

**EXPLANATORY  
NOTES**



# **GEOLOGY OF THE MARYMIA 1:100 000 SHEET**

by L. Bagas

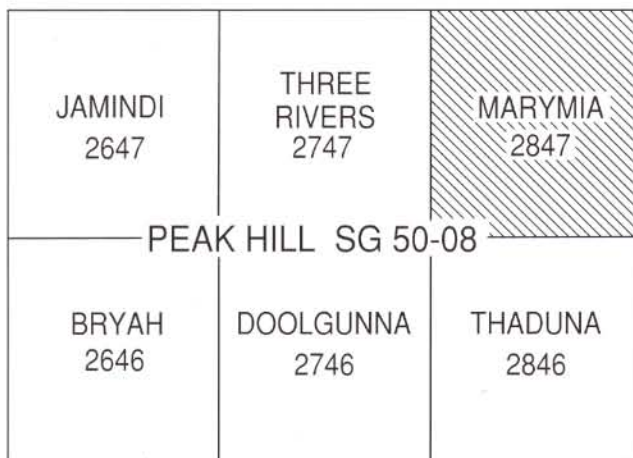
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**GEOLOGICAL SURVEY OF WESTERN AUSTRALIA**

**DEPARTMENT OF MINERALS AND ENERGY**







**GEOLOGICAL SURVEY OF WESTERN AUSTRALIA**

**GEOLOGY OF THE  
MARYMIA  
1:100 000 SHEET**

**by  
L. Bagas**

**Perth 1998**

**MINISTER FOR MINES**  
**The Hon. Norman Moore, MLC**

**DIRECTOR GENERAL**  
**L. C. Ranford**

**DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA**  
**David Blight**

**Copy editor: J. Comrie-Greig**

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**Cover photograph:**

**Interbedded shale and greywacke beds of the Thaduna Formation, south of the Green Dragon mine on the MARYMIA 1:100 000 map sheet.**

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# Geology of the Marymia 1:100 000 sheet

by

L. Bagas

## Introduction

The MARYMIA\* 1:100 000 map sheet (SG 50-8-2847) covers the northeastern part of the PEAK HILL 1:250 000 sheet (SG 1-1 50-8), between latitudes 25°00' and 25°30'S and longitudes 119°30' and 120°00'E (Fig. 1). The area is included in the Peak Hill Mineral Field, and is named after Marymia Hill (AMG 795200)†.

The nearest town is Meekatharra, which is about 200 km by road to the southwest. In the southern part of MARYMIA, the unsealed Wiluna North Road connects Neds Creek Homestead with the Great Northern Highway to the west. A gravel road in the northern part of MARYMIA links the Marymia gold mines and Marymia Homestead on FAIRBAIRN (1:100 000) with the Plutonic gold mine on THREE RIVERS (1:100 000) to the west and with the Great Northern Highway. Numerous station and exploration tracks provide access to the rest of the sheet area. Habitations on MARYMIA include Neds Creek Homestead in the south, and the Resolute Limited base camps near Marymia Hill.

The region has an arid to semi-arid climate with a mean annual rainfall of between 200 and 240 mm. The rainfall is erratic, however, and the area is subject to drought as well as to localized short-term floods. The wettest period is December to May. January, with an average maximum of 38°C and minimum of 23°C, is the hottest month; July, with an average maximum of 20°C and minimum of 6°C, is the coolest.

## Previous investigations

H. W. B. Talbot made the first geological reconnaissance of the region in 1912–14, producing a geological report (Talbot, 1920) and accompanying maps (Talbot, 1928). He described the 'Warrawoona Series' (Plutonic Well greenstone belt and Yerrida Group), the 'Nullagine Beds' (Earaheedy Group), and the 'Mosquito Creek Beds'

(Baumgarten greenstone belt), and commented that the area was 'a pretty uninteresting place'.

Marston (1979) described the copper mineralization at the Rooneys and Green Dragon mines in the southern part of MARYMIA as part of a State-wide study on copper mineralization by the Geological Survey of Western Australia (GSWA).

Systematic mapping of PEAK HILL at a scale of 1:250 000 was carried out by the GSWA between 1966 and 1968, and again in 1974 and 1975. The results were published by MacLeod (1970) and Gee (1987, 1990). A report summarizing the geology of the Peak Hill and Glengarry regions was published by Gee and Grey (1993).

A detailed, semi-regional study, focusing on the geology, geochronology, and economic geology of the Archaean Plutonic Well greenstone belt (named by Gee, 1987), was completed in 1996 by N. M. McMillan (McMillan and McNaughton, 1995; McMillan et al., 1995; McMillan, 1996).

Recent mapping of the 'Glengarry Basin' as defined by Gee and Grey (1993) has led to a redefinition and its partitioning into the Yerrida, Bryah, and Padbury Basins (Pirajno et al., 1996, fig. 1).

These Notes and the accompanying 1:100 000 geological map are based on detailed regional mapping during 1995 and 1996, and interpretation of Landsat imagery and GSWA aeromagnetic images. Interpretation of geophysical data has helped the GSWA to deduce the nature of the underlying structures and rocks in areas covered by Cainozoic sediments. Archaean orthogneiss and Proterozoic metasedimentary rocks are clearly identifiable as areas of subdued magnetic relief on the aeromagnetic images. More pronounced aeromagnetic areas are identifiable as Archaean greenstone belts and Proterozoic dolerites.

## Physiography

The physiography of MARYMIA is the product of several periods of erosion and deposition. Subramanya et al. (1995) and Gozzard et al. (1995) have described its

\* Capitalized names refer to standard map sheets.

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



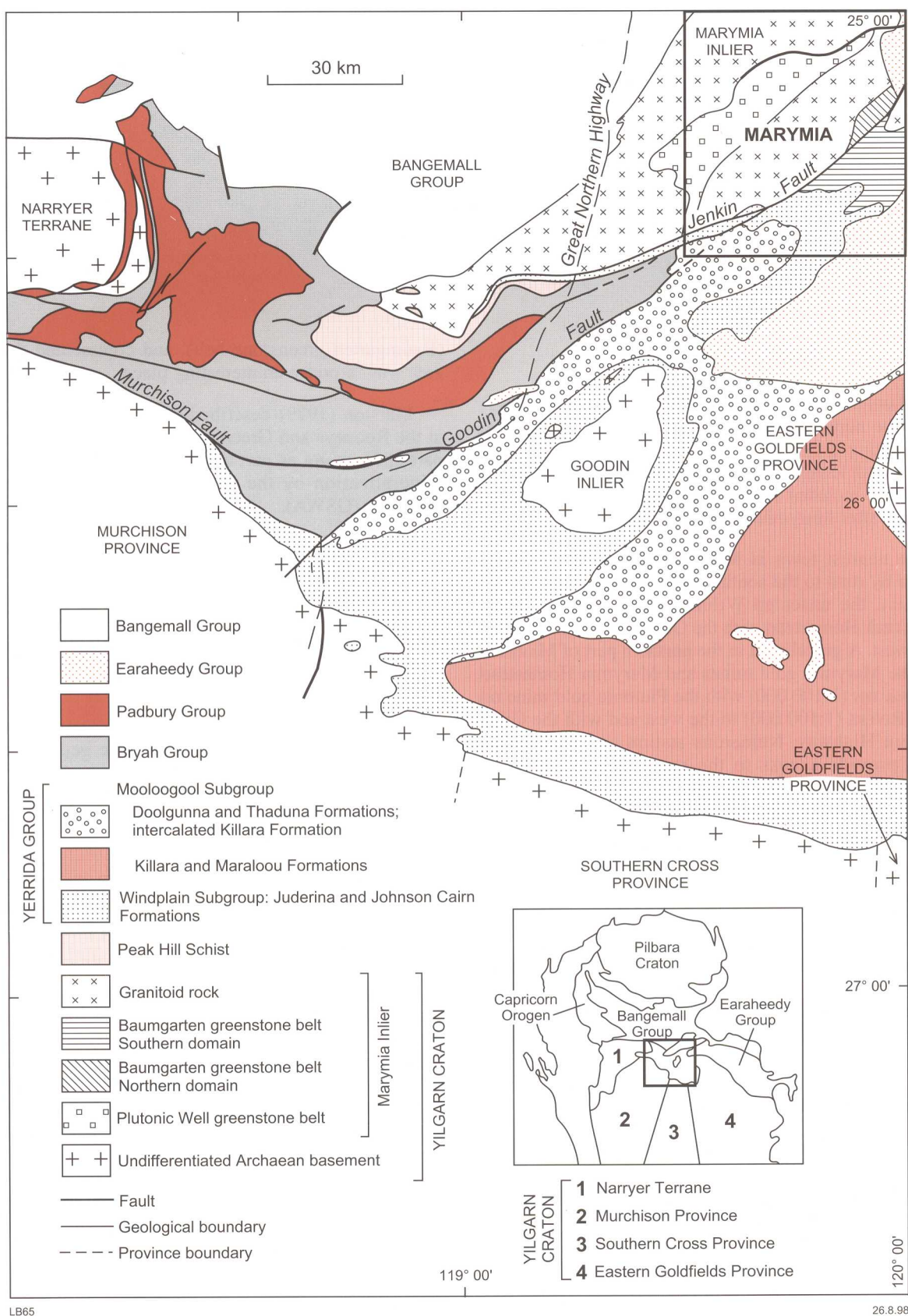


Figure 1. Regional geological setting of MARYMIA



geomorphology in detail in their coverage of PEAK HILL (1:250 000).

MARYMIA covers a segment of the interior plateau of Western Australia (MacLeod, 1970), and is characterized by gentle to moderate topographic relief. Elevations range from 542 m Australian Height Datum (AHD) in the southeast to 673 m at a point 3 km west of Marymia Homestead in the northeast. The average elevation is about 600 m.

The quality of the rock exposure in the area is generally poor. The Plutonic Well and Baumgarten greenstone belts are largely covered by ironstone, clay, and/or sand. Rocks are typically silicified or ferruginized. The depth of weathering ranges from about 40 to 100 m below the surface, as observed in diamond drillcore sampling.

MARYMIA straddles the boundary between the headwaters of the ephemeral 'Middle Branch' of the Gascoyne River, draining to the west, and the Lake Gregory system that drains southeastwards and ultimately feeds Lake Nabberu (Gee, 1987). The divide between these two drainage systems is a broadly linear zone from Johnson Cairn northwards to Marymia Hill. This 'Johnson Cairn divide', which varies in altitude between 600 and 670 m, is thought to be the remnant of a plateau surface that developed in the early part of the Cainozoic. The plateau was subject to deep lateritic weathering in the early Cainozoic (Gee, 1987), with more recent erosion and deposition forming the present land surface.

## Early Cainozoic land surface

Laterite, ferruginous duricrust, and silcrete deposits on MARYMIA represent essentially unmodified remnants of the Cainozoic land surface. Although the age of the peneplain forming the plateau is uncertain, the surface may be a correlative of the Hamersley Surface in the Hamersley Ranges (Campana et al., 1964) or of the Ashburton Surface of central Australia (Jennings and Mabbutt, 1971).

Calcrete deposits in the southeast pre-date the alluvium that partially covers them, and are probably related to alluvial channels and lakes that were active during the early Cainozoic. These deposits form low mounds in low-lying areas and consist of massive, nodular, and vuggy limestone partly replaced by chalcidony.

## Recent land-surface developments

The more recent erosion and deposition developments to which the Cainozoic land surface has been subjected are described below.

### Erosional land surface

The erosional land surface of MARYMIA, which is broadly equivalent to the three units of the 'erosional regime' of Subramanya et al. (1995), is geomorphologically diverse, and includes areas that have undergone different erosional

processes over time. These areas can be taken as representing various stages in the erosion of Cainozoic or pre-Cainozoic peneplains and include dissected, and in part sinuous, sandstone ridges. These rise typically to elevations of about 600 m in the south and 650 m in the northeast, separated by valleys developed over less-resistant rocks. The remainder of MARYMIA is dominated by relatively rounded low hills. Rock type influences the form of the hills: granitoid rocks form flat expanses, amphibolites weather to rounded low hills, and pelites produce more subdued topography. The erosional land surface is subject to active erosion from headwater systems.

### Depositional land surface

The depositional land surface, which is broadly equivalent to the ten units of the 'depositional regime' of Subramanya et al. (1995), includes colluvial, alluvial, and eolian sediments deposited during the Cainozoic. Floodplains are situated along and next to creeks and rivers. Rivers are outlined by consolidated gravel overlain by recent alluvium. The scree, colluvium, sheetwash fans, and playa lakes represent locally derived clastic detritus from streams and channels draining hilly areas. In the north of MARYMIA there are extensive sandplains that cover about 15% of the map sheet area. The topography here is predominantly flat with rare low dunes trending to the northeast, and the area is subject to periodic flooding. The sandplain deposits are dissected in part by the present drainage systems.

## Regional setting

MARYMIA includes the central part of the Archaean Marymia Inlier (Gee, 1979, 1987; Gee and Grey, 1993), the northeastern margin of the Palaeoproterozoic Yerrida Group (Pirajno et al., 1996), and the northwestern edge of the Palaeoproterozoic Earahedy Group (Hall et al., 1977). The area is situated about 150 km south of the Pilbara Craton. It is about 50 km northwest of the Eastern Goldfields Province (Griffin, 1990a), 150 km north of the Southern Cross Province, and 150 km northeast of the Murchison Province (Watkins, 1990) — all three provinces within the Yilgarn Craton (Fig. 1). The area thus falls in the southern part of the Capricorn Orogen (Gee, 1979; Tyler and Thorne, 1990), which formed between 2000 and 1650 Ma (Myers, 1990a). In this region the orogen is about 300 km wide and encompasses the Marymia Inlier (which was reworked during the Palaeoproterozoic), the Yerrida Basin, and probably the Earahedy Basin.

Gee (1979, 1990) and Windh (1992) have suggested that the Pilbara and Yilgarn Cratons are interconnected and continuous beneath geosynclinal deposits of the Capricorn Orogen, and hence postulated an ensialic (or intracontinental) setting. Others have suggested that the Capricorn Orogen was formed as a result of convergence, collision, and post-collisional movements between the Pilbara and Yilgarn Cratons (Muhling, 1988; Tyler and Thorne, 1990; Myers, 1990a, 1993; Martin, 1994; Myers et al., 1996; Tyler et al., in press).

In the ensialic model, the Marymia Inlier is interpreted as a block uplifted during Palaeoproterozoic compressional orogenies (Windh, 1992), or the result of solid-state, crystal-plastic flow and doming (Gee, 1990; Gee and Grey, 1993). In the collisional model, the Marymia Inlier represents a southward-thrust slice of basement.

Tectonic models for the Yerrida Basin, formerly included in the now-superseded 'Glengarry Basin' of Gee and Grey (1993), include development as an ensialic or intracontinental basin (Gee, 1979; Hynes and Gee, 1986; Windh, 1992); development (in part) as a back-arc basin above a subduction zone dipping southward beneath the Yilgarn Craton (Tyler and Thorne, 1990; Myers, 1993); and development as a pull-apart basin, along the northern margin of the Yilgarn Craton, during sinistral transpression resulting from the oblique convergence of, and collision between, the Yilgarn and Pilbara Cratons (Pirajno et al., 1995).

The chronology and tectonic setting of the Earahedy Group are poorly understood, and consequently it is only tentatively included in the Capricorn Orogen.

## Archaean geology

### Marymia Inlier

The Marymia Inlier, a granite–greenstone terrane surrounded by Palaeoproterozoic rocks, is situated about 50 km to the north of the northern margin of the Yilgarn Craton. The inlier is unconformably overlain by, or faulted against, the Palaeoproterozoic Yerrida and Earahedy Groups (Fig. 1), and is intruded by dolerite dykes, quartz diorite – granodiorite, kimberlite, and lamprophyric rocks (Shee et al., 1996).

Very little was known about the geology of the Marymia Inlier until the recognition of the greenstone succession around Plutonic Well (AMG 605091) in the 1970s and the discovery of the world-class Plutonic gold deposits in the late 1980s. Subsequent exploration and mapping has revealed that the inlier is composed of the Plutonic Well and Baumgarten greenstone belts separated by monzogranite intrusions. The Plutonic Well greenstone belt is situated in the centre of the inlier, and trends northeast with a strike length of about 60 km and a width of about 10 km. The Baumgarten greenstone belt is in the southeastern part of the inlier (Fig. 1).

The Marymia Inlier appears to consist of two terranes that are separated by the Jenkin Fault as shown on the **Simplified geology** inset on the MARYMIA sheet. The terrane to the north of the fault includes the Plutonic Well greenstone belt and the northern part of the Baumgarten greenstone belt. The terrane to the south of the Jenkin Fault includes the southern part of the Baumgarten greenstone belt. (As noted below, the northern and southern parts of the Baumgarten greenstone belt form two lithologically distinct domains, separated by the Jenkin Fault.)

### Plutonic Well greenstone belt

The Plutonic Well greenstone belt is surrounded by Archaean granitoid rocks, and hosts the Plutonic gold deposit (on THREE RIVERS) and the Marymia gold deposits (on MARYMIA).

The belt is interpreted as an inclined composite synclinal complex, generally plunging to the southwest, with overturn of the northwestern limb. Foliations and bedding planes dip northwestward, and are commonly parallel. The outer northwestern and southeastern parts of the belt consist of metamorphosed pyroxenite, komatiite, ultramafic schist, banded iron-formation, chert, mafic and felsic schist, pelite, and tholeiitic basalt. In the central part are boulder and pebble conglomerates, with subrounded clasts of monzogranite, banded iron-formation, and mafic schist in a foliated mafic matrix. This conglomerate is interlayered with felsic rocks, quartzite, pelite, and minor amounts of amphibolite.

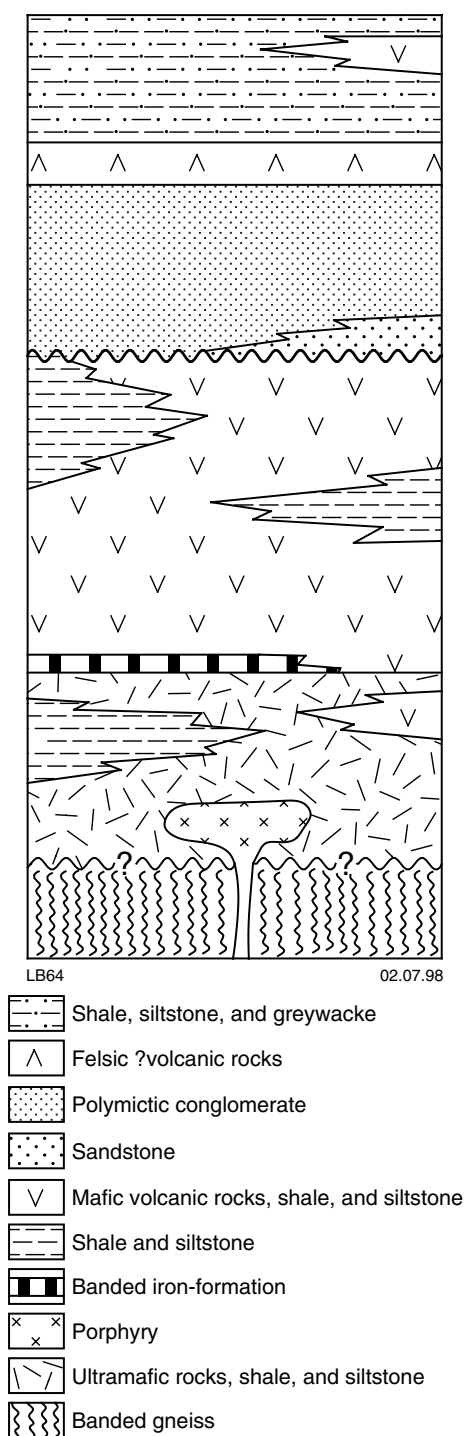
The outer greenstone successions were intruded by monzogranite (c. 2.72 Ga, McMillan and McNaughton, 1995), rhyodacitic porphyries (c. 2.69 Ga, McMillan and McNaughton, 1995), gabbro, and dolerite.

A detailed stratigraphic succession can not be determined because of the tectonic complexity in the area and the lack of continuous rock exposure. However, a possible stratigraphic succession for the greenstone belt is presented in Figure 2. This succession assumes that the northern part of the greenstone belt is overturned towards the southeast, based upon a small number of younging directions observed in ultramafic rocks in the Plutonic Well area.

### Baumgarten greenstone belt

The Baumgarten greenstone belt can be divided into two lithologically distinct domains at the Jenkin Fault (named after the Jenkin Bore in the southeastern section of THREE RIVERS).

Rock types present in the southern domain are similar to the greenstone successions in the Plutonic Well greenstone belt. They consist of deeply weathered and silicified ultramafic rocks (serpentinized peridotites, metakomatiites, and chlorite–carbonate–talc–amphibole schist) that appear to be overlain by ferruginized metamorphosed basalt, gabbro, shale, and quartzite. Lithological contacts between the various rock types have not been observed in the field because of the high degree of weathering and lack of outcrop. The gabbro is probably a subvolcanic sill, and the change from gabbro to fine-grained volcanic rocks appears to be gradational. Compositional banding and foliation in the southern domain are parallel, with a regional trend of approximately 020°, and dip steeply toward the northwest. The belt appears to form an antiformal structure plunging northeast with metamorphosed mafic and ultramafic rocks in its core. The northwest-trending fold, revealed by localized chert outcrops southwest of Baumgarten Reward mine, may be a D<sub>5</sub> structure (see **Structure**



**Figure 2. Schematic stratigraphic column for the Plutonic Well greenstone belt**

below). Granitoid rocks outcrop north of the belt, and the contact with the belt is sheared.

The northern domain consists of weathered and ferruginized pelitic schist, banded iron-formation, chert, and rare amphibolitic and ultramafic rocks. No lithological contacts have been observed between the units. Pelitic rocks also outcrop south of the Jenkin Fault in the area southwest of Bolgera Spring.

## Archaean rock types

Although all Archaean rocks in the MARYMIA area have been deformed and metamorphosed, original rock terminology is used wherever possible. In many areas, deformation, metamorphism, and weathering have so obscured primary characteristics that protolith identity and stratigraphic relations are uncertain.

### Ultramafic rocks (*Au*, *Auk*, *Aux*)

The general rock classification '*Au*' includes intensely deformed and metamorphosed ultramafic rocks with rarely preserved primary textures. The rocks are commonly silicified, but there are local outcrops of fine-grained talcose schist and coarse-grained amphibole–chlorite schist. The amphibole–chlorite schist consists of actinolite–tremolite–chlorite–talc and rare ankerite, serpentinite, and carbonate and/or talc rocks. The talc–carbonate assemblage infills skeletal phenocrysts possibly after olivine or pyroxene. The amphibole forms acicular needles aligned parallel to a penetrative ( $S_1$ ) foliation which is crenulated ( $F_2$ ) in places (see **Structure** below).

Komatiite (*Auk*) is exposed along the northern part of the Plutonic Well greenstone belt near Plutonic Well and also near the Keillor 1 mine (where the exposure is too small to differentiate on the map). This unit includes variably carbonated komatiite with spinifex textures, serpentinites, and tremolite–serpentine rocks interlayered with tremolite–chlorite schist. The locally preserved spinifex textures show a decrease in grain size towards the southeast. This grain size variation suggests that the facing is southward, and that the northwesterly dip in this area reflects overturn to the southeast. This further indicates that the metasedimentary succession in the centre of the Plutonic Well greenstone belt stratigraphically overlies the greenstone succession.

Metapyroxenite (*Aux*) is exposed to the south of the Plutonic Well greenstone belt as rafts in orthogneiss (*Ag*). The metapyroxenite is heavily ferruginized and contains medium- to coarse-grained amphibole after pyroxene intergrown with fine actinolite–tremolite and chlorite. The unit is interlayered with ultramafic schist.

Peridotite has been observed in a number of rotary air-blast (RAB) drillholes in the southern domain of the Baumgarten greenstone belt (GSWA samples 119031 and 119045). It consists of serpentine, tremolite and chlorite, with textural evidence of primary cumulate olivine with interstitial pyroxene.

### Mafic rocks (*Aog*, *Aoh*, *Aba*)

The majority of amphibolite exposures in the Plutonic Well and Baumgarten greenstone belts are of metamorphosed basalt (*Aba*). Medium to coarse-grained amphibolite (*Aog*) and medium-grained amphibolite (*Aoh*) also outcrop on MARYMIA.

Medium- to coarse-grained amphibolite (*Aog*), interpreted as metamorphosed dolerite or gabbro sills, outcrops in the southern domain of the Baumgarten



greenstone belt and around the Apollo gold deposit in the Plutonic Well greenstone belt. The amphibolite consists of hornblende (locally blastoporphyrific after augite), plagioclase (commonly altered), chlorite, epidote, and quartz.

Medium-grained amphibolite (*Aoh*) outcrops about 8 km west of the Keillor 2 mine where it is enclosed in orthogneiss. The medium-grained amphibolite is well foliated and shows distinct centimetre-scale banding, probably due to metamorphic segregation of amphibole-rich and amphibole-poor layers. Sericitized plagioclase and amphibole (hornblende) are the main mineral constituents, with quartz present as an accessory phase. Leucosomes form narrow irregular, discontinuous segregations or dyke-like bodies up to 1 m thick that show the same structural fabrics as the interlayered mafic hosts.

Amphibolite (*Aba*) commonly outcrops as a highly ferruginized fine- to medium-grained rock containing relict plagioclase. The amphibolite is commonly boudinaged in ultramafic schist and is interlayered with thin-banded schist (metashale) in places. Penetrative foliation ( $S_1$ ) is layer-parallel, and in thin section is defined by iron oxide and amphibole trails. The protolith of the amphibolite is interpreted as a tholeiitic basalt interlayered with sedimentary rocks.

Amphibolite (*Aba*) samples from the mines on MARYMIA consist of actinolite rimmed by hornblende, retrograde actinolite–tremolite pseudomorphs after pyroxene microphenocrysts, and plagioclase (oligoclase or andesine) partially altered to albite. Retrograde minerals include chlorite with epidote and carbonate after amphibole, epidote after amphibole, lesser amounts of quartz, clinozoisite, and carbonate, and accessory iron oxide. Epidote patches are locally prominent. Primary igneous textures are poorly preserved. Thin-banded schist (metashale) consists of quartz–amphibole–biotite–chlorite, garnet–biotite–chlorite(–sericite–epidote – sericitized feldspar), or quartz–graphite.

### **Felsic porphyry, volcanic, and volcanoclastic rocks (*Af*, *Afp*)**

Several generations of porphyritic intrusions of a felsic composition (*Afp*) outcrop throughout the Plutonic greenstone belt. Although commonly recognizable as sills or dykes, some outcrops of this rock are too poorly exposed to allow their form to be identified. These are variably deformed, are boudinaged within the regional penetrative foliation ( $S_1$  or  $S_2$ ), have sheared contacts with the country rocks, and may be pre- $D_1$  intrusives in the greenstones. The porphyries are rhyodacitic in composition and have phenocrysts of very fine to coarse-grained quartz, sericitized and albitized plagioclase, and apatite set in a quartzofeldspathic matrix. The matrix contains variable amounts of chlorite after biotite and amphibole, and accessory apatite and iron oxide.

Quartzofeldspathic rock (*Af*) in the Apollo mine area is massive, generally even-grained, pervasively

kaolinized, and cross-cut by various generations of quartz veins. The rock contains angular rock fragments, derived from the greenstones and granite, in a medium-grained matrix composed of sericite, and angular quartz and feldspar grains. The protolith was probably an immature and proximal arkose or lithic wacke derived principally from the erosion of granitic rocks and deposited during late  $D_1$  or syn- $D_2$ .

Another exposure of this rock type can be seen about 8 km northeast of McDonald Well (McDonald Well: AMG 834822), where finely layered felsic volcanic and volcanoclastic rocks (*Af*) are unconformably overlain by the Juderina Formation in the core of an anticline. The rock contains medium-grained quartz, anhedral plagioclase, and rare anhedral K-feldspar phenocrysts in a very fine grained quartzofeldspathic and sericitic matrix. The quartz phenocrysts are embayed, suggesting resorption, and have a later silica overgrowth. These rocks are rhyodacitic in composition.

### **Chemical sedimentary rocks (*Aci*, *Ac*)**

Banded iron-formation (*Aci*), interlayered with metapelite and/or ferruginized chert and/or amphibolite, outcrops near the northwestern edge of the Plutonic Well greenstone belt and in the northern domain of the Baumgarten greenstone belt. This rock type is present as a distinctive unit which extends for about 12 km to the east of the Keillor 1 mine. The unit structurally overlies amphibolite and is overlain by ultramafic schist. This relationship, however, is probably inverted, as inferred from the facing directions of ultramafic rocks in the Plutonic Well area.

Banded iron-formation (oxide facies) consists of thinly bedded to laminated, very fine grained iron oxide and recrystallized quartz. It is interlayered with amphibolite (metabasalt), pelitic schist (including garnet schist and biotite schist), and ultramafic schist. It is commonly boudinaged within less-competent units and shows several phases of folding, including intrafolial isoclinal folds, reclined folds, and crenulations.

The silicate facies of the banded iron-formation units generally consist of magnetite–grunerite (–cummingtonite–actinolite–tremolite)–quartz, with minor quantities of hornblende (as rims around grunerite), sulfides, biotite (variably retrogressed to chlorite), epidote, garnet, and carbonate.

Grey-white chert (*Ac*) is a common rock type in the northern domain of the Baumgarten greenstone belt and the Plutonic Well greenstone belt. It occurs in metamorphosed sedimentary and basaltic rocks and probably represents a silica-rich chemical deposit associated with banded iron-formation.

### **Clastic sedimentary rocks (*As*, *Ash*, *Asq*, *Asp*)**

The general metasedimentary rock classification (*As*) includes highly weathered and poorly exposed sequences of shale (phyllite and schist) and lithic

wacke (quartz–feldspar–mica schist, *Ash*), quartzite (*Asq*), and conglomerate (*Asp*) throughout the greenstone successions on MARYMIA.

Phyllite (*Ash*) is a foliated and metamorphosed laminated shale interbedded with schistose lithic wacke composed of mica, quartz, and rare relict feldspar. The unit outcrops as an iron-enriched, deeply weathered rock with variable amounts of relict garnet, biotite, and andalusite. Local rare units of grey and black phyllite contain carbonaceous material in a fine-grained sericitic and quartz-rich matrix.

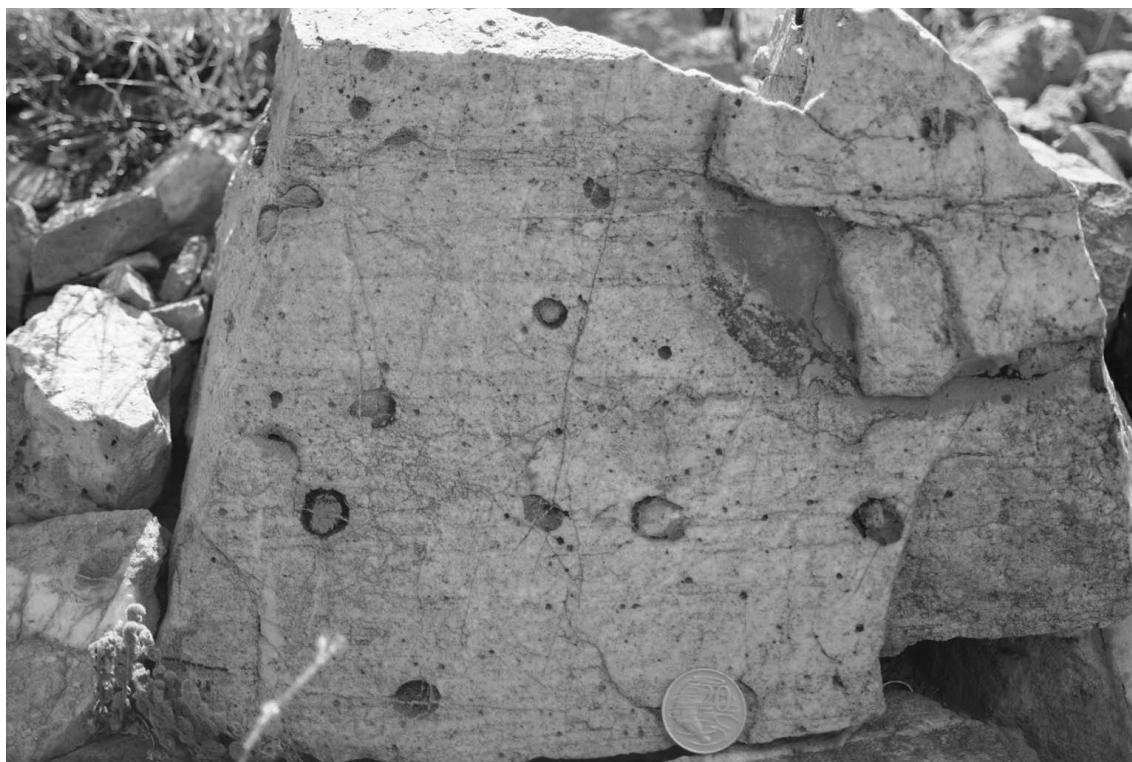
Quartzite (*Asq*) outcrops towards the structural base of the conglomeratic succession in the centre of the Plutonic Well greenstone belt (e.g. AMG 705080), structurally above orthogneiss and greenstone in the core of a synclinal structure 6.5 km west of the Keillor 1 mine (AMG 706213), and in the southwestern corner of MARYMIA (AMG 518823). The quartzite is generally well foliated, but in the southwest is well bedded, cross-bedded, and ripple-marked. There is some uncertainty as to whether the quartzite in the southwest is Archaean or Proterozoic in age. The unit contains iron-stained casts (after ?diagenetic carbonate nodules) and sedimentary structures that are similar in appearance to those in the Juderina Formation (Fig. 3). The unit, although tectonically interleaved with Archaean granitoid rock, is less foliated than quartzite in the centre of the Plutonic Well greenstone belt and may be part of the Juderina Formation.

Polymictic conglomerate (*Asp*) contains subrounded to angular pebbles, cobbles, and boulders of granite, banded iron-formation, amphibolite, mafic schist, ultramafic schist, and vein quartz in a foliated fine- to medium-grained, poorly sorted mafic matrix. The unit outcrops as boulder-strewn areas in the central part of the Plutonic Well greenstone belt, where it is interlayered with felsic volcanic rocks or arkosic sandstone (*Af*, described below), pelitic schist, schistose lithic wacke, and rare mafic amphibolite and ultramafic schist. The unit was previously thought to be a poorly exposed granite due to the predominance of granitic clasts and because the polymictic and rounded nature of the clasts was not recognized.

The best exposures of the conglomerate can be seen at the northern end of the Apollo mine, where elongate and flattened clasts are supported by a foliated (late  $S_1$  or  $S_2$ ) mafic matrix. The unit coarsens upward to the north (i.e. towards the mafic successions). The upward coarsening may suggest that the unit is overturned towards the south. The contact between the conglomerate and the greenstone succession to the north is poorly exposed but the greenstones, which rest at a structurally higher level, are more highly sheared and more strongly foliated.

### **Granitoid rocks (*Ap*, *Ag*, *AgI*)**

Granitoid rocks on MARYMIA are generally deeply weathered and poorly exposed in low, patchy outcrops.



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**Figure 3.** Casts after ?diagenetic carbonate nodules in laminated ?Archaean quartzite from southwestern MARYMIA (AMG 525823)

They range in composition from syenogranite to granodiorite, with monzogranite being the most abundant. They are intruded by at least two generations of pegmatites (*Ap*) and aplites, various generations of quartz veins, and Proterozoic dolerite dykes. The earlier pegmatite and aplite dykes trend parallel to the gneissic fabrics (*S*<sub>1</sub>) and are folded (*F*<sub>2</sub>). These rocks may be of similar age to some of the felsic porphyritic rocks.

Undivided granitoid rocks (*Ag*) are commonly leucocratic, equigranular to slightly porphyritic, medium- to coarse-grained, variably foliated, show evidence of recrystallization, and are commonly gneissic or sheared near the greenstone contacts. The gneissic texture, marked by the alignment of phenocrysts or augens and biotite, is locally folded (*F*<sub>2</sub>) and refolded (*F*<sub>4</sub>). Feldspars are commonly altered to sericite, epidote, and titanite. Microcline is perthitic in places, quartz is strained, and plagioclase is commonly zoned with development of antiperthitic and myrmekitic textures. Biotite (<5%) and muscovite (<5%) are minor components. Apatite, zircon, and iron oxide are common accessories.

A complex zone of interleaved greenstone and granitoid rocks is present along the northwestern edge of the Plutonic Well greenstone belt. The southeastern edge is marked by a mica schist (sheared granitoid rock). The contacts between the greenstones and granitoid rocks dip shallowly to the northwest, with a down-dip stretching lineation, and locally cross-cut the greenstones (such as near Plutonic Well and the Keillor 2 mine). The contacts are probably long-lived faults that have been reactivated a number of times. The youngest movement recognized was during *D*<sub>5</sub>; it displaced the Earahedy Group at the Keillor Fault in the northeast of MARYMIA.

Leucocratic monzogranite (*Ag*<sub>l</sub>) is exposed about 5 km west of the Keillor 1 mine. The monzogranite forms east-northeasterly trending linear bodies in well-foliated gneissic monzogranite (*Ag*). The leucocratic monzogranite is homogeneous, medium- to coarse-grained, and weakly foliated with primary muscovite (<5%) and biotite (<5%). Metamorphic effects include sericitization of plagioclase and variable chloritization of biotite. Quartz and K-feldspar (microcline) crystals are strained. It is not certain if the monzogranite intrudes *Ag* or if it represents a non-foliated variation of *Ag* preserved in pressure shadows during deformation.

## Proterozoic geology

### **Dolerite sills (*Ed*<sub>1</sub>) and dykes (*Ed*)**

Dolerite sills (*Ed*<sub>1</sub>) outcrop towards the top of the Yelma Formation in the northeastern part of MARYMIA within the recessive fissile siltstone and shale sequences. This rock association implies that the sills are stratigraphically controlled by the fissile nature of the host rocks. The absence of dolerite in the lower part of the formation also suggests that a tensional tectonic regime developed before intrusion of the dolerite. The sills are folded concordantly with the host rocks and were, therefore, intruded before folding of the Earahedy Group. The

dolerite is medium-grained and consists of deuterically or diagenetically altered plagioclase and clinopyroxene (augite), orthoclase granophyrically intergrown with quartz, and sulfides. Clinopyroxene is altered to chlorite, and plagioclase to sericite and calcite.

Fine- to medium-grained dolerite dykes (*Ed*) cross-cut the Archaean granitoid rocks and greenstone successions on MARYMIA. These dykes are probably all Proterozoic in age, generally trend northeast, and are expressed as either magnetic highs or lows on the GSWA aeromagnetic maps for the area. The rock consists of albitized plagioclase and corroded anhedral augite microcrysts in a fine-grained matrix containing quartz, chlorite, and epidote. The plagioclase is altered to chlorite and epidote, and the augite is altered to actinolite–tremolite. This mineral assemblage is indicative of greenschist-facies regional metamorphism.

## Yerrida Group

The former Glengarry Basin has been redefined and subdivided into three groups — the Yerrida, Bryah, and Padbury Groups (Pirajno et al., 1996). One of these, the Yerrida Group, occupies the southern part of MARYMIA. The Yerrida Group is further subdivided into a basal sag-basin sequence — the Windplain Subgroup — and a conformably overlying rift-basin sequence — the Mooloogool Subgroup (Pirajno et al., 1996).

Figure 4 is a composite section from the hinge zone of the Rooneys Syncline (named after the Rooneys copper deposit) and summarizes the lithologic succession of the Yerrida Group. However, due to the lack of continuous outcrop and the possible presence of early thrusting, this summary should be regarded as tentative.

### Windplain Subgroup

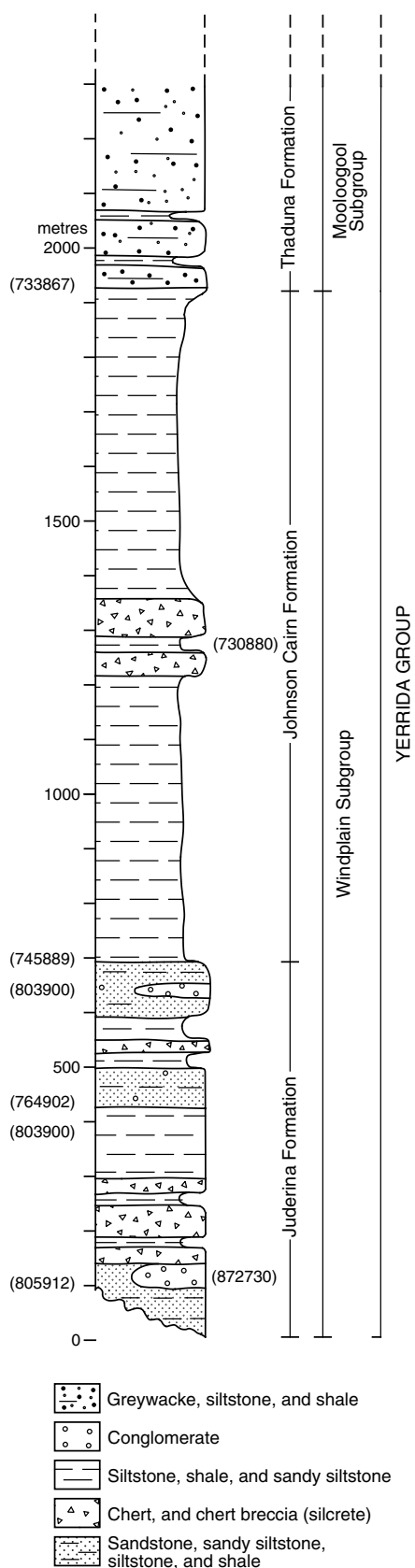
The Windplain Subgroup consists of the Juderina and Johnson Cairn Formations. Both outcrop in southern MARYMIA.

#### **Juderina Formation (*Pvj*, *Pvjs*, *Pvjps*, *Pvja*)**

The Juderina Formation (Gee and Grey, 1993; *Pvj*), exposed in the northeastern end of the Rooneys Syncline, is the lowest stratigraphic unit of the Yerrida Group (Fig. 4). The formation unconformably overlies Archaean basement rocks around AMG 872865 (*Af*), is faulted against Archaean rocks to the northwest around AMG 730894 along the Jenkin Fault, and is transitionally overlain by the Johnson Cairn Formation. The upper contact is here defined as the top of the uppermost major quartz sandstone unit in the Juderina Formation.

The Juderina Formation includes three units of well-sorted and mature, fine- to medium-grained quartz sandstone interbedded with clayey sandstone and siltstone (*Pvja*). These units are up to 150 m thick, and are separated by thicker successions of poorly exposed chert breccia, shale, siltstone, sandy siltstone, and discontinuous thin sandstone (*Pvjs*).





**Figure 4. Composite and schematic section for the Yerrida Group on MARYMIA; the numbers in brackets are AMG references**

The fine- to medium-grained quartz sandstone (*Eyja*) is characteristically silicified, although sedimentary features are well preserved locally. The lowest exposed sandstone unit varies in thickness from about 3 to 100 m. It is characterized by herring-bone and trough cross-bedding sets that are less than 150 mm thick, and planar bedding sets that are less than 150 mm thick. It is also characterized by multidirectional symmetric and asymmetric ripple marks with silty drapes, clay pellet casts showing polygonal mudcracks, and rare trails of heavy minerals. The sandstone contains well-rounded to subangular quartz grains cemented by silica overgrowths, rounded detrital zircon, and rare interstitial sericite. Interbedded silty sandstone contains subangular quartz grains in a clay-rich matrix with small quantities of sericite.

The sandstone is locally and sharply overlain by a poorly sorted, matrix-supported, and lenticular polymictic conglomerate (*Eyjp*). The conglomerate varies in thickness from about 3 m at AMG 880883 (where the exposure is too small to be differentiated on the map from the surrounding sandstone) to tens of metres at AMG 868850, and contains intraformational angular boulders and pebbles of quartz sandstone, vein quartz, and rare chert in a medium- to coarse-grained quartz-rich matrix.

The lowest sandstone unit is overlain by interlayered chert breccia, blue-grey laminated chert, and siltstone just west of AMG 880881. The chert ranges in thickness from about 70 to 140 m without apparent bedding, and weathers to a smooth bouldery outcrop forming a copious scree of silicified rubble (*Czz*). Gee (1987) recognized that the unit has remnant stromatolitic forms that are considered to be silicified microbial mats containing carbonate and evaporite minerals. The relict stromatolitic forms suggest that the unit may be a correlative of the Bubble Well Member of the Juderina Formation, which outcrops in the southern part of the Yerrida Basin (Gee and Grey, 1993).

The lower chert horizon is overlain by poorly exposed, well-cleaved, and commonly ferruginized shale and siltstone with thin sandstone interbeds. The siltstone is similar in appearance and composition to that of the Johnson Cairn Formation, and weathers to an irregular, flint-like rubble.

In general, the higher quartz sandstone units contain thin pebbly horizons, are slightly more feldspathic than the lowest unit (giving them a light pink colour), and silicification has significantly masked their sedimentary textures. The upper sandstone units are massive, thickly bedded, and generally structureless. They are characterized by the presence of subrounded to rounded cavities that range up to 30 mm in diameter, giving them a spotted and mottled appearance. The cavities are coated with limonite, appear to cross-cut bedding planes and, where the host rock is freshly broken, contain loosely cemented quartz grains. It is difficult to determine the origin of these spots but, judging from their cross-cutting relationship with bedding, they may be after diagenetic carbonate. Gee (1987) similarly suggested that the brown mottled sandstone probably had a carbonate cement.

There are similar structures in quartzite (*Asq*) from the southwestern section of MARYMIA (Fig. 3).

### **Johnson Cairn Formation (*Eyc*)**

The Johnson Cairn Formation (Gee and Grey, 1993; *Eyc*) is poorly exposed, and outcrops as low, flaky, iron-enriched rises or at breakaways along the edges of lateritic cover. The formation conformably overlies the Juderina Formation and is, in turn, conformably overlain by the Thaduna Formation of the Mooloogool Subgroup (Fig. 4). The upper contact is here defined as the base of the lowermost lithic wacke bed in the Thaduna Formation.

The Johnson Cairn Formation is about 1250 m thick in the least tectonized area around AMG 740880. It consists of a laminated to thinly bedded sequence of interbedded ferruginous (?sulfidic) and grey-banded shale, silicified (?carbonaceous) shale, upwardly graded ferruginous (?sulfidic) siltstone, and thin dololutite. The dololutite is purplish, laminated, and micritic, and locally contains authigenic pisolites of magnesite. The dololutite beds have slightly undulating contacts, showing local flame structures, and are generally less than 300 mm thick. Banded chert or silcrete interlayered with shale occurs towards the middle of the formation around AMG 730880 (Fig. 4). The chert is discontinuous, tens of metres thick, and probably represents silicified shale or carbonate.

## **Mooloogool Subgroup**

The Mooloogool Subgroup is represented in southern MARYMIA by the Thaduna Formation.

### **Thaduna Formation (*Eyt*)**

The Thaduna Formation (MacLeod, 1970; Gee, 1979, 1987; *Eyt*) is the youngest unit of the Yerrida Group on MARYMIA. The formation forms the base of the Mooloogool Subgroup (Pirajno et al., 1996) and outcrops in the core of the Rooneys Syncline. Exposures are generally poor, except south of the Green Dragon copper mine where the formation is best exposed. The formation conformably and transitionally overlies the Johnson Cairn Formation (e.g. at AMG 740839), and is estimated to be at least 5 km thick (Gee, 1979).

The Thaduna Formation is a turbiditic sequence characterized by rhythmic alternation of coarse- to fine-grained lithic wacke with interbeds of finely laminated purple shale and siltstone. These sequences may vary locally from predominantly lithic wacke (with thin siltstone and shale interbeds) to dominantly siltstone and shale with thin lithic wacke interbeds. Each lithic wacke bed is marked by a sharp base with scour and rip-up structures (Fig. 5), and a top that is transitionally overlain by shale. The lithic wacke is commonly graded, and locally displays small-scale cross-bedding, ripple marks, and slump structures.



**Figure 5.** Rip-up structures in the Thaduna Formation, at the contact between purple shale and lithic wacke (AMG 638799)

Lithic wacke consists of angular clasts up to 30 mm across supported by a hematitic matrix composed of sericite, clay, disseminated epidote of uncertain origin, and fine-grained quartz, calcite, plagioclase, and K-feldspar. The clasts are angular and tabular to rounded, corroded, and are commonly elongated along the bedding plane. The clasts are intraformational shale and siltstone, quartz, plagioclase, microcline (possibly derived from Archaean granitoid rocks), and mafic rocks (of uncertain origin). The volcanic clasts are composed of albite-chlorite – fibrous amphibole – relict clinopyroxene and rare quartz. Chlorite and epidote are commonly associated in single grains and are metamorphic in origin. These clasts may have been derived from the mineralogically similar metavolcanic rocks of the Archaean greenstones, but it is also possible that some components are derived from the volcanics in the Yerrida and Bryah Groups south of MARYMIA, namely the Killara (Yerrida) and Narracoota (Bryah) Formations (Pirajno and Adamides, in prep.).

The interbedded shale and siltstone consist of angular to subrounded quartz and rare plagioclase grains in a very fine grained matrix composed of sericite, quartz, feldspar, clay, small amounts of carbonate, rare chlorite, and disseminated very fine grained hematite particles (giving the rock a purple colour). A conspicuous feature of the shale and siltstone is the common presence of hematite overgrowths, which appear as dark purple spots up to 3 mm in diameter, arranged along bedding planes. These hematitic spots are probably diagenetic in origin and appear to be surficial patches of alteration.

## Depositional environment of the Yerrida Group

The earliest sedimentary unit of the Windplain Subgroup on MARYMIA is a mature quartz sandstone at the base of the Juderina Formation. The maturity of the sandstone, together with its multidirectional ripple marks, herring-bone cross-bedding and desiccation cracks, indicates that it was affected by tidal currents and was most probably deposited in a shallow marine environment that was periodically subjected to subaerial exposure. A sharp transgression led to the deposition of a lensoidal conglomerate followed by deposition of the chert (?carbonate) and pelite unit in an intertidal-flat environment. This was interrupted by periodic regressive deposition of sandstone and rare conglomerate. The overlying Johnson Cairn Formation marks another transgression, indicated by the re-establishment of a low-energy intertidal to subtidal environment with the deposition of siltstone, shale, and carbonate.

The Thaduna Formation represents a significant and rapid change in depositional environment from a relatively quiet sag basin (represented by the Windplain Subgroup) to a more active rift- or graben-basin setting. This change is marked by the introduction of lithic wacke as Bouma sequences in a succession that is otherwise similar to that of the Johnson Cairn Formation. The deposition of the lithic wacke was synchronous with subaqueous mafic-volcanism in the Killara Formation

(Pirajno and Adamides, in prep.). The lithic wacke beds are interpreted as representing turbidity flow deposits initiated during short-lived and periodic instability in the depositional environment.

## Earaheedy Group (*PEya*, *PEys*, *PEyc*, *PEyp*)

The rocks in the northeastern corner of MARYMIA were previously assigned to the Wonyulgunna Sandstone of the Bangemall Group (Gee, 1987). They are now tentatively assigned to the Yelma Formation of the Earraheedy Group (Hall et al., 1977; Bunting, 1986), along with similar rocks now recognized in the northwestern corner of MARYMIA, following identification of *?Ephyalthes edingunnensis* Grey 1994 stromatolites by Grey (1997). The stromatolite specimens were collected from around AMG 967149 and are poorly preserved, but they show some resemblance to those previously recorded from the Yelma Formation (Grey, 1984; Gee and Grey, 1993; Grey, 1994).

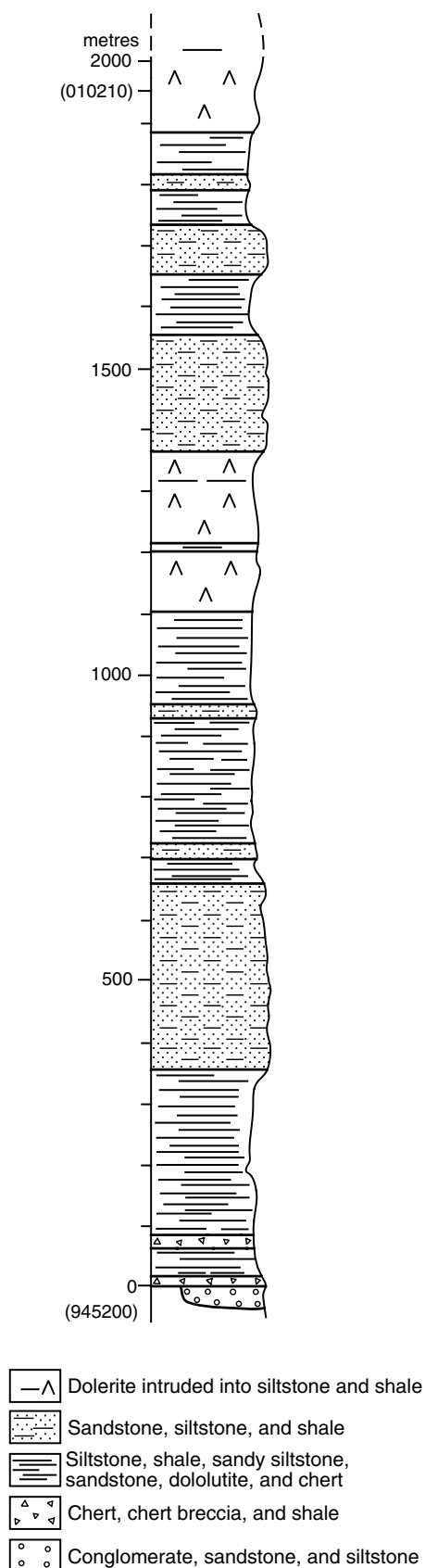
The Yelma Formation unconformably overlies the Archaean Marymia Inlier and is estimated to be around 1600 m thick (excluding dolerite sills) on MARYMIA (Fig. 6). The formation consists of an upward-fining and lenticular polymictic conglomerate interbedded with sandstone and laminated siltstone (*PEyp*), chert (*PEyc*), shale interbedded with minor quantities of chert and dololuite (*PEys*), and sandstone interbedded with shale (*PEya*).

The conglomeratic unit (*PEyp*) is exposed locally at the base of the Yelma Formation to the south of the Baumgarten Reward mine (e.g. at AMG 970990). It is weakly cemented, matrix- to clast-supported, and contains cobbles and pebbles of subrounded quartz, jasperoidal chert, cream-coloured chert (probably derived from the Juderina Formation), sandstone (also probably derived from the Juderina Formation), and granite clasts in an arkosic matrix. The interbedded sandstone is medium-grained to granular, ripple-marked, cross-bedded, arkosic, and contains quartz, phyllite, and silicified sandstone granules and pebbles.

The conglomeratic unit is overlain by a poorly exposed and ferruginized shale-rich unit (*PEys*) southeast of the Baumgarten Reward mine. The shale-rich unit appears to conformably overlie the conglomerate, and its northwestern side is faulted against greenstone. It consists of cleaved ( $S_1$ ) shale, siltstone, and fine-grained lithic sandstone (or wacke). The shale is finely laminated, wavy-bedded, and locally cross-bedded. The unit was previously included in the Archaean Baumgarten greenstone belt (Gee, 1987).

The Yelma Formation, exposed in the northwest of MARYMIA (AMG 642320) and in the Yadgymurrin Syncline (named after Yadgymurrin Creek) in the northeast of MARYMIA, is partly fault-bounded and unconformably overlies Archaean granitoid rocks without a basal conglomerate. The formation consists of shallow-water chemical and clastic sedimentary rocks, with the





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**Figure 6.** Section for the Yelma Formation on Marymia; the numbers in brackets are AMG references

local intrusion of dolerite sills towards its top. The basal unit is a 5–9 m-thick pale chert that is conformably overlain by shale and sandstone.

The chert (*BEyc*) most likely developed from a dolomitic precursor and has been diagenetically or recently silicified. The chert is mid-grey to black in colour, wavy-bedded, stromatolitic (?*Ephyaltes edingunnensis* Grey 1994; Grey, 1997), and laminated with thin (100 mm thick) syndepositional breccia interbeds. The stromatolitic surfaces are cone-shaped and bound by laminated chert. The laminated beds contain relict gypsum crystals, syneresis cracks, and tepee and rip-up structures. These sedimentary features are indicative of shallow-water and quiet conditions during sedimentation that were periodically interrupted by high-energy storm conditions (now represented by breccia units). The laminated chert is capped by chert breccia possibly formed by silica deposition in more recent times.

The basal chert is overlain by a 1600 m-thick assemblage of interbedded siltstone, shale, rare chert, dololuite (*BEys*), and finely laminated sandstone interbedded with siltstone and shale (*BEya*). The siltstone and shale are light to dark grey, brown, and purple (and rarely green), and are laminated and fissile. The shale also contains rare gypsum crystals that may have crystallized during weathering of the host rock. The sandstone is fine- to medium-grained, and contains halite casts, clay pellet casts, desiccation cracks and ripple marks; it is rarely cross-bedded.

Exploration companies have recognized a similar stratigraphic succession of rocks (see Fig. 6), during percussion-drillhole exploration programs under Quaternary alluvium (*Qa*, *Qw*) in the southeastern part of MARYMIA. The rocks intersected in these drillholes include a basal chert which is about 9 m thick, overlain by siltstone and shale interbedded with minor amounts of sandstone. This area has been interpreted as part of the Earahedy Group by previous workers (Gee, 1987; Pirajno and Adamides, in prep.).

## Cainozoic geology

Recent sediments that are presently being deposited have been mapped as Quaternary (*Q*). Older and significantly dissected sediments no longer being deposited have been mapped as Cainozoic (*Cz*). Some of the older sediments, such as laterite and silcrete, may be early Cainozoic in age or older, as in other areas of Australia (Idnurm and Senior, 1978); however, in the absence of empirical dating evidence they have been mapped here as Cainozoic.

Most Precambrian outcrops show some evidence of ferruginization, leaching or silicification typical of lateritic profiles. Gently undulating cappings of duricrust include ferricrete or ironstone deposits (*Czl*) and silcrete deposits (*Czz*). The duricrust represents remnants of Cainozoic weathering profiles in which the original rock structures or textures are poorly

preserved. These sediments are probably early Cainozoic in age and may represent a continent-wide weathering event (Idnurm and Senior, 1978), represented in Western Australia by the Cainozoic land surface (see **Physiography** above).

Colluvium, sheetwash, fan deposits, and talus (*Czc*) are composed of red-brown ferruginous gravel, sand, and silt. The colluvium is derived from various rock types, which now form the adjacent hilly areas.

Calcrete (*Czk*), consisting of massive, vuggy, or nodular sandy limestone, occupies old drainage channels in southeastern MARYMIA. Secondary silicification locally has resulted in incomplete replacement by a vuggy and opaline silica caprock. The calcrete is transgressed and overlain by Quaternary alluvium.

Sand containing laterite granules and pebbles (*Czf*) stands out as characteristic dark patterns on aerial photographs. This unit is a mixture of partly residual and partly transported ferricrete granules, pebbles, and eolian sand. Being partly residual in origin, the unit indicates relatively high iron content in bedrock, and commonly overlies shale, pelitic schist, amphibolite, or nodular laterite.

## Quaternary

Locally derived colluvial sands, soil, and gravel (*Qc*) form gently sloping scree and outwash fans alongside hills. The colluvium is weakly incised by watercourses and locally grades downstream into alluvium.

A substantial part of the northern part of MARYMIA is covered by a flat sandplain (*Qs*) consisting of dark-red eolian sand and clayey sand. The sand is composed of iron-stained quartz grains up to 0.5 m in diameter and, as revealed by exposed pediments, is generally less than 2–3 m deep.

The present drainage courses and associated floodplains contain alluvium (*Qa*) consisting of unconsolidated clay, silt, sand, and gravel. The drainage from hilly areas eventually terminates in floodplains and sheetwash (*Qw*).

Poorly developed red-earth soils (*Qw*) cover large parts of MARYMIA. Most of this unit is covered with dense mulga; viewed from the air, the mulga can be seen to have grown in a distinctive wavy or swayed pattern at right angles to the direction of drainage. The soils have formed over mature, deeply weathered plains or after mature alluvium in floodplains; they contain ferricrete granules (*Qwf*) and are calcareous in places.

Playa-lake deposits (*Ql*) consist of clay, silt, and evaporites. They occupy low-lying areas marginal to drainage channels. Beneath the surface of these lake areas is a mixture of black to brown mud, evaporites, and sand. The lake surfaces are sparsely vegetated with seasonal grasses and scattered eucalypts.

## Structure

The greenstones on MARYMIA have been subjected to five major phases of deformation and two regional metamorphic events (*D*<sub>1</sub>, *D*<sub>2</sub>, *D*<sub>3</sub>, *D*<sub>4</sub>, *D*<sub>5</sub>; *M*<sub>1</sub> and *M*<sub>2</sub>). The first two deformation events, *D*<sub>1</sub> and *D*<sub>2</sub>, were late Archaean in age, with *D*<sub>2</sub> occurring at around 2.66 Ga (McMillan and McNaughton, 1995). The third event (*D*<sub>3</sub>) was probably related to the Palaeoproterozoic rift-basin formation of the Mooloogool Subgroup in the Yerrida Basin. The fourth event (*D*<sub>4</sub>) is recorded by folding and faulting, which also affected the Yerrida and Earahedy Basins; it took place around 1.72 Ga (McMillan, 1993; McMillan et al., 1995; McMillan, 1996). The fifth event (*D*<sub>5</sub>) involved faulting and associated minor folding (*F*<sub>5</sub>).

The tentative tectonic history for MARYMIA is given in Table 1, which assumes that the rocks previously assigned to the Bangemall Group in northeastern MARYMIA are part of the Earahedy Group. A more detailed account of the tectonic history of the Marymia Inlier appears in Bagas (in press); this description also correlates the Marymia Inlier with the Yilgarn Craton.

### *D*<sub>1</sub> structures (late Archaean thrusting)

The first major deformation event (*D*<sub>1</sub>) produced a layer-parallel penetrative *S*<sub>1</sub> foliation (Fig. 7). The *S*<sub>1</sub> foliation developed during prograde regional metamorphism (*M*<sub>1</sub>) at the transitional upper greenschist – lower amphibolite facies. This is suggested by the alignment of actinolite–tremolite, biotite, and calcite within the *S*<sub>1</sub> fabric in a 1.6 km-deep vertical diamond-drillhole at the Jiminya Pool prospect (JPD1, west of the Plutonic gold mine on THREE RIVERS).

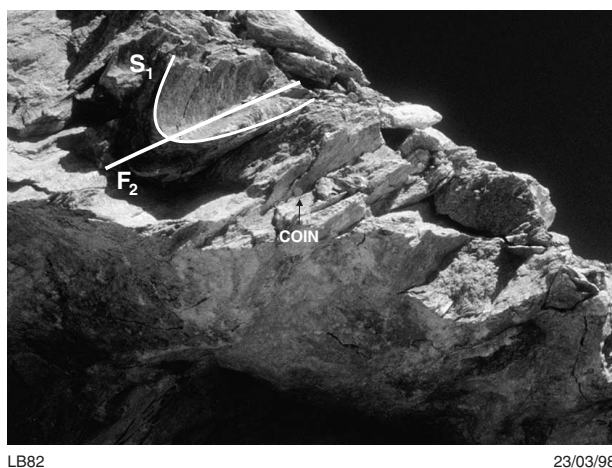
The *S*<sub>1</sub> foliation in the Plutonic Well greenstone belt regionally trends northeast and dips northwest, but may have originally trended in a northerly direction judging from the orientation of the belt south of the MMR Fault (the informal name for the fault near Simpson Well in the west of MARYMIA used by Plutonic Resources Limited — from Magneto Metric Resistivity). This approximately 30° clockwise rotation is attributed to compression and thrusting during the *D*<sub>4</sub> event. Due to poor exposure and extensive ferricrete cover, the regional trend of penetrative foliations in the Baumgarten greenstone belt is poorly defined. The foliations in both domains of the belt appear to regionally trend north-northeast; however, the aeromagnetic data suggest that the southern domain trends to the northwest in an orientation similar to that of the Merrie greenstone belt on MERRIE to the southeast.

The *S*<sub>1</sub> foliation is strongly developed along lithologic contacts, with the local development of mylonitic fabrics, especially along the granite–greenstone rock contacts where granite overrides the greenstones or vice versa. The southeastern and northwestern contacts of the Plutonic Well greenstone belt with the monzogranite are intensely foliated, locally mylonitic, and form complex

**Table 1. Tectonic history of MARYMIA**

<i>Sequence of events</i>	<i>Description</i>	<i>Interpreted kinematics</i>
<b>Archaean, c. 2.9–2.624 Ga</b>		
(a)	Deposition of the greenstone belts between c. 2.9 and 2.72 Ga. This age is constrained by the minimum age for xenocrystic zircons in porphyries and the age of intrusive granitoid rocks (McMillan, 1996). Greenstones may have been deposited on gneissic basement rocks, similar to those observed below the greenstone succession in diamond-drillhole JPD1 on THREE RIVERS	
(b)	Intrusion of granitoid rocks at c. 2.72 Ga (McMillan and McNaughton, 1995). Zircon xenocrysts as old as c. 3.35 Ga in the granitoid rocks indicate the presence of older crust	
(c)	?Early syn-D <sub>1</sub> intrusion of felsic rocks at c. 2.69 Ga (McMillan and McNaughton, 1995)	
(d)	D <sub>1</sub> deformation involving thrusting along the granite–greenstone contact and within the greenstones causing local thickening of sequences. This event took place during prograde regional metamorphism at upper greenschist – lower amphibolite facies. At this stage, a strong penetrative foliation (S <sub>1</sub> ) developed axial planar to F <sub>1</sub> , and now dips northwest	Compression
(e)	Late-D <sub>1</sub> to syn-D <sub>2</sub> intrusion of a felsic to intermediate porphyry, and deposition of polymictic conglomerate, felsic volcanic rocks, and arkose in extensional basins. The conglomerate and arkose are probably erosional products of local greenstones and granitoid rocks. This event was probably related to the onset of the D <sub>2</sub> deformation event	?Extension
(f)	D <sub>2</sub> deformation probably involving an extensional collapse at the last stages of D <sub>1</sub> , with development of rootless (reclined) folds in high-strain zones. This deformation boudinaged porphyries and produced a penetrative foliation that is subparallel to S <sub>1</sub> except at the hinge zones of F <sub>2</sub> folds. D <sub>2</sub> took place during peak regional metamorphism at lower amphibolite facies at c. 2.66 Ga (McMillan and McNaughton, 1995)	
(g)	Intrusion of post-D <sub>2</sub> granite at 2624 ± 8 Ma at the Goodin Inlier south of MARYMIA (Nelson, 1996). The Goodin Inlier may be an extension of the Southern Cross Province of the Yilgarn Craton and may not be related to the Plutonic Well greenstone belt	
<b>Palaeoproterozoic</b>		
(h)	Deposition of the Windplain Subgroup of the Yerrida Group in a sag-basin setting; probably around 2.26 Ga (Pirajno et al., 1996)	
(i)	D <sub>3</sub> deformation of the granite–greenstones, involving east to northeasterly trending normal faults. These faults may have controlled the deposition of the Mooloogool Subgroup in a rift-basin setting	Northwest–southeast extension
(j)	Deposition of the Yelma Formation (Earaheedy Group) in a sag basin	
(k)	Intrusion of northeast-trending dolerite dykes, forming distinct aeromagnetic lineaments; may have intruded D <sub>3</sub> , D <sub>4</sub> , and/or D <sub>5</sub> structures	
(l)	D <sub>4</sub> deformation, involving major southeasterly directed thrusting during the Capricorn Orogeny, and regional metamorphism at greenschist facies. This event may have reactivated D <sub>1</sub> thrusts along granite–greenstone contacts, and thrust granite over the Yerrida Group along the Jenkin Fault. D <sub>4</sub> may have taken place over a protracted period of time, involving a progressive series of events not recognized in outcrop on MARYMIA that culminated at 1.72 Ga (McMillan and McNaughton, 1995)	Northwest–southeast compression
<b>?Mesoproterozoic</b>		
(m)	D <sub>5</sub> deformation, involving brittle wrench faulting of the granite–greenstones and of the Yerrida and Earahedy Groups. Structures are east- to northeast-trending faults with sinistral displacements, southeast-trending faults with dextral displacements, and open folds with axes trending in a southerly direction. Some of these structures host dolerite dykes	North–south compression





**Figure 7.**  $F_2$ -folded  $S_1$  foliation in ultramafic schist at the Mareast mine

zones of interleaved greenstones and variably deformed monzogranite (e.g. west of Keillor 1 and near Marymia Hill). This highly foliated interleaving may be a result of granitic intrusion followed by  $D_1$  thrust repetitions. The sense of the  $D_1$  movement along the thrusts cannot be determined because of later tectonic overprinting and the lack of fresh outcrop; however, evidence from JPD1 indicates that the deformation was compressional. The contacts do not mark significant changes in metamorphic grade, suggesting that vertical movements were not significant or that metamorphism post-dates  $D_1$  thrusting.

## $D_2$ structures (late Archaean ?extensional collapse after $D_1$ )

The  $S_1$  fabric is folded by reclined folds ( $F_2$ ) as illustrated in Figure 7. The  $F_2$  folds are rootless, tight, and asymmetric; are associated with a mineral lineation parallel to the fold axes; and have a shallow axial  $S_2$  cleavage. The  $S_2$  cleavage cross-cuts  $S_1$  at the  $F_2$  fold hinges and is subparallel to  $S_1$  away from the fold hinges.

The  $F_2$  axial planes dip southeast at the Keillor 1 mine, west at the Marwest mine, northwest near Plutonic Well, and west in the southwestern portion of MARYMIA. The  $F_2$  folds at Keillor 1 have shallow dipping axial planes and are doubly plunging. They have boudinaged more competent mafic units, and swing towards the north in the northeastern end of the open-cut. This swing is attributed to refolding and shearing during  $D_4$ .

The  $D_2$  event involved the recrystallization of amphibole (hornblende) and garnet along  $S_2$  during peak metamorphism in the area, suggesting that  $D_1$  and  $D_2$  were progressive events during a regional  $M_1$  metamorphism. The  $D_2$  event may represent a local extensional collapse shortly after  $D_1$ , and may have controlled the deposition of the clastic succession in the central part of the belt.

## $D_3$ structures (?Capricorn Orogeny — extension)

The  $F_2$  folds at the Keillor 1 mine are cross-cut by a series of brittle-ductile, normal faults, and the mylonitic contact between granite and greenstone has been reactivated by extensional faults. These  $D_3$  faults trend east to northeast, dip steeply towards the north or south, and are cross-cut by later northeast-trending  $D_4$  faults. The understanding of  $D_3$  faults has been made difficult by reactivation in later tectonic events.

The  $F_2$  folds, as indicated in diamond-drillhole JPD1, are cut by  $D_3$  chloritic shear zones containing pyrite. The shear bands are defined in mafic rocks by sheared actinolite–tremolite–biotite with thin chloritic zones. The chlorite partially replaces the amphibole, suggesting that fluid flow was insufficient to totally convert amphibole into chlorite during  $D_3$ , and that this chloritization was associated with hydrothermal fluids not related to the later greenschist facies metamorphism that occurred synchronous with  $D_4$ .

The  $D_3$  faults define a period of extensional faulting and shearing. This faulting may have controlled the development of the Mooloogool Subgroup in the Yerrida Basin during Palaeoproterozoic rifting (Pirajno et al., 1996), although there are no geochronological data to support this hypothesis.

The  $D_3$  extensional event was probably followed by a period of relatively passive sag-basin development resulting in the deposition of the Earacheedy Group, sometime after deposition of the Mooloogool Subgroup ceased (Pirajno et al., 1996).

## $D_4$ structures (Capricorn Orogeny — compression)

The  $D_4$  event is characterized by northeast-trending open to tight  $F_4$  folds, east- to northeast-trending thrusts (e.g. the early movements along the Keillor and Jenkin Faults) in the Plutonic Well greenstone belt and the Yerrida and Earacheedy Groups, and southeast-trending strike-slip faults (e.g. the Airstrip Fault at AMG 790250)\* in the Plutonic Well greenstone belt.

The  $F_4$  folds in the Keillor 1, Keillor 2, and Plutonic Well areas are shallow and doubly plunging with steep axial planes dipping northwest and a moderately developed  $S_4$  axial planar cleavage. The southern limb of the  $D_4$  Keillor Syncline is exposed as a series of southeast-overturned and doubly plunging z-folds in banded iron-formation and ultramafic units. The z-folds plunge between 5 and 20° towards the northeast and southwest, and their convergence indicates that the fold closes to the southwest, probably near the Keillor 2 mine.

\* It should be noted that the label for the Airstrip Fault on the **Simplified geology** inset on the MARYMIA sheet was erroneously transposed to the northwest–southeast fault immediately to the southwest of the Airstrip Fault.

The northern limb is poorly exposed or concealed by thrust granite. The doubly plunging nature of the z-folds may be explained by fold-tightening during progressive deformation, culminating in thrusting along the Keillor Fault during  $D_4$ , or by minor refolding in a west-northwest direction during  $D_5$ .

The Keillor thrust fault north of the Keillor 1 mine dips at a low angle to the northwest and is characterized by a down-dip lineation ( $L_4$ ). This fault has emplaced granite above the greenstones. The southeastern contact between the Plutonic Well greenstone belt and granitoid rock is also a  $D_4$  thrust, with the greenstone succession overlying granite.

The northeastern part of the Plutonic Well greenstone belt is disrupted by widely spaced southeast-trending faults and shear zones, such as the Airstrip Fault. The Airstrip Fault is a strike-slip shear zone deforming the granite–greenstone thrust contact near Marymia Hill. It appears as an abrupt break on the aeromagnetic images and extends northwestwards under Cainozoic cover. The southeasterly extension of the shear is not easily definable on the aeromagnetic images, but appears to splay into the greenstone to the east. The structure dips steeply to the northeast, and dextrally offsets and displaces the greenstone belt by about 5 km. Stretching lineations ( $L_4$ ) in the greenstones and granitoid rocks plunge shallowly towards the northwest, and foliations dip towards the northeast. The zone is interpreted as a tear fault related to late  $D_4$  thrusting that may have been reactivated during  $D_5$ . A similar structure is situated about 4 km to the east.

In the Yerrida Group,  $F_4$  folding is best exposed in the sandstone beds of the Juderina Formation as a series of parasitic synclines and anticlines around the Rooneys Syncline. The overall trend of the synclinorium is southwesterly, plunging at about  $30^\circ$ .

The Jenkin Fault marks part of the contact between the Juderina Formation and Archaean granitoid rock north of Johnson Cairn. Recent mineral exploration drilling by Resolute Limited to the north of Johnson Cairn has shown that the Yerrida Group is overlain by granitoid rock to the north of the fault, suggesting that the contact is a relatively early thrust. The Juderina Formation on both sides of the fault is complexly interleaved with granitoid rock. This interleaving is the product of late  $D_4$  thrusting. The fault is also associated with the reclined folds in the interbedded lithic wacke and pelite of the Thaduna Formation on THREE RIVERS (AMG 481789). The Jenkin Fault has been reactivated as a  $D_5$  sinistral wrench fault that has offset  $F_4$  folds in the Earraheedy Group of northeastern MARYMIA.

The northeast-trending  $D_4$  Yadgymurrin Syncline in the Earraheedy Group is a doubly and gently plunging fold. The dip of the bedding around the syncline is generally less than  $40^\circ$  and cleavage is rare except in the pelitic units. The syncline is disrupted by both sinistral and dextral quartz-filled fault breccias, which run subparallel to the  $D_4$  fold axes.

Late movement along the  $D_4$  Keillor Fault has dextrally displaced the Earraheedy Group by about 4 km. Its orientation and sense of movement are suggestive of northwest–southeast compression, consistent with the orientation of the  $D_4$  compression.

The  $D_4$  event involved a major northwest–southeast regional shortening event that controlled most of the regional geometry in the area (possibly including a  $30^\circ$  clockwise rotation of the Plutonic Well greenstone belt north of the MMR Fault). It is correlated with the Capricorn Orogeny, which was active as late as c. 1720 Ma in the southern part of the Capricorn Orogen (McMillan et al., 1995).

## $D_5$ structures

The last major tectonic event involved brittle wrench faulting of the Archaean and Proterozoic rocks on MARYMIA. Sinistral faults are commonly associated with brecciated quartz veins, suggestive of repeated movements (e.g. in the northern part of MARYMIA); they are subvertical and trend in an easterly to northeasterly direction. Some of these faults host dolerite dykes, for example along the Jenkin Fault. The southeast-trending dextral faults generally have minor displacements of less than 1 km, such as around AMG 514820 (on THREE RIVERS) and AMG 746900.

The  $D_4$  Jenkin Fault was reactivated as a strike-slip fault during  $D_5$ . The fault trends about  $055^\circ$  and dips about  $70^\circ$  northwest, and appears as a negative anomaly on the aeromagnetic images of MARYMIA. Drag structures at AMG 724890 show that the latest movement along the fault is sinistral. The northeastern extension of the Jenkin Fault has sinistrally displaced the Earraheedy Group tens of kilometres southwest against Archaean granitoid rock.

The easterly to northeasterly trending MMR Fault and subparallel faults to the south on southwestern MARYMIA are interpreted as  $D_5$  structures, and are probably reactivated  $D_4$  structures. These faults are not exposed but can be recognized on the aeromagnetic images of the area. The MMR Fault cross-cuts the Plutonic orebody on THREE RIVERS (Jockel, F., 1995, pers. comm.) and extends eastward along or near the granite–greenstone contact. The apparent movement along these faults is sinistral, with a reverse component that could have taken place during  $D_4$  thrusting. This postulated earlier  $D_4$  thrusting would explain the relative thinning of the belt to the south of the faults.

The  $F_4$  Yadgymurrin Syncline south of the Keillor Fault was flattened in a north-northeast to south-southwest direction during  $D_5$ .

The orientation and sense of movement of the  $D_5$  faults on MARYMIA and the flattening of the  $F_4$  Yadgymurrin Syncline are attributed to compression in a north–south direction. The age of the  $D_5$  event is not known, but it may be Mesoproterozoic or younger.

Table 2. Metamorphic mineral assemblages for rocks on MARYMIA

<i>Rock type</i>	<i>Metamorphic mineral assemblages</i>
<b>M<sub>1</sub> Archaean rocks</b>	<b>Upper greenschist – amphibolite facies</b>
	Prograde metamorphism (during D <sub>1</sub> )
Amphibolite	Actinolite–tremolite amphiboles rimmed locally by hornblende
Ultramafic rocks	Talc–serpentine – fibrous amphibole (actinolite–tremolite) – chlorite–magnetite; chlorite and serpentine pseudomorphing olivine and pyroxene
Banded iron-formation	Cummingtonite–grunerite, garnet, biotite, quartz, and magnetite
Pelite	Hornblende and actinolite, biotite, garnet, calcite, and quartz
	Peak to regressive metamorphism (during D <sub>2</sub> )
Amphibolite	Recrystallized hornblende
<b>M<sub>2</sub> Archaean rocks</b>	<b>Greenschist facies</b>
Amphibolite	Chlorite and epidote after amphibole and plagioclase, albite and sericite after plagioclase, biotite after hornblende, and calcite; microfractures filled with quartz, carbonate, and biotite
Granite	Epidote and sericite after feldspar, and chlorite after biotite
<b>M<sub>2</sub> Proterozoic rocks</b>	<b>Greenschist facies</b>
Thaduna Formation	Chlorite, epidote, and calcite

## Metamorphism

Two regional metamorphic events (M<sub>1</sub> and M<sub>2</sub>) have been recognized on Marymia. The Archaean greenstones were metamorphosed to the transitional upper greenschist – lower amphibolite facies (M<sub>1</sub>) during late Archaean deformation, and retrogressively metamorphosed to greenschist facies (M<sub>2</sub>) during the Capricorn Orogeny. The Yerrida Group on MARYMIA was metamorphosed to greenschist facies (M<sub>2</sub>). Table 2 lists the metamorphic mineral assemblages in the rocks on MARYMIA.

No details are available on the metamorphic grade of rocks from the Earahedy Group due to their high degree of weathering and their recent silicification.

### Prograde to peak metamorphism

The mineralogy of mafic rocks in the greenstone belts is dominated by amphiboles of the actinolite–tremolite group, rimmed locally by green to weakly brown hornblende. In rare cases, such as in the Plutonic Well area, the dominant amphibole is hornblende. These amphiboles are aligned within the S<sub>1</sub> fabric. The S<sub>1</sub> fabric is crenulated and tightly folded about shallowing dipping F<sub>2</sub> axes, which contain recrystallized amphibole oriented along the S<sub>2</sub> axial planar cleavage.

Ultramafic rocks contain the prograde assemblage talc–serpentine – fibrous amphibole (actinolite–tremolite) –chlorite–magnetite. Rare spinifex textures, defined by chlorite and serpentine pseudomorphing olivine and pyroxene, are preserved locally. Banded iron-formation contains cummingtonite–grunerite, garnet, biotite, quartz, and magnetite.

Mafic metasedimentary rocks interlayered with the metavolcanic rocks contain amphibole (hornblende and actinolite), biotite, garnet, calcite, and quartz. The tectonic contacts with the granitoid rocks are marked by silicified and quartz-veined mica schist.

These observations indicate that a prograde metamorphic event at the transitional upper greenschist – amphibolite facies took place during the early (D<sub>1</sub>) tectonic history of the greenstones. Peak metamorphic conditions were reached during D<sub>2</sub> at lower amphibolite facies. The earliest two tectonic events (D<sub>1</sub> and D<sub>2</sub>) are therefore thought to be associated with a single regional metamorphic event (M<sub>1</sub>).

### Retrograde metamorphism and hydrothermal alteration

Brittle-ductile extensional faults and shears, associated with the third deformation event (D<sub>3</sub>), locally define intense and distinct chlorite-rich zones of alteration containing minor amounts of sulfide mineralization (principally pyrite and magnetite) and quartz veining. This alteration indicates that the D<sub>3</sub> event was associated with hydrothermal alteration.

Retrogressive minerals in the greenstone successions, and not related to D<sub>3</sub> chloritic shears and faults, are chlorite and epidote after amphibole and plagioclase, albite and sericite after plagioclase, and calcite. Hornblende is altered to biotite and contains microfractures filled with quartz, carbonate, and biotite. Other minerals present are epidote and titanite. Oligoclase is rarely preserved. Granitoid rocks have undergone recrystallization and contain secondary minerals such as



epidote and sericite after feldspar, and chlorite after biotite. These retrogressive mineral assemblages are indicative of greenschist-facies metamorphism ( $M_2$ ).

Metamorphic mineral assemblages of chlorite, epidote, and calcite in the Yerrida Group are best preserved in the Thaduna Formation. The epidote grains are subhedral, some showing later overgrowths. Some shale and volcanic clasts are rimmed by epidote, which is a feature of post-depositional growth. Calcite appears to be a replacement mineral in the volcanic clasts and infills fractures in the matrix. Chlorite also infills cavities or is an overgrowth on chlorite–plagioclase(–amphibole) clasts. These secondary minerals are characteristic of metamorphism at greenschist facies.

This greenschist-facies metamorphic event in the Yerrida Group was, at least partly, synchronous with the retrogressive  $M_2$  event in the greenstones (see **Geochronology** below).

## Geochronology

McMillan (1996) published a detailed geochronological study of northern MARYMIA. The dating was constrained by Pb-isotope studies and Sensitive High-Resolution Ion-Microprobe (SHRIMP) U–Pb analyses that were carried out on zircons from granitoid rocks west of the Keillor 1 mine and from felsic to intermediate porphyry intrusions within greenstone. The results show that the granitoid rocks were emplaced at c. 2.72 Ga and the porphyries were emplaced at c. 2.69 Ga. Zircon xenocrysts as old as 3.35 Ga indicate that older crust existed at the time of granitic emplacement. These zircon xenocrysts have

a similar age to an early Archaean gneiss in the Narryer Gneiss Terrane (Myers, 1990b), which contains several populations of ages ranging between 3730 and 3300 Ma dated by SHRIMP (Nutman et al., 1993). Zircon overgrowth and Pb-isotope resetting also indicate at least two major thermal events: one in the late Archaean at c. 2.66 Ga ( $M_1$ ) and the last in the Palaeoproterozoic at c. 1.72 Ga ( $M_2$ ).

A SHRIMP zircon age of  $2624 \pm 8$  Ma was obtained from an oval-shaped, non-foliated syenogranite in the Goodin Inlier south of MARYMIA (Nelson, 1996). The inlier may be the northern extension of the Southern Cross Province (Griffin, 1990b) of the Yilgarn Craton and is possibly unrelated to the granite–greenstones of the Plutonic Well greenstone belt. The granite is relatively unaltered except for sericitization of plagioclase, recrystallization of feldspar to polygonal mosaics, and secondary growth of epidote. These secondary minerals may have formed during late greenschist-facies metamorphism ( $M_2$ ).

Geochronological constraints on the deposition and deformation of the Yerrida and Earraheedy Groups are poorly defined. The currently available geochronological data on the groups are summarized in Table 3.

Gee (1990) implied that the (now-superseded) ‘Glengarry Basin’, which includes the Yerrida Group, was deposited and deformed on the northern margin of the Yilgarn Craton between 2000 and 1650 Ma. Russell et al. (1994) reported a Pb–Pb isochron of  $2258 \pm 180$  Ma for stromatolitic carbonate in the basal Juderina Formation of the Yerrida Group, Woodhead and Hergt (1997) obtained a Pb–Pb isochron of  $2173 \pm 64$  Ma from the Yerrida Group, and Nelson (1996) obtained a

**Table 3. Current geochronology of the Marymia Inlier, and of the Yerrida and Earraheedy Groups**

Age	Group/Formation	Dating method	Interpretation
c. 2.9–2.72 Ga	Granite from the Marymia area	SHRIMP U–Pb zircon age <sup>(a)</sup>	Minimum age constraint for the Plutonic Well greenstone belt
2.72 $\pm$ 6 Ga	Granite from the Marymia area	SHRIMP U–Pb zircon age <sup>(a)</sup>	Crystallization age for the granitoid
c. 2.69 Ga	Porphyry from the Keillor 1 area	SHRIMP U–Pb zircon age <sup>(a)</sup>	Crystallization age for the porphyry
c. 2.66 Ga	Porphyry from the Keillor 1 area	SHRIMP U–Pb zircon age <sup>(a)</sup>	Metamorphism/hydrothermal activity
2624 $\pm$ 8 Ma	Granite in the Goodin Inlier	SHRIMP U–Pb zircon age <sup>(b)</sup>	Crystallization age for the granite
2258 $\pm$ 180 Ma	Yerrida Group, carbonate from the Juderina Formation	Pb–Pb isochron <sup>(c)</sup>	Depositional age
2.2–1.8 Ga	Yerrida Group	Pb–Pb isochron <sup>(d)</sup>	Depositional age
1785 $\pm$ 11 Ma	Earraheedy Group, Mount Leake Formation	SHRIMP U–Pb zircon age <sup>(b)</sup>	Maximum age of the Mount Leake Formation based on the minimum age of detrital zircons
c. 1.72 Ga	Granitoid from the Keillor 1 area	SHRIMP U–Pb zircon age <sup>(a)</sup>	Metamorphism/hydrothermal activity
1638 $\pm$ 14 Ma	Bangemall Group, Coobarra Formation	SHRIMP U–Pb zircon age <sup>(e)</sup>	Age of porphyritic rhyolite emplacement in the lower Bangemall Group; minimum age for the Capricorn Orogen

NOTES: (a) McMillan (1996)  
 (b) Nelson (1996)  
 (c) Russell et al. (1994)  
 (d) Woodhead and Hergt (1997)  
 (e) Nelson (1995)

SHRIMP age of  $1785 \pm 11$  Ma on detrital zircons from the Mount Leake Formation of the Earraheedy Group. These dates constrain the age of the Yerrida Group to between 2.2 and 1.8 Ga, and define a maximum age of 1.8 Ga and a minimum age of about 1.64 Ga for the Earraheedy Group.

The age of the Bangemall Group, which post-dates the Capricorn Orogeny, has been used to constrain the minimum age for the Capricorn Orogen (Myers, 1990a). A SHRIMP age of  $1638 \pm 14$  Ma was obtained for felsic volcanic rocks in the lower Bangemall Group (Nelson, 1995); this indicates that the Capricorn Orogen is older than about 1.64 Ga.

## Comparison between the Marymia Inlier and the provinces of the Yilgarn Craton

The Archaean history of the Marymia Inlier closely resembles that of the granite–greenstone provinces in the Yilgarn Craton, in terms of lithology, geochronology, and tectonic history. Table 4 compares the tectonic history of the Plutonic Well greenstone belt and nearby granitoid rocks with those of the Murchison Province (Watkins and Hickman, 1990), the Southern Cross Province (Griffin, 1990b), and the Eastern Goldfields Province (Swager, 1997).

As shown in the table, the four regions have strikingly similar tectonic histories. In each region, the greenstones comprise volcano-sedimentary successions that were in place by c. 2.7 Ga, were intruded by ?syntectonic granitoid rocks between 2.7 and 2.64 Ga, and were regionally metamorphosed between 2.66 and 2.64 Ma. Each region also records a gold-mineralizing event that was synchronous with or just post-dated the 2.66–2.64 Ga regional metamorphism. These similarities indicate that the four regions have experienced the same geological history at least after c. 2.8 Ga. The Plutonic Well greenstone belt, therefore, resembles the Yilgarn Craton in terms of lithologies, early tectonic and regional metamorphic histories, and the age of gold mineralization. This strongly suggests the Marymia Inlier is a northern extension of the Yilgarn Craton.

On the basis of the present data, it is difficult to suggest with any degree of confidence that the Plutonic Well greenstone belt would resemble the Murchison, Southern Cross, or Eastern Goldfields Provinces, mainly because of the poorly constrained data for the Murchison and Southern Cross Provinces. However, distinct features common to the Plutonic Well greenstone belt, the Murchison Province, and the Southern Cross Province, and not recognized (as yet) in the Eastern Goldfields Province, are the older (c. 2.96–2.72 Ga) greenstones. The Plutonic Well greenstone belt and Murchison Province also have older (c. 2.75–2.70 Ga) intrusive

granites. These data suggest that the Plutonic Well greenstone belt of the Marymia Inlier is most likely part of the Murchison Province or of the Southern Cross Province. However, it is not certain if the whole of the Marymia Inlier is an extension of the Murchison or Southern Cross Provinces.

Interpretation of the aeromagnetic data for the region suggests that the southern domain of the Baumgarten greenstone belt is the northwestern extension of the Merrie greenstone belt in the Eastern Goldfields Province. The contact between the southern domain and the northern part of the Marymia Inlier is along the Jenkin Fault, which extends southwestward through Palaeoproterozoic sedimentary rocks towards the Murchison Province (Pirajno et al., 1996). This juxtaposition of the northern part of the Marymia Inlier against the southern domain of the Baumgarten greenstone belt at the Jenkin Fault took place during the Proterozoic.

## Economic geology

The earliest recorded mineral exploration of MARYMIA was at Baumgarten during the 1920s. The British Metals Corporation, Freeport of Australia, and New Consolidated Gold Fields Australia worked the Thaduna copper field between 1962 and 1971.

The Plutonic Well greenstone belt was explored for nickel mineralization by International Nickel, INCO, and the Dampier Mining Company between 1969 and 1977. They were the first to recognize the greenstone successions in the region, but abandoned the area after failing to detect economic mineral deposits. Amax and Pennzoil sampled gossanous black shales in the greenstone belt in 1976, but did not detect significant mineralization.

The area became the locus of extensive exploration following the discovery of the Plutonic gold deposit on THREE RIVERS in 1988 and the Marymia gold deposits on MARYMIA between 1988 and 1992. Stockdale Prospecting discovered kimberlite pipes, lamprophyres, and micro-diamonds in 1992.

## Gold

The main gold-producing areas on MARYMIA are in the Plutonic Well greenstone belt. Deposits mined include those at the Keillor 1, Keillor 2, Apollo, and Pythagorus mines near Marymia Hill; at the Mareast, Marwest and Triple P mines 10 to 15 km further to the southwest; and at the Salmon mine (AMG 560995) 11 km south-southwest of Plutonic Well. Production from this belt on MARYMIA to December 1996 has been more than 6.4 t of gold from 1 500 000 t of ore. Production, albeit minor, has also been reported from the southern domain of the Baumgarten greenstone belt, with a total recorded production since 1926 of 7.45 kg from about 140 t of ore.

**Table 4. Regional tectonic history of the Murchison, Southern Cross, and Eastern Goldfields Provinces of the Yilgarn Craton, compared with that of the Marymia Inlier**

Timing (Ga)	Murchison Province	Southern Cross Province	Eastern Goldfields Province	Marymia Inlier
<b>2.96</b>	2919 ± 12 Ma: age for pegmatite-banded gneiss in enclaves <sup>(b)</sup> D <sub>1</sub> <sup>M</sup> deformation: folding and thrusting <sup>(c)</sup> c. 2.8 Ga: deposition of the Luke Creek Group (lower greenstone) <sup>(b)</sup>	2958 ± 4 Ma: ‘lower’ felsic volcanism <sup>(a)</sup> 2921–2903 Ma: deposition of ‘lower’ felsic and ultramafic volcanic rocks; nickel mineralization <sup>(d)</sup>		c. 2.9–2.72 Ga: mafic–ultramafic volcanism in northern MARYMIA
<b>2.8</b>				
	c. 2.75–2.7 Ga: granitic plutonism <sup>(b)</sup>		c. 2.72 Ga: ?minor granitic plutonism c. 2.72–2.7 Ga: initial D <sub>E</sub> ?extension, basin formation, and volcanism	c. 2.72 Ga: granitic plutonism
<b>2.7</b>				
	c. 2.7 Ga: deposition of the Mount Farmer Group (upper greenstone) <sup>(b, e)</sup>	c. 2.7 Ga: ‘upper’ felsic volcanism <sup>(f)</sup> 2.7–2.68 Ga: granitic plutonism <sup>(g)</sup>	c. 2.7 Ga: continued D <sub>E</sub> ?extension, continued volcanism c. 2685–2675 Ma: granitic plutonism and felsic volcanism	c. 2.69 Ga: felsic to intermediate porphyry intrusion
<b>2.675</b>				
			D <sub>1</sub> thrusting  post-D <sub>1</sub> and pre-D <sub>2</sub> ?extension (E–W): synclinal basins with clastic infill  2674 ± 6 Ma: post-D <sub>1</sub> /pre-D <sub>2</sub> felsic porphyry intrusion	D <sub>1</sub> thrusting coinciding with prograde M <sub>1</sub> and gold mineralization post-D <sub>1</sub> clastic deposition in the centre of the Plutonic Well greenstone belt in an ?extensional setting
<b>2.66</b>				
		2.66–2.65 Ga: granitic plutonism; ?regional metamorphism <sup>(g)</sup>  2.66–2.65 Ga: gold mineralization <sup>(g)</sup>	c. 2.66 Ga: D <sub>2</sub> regional shortening (ENE–WSW); peak metamorphism; granitic plutonism; local ?extension; D <sub>3</sub> regional E(NE)–W(SW) shortening; ?extension (E–W); post-metamorphic orogenic collapse? ?2.66 Ga: gold mineralization <sup>(h)</sup>	c. 2.66 Ga felsic to intermediate porphyry intrusion ≤ c. 2.66 Ga: D <sub>2</sub> coinciding with peak to retrograde M <sub>1</sub>  2.66–2.64 Ga: gold mineralization
<b>2.64</b>				
	2.64–2.63 Ga: gold mineralization <sup>(i, j)</sup> ; 2.64–2.60 Ga: ‘late-tectonic’ granitic plutonism <sup>(c)</sup>	2.64–2.62 Ga: ‘late-tectonic’ granitic plutonism <sup>(g, k)</sup>	c. 2.64 Ga: ‘late tectonic’ granitic plutonism; D <sub>4</sub> regional shortening (E–W) c. 2.63 Ga?: gold mineralization <sup>(l)</sup>	
<b>2.62</b>				
		2624 ± 8 Ma: ‘post-tectonic’ granitic plutonism <sup>(m)</sup>	c. 2.62–2.60 Ga: ‘post-tectonic’ granitic plutonism <sup>(m)</sup>	

**NOTES:** (a) Nelson (1995) (e) Wang, Campbell, and Schiøtte (1996) (h) Witt et al. (1996) (k) Hill et al. (1992)  
(b) Schiøtte and Campbell (1996) (f) Pidgeon and Wilde (1990) (i) Wang et al. (1995) (l) Groves et al. (1992)  
(c) Wiedenbeck and Watkins (1993) (g) Qiu et al. (1995) (j) Yeats and Groves (in press) (m) Nelson (1996)  
(d) Wang, Schiøtte, and Campbell (1996)

The data for the Eastern Goldfields Province are from Swager (1997). The ages quoted for the Marymia Inlier are from McMillan and McNaughton (1995). Dashed lines are time tie-lines. D<sub>1</sub><sup>M</sup>–D<sub>3</sub><sup>M</sup>: deformation in Murchison Province. D<sub>E</sub>: initial basin formation



## Plutonic Well greenstone belt

The gold mineralization in the Plutonic Well greenstone belt is epigenetic, and is in both stratigraphically and structurally controlled sites. The higher grade deposits are in metamorphosed fine-grained mafic rocks and banded iron-formation (e.g. at Keillor 2), ultramafic rocks (e.g. at Marwest), or in sheared contacts between mafic rocks and ultramafic rocks (e.g. at Keillor 1, Mareast, and Salmon). Gold is also at the faulted contacts between metasedimentary and mafic rocks (e.g. at Triple P and Pythagorus) or arkosic rocks (e.g. at Apollo). Laterite-hosted gold deposits include those of the Triple P area, and of the area between Mareast and Keillor 2. This mineralization consists of fine disseminated gold in the thin ferricrete duricrust of the laterite profile. Anomalous gold contents (at undisclosed concentrations) have also been detected in the granitoid rocks by the exploration companies working in the area.

The bulk of the epigenetic mineralization is in  $D_{1-2}$  faults and shears that are parallel to the penetrative  $S_1$  and  $S_2$  foliations. The mineralization hosted by the  $D_1$  structures is in irregular centimetre-thick zones of intense silicification containing quartz veins parallel to  $S_1$ . The quartz veins also contain amphibole (tremolite–hornblende), biotite, sulfides (principally arsenopyrite, pyrite, pyrrhotite, and chalcopyrite, with lesser amounts of scheelite and galena), and gold (McMillan, 1993). This mineralization is boudinaged around  $F_2$  fold hinges (e.g. at Keillor 1 and Marwest).

The Triple P deposit is at the contact between a metamorphosed succession of conglomerate and rhyodacitic rocks and the underlying mafic and ultramafic rocks. The contact between the two successions is intensely foliated, shallow dipping, and shows intense biotite–quartz–albite–carbonate–sulfide alteration, the biotite being partly retrogressed to chlorite. The gold mineralization is in quartz veins containing arsenopyrite and pyrite, predominantly hosted by the mafic units. The mineralization hosted by the  $D_2$  structures (e.g. at Triple P) is in thin calcite–biotite(–chlorite) alteration zones containing arsenopyrite and gold.

These relationships suggest that the gold mineralization in the Plutonic Well greenstone belt could have commenced during late  $D_1$ , and continued during  $D_2$  and peak  $M_1$  metamorphism. Samples of galena intergrown with gold from the Keillor 1 and 2 area, and galena from gold-mineralized zones at Triple P provide a Pb–Pb model age of c. 2.66 Ga (McMillan and McNaughton, 1995). This age is consistent with at least some of the mineralization that took place during  $D_2$  (see **Geochronology** and **Structure** above).

## Baumgarten greenstone belt

The Baumgarten gold-mining area is in the southern domain of the Baumgarten greenstone belt. The gold is in steeply dipping quartz lenses (up to 5 m thick) that strike about  $020^\circ$  parallel to the regional penetrative foliation in the country rocks. The quartz lenses are in alteration zones that are rich in carbonate and sericite,

and are in sheared metabasalt, metagabbro, and ultramafic rocks. The deposits are also anomalous in silver, arsenic, copper, and zinc. The northern workings in the domain are at the contact between metamorphosed mafic rocks and gabbro. The southern workings are on auriferous quartz veins in both ferruginized mafic and silicified ultramafic rocks. It is not known if the mineralization in the Baumgarten area took place during the  $D_1$  or the  $D_2$  deformation events, or both.

## Copper

The Green Dragon mine was worked between 1945 and 1965 with a reported ore production of about 200 t with a grade of 8% Cu. The deposit was worked as an openpit in early 1970 and as a satellite deposit of the Thaduna copper mine on THADUNA. The Green Dragon deposit was abandoned in late 1970 when operations at the Thaduna mine ceased. North Flinders Mines took an interest in the mine area between 1973 and 1975 and proved a reserve of 79 300 t of ore at 5.28% Cu. Seltrust Mining Corporation explored the shear zone hosting the mineralization at the Green Dragon mine for epigenetic Cu and Ag mineralization. Samples from the mine waste dumps assayed 14.3 g/t Ag. The orebody consists of malachite, chalcopyrite, chrysocolla, cuprite, and minor amounts of chalcocite associated with massive graphite. The mineralization is a flat-lying supergene zone over a mineralized east-trending shear zone. The shear zone cuts steeply dipping shale, siltstone, and lithic wacke of the Thaduna Formation, which strike approximately  $035^\circ$  and dip up to  $80^\circ$  west. The secondary mineralization is exposed over 60 m in the southern wall of the Green Dragon pit and is probably controlled by groundwater levels. Surface exposure is poor. The mineralization is hydrothermal in origin, is controlled by faulting, and has been supergene-enriched.

Rooneys mine, 4 km to the west of the Green Dragon mine, was established to exploit a small copper deposit in a subvertical fault containing veinlets of malachite.

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