volcaniclastic rocks. The latter are characterized by thin- (centimetre-scale) to thick-bedded ($\leq$10 m) units of chaotic, unstratified aggregates of mafic lava clasts. These include glassy (vitric) basalt, vesicular trachybasalt, and fine-grained amygdaloidal, vesicular basalt and andesite. South of Barramine Homestead, welded volcanic agglomerate and breccia appear to be proximal explosive magmatic deposits.

Some of the volcaniclastic deposits show cross-bedding and normal and reverse graded bedding, but there is no strong evidence for water-lain turbiditic conditions (Williams and Trendall, 1998a). The bedforms in the Baramine Volcanic Member resemble pyroclastic surge deposits associated with phreatomagmatic eruptions and debris-flow deposits (cf. McPhie et al., 1993).

Isabella Member (*AFji*)

The Isabella Member (Williams and Trendall, 1998a) is a lensoid unit conformably enclosed within the Jeerinah Formation, and separated from the underlying Baramine Volcanic Member by fine-grained epiclastic rocks.

The Isabella Member is discontinuous along strike and reaches a maximum thickness of about 200 m south of the Barramine Homestead. It consists of brown-weathering, grey to blue, fine-grained or porphyritic rhyolite. It is characterized by small spherical amygdales filled with quartz, chlorite and carbonate restricted to some layers. Phenocrysts are K-feldspar, quartz and rare plagioclase. The groundmass can be granular or spherulitic. Blue silicified shales are interlayered with the rhyolite. The Isabella Member is interpreted as a felsic volcanic unit that includes some fine-grained synvolcanic intrusive units (Williams, 2001).

Mafic intrusive rocks (Ad)

Medium- to coarse-grained, weakly metamorphosed subophitic- to ophitic-textured dolerite dykes (*Ad*) intrude the Muccan and Warrawagine Granitoid Complexes and the Coppin Gap Granodiorite. The dykes trend from north-northwesterly to north-northeasterly. Although they can be traced over a distance of 10 km, they are made up of short (<2 km) linear dykes, discontinuous or en echelon along strike. The dykes also intrude the Mount Roe Basalt and hence are younger than the Black Range Dolerite (2772 ± 2 Ma; Wingate, 1999).

Similar medium- to coarse-grained, weakly metamorphosed dolerite and some gabbro form thick sills (*Ad*) in the Tumbiana Formation, particularly the Meentheena Carbonate Member, and in the Kuruna Member of the Maddina Formation. The dykes may be feeders to the sills in the Tumbiana Formation and Kuruna Member as well as flows in the Maddina Formation.

The dolerite sills in the Jeerinah Formation post-date the Maddina Formation basalts and are of unknown age.

Hamersley Group

The Hamersley Group (MacLeod et al., 1963) on YARRIE is represented solely by the Neoarchaean Carawine Dolomite (*AHc*).

Carawine Dolomite (AHc)

The Carawine Dolomite (Noldart and Wyatt, 1962; Hickman, 1983) is a major lithological component of the Gregory Range Inlier. In contrast, the Carawine Dolomite is restricted to a few rocky exposures along the Nullagine River north of Myolla Bore on the northern limb of the Oakover Syncline. In both areas the dolomite is capped or enclosed by the overlying Palaeoproterozoic Pinjian Chert Breccia (*Ꝑcb*). The Carawine Dolomite is exposed in irregular-shaped outcrops of cliff-forming dolomite that are enclosed within, or are overlain by, rubble-strewn Pinjian Chert Breccia.

The Carawine Dolomite is predominantly a brown-weathering, grey, recrystallized dolomite locally stained orange, red-brown, and blue-black from iron and manganese impurities. The structural complexities of the Gregory Range Inlier area, together with extensive Pinjian Chert Breccia cover, preclude valid thickness estimates. The Carawine Dolomite exhibits a wide variety of sedimentary structures. These include wave ripples, flat-pebble conglomerate, oolites, evaporitic crystal pseudomorphs, oncolites, and stromatolites (Simonson et al., 1993).

Simonson et al. (1993) considered the Carawine Dolomite to be a shallow-water platform deposit. A Pb–Pb isochron age of 2541 ± 32 Ma, interpreted to be a minimum age and possibly reflecting regional diagenesis, has been obtained from the Carawine Dolomite (Jahn and Simonson, 1995).

Structure

The Neoarchaean (c. 2775–2541 Ma) Fortescue Group and Carawine Dolomite of the Hamersley Group in the Hamersley Basin are exposed in two structurally different tectonic settings on YARRIE: the Oakover Syncline and the Gregory Range Inlier.

In the southwestern quarter of YARRIE, the Fortescue Group and Carawine Dolomite are now preserved in the large, open, southeasterly plunging Oakover Syncline (Hickman et al., 1983). The Fortescue Group is unconformable on what was considered to be a largely stabilized and cratonized East Pilbara Granite–Greenstone Terrane (Blake, 1984). The Oakover Syncline overlies older greenstone belts made up of the Warrawoona and Gorge Creek Groups. These, in turn, occupied earlier synclinal belts lying between the Warrawagine Granitoid Complex and Muccan Granitoid Complex to the west, and the Warrawagine Granitoid Complex and the Mount Edgar Granitoid Complex to the southwest.

The presence of a deep, older synclinal keel beneath the younger Fortescue Group is supported by 3D geometry studies of gravity and TMI data (Wellman, 2000). The easterly extension of the Gorge Creek Group, which is also unconformable on the Warrawagine Granitoid Complex beneath the Fortescue Group in the Oakover Syncline, has been discussed by Williams (2001).

The relationship between the older greenstones in the nested synclinal structures and adjacent granitoid complexes in the EPGGT, and the later preservation of the Fortescue Group over such areas, has been discussed by Hickman (1983, 1984) and Blake (1984, 1993). Such Fortescue Group-bearing synclinal structures may be the result of ongoing or renewed mild, intra-cratonic diapiric readjustments between the granitoid complexes and the adjoining and commensurate sinking greenstones (Hickman, 1984; Blake, 1984, 1993; Van Kranendonk et al., 2002).

The Oakover Syncline is truncated by northerly to north-northwesterly trending brittle faults. Some appear to be reactivated basement faults or extensions thereof (Elephant Rock Fault;

Williams, 1999a), whereas others may be related to successive Proterozoic events evident in the Gregory Range Inlier to the east (Williams and Trendall, 1998a; Williams, 2001). Although most faults are steep normal faults (block faults), some in the western parts show a small dextral strike-slip component (Williams, 1999a), and in the eastern parts, steep reverse movement with east-block up (Williams, 2001). The Oakover Syncline, in the present schema, would be a D_6 structure (Hickman et al., 1983).

Lithostratigraphically, the Fortescue Group and Carawine Dolomite of the Oakover Syncline area are linked subsurface to the same rocks of the Gregory Range Inlier in the southeast quarter of YARRIE. Seismic refraction profiles across the Nullagine and Oakover river valleys show that the Precambrian basement beneath Permian rocks is as much as 660 m below the present-day surface (Sentinel Mining Company, 1967).

The major difference between the rocks of the Fortescue Group in the Oakover Syncline and Fortescue Group rocks of the Gregory Range Inlier is that in the latter area they pass gradationally down into the Gregory Granitic Complex (c. 2764–2757 Ma) and do not unconformably overlie the EPGGT (c. 3510–2831 Ma).

The distribution of the Fortescue Group and Carawine Dolomite in the Gregory Range Inlier is controlled by numerous, in places anastomosing northwesterly to north-northwesterly striking, steep northeasterly dipping reverse faults. These faults post-date north-northwesterly plunging open to tight folds. The fold profiles are asymmetric with steeply west-dipping and moderately east-dipping bedding on the anticlinal folds. Most synclines are sheared or faulted.

The deformation of the Fortescue Group and Carawine Dolomite is connected to Mesoproterozoic and Neoproterozoic tectonic events discussed later (see **Structure** — Proterozoic).

It has been argued that some of the large, steep reverse faults with transport from east to west may originally have been listric growth faults, with east-side down, during the early depositional history of the Fortescue Group (Trendall, 1991; Williams and Trendall, 1998a,b,c). The extensional or rift regime, active during this time (Blake and Groves, 1987; Blake and Barley, 1992; Blake, 1993; cf. Thorne and Trendall, 2001), may also be connected with the generation and emplacement of the anhydrous, alkaline, A-type Gregory Granitic Complex. The complex has been shown to be chemically and geochronologically related to the overlying basal Koongaling Volcanic Member of the Hardey Formation (Williams and Trendall, 1998b,c). Negative ε_{Nd} values, obtained from the Koongaling Volcanic Member, suggest that the older granite–greenstones of the EPGGT were the probable source material for the Gregory Granitic Complex (Nelson et al., 1992).

PROTEROZOIC ROCKS

Sedimentary rocks

Pinjian Chert Breccia (Ɇcb)

The Pinjian Chert Breccia (Noldart and Wyatt, 1962) has the same regional distribution as the Carawine Dolomite of the Hamersley Group. In many areas it is the dominant lithology enclosing numerous remnants of the Carawine Dolomite. The breccia is found in the Myolla Bore area in the Oakover Syncline, and is a major unit along the western side of the Gregory Range Inlier.

The Pinjian Chert Breccia unconformably overlies the Carawine Dolomite. The highly irregular contact is the result of infilling of a coevally developing palaeokarst surface in subaerially exposed dolomite, a process that has continued intermittently to the present day (Hickman, 1983; Williams and Trendall, 1998b). The Pinjian Chert Breccia weathers to large rounded, rubble-strewn hills and contrasts strongly with cliff-forming Carawine Dolomite.

The Pinjian Chert Breccia consists of randomly mixed, chaotic or crudely bedded, chert and banded chert fragments. The chert fragments appear to come from a number of sources. These include primary banded chert that was locally deposited above the dolomite and may be equivalent in age to the Palaeoproterozoic component of the Hamersley Basin. This chert would have been locally deposited on the Carawine Dolomite before uplift and commencement of subaerial karstification and solutional collapse of the underlying dolomite. A second origin would be the release of primary chert beds interlayered with the dolomite during the dissolution of the carbonate. The third contribution may have come from secondary chert formed during diagenetic silicification of the carbonate also being released by later dissolution (Williams and Trendall, 1998b).

Felsic and mafic intrusive rocks

A distinctive suite of hornblende-bearing granitoid plutons and hornblende-phyric trachyandesite dykes intrude the EPGGT and Fortescue Group of the Hamersley Basin in the southwest corner of YARRIE.

These dykes and plutons lie at the northern end of a broad zone some 50 km wide that extends about 250 km to the south-southeast from near Yarrie Village in the north to about 16 km west of Balfour Downs Homestead in the south (Hickman, 1983; Rock and Barley, 1988; Williams, 1989, 1999a). Both dykes and plutons have been recently assigned to the Bridget Suite (Budd et al., 2002; Williams and Bagas, in prep.).

Hornblende monzogranite and granodiorite (Ꞓgh)

Pinkish-green to grey-green hornblende monzogranite, granodiorite, and sporadic monzogranite and syenite plutons intrude the Apex and Euro Basalts southwest and southeast of the Bamboo Creek Mining Centre. A larger cluster of eight similar plutons intrudes the Kylena Formation and Mingah Tuff Member of the Tumbiana Formation 25 km northeast of the Bamboo Creek Mining Centre. Other small intrusions lie just south and southwest of Yarrie Village, and just south of Thomas Well.

The plutons are fine to medium grained with hypidiomorphic to allotriomorphic granular-textured assemblages of plagioclase (oligoclase–andesine), K-feldspar, green to light-brown pleochroic hornblende, and some quartz. The K-feldspar is commonly perthitic. Some hornblende grains have clinopyroxene cores, and are partially altered to chlorite (Williams, 1999). The plutons are characterized by sharp contact aureoles with hornblende-hornfels-facies metamorphism. In some areas trachyandesite dykes are connected with these plutons. Similar plutons have been described by Lewis and Davy (1981), Hickman (1983), Hickman et al. (1983), Rock and Barley (1988), and Williams and Bagas (in prep.).

A similar pluton of medium-grained hornblende granodiorite and fine-grained hornblende monzogranite intrudes the Coppin Gap Granodiorite near No. 3 Bore.

This pluton was originally assigned to the Hardey Formation on the basis of a U–Pb zircon age of 2557 ± 7 Ma (Nelson, 1998, p. 148–150, GSWA Sample 142825; see Table 2).

However, recent K–Ar and ^{46}Ar/^{39}Ar dating has shown that the pluton is of Proterozoic age and that the zircons are xenocrysts and do not give the age of intrusion.

The oldest K–Ar date of 1598 ± 32 Ma, obtained from hornblende, is interpreted as a minimum age for igneous crystallization of the granodiorite (Nelson, 2002, p. 258–259, GSWA Sample 14285; Table 3). In addition, the Ar–Ar dating of the hornblende obtained a ^{46}Ar/^{39}Ar date of 1730 ± 9 Ma. This is also interpreted as a minimum age but is much closer to the age of igneous crystallization (Nelson, 2003, p. 126–128, GSWA Sample 14285).

Trachyandesite and lamprophyre dykes (Ꝑph)

Swarms of porphyritic trachyandesite and lamprophyric dykes intrude the Chimingadgi Trondhjemite, Mullugunyagh and Coppin Gap Granodiorites, and the southeastern part of the Muccan Granitoid Complex. A few dykes also intrude the Warrawagine Granitoid Complex, the Warrawoona Group southwest of the Bamboo Creek Mining Centre, and the Fortescue Group. A characteristic of the dykes is the sinuous outcrop pattern in the granitoid complexes, and straight or slightly arcuate trends in the supracrustal rocks. Four main dyke trends are recorded in the granitoid complexes: 315°, 360°, 040°, and 080° (Williams, 1999a).

The dykes are pinkish grey to pinkish grey-green porphyritic rocks with a fine-grained groundmass. Mafic phenocrysts are dominant, mainly acicular or platy, idiomorphic hornblende, some biotite, and occasional clinopyroxene. In some dykes plagioclase phenocrysts are also common, whereas K-feldspar and quartz phenocrysts are always minor. The groundmass varies between a swirly, trachytic-textured acicular hornblende and microlath feldspar matrix to a more fine-grained granular, micropoikilitic-textured groundmass of K-feldspar, quartz, and opaques.

PATERSON OROGEN

The Paterson Orogen (Williams and Myers, 1990; Bagas et al., 1995) is exposed on the eastern side of the Gregory Range Inlier, in the southeast quarter of YARRIE (Fig. 4). These outcrops are the northwesternmost exposures of the Paterson Orogen, an arcuate belt of Palaeoproterozoic to Neoproterozoic sedimentary, metamorphic, and igneous rocks. This arcuate belt, delineated by gravity highs known as the Warri Gravity Ridge (Iasky, 1990) beneath Phanerozoic cover, extends over 1200 km southeast to the Musgrave Complex area in Central Australia. The Warri Gravity Ridge also marks the boundary between the Phanerozoic Canning Basin to the north and the stacked, Proterozoic Officer and Phanerozoic Gunbarrel Basins to the south (Hocking, et al., 1994).

On YARRIE, exposures of the Paterson Orogen consist of the metasedimentary Mesoproterozoic to Neoproterozoic Throssell Group in the east separated from the Neoproterozoic sedimentary Tarcunyah Group in the west by the dextral transpressional, steeply east-dipping Vines Fault (Williams, 1990). The Tarcunyah Group unconformably overlies the Pilbara Craton (Fig. 5). Along the southern boundary of YARRIE, east of the Throssell Group outcrops, shallow exploration drillholes have intersected shale and dolomite, beneath Permian cover rocks, that have been correlated with the Lamil Group (Williams and Trendall, 1998a). The Throssell and Lamil Groups make up the Yeneena Supergroup of the Yeneena Basin (Williams and Bagas, 1999; Bagas et al., 1995, 1999; Figs 5 and 6c). The metamorphosed and deformed Yeneena Supergroup is considered to be slightly older than the less deformed and unmetamorphosed Tarcunyah Group. The

Tarcunyah Group is correlated with Supersequence 1 of the Centralian Superbasin (Bagas et al., 1999; Williams and Bagas, 1999) and has been shown to be the northwestern extension of the Officer Basin (Bagas et al., 1995, 1999; Grey and Stevens, 1997; Williams and Bagas, 1999). The Eel Creek Formation that unconformably overlies units of the Pilbara Craton in the central-west part of YARRIE has been correlated with the Neoproterozoic Tarcunyah Group (Williams, 1999a, 2001; Fig. 5).

Throssell Group

The Throssell Group (Williams and Bagas, 1999) consists of the basal Coolbro Sandstone and overlying Broadhurst Formation. Both formations have undergone low-grade greenschist-facies metamorphism and have been multiply deformed during the Miles Orogeny (Proterozoic D_3–D_4) and later Paterson Orogeny (Proterozoic D_6; Bagas and Smithies, 1998; Williams and Bagas, 1999, 2000; Table 1).

The Throssell Group rocks lie to the east of the Tarcunyah Group, from which they are separated by the major Vines Fault. The Throssell Group has a distinctive regional north-northwesterly trending magnetic signature on the YARRIE TMI image (Fig. 6; AGSO, 1993a). This magnetic signature can be traced north-northwest across YARRIE beneath the sedimentary rocks of the Phanerozoic Canning Basin (Williams and Trendall, 1998a).

A quartzite intersected 99 m below Permian sandstone in a 150 m exploration drillhole 25 km north of Mount Cecelia (Johnson, 1993) is assigned to the Throssell Group. The Throssell Group constitutes the basement for the Wallal Platform tectonic unit of the Canning Basin (Fig. 4; Williams and Trendall, 1998a).

Coolbro Sandstone (ꝐTc)

Scattered exposures of Coolbro Sandstone (Williams et. al., 1976) lie east and north of Myijimaya, where they form north-northwesterly striking ridges. At Iron Hill, The Coolbro Sandstone is separated from thin-bedded dolomite of the Waroongunah Formation of the Tarcunyah Group by the Vines Fault. The thickness of the Coolbro Sandstone on YARRIE is difficult to estimate due to isoclinal folding but it appears to be at least 200 m thick (Williams and Trendall, 1998a).

The Coolbro Sandstone is predominantly a metamorphosed, fine- to coarse-grained, blue, grey, cream, and white quartz sandstone. Interbedded quartz-pebble conglomerate and brown shale are also present. In thin section the sandstone is recrystallized, with a weak to moderate fabric enhanced by secondary white mica and biotite. Chert, jasper and detrital muscovite are minor components. Pyrite, both nodular and crystalline, is locally abundant. Graded bedding, symmetrical wave-generated ripple marks and minor cross-beds are locally present. Palaeocurrent data are inconclusive.

The Coolbro Sandstone is interpreted as a deltaic–fluviatile succession (Hickman and Clarke, 1994).

Broadhurst Formation (ꝐTb, ꝐTbd, ꝐTbt)

The Broadhurst Formation (Williams et al., 1976) is exposed in a series of low hills 17 km east of Myijimaya. Overall exposure is poor but the economic potential for base metal prospects in the Broadhurst Formation (Smith and Gemmell, 1994) has led to numerous shallow exploration drillholes outlining the subsurface distribution of the Broadhurst

Formation. The conformable contact with the underlying Coolbro Sandstone is not exposed on YARRIE. The thickness has been estimated to be about 2500 m but poor outcrop and suspected isoclinal folds make this difficult to confirm (Williams and Trendall, 1998a).

Two distinct lithological assemblages are recognized in the Broadhurst Formation on YARRIE. The main assemblage (*ЕTb*), intersected in numerous shallow exploration drillholes, comprises poorly outcropping black to dark-grey carbonaceous shale and siltstone, interbedded with fawn to greenish-grey dolomitic siltstone, shale, and cream, fine-grained sandstone. This assemblage is typical of the Broadhurst Formation elsewhere (Hickman and Clarke, 1994; Williams and Bagas, 1999). Olive-green biotite, white mica, carbonate and quartz assemblages in these rocks indicate greenschist-facies metamorphism.

The second lithological assemblage (*ЕTbd*) is well exposed in low hills and rises 8 km east of Iron Hill. It consists of karstic-weathered, and silicified limestone and dolomite with thin blue chert beds and pods. The carbonate rocks range from dark-blue and grey, thick-bedded limestone, to thin-bedded, multicoloured (white, cream, pink, brown, green-grey, purple and violet) dolomite. A thick chert bed (*ЕTbt*), possibly replacing dolomite or limestone, contains poorly preserved microbial laminations and some broad, domical, fenestrated stromatolites. Minor interbeds of shale, thin-bedded sandstone and quartz-pebble conglomerate are also present in the carbonate assemblage.

The Broadhurst Formation is a transgressive shallow-marine deposit. The high percentage of carbonaceous shale suggests euxinic conditions. The presence of stromatolites indicates shallow-water conditions.

Tarcunyah Group

Tarcunyah Group rocks (Williams and Bagas, 1999) are found in two main localities on YARRIE (Figs 5 and 6d). In the southeast part of YARRIE the Tarcunyah Group is exposed in a narrow belt on the eastern side of the Gregory Range Inlier where the group unconformably overlies Hamersley Basin components of the Pilbara Craton. The second locality, the Eel Creek Embayment, is situated in the central west of YARRIE. Here, the Eel Creek Formation, a correlate of units in the Tarcunyah Group (Williams, 1999, 2001), unconformably overlies elements of the EPGGT of the Pilbara Craton (Fig. 5). These two areas are postulated to be linked beneath later Phanerozoic-cover rocks deposited in the Canning Basin and on the Lambert Shelf (Fig. 6d).

The Tarcunyah Group is correlated with Supersequence 1 of the Centralian Superbasin (Bagas et al., 1999) and is the northwest continuation of the Officer Basin (Stevens and Grey, 1997; Bagas et al., 1995, 1999; Williams and Bagas, 1999). The Tarcunyah Group is largely unmetamorphosed but was moderately to tightly folded during the Paterson Orogeny (Proterozoic D_6; Bagas and Smithies, 1998) on YARRIE (Fig. 5).

Overall, the Tarcunyah Group east of the Gregory Range Inlier is not well exposed. It is bordered to the east by the transpressional Vines Fault that may have overridden the entire succession 20 km southeast of Myijimaya. On the western side, the group unconformably overlies or is in faulted contact with the Gorge Creek Group, the Gregory Granitic Complex and units of the Fortescue Group, all part of the Pilbara Craton. The unconformity is tightly folded and thin slivers of Tarcunyah Group are preserved in faulted synclines just southeast of Myijimaya and south of Mount Cecelia.

The Tarcunyah Group east of the Gregory Range Inlier is represented by the basal Googhenama and overlying Waroongunyah Formations on YARRIE.

Googhenama Formation (ꝒUg)

The basal Googhenama Formation (Williams, 1990) is a mixed sandstone unit up to 300 m thick that thins northwards and is overlapped by the Waroongunyah Formation southeast of Myijimaya. It unconformably overlies the Gregory Granitic Complex, the Koongaling Volcanic and Warroo Hill Members of the Hardey Formation, and the Kylena Formation of the Fortescue Group.

The Googhenama Formation, overall an upward-fining succession, consists of intermixed white, grey and cream, medium- to very coarse grained quartz sandstone, red brown ferruginous sandstone, pebbly sandstone, and pebble to cobble conglomerate. Feldspar, detrital muscovite and chert fragments are a minor component in some beds. Palaeocurrent directions, derived from both planar and trough cross-beds, indicate transport to the east off the Pilbara Craton.

Waroongunyah Formation (ꝒUw, ꝒUws, ꝒUwd)

On YARRIE, the Waroongunyah Formation (Williams, 1989) is best exposed east and north-northwest of Myijimaya, where it unconformably overlies or is faulted against the Kylena Formation of the Fortescue Group. The Waroongunyah Formation in this area is at least 700 m thick.

The Waroongunyah Formation is characteristically a mixture of thin-bedded and laminated, multicoloured dolomite and brown to grey, calcareous shale and siltstone (*ꝒUw*). Thin beds of medium- to coarse-grained dolomitic sandstone and wacke and pebbly dolomite are found at irregular intervals throughout this succession. North-northwest of Myijimaya the formation comprises cross-bedded, maroon, and brown fine- to medium-grained sandstone and siltstone (*ꝒUws*) and light-brown, medium-bedded to laminated dolomite and stromatolitic dolomite (*ꝒUwd*). A small klippe of tightly folded, khaki-green to grey, banded, sandy and shaly dolomite and thin-bedded chert (*ꝒUw*) is faulted against the Nimingarra Iron Formation of the Gorge Creek Group on the northern side of Mount Cecelia.

The Waroongunyah Formation is a transgressive shallow-marine succession. It was probably deposited shorewards from barrier islands or carbonate platforms marginal to the Pilbara Craton (Williams and Trendall, 1998c; Williams and Bagas, 1999).

Eel Creek Formation (ꝒUe, ꝒUeh, ꝒUeq)

The Eel Creek Formation is well exposed in the central western part of YARRIE in a southeasterly trending band between Cattle Gorge Bore and Moxon Well. It is an unmetamorphosed epiclastic succession, with a minor volcanic component, over 500 m thick that unconformably overlies the Warrawoona, Gorge Creek, and De Grey Groups, and Muccan and Warrawagine Granitoid Complexes. It is, in turn, unconformably overlain by the fluvioglacial Permian Paterson Formation and Jurassic–Cretaceous Callawa Formation. The formation is widely intruded by fine- to medium-grained dolerite and quartz dolerite sills and dykes (*Ꝓde*)

The Eel Creek Formation consists of black, grey, blue and green mudstone, shale, siltstone and fine-grained, thin-bedded sandstone (*ꝒUe*). Between Cattle Gorge Bore and Cabbage Tree Well the basal unit is a distinctive, but discontinuous, hematite-clast-rich conglomerate with thin, interbedded, ferruginous siltstone and sandstone (*ꝒUeh*) up to 12 km thick (Waters, 1998). To the north and east the basal hematite conglomerate is overlapped by shale, mudstone, siltstone, resedimented pyroclastic rocks and possible devitrified rhyolite and dacite tuffs (Williams, 1999a).

Overall, the formation is an upward-coarsening succession. The upper unit consists of fine- to coarse-grained sandstone, white quartz sandstone, and brown to grey micaceous siltstone (*Ꝑυeq*). Red-brown, fine-grained sandstone northeast of Reid Bore carries halite pseudomorphs. Glauconite has been identified in siltstone east of the Y10 iron ore mine (Williams, 1999a). The interbedded siltstone and sandstone preserve numerous sedimentary structures including flute casts, tool marks, small-scale wave and current ripple marks, cross-beds, including rib and furrow structures, mud cracks, and subaqueous syneresis cracks.

The Eel Creek Formation, which is deposited in the shallow-marine Eel Creek Embayment overlying the Pilbara Craton, is an easterly to northerly dipping succession. As shown in Figure 6d, the Eel Creek Embayment is postulated to extend eastwards and southeastwards to link up with the Neoproterozoic Tarcunyah Group (north of Mount Cecelia and beneath the Phanerozoic cover of the Canning Basin and Lambert Shelf (Williams, 2000)).

A stratigraphic well, Pandanus 1, drilled to 880 m 12 km northeast of Callawa Homestead, intersected green to dark-grey quartzite at 854 m (Pandanus Resources, 1985). These quartzites resemble those found in the Eel Creek Formation and Tarcunyah Group.

Mafic intrusive rocks (Ꝑd, Ꝑde)

Some north-trending dolerite dykes (*Ꝑd*) intrude the Gregory Granitic Complex 20 km southeast of Myijimaya. The medium-grained dolerite dykes are cut by quartz veins attributed to the Paterson Orogeny (Proterozoic D_6; 550 Ma, Bagas, 2000). Dolerite sills have been intersected in the Broadhurst Formation by exploratory mineral drilling 6 km east-northeast of Myijimaya.

Fine- to coarse-grained dolerite sills and feeder dykes (*Ꝑde*) are prominent in the Eel Creek Formation. The dolerite has a subophitic texture with local amygdales suggesting a shallow emplacement. The dolerite is made up of plagioclase laths, interstitial clinopyroxene, minor green and brown hornblende, and sparse olivine. Patchy myrmekitic intergrowths of K-feldspar and quartz are found in the coarse-grained sills. Baddeleyite is visible in thin section. The larger dolerite intrusions have contact metamorphosed the enclosing shale and siltstone producing blue-black hornfels.

Structure

The Proterozoic Paterson Orogen demarcates the north-northeast boundary of the Archaean–Palaeoproterozoic Pilbara Craton on YARRIE. Although the lithostratigraphic components of the Paterson Orogen, and the Throssell and Tarcunyah Groups, are exposed just east and north of the Gregory Range Inlier, gravity and TMI data (BMR 1979, AGSO 1993b) show that the Pilbara Craton – Paterson Orogen contact continues north-northwesterly across YARRIE beneath Phanerozoic cover rocks of the Canning Basin (Figs 5 and 6c,e,f). However, the tectonic relationships between the Tarcunyah Group and the Pilbara Craton, and the Throssell Group and the Pilbara Craton are very different. The Tarcunyah Group, now part of the northwest Officer Basin (Bagas et al., 1995, 1999; Williams and Bagas, 1999), together with its northwesterly lying coeval equivalent, the Eel Creek Formation, unconformably overlies the Pilbara Craton. Clast composition and palaeocurrent data strongly support a Pilbara Craton provenance for epiclastic rocks of the Tarcunyah Group (Williams and Trendall, 1998a,b,c).

The Throssell Group, on the other hand, is faulted against both the Tarcunyah Group and the Pilbara Craton. This tectonic contact most probably marks the true edge of the Pilbara Craton, as highlighted by the marked change in the TMI signature and gravity data (Figs 5 and 6c). East of the Gregory Range Inlier, this tectonic contact corresponds to the Vines Fault that separates the Throssell Group from the Tarcunyah Group. The Vines Fault (Williams and Myers, 1990; Williams, 1990; Bagas et al., 1995) is a dextral, transpressional, steep reverse fault that has transported the Throssell Group up and west-southwest over the Tarcunyah Group and onto the Pilbara Craton.

Recent studies (Bagas et al., 2002) on the Throssell and Lamil Groups of the Yeneena Basin (Williams and Bagas, 1999) have tentatively concluded that the Throssell and Lamil Groups may be allochthonous in respect to the Pilbara Craton and Tarcunyah Group. Detrital zircon geochronological studies of samples collected from the Throssell and Lamil Groups have indicated that the provenance for the epiclastic rocks is more likely to be the Musgrave Complex, which lies 800 km to the southeast, than the adjacent Pilbara Craton. The transpressional Mackay Fault, Southwest Thrust, and Vines Fault are connected with the west-southwesterly directed transport process (Bagas et al., 2002).

Previous research in the Paterson Orogen had come to recognize six major deformation episodes and three regional metamorphic events connected with the Yapungku Orogeny (Proterozoic D_{1-2}; c. 2000–1760 Ma; Bagas and Smithies, 1998), Miles Orogeny (Proterozoic D_{3-4}; c. 1250–800 Ma; Bagas and Smithies, 1998), Blake Movement (Proterozoic D_5; <800 Ma; Williams and Bagas, 1999) and Paterson Orogeny (Proterozoic D_6; c. 550 Ma; Bagas and Smithies, 1998).

On YARRIE, the Throssell Group exhibits two periods of folding (Proterozoic D_3 and D_4, Miles Orogeny) intersected by later shearing (Proterozoic D_6; Paterson Orogeny; Williams and Trendall, 1998a). Folds are inclined or overturned to the southwest. The bedding is cut by a pervasive, steep northeast-dipping axial-planar cleavage. The Proterozoic D_4 event is closely associated with low-grade greenschist-facies metamorphism. Narrow shear zones post-date the Proterozoic S_4 foliation. These have been attributed to imbrication associated with the Proterozoic D_6 Vines Fault.

The adjacent Tarcunyah Group is folded and faulted by the Proterozoic D_6 Paterson Orogeny. This has produced moderate to tight upright to southwesterly inclined folds that possess a weak axial-planar, spaced cleavage. Metamorphism is absent or very low grade in localized strongly sheared areas. The Tarcunyah Group is also preserved as slivers in tight, faulted-out synclines, coupled with broad southwest-inclined, northwesterly plunging anticlines that involve the underlying Fortescue Group rocks of the Gregory Range Inlier. The close relationship between faulting and folding of the unconformably overlying Tarcunyah Group points to reactivation of pre-existing faults in the Fortescue Group basement.

As reported in the section on the Hamersley Basin **Structure**, the extensional regime extant during deposition of the lower Fortescue Group (Blake, 1993; Thorne and Trendall, 2001) may have produced east-dipping listric growth faults in the Gregory Range Inlier (Trendall, 1991). These major faults may subsequently have acted as zones of weakness in later events that saw successive compressional episodes associated with the Yapungku, Miles, and Paterson Orogenies of the Paterson Orogen. What had been normal, east-dipping listric faults, were reactivated as steep reverse and thrust faults, with movement up and directed towards the west and southwest.

The regional events in the Proterozoic Paterson Orogen that brought about the deformation recorded along the eastern margin of the Pilbara Craton in the Gregory Range Inlier is discussed by Myers (1993), Hickman et al. (1994), Myers et al. (1996), Smithies and Bagas (1997), Bagas and Smithies (1998), Hickman and Bagas (1998), Williams and Trendall (1998a,b,c), and Tyler (2000).

In summary, these processes were initiated by the collision of the North Australian Craton with the West Australian Craton during the Yapungku Orogeny (Myers et al., 1996; Bagas and Smithies, 1998; Tyler, 2000). Later, continent–continent compressional movement initiated strike-slip movement (Hickman et al., 1994), This is revealed in the Gregory Range Inlier as sinistral strike-slip movement of up to 38 km in Fortescue Group rocks and possible, vertical movement of some 15 km in the granitoid gneisses of the Gregory Granitic Complex (Williams and Trendall, 1998b,c). This activity is attributed to the Miles Orogeny ($D_{3–4}$). Rubidium–strontium mineral isochron biotite ages of 1226 and 1194 Ma obtained from the Gregory Granitic Complex (de Laeter et al., 1977) may indicate the age of uplift (Hickman et al., 1994; Williams and Trendall, 1998c).

During the later Paterson Orogeny (Proterozoic D_6) the pre-existing sinistral strike-slip fault was reactivated, this time with dextral transpressional reverse movements. This deformation also folded and faulted the unconformably overlying Tarcunyah Group rocks. Further details of structures within the Gregory Range Inlier on YARRIE, which can be related to Proterozoic events, are found in Williams and Trendall (1998a) and Williams (2001).

The Eel Creek Formation is folded into asymmetric, northerly plunging folds at irregular intervals. The fold profiles have near vertical to overturned western limbs and shallow-dipping eastern limbs. Larger folds are concentric and axial-planar cleavage is absent. Such folds disappear westwards across the Eel Creek Formation exposure. The origin of the folding is attributed to the compressional activity of the Paterson Orogeny (Proterozoic D_6) adjacent to the Pilbara Craton to the east.

Unassigned dolerite dykes (d) and quartz veins (q)

Dolerite dykes (*d*) of unknown age are scattered throughout the Muccan, Warrawagine, and Mount Edgar Granitoid Complexes and pass up through the Warrawoona, Gorge Creek, Fortescue, and Hamersley Groups. Some dykes are well exposed, fine- to medium-grained dolerite, others are weathered, and some are only picked out by magnetic signatures on the regional TMI image (Fig. 6).

The most persistent dykes are northerly trending and consist of fine-grained dolerite with a bouldery surface expression and sinuous outcrop pattern. They are widely spaced across YARRIE and cut D_6 structures in the Gregory Range Inlier. Other dykes trend west-northwesterly to northwesterly (Round Hummock Suite; Hickman, 1983) and east-northeasterly to northeasterly (Mundine Well Suite; Hickman, 1983). The latter have recently been dated, using SHRIMP U–Pb baddeleyite geochronology, at 755 ± 3 Ma (Wingate, 1997).

Prominent quartz veins (*q*) infill major fault lines in the Warrawagine and Muccan Granitoid Complexes. Quartz ridges up to 70 m high lie southeast of Callawa Homestead and just west of Du Valles Well. Quartz veins, comprising massive to faintly banded cryptocrystalline quartz, occupy joints and shear zones. These are particularly common in the southern and eastern parts of the Warrawagine Granitoid Complex and the southern part of the Muccan Granitoid Complex.

PHANEROZOIC ROCKS

The Third Edition YARRIE sheet (Williams, 2002) does not include detailed field remapping of the Phanerozoic component. Some widely spaced traverses were carried out on ISABELLA, WARRAWAGINE, and COORAGOORA 1:100 000-scale sheets for checking purposes. No field work was undertaken on CARDOMA and BULGAMULGARDY 1:100 000 sheets, although photointerpretation, using black and white aerial photographs flown in 1994, and Landsat TM images were used to establish rock outcrops and superficial-cover boundaries in order to bring them into line with the mapping carried out on the adjacent 1:100 000-scale sheets. A review of the literature and a reassessment of the structural framework was also undertaken in the light of recent work (Hocking et al., 1994).

CANNING AND NORTHERN CARNARVON BASINS

The Canning Basin (Towner and Gibson, 1983; Fig. 4) occupies the eastern margin and the northeastern quadrant of YARRIE (57% of the sheet by area), most of which is covered by red sand plain and dunes of the Great Sandy Desert. The primary Canning Basin subdivisions on YARRIE are from west to east, the Wallal Embayment, Carawine Embayment, Wallal Platform, Waukarlycarly Embayment, and Samphire Graben (Figs 5 and 6e).

The Canning Basin on YARRIE consists of poorly exposed scattered outcrops of Lower Permian Paterson Formation and Poole Sandstone; scattered mesas, buttes, and small, but prominent outcrops of Jurassic–Cretaceous Callawa Formation; widely separated laterite-capped Cretaceous Parda Formation; and a few mesas of Cretaceous Frezier Sandstone.

Hydrogeological investigation bores (Leech, 1979a,b) in the northwest quadrant of YARRIE intersected 355 m of Permian Grant Group in the Wallal Embayment just north of the northwest margin of the sheet (Fig. 5; Towner and Gibson, 1983; Apak and Backhouse, 1998; Williams, 2000). Corbett 1, a new-field wildcat well on the central northern margin of YARRIE, intersected 365 m of Grant Group. This was overlain by 111 m of Permian Liveringa Group and 321 m of Jurassic Wallal Sandstone (Stirling Resources N.L., 1994).

Similarly, it can be inferred from stratigraphic and structural drilling north of YARRIE — for example Samphire Marsh No. 1 (Johnstone, 1961) — that the Samphire Graben (Fig. 5) on YARRIE probably contains Permian Grant Group and Lower Ordovician rocks (Towner and Gibson, 1983).

The Northern Carnarvon Basin (Fig. 4; Hocking et al., 1994) covers most of the northwest quadrant of YARRIE (about 15% of the sheet by area). It is a major Mesozoic depocentre and covers the southern third of the Westralian Superbasin (Hocking et al., 1994). On YARRIE, the Northern Carnarvon Basin is represented by the marginal Lambert Shelf subdivision (Fig. 5). The Lambert Shelf is made up of a thin skin of Mesozoic rocks that reach a thickness of around 280 m in the northwest corner of YARRIE (Hickman et al., 1983). The Mesozoic rocks unconformably onlap the Archaean Pilbara Craton and the unconformably overlying Neoproterozoic Eel Creek Formation of the Eel Creek Embayment (Fig. 5; Williams, 1999a, 2000). Permian rocks appear to be absent from the Northern Carnarvon Basin.

The Mesozoic succession of the Northern Carnarvon Basin on YARRIE consists of two exposed formations, the Jurassic–Cretaceous Callawa Formation and Cretaceous Parda Formation, and two subsurface formations, the Jurassic Wallal Sandstone and Jarlemai Siltstone. The subsurface formations have been intersected and identified in a series of hydrogeological investigative bores (Leech, 1979a,b; Hickman et al., 1983; Williams, 2000).

The subsurface continental to marginal-marine Wallal Sandstone and shallow-marine Jarlemai Siltstone are not shown on the YARRIE 1:250 000 sheet (Williams, 2002). The Wallal Sandstone is a major aquifer and the water source for the Shay Gap Borefield (Rowston, 1976). Further information on these two subsurface formations can be found in Brunnschweiler (1954), Leech (1979a,b), Towner and Gibson (1980), Hickman et al. (1983), and Williams (2000).

Some Mesozoic rocks of the Northern Carnarvon Basin, particularly the Callawa and Parda Formations, extend eastwards to lie disconformably or unconformably on Permian rocks in the adjacent, structurally controlled Canning Basin (Fig. 6f).

Permian rocks

Paterson Formation (Pa)

Exposures of the Paterson Formation (Traves et al., 1956; Towner and Gibson, 1980, 1983) are limited to a few scattered mesas, rocky rises, and low breakaways lying between longitudinal dunes east of the Gregory Range Inlier and north of Larson Well. Mesas of Paterson Formation also unconformably overlie the Pinjian Chert Breccia south of Myijimaya, pointing to a previously more extensive Permian cover in this area. Patches of Paterson Formation lie unconformably beneath cliff-forming Mesozoic Callawa Formation north of the Yarrie iron mine and north of Callawa Homestead. Paterson Formation also occupies palaeoglacial valleys eroded in Gorge Creek Group and Eel Creek Formation north and northeast of Shay Gap (Williams, 1999a).

The wide subsurface extent of the Paterson Formation is revealed in mineral exploration drillholes, particularly in the Wallal Embayment overlying the Pilbara Craton, where up to 654 m has been intersected in the Pandanus 1 stratigraphic hole (Pandanus Resources N.L., 1985), and on the Wallal Platform, overlying the Paterson Orogen, where over 220 m of Paterson Formation has been intersected (Figs 5 and 6e; Williams and Trendall, 1998a; Johnson, 1993).

The existence of the Paterson Formation is commonly indicated by scattered boulders, cobbles, and pebbles (*Qcp*) weathered from the underlying diamictite component of the formation. The distribution of the Paterson Formation on the Pilbara Craton basement is confined to palaeoglacial valleys, the largest of which underlies the present-day Nullagine and Oakover river valleys (Williams and Trendall, 1998a,b,c; Williams, 1999a, 2001; Playford, 2001).

The Paterson Formation consists of a poorly exposed basal diamictite. This is a blue-grey mudstone and sandy mudstone containing pebbles, cobbles, and boulders up to 2 m in diameter. Weathered clasts may be polished, striated, and faceted. These characteristics strongly suggest a glacial origin, although glacial pavements have not been found on YARRIE. White claystone, cream to brown siltstone, and brown thin-bedded, fine- to coarse-grained sandstone, commonly silicified, and minor conglomerate overlie the diamictite. These fluviatile deposits are found in the scattered mesas and breakaways north of Larson Well and east of the Gregory Range Inlier. Graded bedding, cross-bedding, wave and current ripples, and slumps are visible in the coarser clastic rocks. Wrinkle marks in the siltstone indicates deposition in very shallow water. The formation as a whole is interpreted to be a fluvioglacial deposit (Towner and Gibson, 1983).

The Paterson Formation is part of depositional sequence Pz5 (Middleton, 1990). Mory and Backhouse (1997) have more recently correlated these rocks with similar early Sakmarian–Asselian age (Lower Permian) rocks of the Carnarvon Basin.

Poole Sandstone (Pp)

The Poole Sandstone (Crowe et al., 1978; Towner and Gibson, 1983) is exposed on the southeastern margin of YARRIE in low breakaways. It is a red to yellow-brown, fine- to coarse-grained sandstone with lenses of white claystone and siltstone and thin beds of matrix-supported pebble conglomerate. Ripple marks and cross-bedding are common. Some trace fossils, interpreted as grazing trails, were found on ripple-marked siltstone (Williams and Trendall, 1998a).

The formation is postulated to be a shallow-water marine or lagoonal deposit (Towner and Gibson, 1983). The Poole Sandstone is part of depositional sequence Pz5 (Middleton, 1990) and is allocated an early Sakmarian age (Towner and Gibson, 1983).

Jurassic–Cretaceous rocks

Callawa Formation (JKc)

Outcrops of the Jurassic–Cretaceous Callawa Formation (Reeves, 1951; Towner and Gibson, 1980, 1983; Williams, 1999a, 2000, 2001) are well exposed in cliffs in the Callawa Hills, 25 km northeast of Callawa Homestead, where it unconformably overlies Permian Paterson Formation. Similar good exposures are found in the Shay Gap – Nimingarra area and in the headwaters of the Eel and Salt creeks, where the formation unconformably overlies Mesoarchaean Gorge Creek and De Grey Groups and Neoproterozoic Eel Creek Formation. The cliff-forming Callawa Formation also forms low tablelands, numerous mesas and buttes and rocky outcrops liberally sprinkled through the red desert sand (*Qs*) of the Great Sandy Desert, particularly on the Lambert Shelf (Hocking et al., 1994) in the northwest quarter of YARRIE. In this area, the Callawa Formation also onlaps the Jurassic Wallal Sandstone and Jarlemai Siltstone. Reeves (1951) recorded 94 m of Callawa Formation in the No. 3 Desert Bore, 35 km north-northeast of Yarrie Village.

The Callawa Formation consists of lower and upper units (Williams, 1999a, 2000). The lower unit comprises a basal conglomerate overlain by interbedded fine- to coarse-grained sandstone, siltstone, thin conglomerate beds, plant-fossil-bearing ferruginous sandstone, bioturbated claystone and sandy claystone. The thick bioturbated claystone, with burrows up to 75 cm long, lies towards the top of the lower unit. Cross-bedding in the lower unit indicates that there were variable current directions. The upper unit of thick-bedded, matrix-supported, pebble to cobble conglomerate, medium- to coarse-grained sandstone and minor plant-fossil-bearing claystone forms the main cliff-lines and erosion-resistant cappings on the mesas and buttes (Traves et al., 1956). Conglomerate clasts in the upper unit include chert, jaspilite, BIF, vein quartz, quartzite and minor granitoid rocks. These have been locally eroded from the Nimingarra Iron Formation and adjacent granitoid complexes. Palaeocurrents are persistently directed north to northwest from the Pilbara Craton.

Although a fluvial depositional environment is attributed to the entire Callawa Formation (Traves et al., 1956; Hickman et al., 1983), recent studies suggest that the lower unit, particularly the bioturbated claystones, may have been deposited in lacustrine or littoral shallow-marine conditions that existed prior to being overwhelmed by the coarse fluvial material of the upper unit (Williams, 1999a, 2000). The lower unit may be a shoreline facies of the underlying Jarlemai Siltstone (Williams, 1999a).

The Callawa Formation belongs to depositional sequence Mz4 (Middleton, 1990) and is Late Jurassic – Early Cretaceous in age (Towner and Gibson, 1983).

Cretaceous rocks

Parda Formation (Kp)

The Parda Formation (Towner and Gibson, 1983; Hickman et al., 1983) disconformably overlies the Callawa Formation in the Callawa Hills (Fig. 1). It is poorly exposed in a series of breakaways that extend northwest across the Lambert Shelf from the Callawa Hills and northeast along both sides of the old Marble Bar – La Grange telegraph line track (Fig. 1). Exposures are also found in the Radi Hills (Fig. 1) along the northeast margin of YARRIE. In all areas, the Parda Formation has a distinctive white airphoto pattern and is commonly capped by laterite (*Czrf*). It is probable that most laterite-capped hills positioned along major drainage divides in the northwest and northeast quarters of YARRIE overlie the Parda Formation.

The Parda Formation consists of thin-bedded to massive white mudstone and claystone intercalated with lenticular, fine-grained siltstone and sandstone. The typically poor outcrop on YARRIE makes thickness estimates difficult, but over 20 m has been recorded (Hickman et al., 1983).

A white, porcelanous fine-grained claystone, 2.5 km east-southeast of the Shay Gap Borefield, yielded a mold of an ammonoid, the first recorded for this formation (Williams, 2000). It has been tentatively identified as *Eofolciferella condoni* Brunnschweiler 1959 (Backhouse, 1999). Similar ammonites have been recorded in the Windalia Radiolarite of the Carnarvon Basin, 500 km to the west. This correlation suggests that the Parda Formation is late Aptian age (Backhouse, 1999).

The Parda Formation is interpreted to be a shallow-marine deposit (Hickman et al., 1983). The Parda Formation is assigned to depositional sequence Mz4 (Middleton, 1990).

Frezier Sandstone (Kf)

Sandstone mesas in the extreme northeast corner of YARRIE have been mapped as Frezier Sandstone (Hickman et al., 1983; Towner and Gibson, 1983).

The Frezier Sandstone (Lindner and Drew, in McWhae et al., 1958) on YARRIE consists of ferruginized, partly bioturbated, poorly sorted, coarse-grained sandstone, conglomerate, and minor siltstone (Hickman et al., 1983). The sandstone in this area is about 20 m thick.

The Frezier Sandstone disconformably overlies the Parda Formation. It is interpreted to be a fluvial to deltaic deposit (Towner and Gibson, 1980) of Aptian age (Veevers and Wells, 1961), and has been assigned to depositional sequence Mz4.

Cainozoic deposits

Cainozoic deposits cover about 80% of YARRIE and, of these, some 80% consist of red-brown eolian sand (*Qs*) of the Great Sandy Desert that occupies the northern and eastern parts of the sheet.

The Cainozoic deposits can be divided into two broad categories. The first category includes consolidated and eroded lacustrine, fluvial, and chemical deposits that include older alluvial, colluvial, and eluvial material and range from Eocene to Pleistocene in age. These deposits are found mostly in the southwest quarter of YARRIE, where there is an active drainage regime.

The second category includes the unconsolidated, currently or recently active erosional and depositional material, which is mainly Quaternary, and is represented by alluvial (including lacustrine, colluvial, eluvial, and eolian) deposits.

Eocene to Pleistocene

Lacustrine, fluvial, and chemical deposits (Czos, Czoc, Czaa, Czag, Czak, Czap, Czaz, Czc, Czcf, Czcg, Czrf, Czrz, Czrk)

The most distinctive, and the only formally named Cainozoic deposit on YARRIE, is the Oakover Formation (Noldart and Wyatt, 1962). The formation caps extensive dissected tablelands, mesas and buttes up to 60 m above the Oakover River. The distribution of the eroded remnants show that the Oakover Formation once occupied the broad valley of the Oakover and lower Nullagine rivers and extended north into the valley of the Percival Palaeoriver to north and east of Mount Cecelia (Fig. 1).

Recent studies have divided the Oakover Formation into an upper (*Czos*) and lower unit (*Czoc*) (Williams and Trendall, 1998b). The upper unit (*Czos*) is a cliff-forming, grey, white, to bluish white, locally translucent vuggy opaline silica and chalcedony with minor calcareous sandstone interbeds up to 8 m thick. The lower unit (*Czoc*) comprises blue, grey, and fawn limestone and calcareous sandstone up to 40 m thick that forms rubbly outcrops and lower, rounded hills. The lower unit intertongues with consolidated older alluvium (*Czag*) and colluvium (*Czcg*) along the western side of the Gregory Range Inlier. North of Mount Cecelia the Oakover Formation is overridden by eolian sands (*Qs*).

The Oakover Formation is a possible lacustrine deposit (Towner and Gibson, 1983), the western boundary of which is unknown. The age of the Oakover Formation is conjectural (Williams and Trendall, 1998b), although Cockbain (1978) postulated a post-Miocene age.

Consolidated alluvial deposits of clay, silt, and sand (*Czaa*) are exposed in deeply eroded banks of streams and gullies distal from rock outcrop on the northern side of the De Grey River and along the Callawa Creek. Related higher energy alluvial deposits of consolidated gravel, coarse sand and silt with local carbonate cement (*Czag*) are found along incised streams issuing from ranges on the southern side of the De Grey River and along the eastern side of the Oakover River. These were probably old consolidated alluvial fans.

Valley calcretes, comprising secondary grey-white, pisolitic, nodular and laminar carbonate (*Czak*), occupy palaeodrainage lines such as the Percival Palaeoriver valley in the southeast corner of YARRIE. Dissected calcrete remnants also are found along some active streams such as Eel Creek (Fig. 1).

More restricted alluvial valley fills, now exposed in individual, dissected elongated mesoform hills, elevated tongues and lobate-shaped rises adjacent to the Nimingarra Iron Formation around Yarrie iron mine and Mount Cecelia, consist of pisolitic limonite, goethite, and hematite-filled channel deposits (*Czap*) and silica- and iron-cemented conglomerate of chert, jaspilite and BIF (*Czaz*). The pisolitic ferruginous channel deposits locally carry plant fossils (Hickman et al., 1983) and are possibly of late Eocene to Oligocene age (Blockley, 1990).

Broad sheets of consolidated and dissected, poorly stratified clay, silt, sand, and pebbly sand, with a clay and silica cement (*Czc*) are found adjacent to outcrops of the Callawa Formation in the Callawa Hills and the Hardey Formation south of Yarrie Homestead. These colluvial deposits are not related to any specific drainage line and are dissected by recent erosion.

A distinctive, dissected and consolidated iron-rich colluvium (*Czcf*), consisting of recemented broken laterite rubble and ironstone pebbles mixed with silt and sand, encircles isolated mesas, buttes, and breakaways of laterite in the Great Sandy Desert region. A similar consolidated colluvium including canga forms aprons adjacent to the Nimingarra Iron Formation, southwest of Yarrie iron mine.

Dissected and consolidated low-slope coarse colluvium (*Czcg*) of poorly stratified pebbles, sand, and silt lies adjacent to rock exposures on the western side of the Gregory Range Inlier. The surface of this unit is marked by a lag of chert and quartz pebbles. This unit intertongues with the Oakover Formation and appears to be an outwash-fan deposit.

Remnants of a ferruginous duricrust surface (*Czrf*), mainly massive, pisolitic, and nodular laterite is generally associated with, and overlies, the Parda Formation in the Great Sandy Desert. This unit is common east of the Callawa Hills, in the Radi Hills, and south of Bulgamulgardy Soak. Scattered outcrops extend from this area to the western boundary of YARRIE. North of the abandoned Shay Gap iron ore mine, laterite rests directly on the Callawa Formation. The laterite surface is absent from the high ranges south of the De Grey River.

A siliceous duricrust, including a grey silcrete (*Czrz*), is restricted to cappings on scattered mesas and hills of Paterson Formation northwest, north, and east of the Gregory Range Inlier. The silcrete consists of angular quartz grains set in a hard siliceous cement. The rock is distinguished by a conchoidal fracture.

The Carawine Dolomite west of the abandoned Barramine Homestead is locally capped by a secondary carbonate or residual calcrete (*Czrk*). These sheets of massive, nodular and cavernous calcrete may be a calcareous tufa precipitated from carbonate-rich water seeping from the underlying or adjacent Carawine Dolomite. Similar residual calcrete overlies altered carbonate-rich ultramafic rocks in the Friendly Stranger gold mine area. Here, the calcrete forms sheets and encrustations, and fills joints within and on carbonate–tremolite–chlorite rocks. Magnesite is also present.

Recent deposits

Lacustrine, alluvial colluvial, eluvial, and eolian deposits (Qlc, Qls, Qaa, Qaas, Qao, Qaoc, Qaob, Qag, Qw, Qwg, Qc, Qcq, Qcp, Org, Qs, Osg)

Scattered through the Great Sandy Desert are claypans, some with a bare clay and silt surface, others with a vegetated, rough gilgai surface (*Qlc*). Some larger areas consist of a mixture of numerous small bare claypans and associated lunette dunes (*Qls*). The presence of claypans commonly indicates local, internal drainage.

The southwest quarter of YARRIE that is underlain by the Pilbara Craton has a well-developed drainage system. Extensive riverine deposits are associated with the Oakover, Nullagine, and De Grey rivers. Away from the main river channels, fluvial units consist of a mixture of unconsolidated clay, silt, sand, and gravel in creek beds and anabranches (*Qaa*). Breakaways in the Great Sandy Desert also focus drainage in short sandy watercourses where overbank and adjacent floodplain have not been separated from alluvial deposits. Unconsolidated silt, sand, and gravel in larger river channels (*Qaas*) is incised within overbank (river terraces) and floodplain deposits (*Qao*). Such channels may be as much as 15 m deep and contain sand and gravel banks and pointbars up to 7 m high.

The overbank deposits, including the levee banks, consist of clay, silt, and silty sand on flood plains (*Qao*). Shallow channels in this surface are typically vegetated. Large floodplains adjacent to the main channels are commonly covered with numerous small claypans (*Qaoc*). These contain clay, silt, and silty sand and sometimes carry a sparse veneer of pebbles. Slightly depressed areas in the floodplain contain swelling-clay (gilgai) and silt deposits (*Qaob*) that appear to correspond to older but subsequently filled drainage channels. These floodplain deposits are particularly widespread around Warrawagine Homestead and the confluence of the Nullagine and Oakover rivers.

A distinctive pebble- and cobble-veneered sand and silt deposit (*Qag*) lies on the eastern side of Miningarra Creek, northwards from where it debouches from a gorge incised in the Fortescue Group rocks. This deposit appears to lie on an active, high-energy, alluvial fan deposit that overlies older consolidated alluvial deposits (*Czag*) with similar genesis.

Small areas of low-slope sheetwash deposits (*Qw*) are found in the Oakover River valley adjacent to Tanguin Creek, and scattered through the Great Sandy Desert downstream from breakaways or large outcrops. These sheetwash areas are recognizable by distinctive vegetation banding ('tiger-bush' banding; Wakelin-King, 1999). The bare sandy and silty ground between the bands of vegetation is characteristically covered with a veneer of quartz and small rock pebbles. A similar low-gradient sheetwash deposit of sand with a veneer of white vein-quartz and weathered granitoid pebbles (*Qwg*) is common on the Warrawagine and Muccan Granitoid Complexes. The banded vegetation pattern is not always so obvious on this sheetwash unit.

Recent colluvium, including scree and talus deposits (*Qc*) is found in the rugged and hilly country of the Gregory Range Inlier and Oakover Syncline. It also forms aprons against the ranges of Nimingarra Iron Formation abutting the granitoid complexes. Large quartz ridges, cutting the Muccan and Warrawagine Granitoid Complexes, have talus and scree slopes composed entirely of broken quartz fragments (*Qcq*). Likewise, the Paterson Formation can weather to boulders and cobbles sitting in unconsolidated silt sand and clay (*Qcp*). This is a mixed colluvial and eluvial deposit weathered from the diamictite component of the fluvioglacial Paterson Formation.

Patches of medium- to coarse-grained quartz and feldspar sand, sometimes with a white quartz pebble and granitoid rock veneer (*Qrg*), represent a residual, eluvial deposit derived from the underlying granitoid rock. This sand is associated with fresh granitoid rock outcrop and is found in the Muccan, Warrawagine, and Mount Edgar Granitoid Complexes.

By far the most extensive Recent deposit on YARRIE is the red to red-brown eolian sand (*Qs*) of the Great Sandy Desert. Extensive sandplains with a few short longitudinal dunes occupy the northwest quarter and northern margin of YARRIE. In the remaining area, southeast of Callawa Hills and east of Bulgamulgardy Soak, the sandplain is dominated by numerous east-southeasterly trending longitudinal and chain dunes. Such dunes can be up to 70 km long and 20 m high. The sandplain and interdunal areas in this region commonly carry a fine-grained ironstone pebble veneer, supplemented in the area east of the Gregory Range Inlier by fine-grained rock fragments. Red-brown, medium- to coarse-grained quartz sand sheets (*Qsg*) lie distal from granitoid outcrops on the Muccan and Warrawagine Granitoid Complexes. The sand is a mixture of eluvial and eolian-derived components.

ECONOMIC GEOLOGY

A recent review of the economic mineral potential, production, and mineral occurrences of the east Pilbara, including the region occupied by YARRIE, can be found in GSWA Report 81 (Ferguson and Ruddock, 2001). Further information on exploration company data for YARRIE can be obtained from the WAMEX* open-file system held in the DoIR library.

* WAMEX and MINEDEX are available on DoIR website

Such information, extracted up to the time of publication, can also be found referenced in the explanatory notes for MUCCAN (Williams, 1999a), COORAGOORA (Williams, 2000), WARRAWAGINE (Williams, 2001), and ISABELLA 1:100 000 sheets (Williams and Trendall, 1998a). The MINEDEX database (Townsend et al., 1996, 2000) also has current information on all mines, deposits, and process plants, with the exception of petroleum and gas, for Western Australia.

Significant economic mineral production from YARRIE is limited to gold from the Bamboo Creek Mining Centre (Finucane, 1936; Hickman, 1983; Gonnella, 1998; Murphy, 2000), and iron ore from openpits in the Shay Gap, Sunrise Hill, Nimingarra, and Yarrie areas (Podmore, 1990; Waters, 1998; Murphy, 2002).

Minor gold production has also been recorded from the Friendly Stranger and Battler mines south of Yarrie Homestead (Hickman et al., 1983) and more recently from alluvial workings at the Friendly Stranger, and Nuggety Gully, Jarmans, and Strattons in the Bamboo Creek Mining Centre region (Williams, 1999a).

Both the gold and iron ore are hosted by rocks of the Archaean East Pilbara Granite–Greenstone Terrane in the southwest corner of YARRIE. Gold is found in the Euro and Apex Basalts of the Warrawoona Group, and iron ore is associated with the Nimingarra Iron Formation of the Gorge Creek Group (Williams, 1999a).

Over the last 40 years a number of occurrences and potential prospects for iron ore, gold, copper, molybdenum, zinc, lead, chromium, and nickel have been investigated in the EPGGT component of YARRIE (Baxter, 1978; Marston, 1979; Hickman et al., 1983; Jones, 1990; Zegers, 1996; Williams, 1999a; Ferguson and Ruddock, 2001).

Similarly, the Fortescue and Hamersley Groups rocks of the Hamersley Basin on YARRIE that carry traces of, and prospects for, copper, lead, and manganese have been investigated over the last 100 years (Ostlund, 1902; Blatchford, 1925; Finucane, 1938; Blockley, 1971; Marston, 1979; Williams and Trendall, 1998a; Williams, 2001; Ferguson and Ruddock, 2001). The main area of interest on YARRIE is in the Gregory Range Inlier, which lies at the northern end of the Braeside lead field (Blatchford, 1925; Finucane, 1938). Following the discovery of manganese in the Gregory Ranges in the early 1950s (Owen, 1953; de la Hunty, 1963), the Carawine Dolomite has been a focus for manganese prospecting. The Fortescue and Hamersley Group rocks are also considered prospective for volcanogenic massive sulfides, epithermal gold, sedimentary-hosted stratabound and stratiform base-metal deposits, and diamonds (Williams and Trendall, 1998a).

The poorly exposed Proterozoic rocks of the Paterson Orogen on YARRIE have been explored for sedimentary-hosted base-metal deposits, uranium, and diamonds (Eaton, 1993; Johnson, 1993; Williams and Trendall, 1998a; Williams, 2001). Western Mining Corporation Limited intersected anomalous lead, zinc, and copper mineralization at the sand-covered Baton prospect, 22 km east-southeast of Myijimaya (Eaton, 1993).

The Canning Basin component of YARRIE has been partly investigated for its hydrocarbon potential. Bulldozing of seismic reflection lines and the drilling of one new-field wildcat well, Corbett 1 (Stirling Resources, 1994), has been carried out in the north-central part of YARRIE. A stratigraphic hole, Pandanus 1 (Pandanus Resources NL, 1985), was drilled on the northern side of the Callawa Hills. Both holes gave negative results for hydrocarbons.

Hydrogeological (Leech, 1979a,b) and groundwater geophysical surveys (Rowston, 1976) were conducted for artesian water on the Lambert Shelf area of the Northern Carnarvon Basin in the northwest quarter of YARRIE (Williams, 2000). The Shay Gap Borefield

(Rowston, 1976) in this area supplies water to Yarrie Village and minesites to the south via a 42 km-long pipeline (Hickman et al., 1983; Williams, 2000).

Gold

Gold was discovered in the Bamboo Creek district around 1890 (Maitland, 1904). From that time, the Bamboo Creek Mining Centre was in almost continuous production till 1996, when the current owners, Haoma Mining NL, placed the treatment plant, located adjacent to the large Mount Prophecy – Perseverance Mines, under care and maintenance (Gonnella, 1998). Following re-engineering of the plant and test runs of the Elazac process used at the plant, production recommenced in 2002, using higher grade bulk samples from a number of small mines throughout the East Pilbara region (Murphy, 2002).

Records show that the Bamboo Creek Mining Centre has produced a total of 6512.489 kg of gold from 779 350 t of ore (averaging 8.15 g/t) between 1897 and 1995 (Ferguson and Ruddock, 2001). Over 60% of the gold production has been obtained since 1986. Current indicated and inferred resources as at June 2001 were 4.94 Mt at 1.6 g/t (Murphy, 2002).

The Bamboo Creek Mining Centre stretches over a distance of 16 km from Nuggety Gully alluvials in the north to Strattons alluvial patch in the south. Currently, the main mines are the Mount Prophecy – Perseverance mines, where a major treatment plant is situated (Williams, 1999a). Thirty-seven mines and prospects are recorded from this area (Ferguson and Ruddock, 2001).

The gold mineralization is associated with the Bamboo Creek Shear Zone (Zegers, 1966). The gold is found within komatiitic boudins in structurally controlled, 1–3 m-wide laminated quartz–carbonate–sulfide veins bordered by wide alteration zones of chlorite, magnesite, dolomite, quartz, and fuchsite. The gold, both free and with pyrite, is closely associated with galena, tetrahedrite, and tourmaline, and less commonly with sphalerite, pyrite, and gersdorffite (Zegers, 1996).

Attempts have been made to date the gold mineralization using galena to obtain a Pb–Pb model age (Richards, 1983; Thorpe et al., 1992a; Zegers, 1996). Samples collected from the Mount Prophecy – Perseverance and Kitchener mines gave Pb–Pb model ages of 3400 ± 4 Ma (Zegers, 1996; Zegers et al., 2002; see Table 3).

Iron ore

Iron ore mining on YARRIE was initiated in 1972 by Mount Goldsworthy Mining Associates, who operated openpit iron mines in the Shay Gap (1972), Sunrise Hill (1972), and Nimingarra (1989) areas (Podmore, 1990). In 1990, BHP Iron Ore Pty Ltd took over these operations and extended mining operations to the Yarrie (Y2/Y3 openpits) and Kennedy Gap (Y10 openpit) areas (Waters, 1998).

BHP Billiton Iron Ore Ltd (managers since June 2001) are currently (2002) working openpits at Yarrie Y2/Y3, Yarrie Y10, Nimingarra, and Sunrise Hill areas. Published total iron ore reserves at Yarrie, as of June 2001, were 32 Mt comprising proven reserves of 30 Mt and probable reserves of 2 Mt. Total resources for the Yarrie–Nimingarra region amount to 82 Mt made up of measured reserves of 49 Mt and indicated resources of 33 Mt (Murphy, 2002).

The iron ore openpits are mostly sourced in supergene-enriched hematite lodes in the Nimingarra Iron Formation (Williams, 1999a, 2000). The exception is Yarrie Y10 openpit, which exploits bedded hematite conglomerate at the base of the Neoproterozoic Eel Creek Formation (Williams, 1999a).

The hematite ore in the Nimingarra Iron Formation at the Yarrie Y2/Y3 deposit grades at 64.7% Fe, 0.034% P, 4.95% SiO_2, and 1.38% Al_2O_3 (Waters, 1998). In contrast, the bedded hematite conglomerate at the Yarrie Y10 deposit contains ore grades of 61.2% Fe, 0.090% P, 6.5% SiO_2, and 3.0% Al_2O_3 (Waters, 1998).

The geological setting and nature of the ore bodies in the Yarrie–Nimingarra regions have been discussed by Brandt (1966), Podmore (1990), and Waters (1998).

Copper

Although some shallow workings have intersected copper mineralization (malachite, chalcopyrite, cuprite, chalcocite) in sheared Jeerinah Formation (Camel Hump area) and Carawine Dolomite (Barramine area) in the Gregory Range Inlier (Blatchford, 1925; Finucane, 1938; Marston, 1979; Williams and Trendall, 1998a; Williams, 2001), no official copper production has been recorded from YARRIE.

A large-tonnage, low-grade copper–molybdenum deposit has been investigated 1.5 km southwest of Coppin Gap (Marston, 1979; Barley, 1982; Jones, 1990). Jones (1990) estimated the ore reserves to be 102 Mt of 0.152% Cu and 0.105% Mo. The deposit is associated with a multiphase stockwork of quartz–carbonate veins developed in the silicified contact zone of an intrusive dacite–rhyolite porphyry (Marston, 1979). The quartz–carbonate veins carry up to 2% chalcopyrite, molybdenite, pyrite, pyrrhotite, rare sphalerite, and scheelite. The intrusive porphyry is postulated to be an apophysis of the nearby Coppin Gap Granodiorite, and has been dated at 3317 ± 1 Ma (Thorpe, R. I., 1992, written comm.; see Table 3).

Copper mineralization (mainly malachite) has been recorded in a number of localities within the EPGGT, in sheared gossanous quartz veins hosted by ultramafic rocks (Hickman et al., 1983), particularly around the Battler gold mine and Du Valles Well areas (Williams, 1999a), and in gossanous quartz veins associated with faulting in the Muccan and Warrawagine Granitoid Complexes (Williams, 1999a, 2001).

A pink, leucocratic muscovite-bearing monzogranite of the Warrawagine Granitoid Complex, 2 km east of 17 Mile Well, was found to carry disseminated chalcopyrite and molybdenite on joint planes (Williams, 1999a).

Silver, lead, and zinc

Silver has been produced as a byproduct of the gold mining at the Bamboo Creek Mining Centre. Production to the end of 1996 amounted to 648.246 kg (Williams, 1999a).

Lead mineralization, mainly as galena, is found in quartz veins cutting the Apex Basalt (Hickman et al., 1983), associated with the gold mineralization in the Bamboo Creek gold mines (Zegers, 1996), and in a quartz vein cutting the unconformity between the Warrawagine Granitoid Complex and Mount Roe Basalt (Williams, 1999a). Lead mineralization, as galena and cerussite in quartz veins hosted by the Baramine Volcanic Member, is recorded from the Camel Hump South prospect (Blatchford, 1925; Williams and Trendall, 1998a) in the Gregory Range Inlier.

Zinc mineralization, as sphalerite, has been recorded from the Battler gold mine (Hickman et al., 1983), the Coppin Gap copper–molybdenum prospect (Jones, 1990), and Bamboo

Creek Mining Centre, particularly from the Mount Prophecy – Perseverance mine (Zegers, 1996). Anomalous lead and zinc have been recorded from the Baton prospect, 22 km east-southeast of Myijimaya (Eaton, 1993). Here, the mineralization is hosted by Mesoproterozoic to Neoproterozoic Broadhurst Formation of the Throssell Group in the Paterson Orogen (Eaton, 1993; Williams and Trendall, 1998a).

Other minerals

The Nobb Well Intrusion, which lies 7 km southwest of the Mount Prophecy – Perseverance mine, is a chromite-bearing serpentinized peridotite intruding basal Apex Basalt. The intrusion carries small chromite pods near the base and disseminated chromite crystals throughout the body. The chromite pods assay up to 3.15% Cr and 0.18% Ni (Baxter, 1978; Hickman et al., 1983)

A blind nickel orebody comprising disseminated gersdorffite (NiAsS) was encountered during drilling near the Mount Prophecy gold mine in 1969 by Woodreef Mines (Marston, 1984). The host rock is a silicified and brecciated, carbonate-rich ultramafic rock. Assays up to 1.69% Ni over 5.09 m were recorded (Marston, 1984; Williams, 1999).

A thin-bedded seam of pyrolusite (manganese oxide) has been prospected northeast of 6 Mile Well (Yarrie Station). The deposit lies in basal shales of the Hardey Formation and is possibly a syngenetic deposit (de la Hunty, 1963; Williams, 1999a).

Scattered occurrences of manganese oxides, as surface encrustations and small pods, are found on, or close to, the contact between the Pinjian Chert Breccia and Carawine Dolomite in the Gregory Range Inlier. An example lies 3.5 km northwest of the abandoned Barramine Homestead (Williams, 2001). Manganese has also been recorded from Carawine dolomite 2.5 km north of Myolla Bore, on the east side of the Nullagine River (Williams, 2001).

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Appendix

Gazetteer of localities

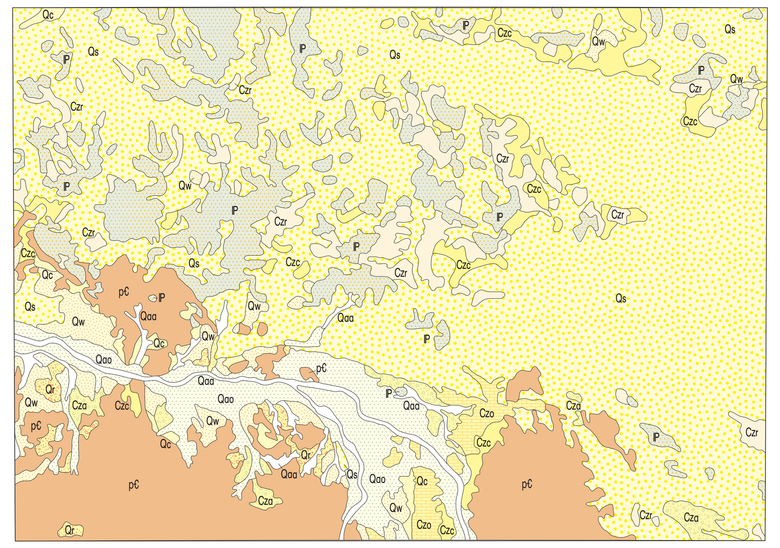
Locality	MGA coordinates Easting	Northing	Locality	MGA coordinates Easting	Northing
Andy Creek	204000	7679500	Myijimaya Community (abn)	294800	7700300
Bamboo airstrip	204900	7681200	Myolla Bore	256700	7676600
Bamboo Creek Mining Centre	209000	7684400	Narrana Well	233800	7699800
Barramine Homestead (abn)	289100	7692400	Near Home Well	193800	7719600
Baton prospect (Pb, Zn)	314200	7690400	Nimingarra (Fe)	187900	7740000
Battler Mine (Au, Cu)	206600	7604400	Nobb Well	206100	7676600
Bulgamulgardy Soak	295000	7764000	No. 2 Well	193700	7680900
Cabbage Tree Well	229600	7621800	No. 3 Bore	200900	7678600
Callawa Homestead (abn)	239900	7616700	No. 3 Desert Bore	226300	7752900
Camel Hump South prospect (Cu, Pb)	297700	7784400	Nuggety Gully (Au)	206500	7685700
Cattle Gorge	213900	7726000	Old House Well	198600	7702200
Cattle Gorge Bore	214700	7728700	Pandanus 1	260400	7739600
Cattle Pool	213800	7726300	Pinjian Pool	255900	7677200
Chintabul Dam Well	238400	7699100	Reid Bore	219600	7725800
Coppin Gap	200600	7687200	Shay Gap	201800	7727900
Corbett 1	250300	7779200	Shay Gap Borefield	207500	7752200
Cundaline Gap	209100	7722200	Shay Gap 7 (Fe)	194600	7733900
Don Well	194300	7726800	Shay Gap Townsite (abn)	204600	7731400
Du Valles Well	236300	7713000	Simpson Well	241500	7705800
Five Mile Hill	253100	7686000	Snell Well	300300	7690800
Five Mile Hill microwave repeater station	253100	7686000	Sunrise Hill West 4 (Fe)	191000	7736300
Fred Well	200200	7697100	Strattons (Au)	218600	7675800
Friendly Stranger mine (Au)	207000	7703400	Surface Well	205600	7702200
Gap Bore	196900	7684900	Thomas Well	204900	7698000
Gap Well	200000	7739800	Wattle Well	191200	7699000
Granite Well	250800	7687500	Warrawagine Homestead	260100	7692800
Iron Hill	300900	7700800	Wolline Well	194200	7696200
Jarmans (Au)	215600	7678700	Yarrie Homestead	208700	7711600
Jarman Well	218711	7698919	Yarrie microwave repeater station	208600	7705900
Kennedy Gap	218100	7721400	Yarrie Village	217000	7720000
Kittys Gap	195500	7687800	Yarrie Y2/Y3 (Fe)	219100	7718200
Lance Bore	224100	7682800	Yarrie Y10 (Fe)	221600	7721600
Larson Well	271200	7709200	Zulu Well	215500	7675700
Leo Bore	213500	7710200	3 Mile Well	191300	7679200
Mount Cecelia	291100	7701300	6 Mile Well (Yarrie Station)	213600	7704200
Mount Prophecy – Perseverance (Au)	209600	7683600	6 Mile Well (Warrawagine Station)	251000	7696100
Moxon Well	235400	7719400	10 Mile Well	244500	7693300
Muccan Homestead	193200	7715600	17 Mile Well	234500	7687100

NOTE: abn: abandoned

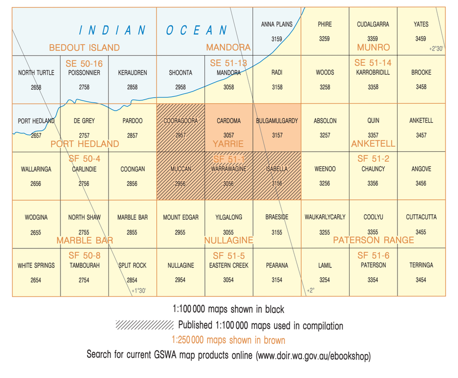
YARRIE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

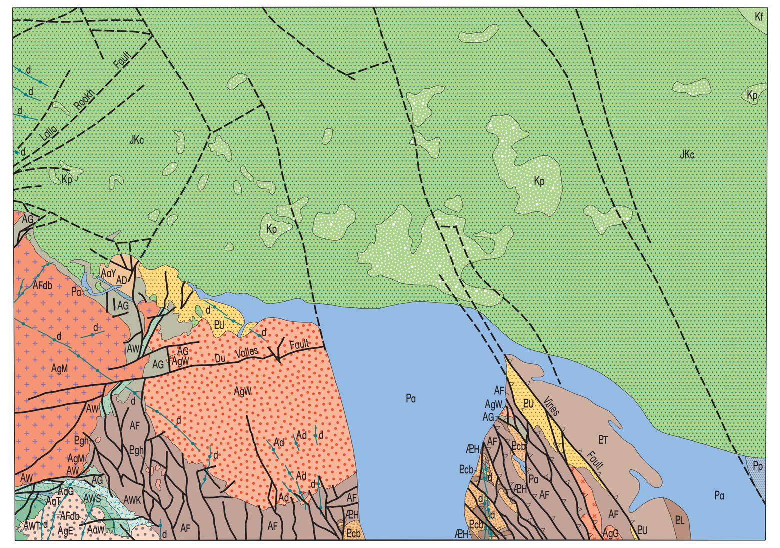
SIMPLIFIED REGOLITH



SHEET INDEX

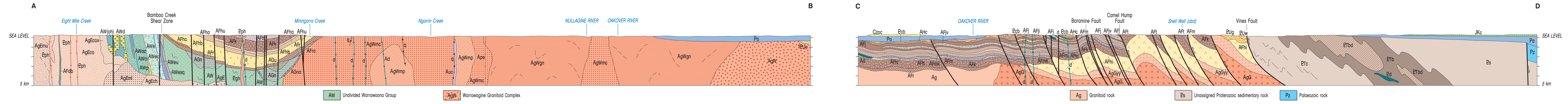


INTERPRETED BEDROCK GEOLOGY



DIAGRAMMATIC SECTIONS

Natural Scale



Compiled by I. R. Williams 2001

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(2) D. R. Nelson, 2001, GSWA Record 2001/2, p. 189–193.
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(1) L. Bagas et al., 1995, GSWA Annual Review 1994–95, p. 55–63.

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

Government water exploratory and monitoring bore data supplied by Waters and Rivers Commission, Department of Environmental Protection

Mineralization and rock commodity information from non-confidential data held in the WAMIN database, GSWA, at 28 August 2003. Data points filtered for clarity on the plotted product; full set of data points available in digital data

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Department of Industry and Resources

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

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Geological Survey of Western Australia

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NGA

PRODUCT OF THE NATIONAL GEOSCIENCE AGREEMENT

SCALE 1:250 000

5000 Metres 0 5 10 15 20 25 Kilometres

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM
BATHYMETRIC DATUM: LOWEST LOW SEA LEVEL

Grid lines indicate 20 000 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

YARRIE

SHEET SF 51-1

THIRD EDITION 2004

Version 2 – March 2004