Department of
Industry and Resources

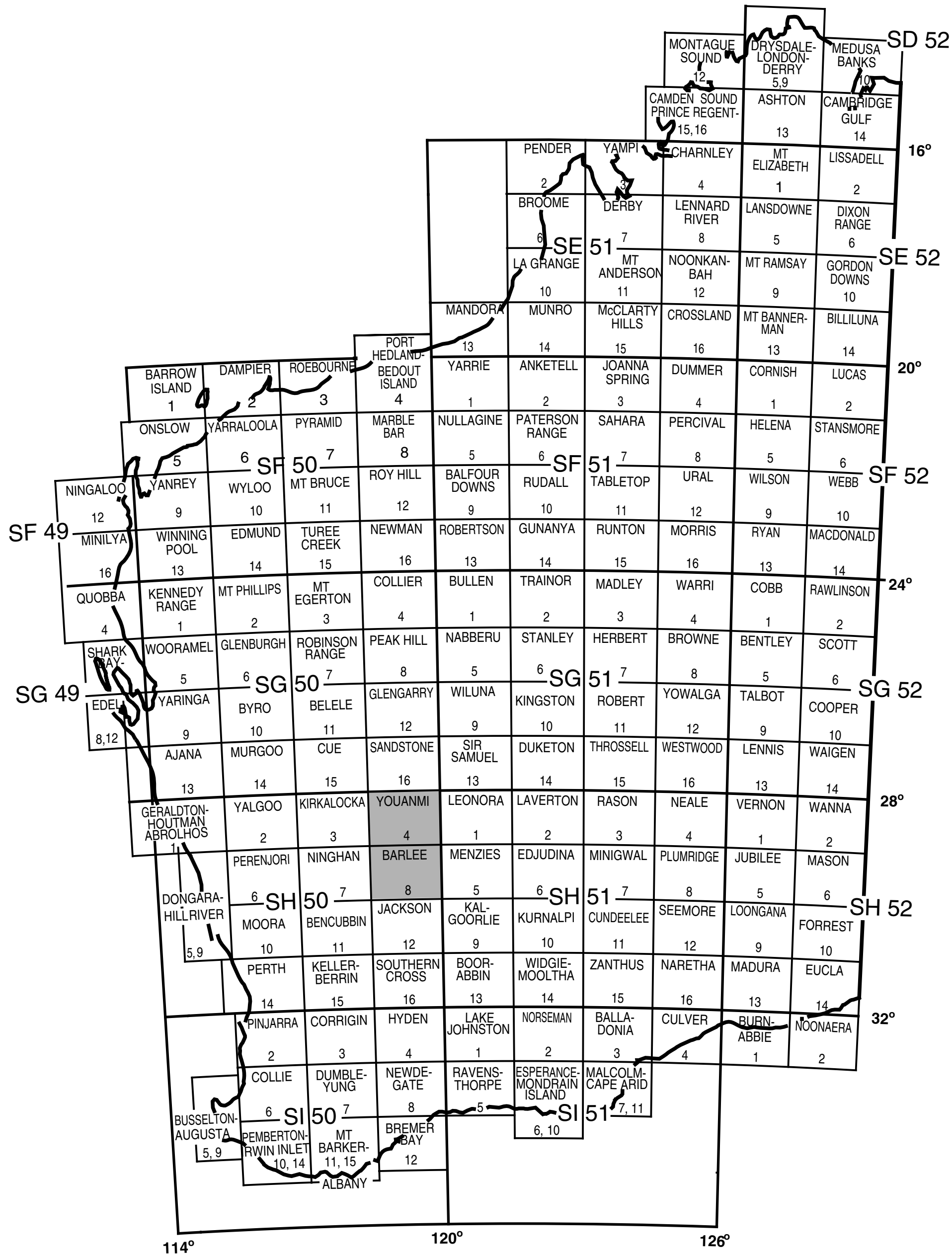
EXPLANATORY NOTES

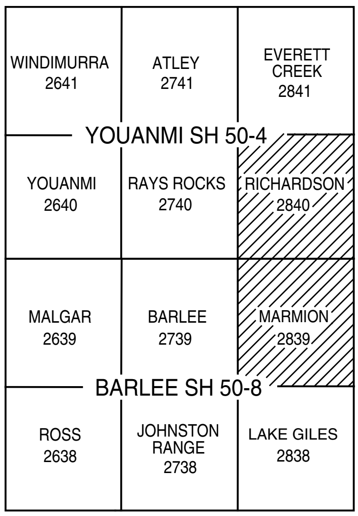
GEOLOGY OF THE MARMION AND RICHARDSON 1:100 000 SHEETS

by S. F. Chen

1:100 000 GEOLOGICAL SERIES

Geological Survey of Western Australia





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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF THE MARMION AND RICHARDSON 1:100 000 SHEETS

by
S. F. Chen

Perth 2004

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Cover photograph:
Basalt with pillow-lava structures on a small island within Lake Barlee (MGA 759900E 6752550N)

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by

S. F. Chen

Abstract

The MARMION and RICHARDSON 1:100 000 sheets lie in the central-northern part of the Southern Cross Granite–Greenstone Terrane, Yilgarn Craton. They include the Mount Elvire and South Cook Well greenstone belts, the northern parts of the South Elvire, Mount Marmion, and Illaara greenstone belts, and the southern parts of the North Cook Well and Maynard Hills greenstone belts. Greenstone belts are separated by granitoid rocks of mainly monzogranitic composition.

Archaean greenstones on MARMION and RICHARDSON are dominated by metamorphosed tholeiitic and komatiitic (high-Mg) basalts, gabbro, banded iron-formation, and chert, with subordinate ultramafic and clastic sedimentary rocks. Greenstone associations are broadly similar to those in the lower greenstone succession of the Marda–Diemals greenstone belt to the south. The Mount Elvire, South Elvire, and South Cook Well greenstone belts contain more ultramafic rocks (mainly tremolite–chlorite–talc schist and serpentinized peridotite) than other greenstone belts on MARMION and RICHARDSON. Quartz-rich metasedimentary rocks including abundant quartzite at the stratigraphic base of the Illaarra and Maynard Hills greenstone belts have yielded a maximum depositional age of c. 3130 Ma based on SHRIMP U–Pb zircon dating of detrital zircons.

Archaean granitoid rocks include massive to weakly deformed monzogranite that occupies extensive areas between different greenstone belts, and strongly deformed granitoid rocks (foliated monzogranite, gneissic granitoid rock, and granitoid gneiss). The latter are distributed predominantly along regional-scale shear zones and close to granite–greenstone contacts, although there are some significant exceptions.

Like other areas in the central Yilgarn Craton, three major deformation events (D_1–D_3) have been recognized on MARMION and RICHARDSON. D_1 north–south compression produced originally east-trending, layer-parallel foliation, thrust faults, and tight to isoclinal folds. D_2 east–west shortening that was accompanied by intrusion of voluminous granitoid rocks produced macroscopic folds with a weak axial-planar foliation in greenstones, and a northerly trending gneissic banding and foliation in granitoid rocks. D_3 progressive and inhomogeneous east–west shortening reoriented and folded earlier structures, and produced the northwest-trending, sinistral Edale and Yuinmery Shear Zones and the northeast-trending, dextral Evanston Shear Zone. The Edale and Evanston Shear Zones are linked by a north-trending contractional zone, forming a regional-scale arcuate structure. The SHRIMP U–Pb zircon ages of granitoid rocks in the MARMION–RICHARDSON and adjacent areas constrain the timing of D_2 to c. 2755–2680 Ma, and of D_3 to c. 2680–2655 Ma.

All Archaean greenstones and granitoid rocks have been metamorphosed. Greenstones were typically metamorphosed to greenschist and amphibolite facies, with higher-grade metamorphism close to granite–greenstone contacts.

Although all greenstone belts on MARMION and RICHARDSON have been explored to some extent for gold, nickel, and base metals, no major mineral deposits have been identified.

KEYWORDS: Archaean, Yilgarn, Southern Cross Granite–Greenstone Terrane, granite, greenstone.

Introduction

Location and access

The MARMION* 1:100 000 geological map sheet (SH 50-8, 2839) occupies the northeastern part of the BARLEE 1:250 000 sheet, and covers the area between latitudes 29°00' and 29°30'S and longitudes 119°30' and 120°00'E (Fig. 1). The name of the map sheet is derived from Mount Marmion† that is 497 m above the Australian Height Datum (AHD). The RICHARDSON 1:100 000 geological map sheet (SH 50-4, 2840) lies in the southeastern part of the YOUANMI 1:250 000 sheet, and is bounded by latitudes 28°30' and 29°00'S and longitudes 119°30' and 120°00'E (Fig. 1). The map sheet is named after Mount Richardson that is 554 m above AHD.

Access to the southwestern part of MARMION is provided by the Menzies–Evanston Road from Kalgoorlie, and by the Southern Cross – Bullfinch – Evanston Road from Perth. These two roads intersect approximately 160 km west of Menzies and 198 km north of Southern Cross. About 5 km east of the intersection, a road north from the Menzies–Evanston Road leads to the Mount Elvire Homestead (Fig. 2). Access to the northeastern part of MARMION is provided by a track from Perrinvale Homestead (on MOUNT MASON), about 130 km northwest of Menzies on the Menzies–Sandstone Road. The Menzies–Sandstone Road and two connecting roads to the Cashmere Downs Homestead provide access to RICHARDSON (Fig. 2) from both Kalgoorlie and Perth. Landing grounds for light aircraft are located near the Mount Elvire and Cashmere Downs Homesteads. Pastoral tracks and mineral-exploration grids provide access within both MARMION and RICHARDSON.

There are no permanent residents on MARMION, and the former Mount Elvire pastoral lease is administered by the Department of Conservation and Land Management (CALM). On RICHARDSON, only the Cashmere Downs Homestead (Fig. 2) is permanently occupied.

Climate, physiography, and vegetation

The climate in the MARMION–RICHARDSON area is semi-arid. Summers are dry and hot, and winters are mild to cold. Summer months have daily maximum temperatures that commonly exceed 30°C and winter months have some frosty nights. The mean annual rainfall in the area is similar to that of the nearby township of Sandstone (245.8 mm; Fig. 1) and the Diemals Homestead (276 mm; Commonwealth Bureau of Meteorology, 2003). Rain falls predominantly in winter months, with occasional thunderstorms in summer.

Most of the MARMION–RICHARDSON area is flat to undulating, ranging in altitude from about 400 to 600 m above AHD (Fig. 2). The most prominent physiographic features are Lake Barlee and Lake Noondie that are approximately 400 m above AHD. They form part of a series of salt lakes that drain southeasterly through the Raeside Palaeoriver (van de Graaff et al., 1977; Hocking and Cockbain, 1990). Mount Elvire (540 m above AHD) and Mount Forrest (596 m above AHD) are the highest points on MARMION and RICHARDSON respectively. Like other parts of the Yilgarn Craton, the landforms of the MARMION–RICHARDSON area are closely related to the differential erosion of greenstones and granitoid rocks. Areas underlain by greenstones are characterized by subdued strike ridges and subrounded hills, whereas areas underlain by granitoid rocks are characterized by scattered exposures, locally developed breakaways, and extensive sandplains. The most prominent ridges are typically composed of banded iron-formation and chert. These ridges and the Lake Barlee and Lake Noondie playa-lake systems have largely controlled the present-day drainage pattern.

The MARMION–RICHARDSON area lies within the Austin Botanical District (or Murchison Region) of the Eremaean Province (Beard, 1990). Vegetation in this area is dominated by mulga in the form of trees or shrubs. Greenstone hills are characterized by low woodlands of *Casuarina* and tall shrubs of *Eremophila*, with patches of *Eucalyptus* woodland on surrounding colluvial flats. Granitoid rocks are typically covered by shrubby mulga with a height of 2–3 m (e.g. *Acacia aneura* and *A. quadrimarginea*). Shrubby *Acacia aneura*, *A. quadrimarginea*, and *A. grasbyi* also grow on laterite and along breakaways. A spinifex cover of *Triodia basedowii* is commonly developed in sandplains. Scattered trees of *Eucalyptus camaldulensis* and *Casuarina obesa* line drainage channels that flow towards salt lakes. Samphire (*Halosarcia halocnemoides*) and saltbush zones of *Atriplex*, *Maireana*, and *Frankenia* prevail in the areas marginal to Lake Barlee and Lake Noondie. Detailed descriptions of the ecosystems in the MARMION–RICHARDSON and adjacent areas are given by Beard (1976, 1990), the Biological Surveys Committee (1992, 1995), and Payne et al. (1998).

Previous and current geological investigations

The MARMION–RICHARDSON area was included in the earliest regional geological studies by Talbot (1912) who produced geological sketch maps for the region between Southern Cross and Sandstone. In his maps, greenstones were separated from granitoid rocks, but both rock types were not further subdivided. Differences in soil and vegetation types were used to interpret the distribution of greenstones and granitoid rocks in areas with no outcrop (Talbot, 1912). MARMION was also included in a regional mapping project by Blatchford and Honman (1917). Early descriptions of gold mining centres on BARLEE and YOUANMI 1:250 000 sheets were given by Gibson (1908), Clarke (1914), and Matheson and Miles (1947).

The Bureau of Mineral Resources (now Geoscience Australia) carried out airborne magnetic and radiometric

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

† MGA coordinates of localities mentioned in the text are listed in Appendix 1.

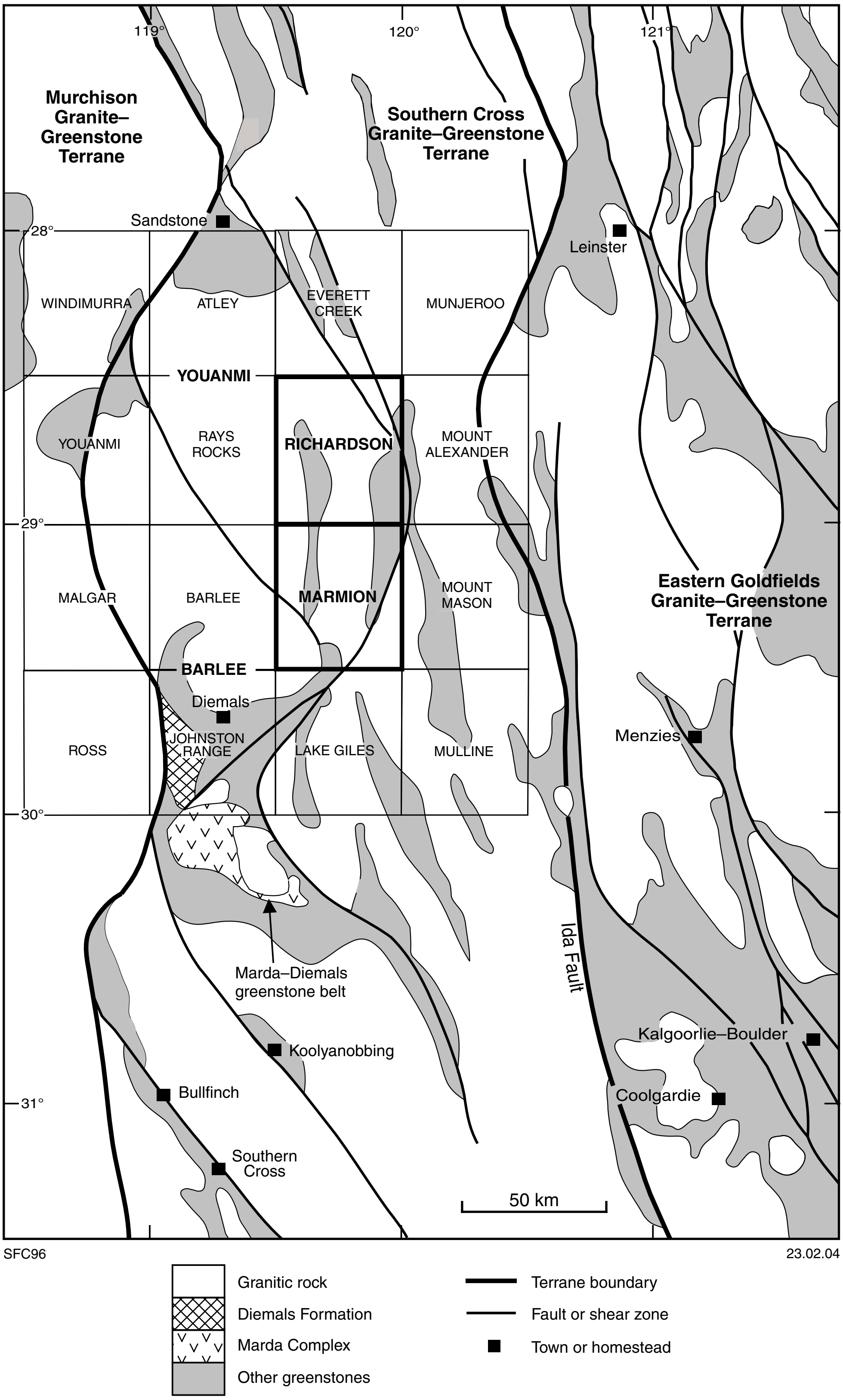

Figure 1. Regional geological setting of MARMION and RICHARDSON

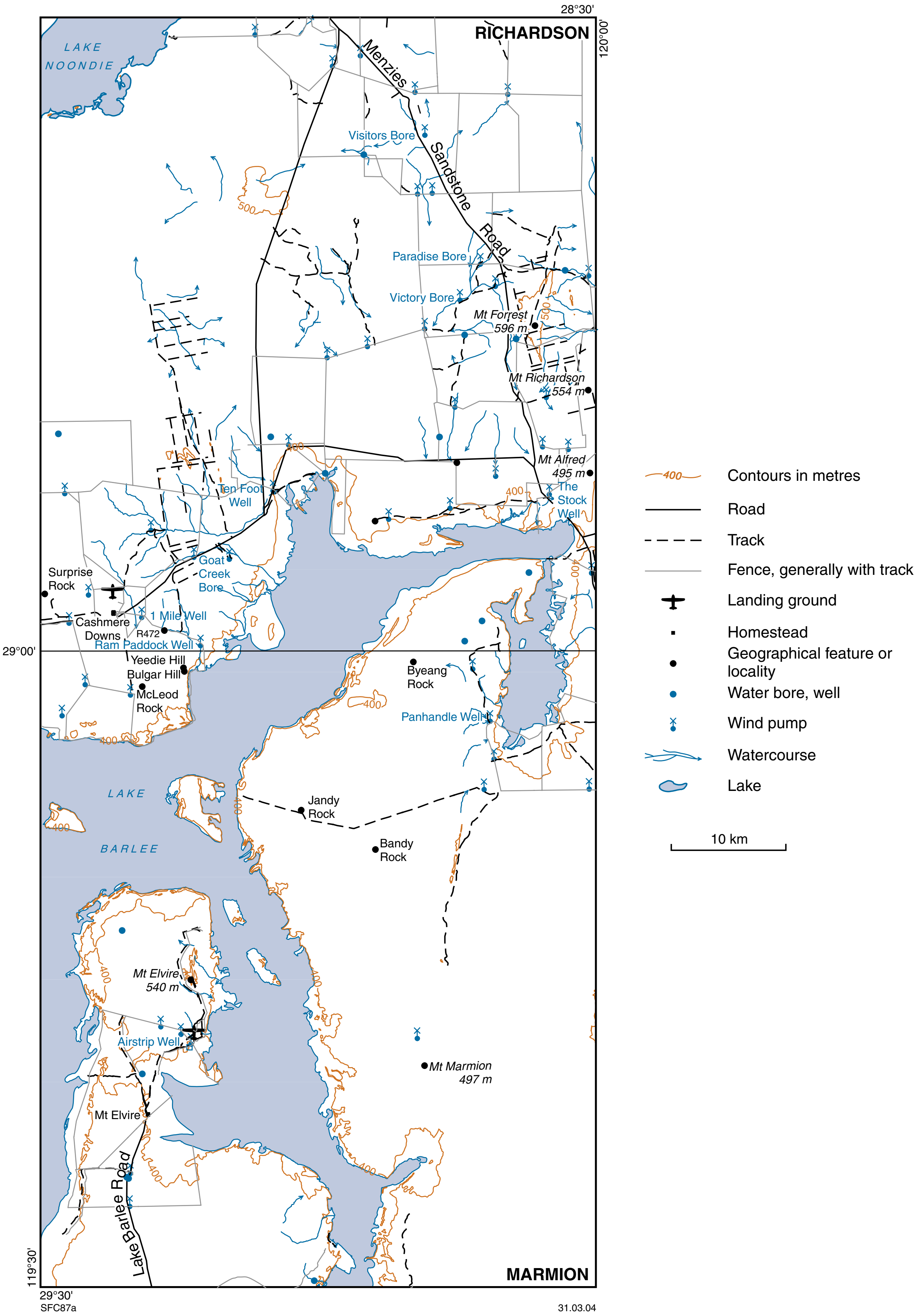

Figure 2. Principal localities, roads, tracks, and physiographic features on MARMION and RICHARDSON

surveys of BARLEE and YOUANMI 1:250 000 sheets in 1957 and 1968, respectively, and published contoured aeromagnetic maps (Bureau of Mineral Resources, 1965; Gerdes et al., 1970). Hallberg (1976) included the MARMION–RICHARDSON area in a regional petrochemical study. Binns et al. (1976) and Ahmat (1986) included the area in their regional metamorphism studies. The first systematic regional geological mapping of the region is represented by the BARLEE and YOUANMI 1:250 000 geological maps (Walker and Blight, 1983; Stewart et al., 1983). Company reports relating to gold, nickel, and base metal exploration in the MARMION–RICHARDSON area are available through the Western Australian mineral exploration (WAMEX) open-file system at the Department of Industry and Resources in Perth, and at the Kalgoorlie Regional Office of the Geological Survey of Western Australia. The index to this information and some of the reports are also available on the internet through www.doir.wa.gov.au.

The current 1:100 000-scale geological mapping on MARMION and RICHARDSON was undertaken in 1999 and 2000. Colour aerial photographs used for field mapping of MARMION (1:25 500 scale) and RICHARDSON (1:24 900 scale) were taken in October 1997 by the Department of Land Administration (DOLA; now Department of Land Information, DLI). Map compilation was assisted by Landsat Thematic Mapper (TM5) imagery, and aeromagnetic images derived from the newly acquired 400 m line-spaced dataset (Geoscience Australia, 1997).

Precambrian geology

Regional geological setting

The Archaean Yilgarn Craton is subdivided into five terranes, which from west to east include the Narryer and Southwest Terranes that are dominated by granite and granitoid gneiss, and the Murchison, Southern Cross, and Eastern Goldfields Granite–Greenstone Terranes (Fig. 3). Greenstones in the Murchison and Southern Cross Terranes are similar in age, and are generally older than those in the Eastern Goldfields Granite–Greenstone Terrane (Pidgeon and Wilde, 1990; Schiøtte and Campbell, 1996; Nelson, 1997, 1999, 2001; Pidgeon and Hallberg, 2000). The Murchison and Southern Cross Granite–Greenstone Terranes share some common features in lithostratigraphy and tectonic history that are substantially different from those of the Eastern Goldfields Granite–Greenstone Terrane (Chen et al., 2003). There is no regional stratigraphy for the Southern Cross Granite–Greenstone Terrane, but local stratigraphies have been described for some greenstone belts.

MARMION and RICHARDSON lie in the central-northern part of the Southern Cross Granite–Greenstone Terrane (Figs 3 and 4), and contain the entire Mount Elvire and South Cook Well greenstone belts and parts of the South Elvire, Mount Marmion, Illaara, North Cook Well, and Maynard Hills greenstone belts (Fig. 5; Griffin, 1990). These greenstone belts form three narrow greenstone chains that are separated by granitoid rocks: the Mount Elvire and South Elvire greenstone belts in the west, the Mount Marmion, South Cook Well, and North Cook Well greenstone belts in the central-east, and the Illaara and Maynard Hills greenstone belts in the far east (Figs 5 and 6). Greenstones on MARMION and RICHARDSON are dominated by metamorphosed mafic and ultramafic volcanic rocks and banded iron-formation, similar to the lower greenstone succession of the Marda–Diemals greenstone belt (Chen et al., 2003), but their lithostratigraphy has been disrupted by complex structures. The upper greenstone succession of the Marda–Diemals greenstone belt that consists of metamorphosed felsic–intermediate volcanic rocks and clastic sedimentary rocks (Chen et al., 2003) is essentially absent from MARMION and RICHARDSON.

Three principal deformation events have been recognized in the central Southern Cross Granite–Greenstone Terrane (Chen and Wyche, 2001; Greenfield, 2001; Wyche et al., 2001; Riganti and Chen, 2002; Chen et al., 2003). D_1 north–south compression produced low-angle thrusts, a gently dipping foliation, and tight to isoclinal folds (Greenfield and Chen, 1999; Chen and Wyche, 2001). D_2 east–west shortening produced north-trending macroscopic upright folds with a weak axial-planar foliation. D_3 progressive, inhomogeneous east–west shortening produced northwest-trending sinistral shear zones and northeast-trending dextral shear zones that formed regional-scale arcuate structures (Chen et al., 2001).

Archaean rock types

Metamorphosed ultramafic rocks (*Au*, *Auk*, *Aup*, *Aur*, *Aut*, *Auxf*)

Ultramafic rocks are present in all greenstone belts on MARMION and RICHARDSON, but are more abundant in the Mount Elvire, South Elvire, and South Cook Well greenstone belts where they occur at various stratigraphic levels. Tremolite–chlorite(–talc) schist (*Aur*) and serpentinized peridotite (*Aup*) are the most abundant ultramafic rock types.

Undivided ultramafic rocks (*Au*) include deeply weathered, poorly exposed serpentinite and schistose rocks that are commonly associated with light-brown silica caprock or white magnesite (for example, at MGA 761038E 6800329N). They also include areas where there is a range of ultramafic rock types that because of the small size of these units cannot be separated on the 1:100 000-scale map (e.g. around MGA 754700E 6817300N small units of weathered tremolite–chlorite (–talc) schist, serpentinized peridotite, and minor metabasalt are closely interleaved).

A komatiite unit (*Auk*), approximately 50 m thick, is discontinuously exposed in the Mount Elvire greenstone belt about 3.3 km north-northwest of Ram Paddock Well (MGA 757034E 6792925N). It is characterized by the presence of relict platy and random olivine-spinifex textures. Olivine plates, up to 3 cm across, are pseudomorphed by tremolite and serpentine, whereas interstitial material consists of fine-grained, intergrown tremolite and chlorite, with minor finely disseminated opaque iron oxides. The komatiite is bounded to the east by medium-

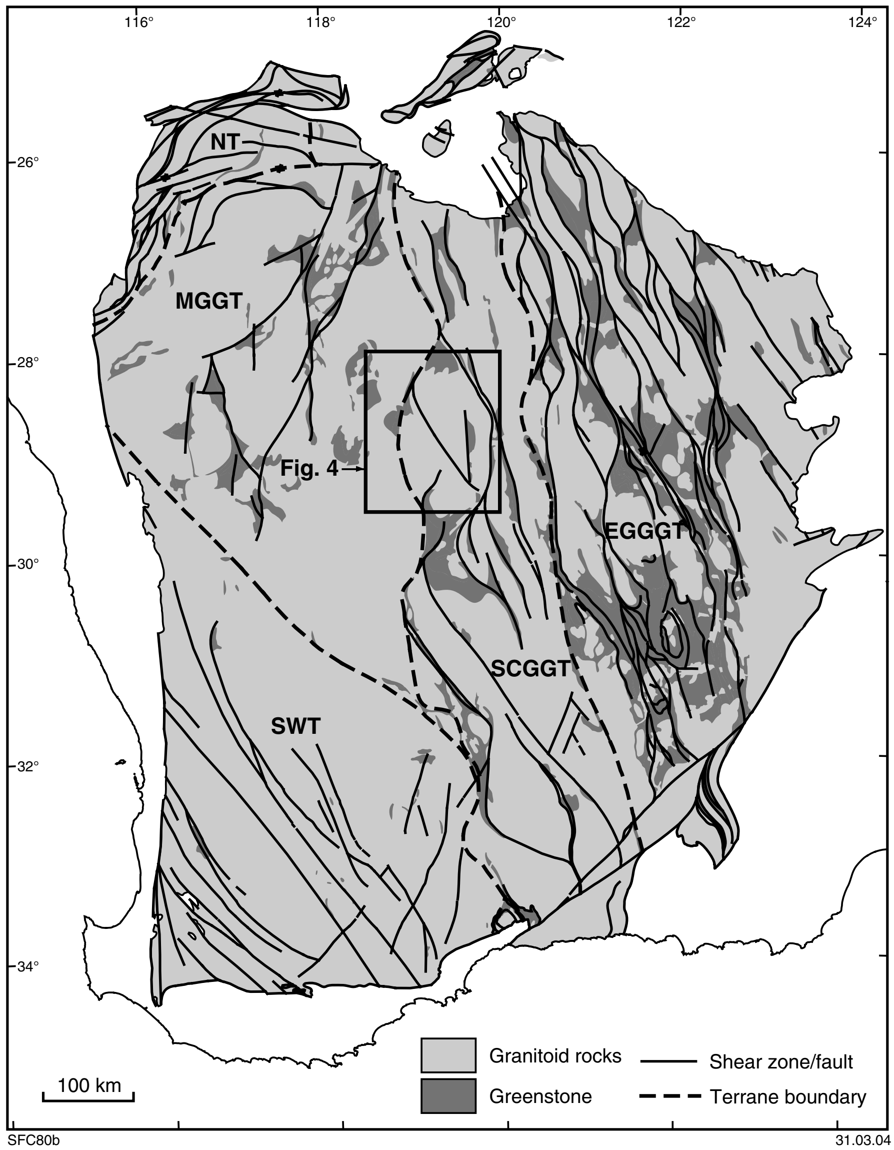

Figure 3. Outline of the Yilgarn Craton, showing distribution of greenstone belts, granitoid rocks, major shear zones and faults. Geology is after Myers and Hocking (1998), and terrane subdivision is after Tyler and Hocking (2001): EGGGT—Eastern Goldfields Granite–Greenstone Terrane; MGGT—Murchison Granite–Greenstone Terrane; NT—Narryer Terrane; SCGGT—Southern Cross Granite–Greenstone Terrane; SWT—South West Terrane

grained peridotite with cumulate texture. Two thin units of komatiite (*Auk*) are associated with komatiitic basalt (*Abk*) in the South Cook Well greenstone belt about 1.4 km west of The Stock Well (MGA 787100E 6802100N).

Massive to weakly deformed peridotite (*Aup*) is commonly serpentinized, and locally carbonated (e.g. at MGA 759100E 6772700N). It is greenish grey to dark grey with a relict medium- to coarse-grained cumulate texture. In thin section, olivine cumulate grains (0.2 – 3.0 mm across) are commonly pseudomorphed by serpentine, although partly altered olivine and pyroxene grains are found locally (e.g. at MGA 760800E 6765900N). Cumulate texture may be also outlined by fine-grained magnetite that is concentrated along the boundaries of former olivine grains (e.g. at MGA 756499E 6804644N). Intercumulus material consists of fine- to very fine grained magnetite, tremolite, serpentine, chlorite, and talc. Small peridotite outcrops are scattered throughout the Mount Elvire greenstone belt, and there are a number of larger outcrops in the South Cook Well greenstone belt north of Churchill Bore (e.g. at MGA 781900E 6783000N).

Tremolite–chlorite(–talc) schist (*Aur*) is the most common ultramafic rock type on MARMION and RICHARDSON. It is pale to dark green when fresh, and light brown when weathered. A pervasive foliation (Fig. 7) is typically subparallel to igneous layering and to the bedding of adjacent banded iron-formation and chert. In thin section, tremolite–chlorite(–talc) schist is composed mainly of fine- to medium-grained, acicular to bladed, pale-green tremolite–actinolite, with various amounts of chlorite and talc.

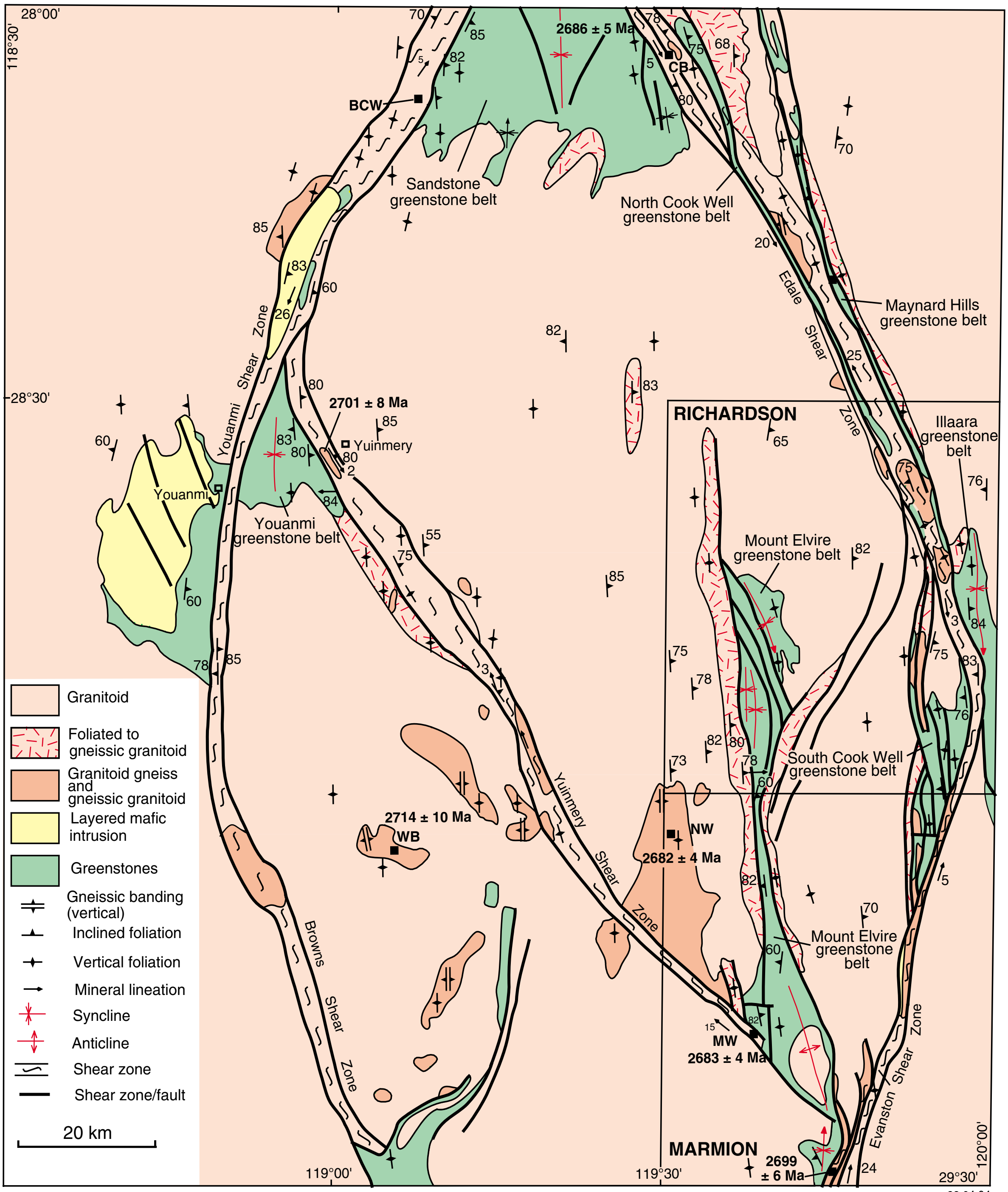

Figure 4. Interpretive geological map of the central-northern part of the Southern Cross Granite–Greenstone Terrane, compiled from published geological maps (Stewart et al., 1983; Riganti, 2002, 2003; Chen, 2003a; MARMION and RICHARDSON in these Explanatory Notes), and interpretation of aeromagnetic images. Locality names: BCW—Bell Chambers Well; CB—Coomb Bore; MW—Mountain Well (now Airstrip Well); NW—Native Well; WB—Willow Bore

Accessory minerals include magnetite, olivine, serpentine, and plagioclase. Although commonly foliated, a relict granular texture of precursor pyroxene is locally preserved (e.g. at MGA 757400E 6763900N). The protoliths of tremolite–chlorite(–talc) schist may be pyroxenite, komatiite, or peridotite, but cannot be readily identified in most cases due to the absence of primary igneous textures. Tremolite–chlorite schist with minor plagioclase may have been derived from komatiitic (high-Mg) basalt.

Tremolite–chlorite(–talc) schist (*Aur*) is in all greenstone belts on MARMION and RICHARDSON, but is most abundant in the Mount Elvire and South Elvire greenstone belts. It is commonly intercalated with banded iron-formation and chert, and is locally associated with komatiitic (high-Mg) basalt (e.g. around MGA 756000E 6792000N), peridotite (e.g. at MGA 760400E 6767100N; 758200E 6810100N), and komatiite (e.g. at MGA 757000E 6793000N). The schist is typically poorly exposed. On

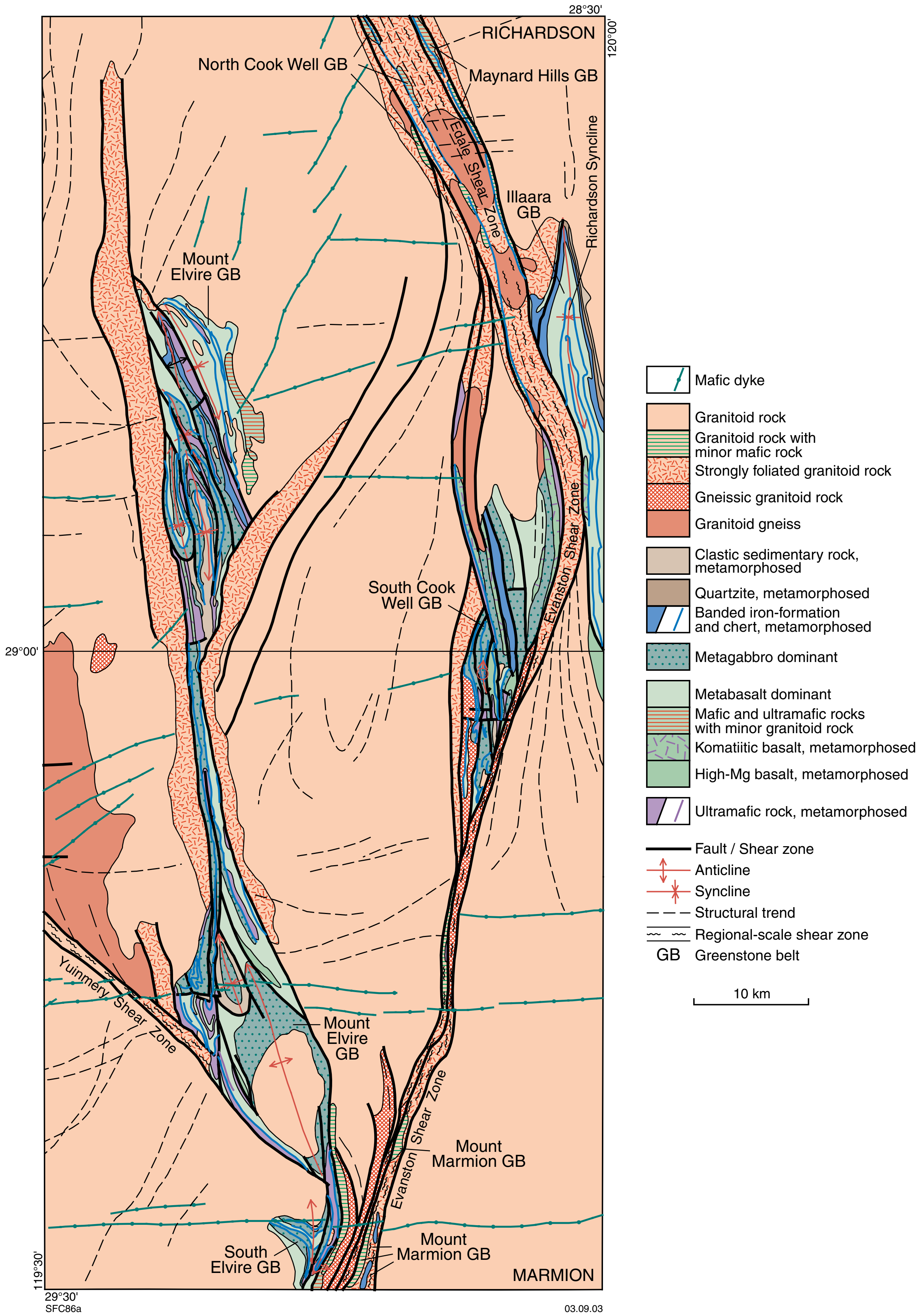

Figure 5. Interpreted bedrock geological map of MARMION and RICHARDSON

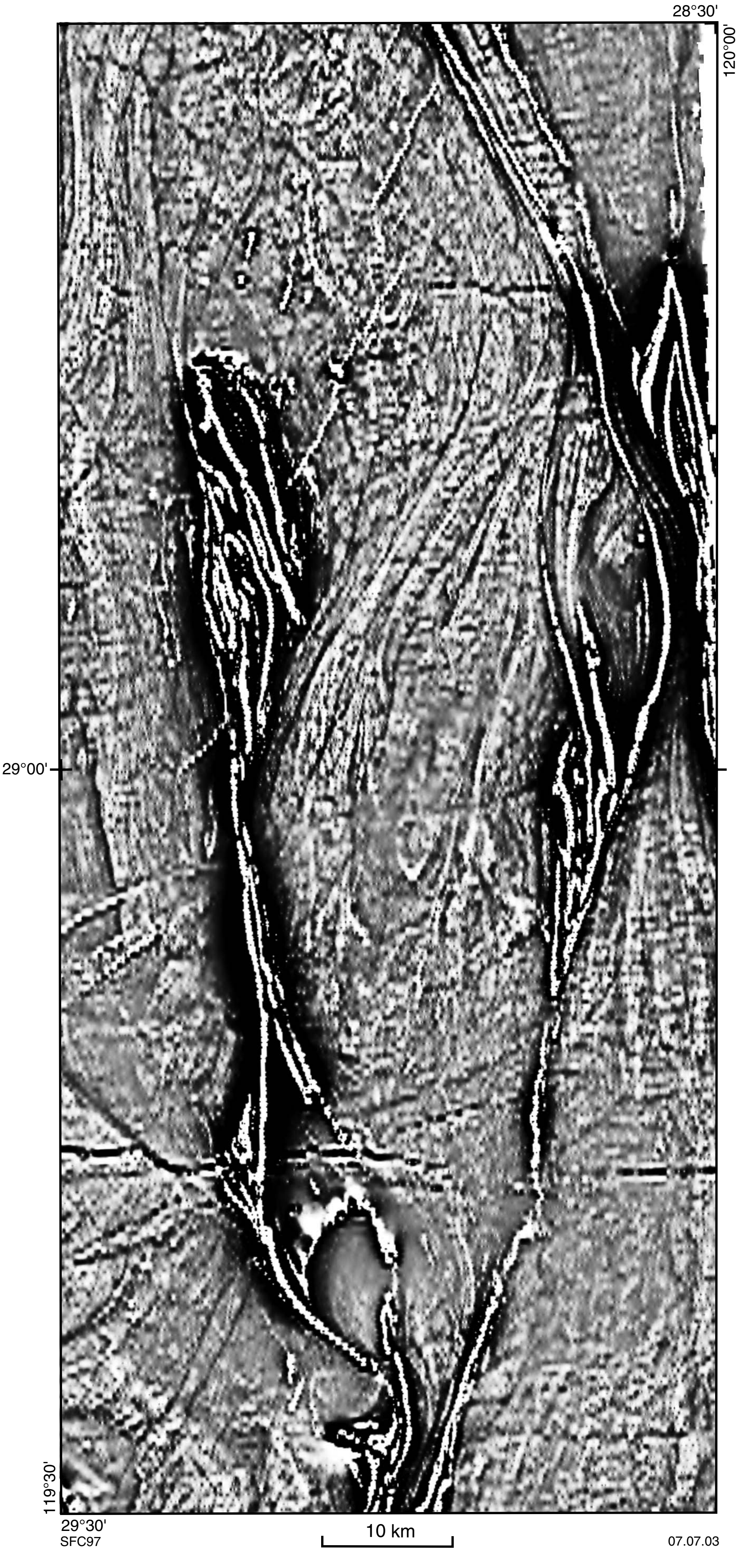

Figure 6. First vertical derivative aeromagnetic image of total magnetic intensity for MARMION and RICHARDSON (based on 400 m line-spaced data)

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Figure 7. Strongly foliated tremolite–chlorite(–talc) schist, with foliation trending 352° and dipping steeply to the east. Looking towards the north (MGA 758000E 6752850N)

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Figure 8. Basalt with pillow-lava structures (at MGA 759900E 6752550N)

slopes of prominent ridges, small outcrops of tremolite–chlorite(–talc) schist are scattered in or covered by debris derived from banded iron-formation and chert. Elsewhere, the schist is exposed on undulating ground, in small valleys, or along creeks.

Talc–tremolite(–chlorite) schist (*Aut*) is strongly foliated, and is typically a subsidiary component of tremolite–chlorite(–talc) schist (e.g. at MGA 760127E 6805948N). Only rarely is it distinguished as a separate unit (e.g. a small outcrop of weathered talc–tremolite (–chlorite) schist at MGA 758033E 6806167N).

A lenticular unit of strongly foliated pyroxenite (*Auxf*) is intercalated with banded iron-formation on the western limb of the Richardson Syncline (MGA 789074E 6823096N). It consists of tremolite and chlorite which pseudomorph medium- to coarse-grained pyroxene in a fine-grained groundmass of mainly acicular tremolite, with accessory magnetite. Although primary granular texture of precursor pyroxene is partly preserved, the foliated pyroxenite has been largely altered to tremolite–chlorite schist.

Metamorphosed fine- to medium-grained mafic rocks (*Ab*, *Aba*, *Abf*, *Abg*, *Abk*, *Abkf*, *Abm*, *Abmf*, *Abmx*, *Abr*, *Abt*, *Abv*)

Greenstones on Marmion and Richardson consist largely of fine- to medium-grained, mafic extrusive rocks in which pillow-lava structures, amygdales, and vesicles are locally preserved. Tholeiitic and komatiitic (high-Mg) basalts have been variously deformed, and metamorphosed to greenschist and amphibolite facies.

Undivided fine-grained mafic rocks (*Ab*) are typically deeply weathered, and are commonly ferruginous. They are locally associated with fresh basalt and contain no primary quartz. They are commonly exposed in the flanks of banded iron-formation and chert ridges (e.g. at MGA 755500E 6819400N, and 757900E 6816300N).

Fine-grained, massive to weakly foliated metabasalt (*Abv*) is widespread on Marmion and Richardson. It is medium to dark grey and typically aphyric, with rare plagioclase phenocrysts, and epidote alteration gives it a greenish colour. Pillow-lava structures are locally well preserved (Fig. 8). Local amygdales (3–5 mm in size) are filled by quartz, calcite, and chlorite. Metabasalt may contain medium-grained gabbro lenses (e.g. at MGA 762500E 6762000N), and narrow high-strain zones (commonly <20 m wide). In thin section metabasalt is composed of fine- to very fine grained plagioclase and decussate green actinolite. Common accessory minerals include chlorite, epidote, and opaque oxides.

Foliated basalt (*Abf*) includes both fresh and weathered, strongly deformed metabasalt with a pervasive foliation. It is typically within or adjacent to shear zones and faults, or in narrow high-strain zones within massive to weakly deformed metabasalt, where it has not been shown as separate units. Foliated basalt has also been intersected by RAB (rotary air-blast) drillholes (e.g. at MGA 789366E 6824639N). Recrystallization of foliated basalt (*Abf*) is generally weak. Where foliated basalt is interleaved with minor tremolite–chlorite schist and they cannot be separated at 1:100 000 scale, they are mapped together as *Abf* (e.g. at MGA 786636E 6818433N). In thin section, foliated basalt is composed mainly of actinolite and plagioclase, with accessory chlorite and opaque minerals.

Amphibolite (*Aba*) is a strongly foliated and completely recrystallized mafic rock. It is dark grey and fine to medium grained. A close spatial relationship with basalt indicates that amphibolite on Marmion and Richardson is predominantly derived from basalt, although primary igneous textures have been obliterated by the recrystallization. Amphibolite is commonly restricted to within 1.5 km of granite–greenstone contacts. It typically has a well-developed foliation that locally contains a steeply plunging mineral lineation defined by preferred alignment of hornblende. In thin section, amphibolite is composed of calcic plagioclase and green to green-blue hornblende, with accessory mica, opaque minerals, and quartz. Mineral segregation forms hornblende-rich and plagioclase-rich zones that are parallel to the foliation (e.g. at MGA 777600E 6843300N). Hornblende is typically aligned along the foliation, but also overgrows it in places.

Where interleaved mafic rocks and minor ultramafic and granitoid rocks are difficult to separate at 1:100 000 scale, they are mapped together as *Abg*. For example, on the eastern margin of the South Elvire greenstone belt (around MGA 766400E 6735100N), amphibolite and foliated basalt are interleaved with strongly foliated to gneissic granitoid rocks, with a pervasive foliation dipping steeply to the southeast. Within the Evanston Shear Zone (MGA 769600E 6735200N), amphibolite, tremolite–chlorite schist, and minor foliated monzogranite are mapped together as *Abg*. On the eastern margin of the Mount Elvire greenstone belt (around MGA 763000E 6808000N), mixed amphibolite, basalt, and patches of monzogranite (*Abg*) are heterogeneously deformed. A weak to strong foliation is vertical or dips 35–85° towards the west-southwest, and locally contains a steeply plunging to downdip mineral lineation (e.g. at MGA 761690E 6809112N).

Komatiitic basalt (*Abk*) on Richardson and high-Mg basalt (*Abm*) on Marmion represent the same rock type, and are distinguished from tholeiitic basalt by the presence of pyroxene-spinifex texture. Pyroxene-spinifex-textured basalt is composed mainly of tremolite–actinolite after pyroxene, with lesser amounts of chlorite, plagioclase, and accessory epidote and opaque minerals. Minor dendritic pyroxene grains have been recognized locally (e.g. at MGA 758700E 6752050N). Coarse-grained skeletal tremolite–actinolite pseudomorphs, up to 15 mm long, are randomly oriented or in sheaves, forming a spinifex texture. Interstitial material consists of fine-grained plagioclase and tremolite–actinolite. Pyroxene-spinifex-textured basalt is associated with variolitic basalt in places (e.g. at MGA 764800E 6735900N; and 786696E 6793774N). Rounded to ellipsoidal, leucocratic varioles up to 10 mm (typically 3–5 mm) in diameter consist of microcrystalline plagioclase and amphibole, and are typically more plagioclase-rich than the groundmass. A thin unit of brecciated high-Mg basalt (*Abmx*) in southeastern RICHARDSON (at MGA 786800E 6793900N) contains breccia clasts up to 10 cm in size.

Strongly foliated komatiitic or high-Mg basalts are shown as *Abkf* and *Abmf* respectively. Relict pyroxene-spinifex texture and variolitic texture are commonly preserved in these rocks despite intense deformation. Pillow-lava structures are preserved locally in foliated komatiitic basalt (e.g. at MGA 786252E 6791958N), but younging direction cannot be determined due to the deformation. Tremolite–chlorite schist containing plagioclase (*Abr*) is probably derived from komatiitic (high-Mg) basalt, but no relict igneous textures are preserved (e.g. at MGA 783700E 6788550N). In places, it is interleaved with minor, less deformed komatiitic (high-Mg) basalt with relict pyroxene-spinifex texture (e.g. at MGA 758450E 6776500N).

Mafic tuff (*Abt*) is grey to pale grey and typically well bedded. A conspicuous mafic tuff unit, about 3 km north-northwest of Panhandle Well (MGA 781600E 6785300N), is thinly bedded and laminated, with individual layers ranging from less than 1 mm to a few millimetres. In thin section, the tuffaceous rock is composed of fine- to very fine grained chlorite, amphibole, plagioclase, and minor quartz. Bedding is defined by compositional variation. Dark layers contain more mafic minerals, and pale layers are more plagioclase-rich. The mafic tuff contains dark, ellipsoidal spots, up to 10 mm long, that are composed mainly of fine-grained mafic minerals with minor plagioclase and quartz, and are probably a result of post-metamorphism alteration.

Metamorphosed medium- to coarse-grained mafic rocks (*Ao*, *Aog*, *Aogf*)

Metamorphosed medium- to coarse-grained mafic rocks dominated by metagabbro represent a major greenstone lithotype on MARMION, and are widespread on RICHARDSON. They are commonly exposed on the flanks of banded iron-formation and chert ridges, or are intercalated with basalt, tremolite–chlorite(–talc) schist, and locally with clastic sedimentary rocks. Metagabbro sills are typically conformable with bedding and igneous layering. Some thick basaltic flows contain thin (typically <50 m) lenticular units of dolerite and gabbro.

In deeply weathered, medium- to coarse-grained mafic rocks (*Ao*), original mineralogy has been altered, but a relict igneous granular texture is partly preserved. These rocks are typically massive and reddish-brown to yellowish-brown, with no primary quartz, and may be ferruginized. They are commonly exposed adjacent to banded iron-formation and chert ridges (e.g. at MGA 763600E 6738700N, and 758900E 6805700N).

Metagabbro (*Aog*) is common in the South Elvire, Mount Elvire, and South Cook Well greenstone belts (Fig. 5). It is a medium to coarse grained, grey to dark-grey mafic rock that is massive to weakly deformed. The primary granular and intergranular textures are commonly pseudomorphed by metamorphic assemblages of actinolitic amphibole and hornblende (after clinopyroxene), chlorite, and plagioclase, with accessory fine-grained opaque minerals. The presence of hornblende indicates local amphibolite-facies metamorphism. Plagioclase is typically finer grained and interstitial to amphibole grains. Some small areas of leucocratic gabbro contain primary quartz (e.g. at MGA 758700E 6759450N, and 784764E 6793152N) but these have not been shown as separate rock units on the map.

Metagabbro is a dominant greenstone rock type in the Mount Elvire area (around MGA 757000E 6761000N), where several thick sills are intercalated and conformable with major banded iron-formation and chert units. Although locally well exposed, patches of metagabbro are commonly surrounded by debris derived from banded iron-formation and chert. Here metagabbro typically has a well-preserved, relict granular texture, and is composed mainly of amphibole after pyroxene, with subordinate plagioclase. Primary pyroxene grains are found locally (e.g. at MGA 757100E 6761950N). The sills are folded together with banded iron-formation and chert units, and are truncated by an east-trending fault that separates metagabbro in the north from clastic sedimentary rocks, basalt, and tremolite–chlorite schist to the south.

Although metagabbro (*Aog*) is commonly intercalated with banded iron-formation and chert on MARMION and RICHARDSON (e.g. at MGA 757300E 6776000N, and 781000E 6786000N), it is also intercalated with various other rock types, such as clastic sedimentary rocks, basalt, and tremolite–chlorite(–talc) schist. For example, in the Mount Elvire greenstone belt, a medium- to coarse-grained, quartz-bearing gabbro sill (at MGA 758700E 6759450N) is bounded by, and conformable with, metamorphosed shale and siltstone. A number of medium-grained gabbro lenses (20–50 m thick) within fine-grained, massive basalt on an island in Lake Barlee (around MGA 762500E 6762000N) may represent coarser grained intervals in thick mafic flows.

Strongly foliated metagabbro (*Aogf*) within or adjacent to shear zones and faults is commonly intercalated with banded iron-formation and chert. In thin section, foliated gabbro is composed of actinolitic amphibole (after pyroxene), and plagioclase, with accessory quartz and opaque minerals. Mineral segregation results in amphibole-rich and plagioclase-rich zones that are parallel to the foliation (e.g. at MGA 784766E 6814274N). Foliated gabbro metamorphosed to amphibolite facies contains hornblende and plagioclase. The hornblende grains are typically flattened, whereas plagioclase grains may be broken, with microfractures oriented at high angles to the foliation (e.g. at MGA 790500E 6807800N).

Metamorphosed felsic volcanic and volcaniclastic rocks (*Af*, *Afs*, *Afv*)

Metamorphosed felsic volcanic and volcaniclastic rocks and their strongly foliated varieties are rare on MARMION and RICHARDSON. Undivided felsic rocks (*Af*) are typically deeply weathered and partly altered to kaolinite, but contain primary quartz crystals (e.g. at MGA 759350E 6804000N, and 759600E 6803500N).

A single exposure (~30 m wide) of moderately weathered, pale-grey to yellowish, probably felsic rock (*Afv*) in the South Elvire greenstone belt (at MGA 765100E 6736000N) contains visible quartz and feldspar grains (1–2 mm) in a fine- to very fine grained quartzo-feldspathic groundmass. The rock is massive to weakly foliated, with a local foliation trending 15° and dipping 52° to the east-southeast. It may be a volcanic rock or a high-level intrusive.

Strongly foliated to schistose felsic rock (*Afs*), about 2 km north of Airstrip Well in the Mount Elvire greenstone belt (at MGA 756500E 6756950N) is underlain by ferruginous chert and overlain by well-bedded pebbly sandstone, sandstone, and siltstone. The strongly foliated felsic rock is composed of partly recrystallized quartz and muscovite, in a micaceous quartzofeldspathic matrix. A pervasive, steeply northeast-dipping foliation contains a local striation pitching 30° to the northwest. The same unit extends discontinuously to the north-northwest (around MGA 755800E 6758750N). A similar, thin unit (1 m thick) of fine-grained felsic rock lies within massive to weakly deformed basalt in the South Elvire greenstone belt (at MGA 764900E 6735900N).

Metamorphosed sedimentary rocks (*As*, *Asf*, *Ash*, *Asq*, *Ass*, *Ac*, *Aci*)

Metasedimentary rocks can be grouped into clastic sedimentary rocks (*As*, *Asf*, *Ash*, *Asq*, *Ass*), and chemical sedimentary rocks (*Aci*, *Ac*). The former outcrop predominantly in three areas: east of Mount Elvire (around MGA 7758300E 6759000N); south of Goat Creek Bore (around MGA 758000E 6792000N); and near the eastern margin of RICHARDSON. Thin units of clastic sedimentary rocks outcrop locally elsewhere. Chemical metasedimentary rocks (*Aci*, *Ac*) are widespread in all greenstone belts, and form most of the prominent ridges on MARMION and RICHARDSON.

Undivided metasedimentary rocks (*As*) are typically deeply weathered and poorly exposed. They are interpreted as sedimentary rocks on the basis of locally preserved primary structures (e.g. bedding) and association with less weathered sedimentary rocks. Where a variety of rock types, such as shale, siltstone, sandstone, and pebbly sandstone, are intercalated with each other and cannot be separated at the map scale, they are also shown as undivided metasedimentary rocks.

In the area east of Mount Elvire (around MGA 758300E 6759200N), undivided clastic sedimentary rocks (*As*) include weathered shale and siltstone that are intercalated with relatively less weathered, fine-grained sandstone (*Ass*). They are pale grey and weather to yellowish- and purplish-brown. Although they are variously foliated and locally crenulated, bedding is generally recognizable. Other primary structures, such as ripple marks (at MGA 758400E 6760350N) and cross-bedding (e.g. at MGA 760300E 6758250N), are locally found in siltstone and fine-grained sandstone. A thin (~5 m) unit of carbonated shale (at MGA 758300E 6759050N) has not been mapped separately. In thin section, shale and siltstone are composed of mica, chlorite, clay minerals, quartz, minor plagioclase, and opaque minerals. Fine-grained sandstone contains quartz in a mafic matrix. The clastic sedimentary rocks and overlying gabbro sills are folded into a northwest-plunging syncline. Cross-bedding indicates younging towards the core of the syncline.

In the area south of Goat Creek Bore on RICHARDSON (around MGA 758000E 6792000N), undivided clastic sedimentary rocks (*As*) are composite units of siltstone, shale, and fine-grained sandstone that are deeply weathered and poorly exposed. They are intercalated with chert, banded iron-formation, and tremolite–chlorite(–talc) schist. Within intercalated shale and siltstone, bedding is indicated by variations in colour and grain size. Shale is typically deeply weathered. Fresh, grey to black shale (*Ash*) has been found only along a creek (at MGA 757400E 679050N) and in mineral-exploration drillhole chips. Fine-grained sandstone is a major clastic sedimentary rock type in places, but more commonly forms thin intervals within siltstone and shale. The clastic sedimentary rocks are strongly foliated adjacent to the granite–greenstone contact, where bedding has been obscured by foliation (e.g. at MGA 758300E 6790500N). In other places, a steep to vertical, north-trending bedding is subparallel to foliation.

Metamorphosed shale (*Ash*), including minor siltstone and mica schist, is commonly associated with banded iron-formation and chert (e.g. at MGA 782700E 6781500N; 780350E 6781900N). These metasediments are grey to black when fresh, but commonly weather to yellowish-brown, and are locally ferruginous. The millimetre-scale laminations in shale represent bedding or bedding-parallel foliation. In thin section, shale and siltstone are composed of fine- to very fine grained mica(–chlorite), clay minerals, quartz, and plagioclase that are permeated by iron oxides.

A unit of strongly foliated metasedimentary rocks (*Asf*), approximately 100 m thick, includes shale, siltstone, sandstone, and pebbly sandstone (around MGA 759500E 6756550N). In these rocks, bedding dips gently (15–20°) to the north-northwest, and is transected and locally transposed by a steep to vertical, northerly trending foliation. Andalusite porphyroblasts (2–5 mm long) in shale are commonly flattened and some have been pseudomorphed by aggregates of fine-grained muscovite, quartz, and plagioclase during retrograde metamorphism.

Quartz-rich sandstone (*Ass*) with minor siltstone and pebbly sandstone in the Illaara greenstone belt is discontinuously exposed at the basal stratigraphic contact with granite, and is overlain by quartzite and banded iron-formation. The sandstone is fine to medium grained, and massive to well bedded, with a steep, westerly dipping bedding. Pebbly sandstone contains vein-quartz clasts up to 10 mm in size. In thin section, the sandstone is composed mainly of quartz (up to 3 mm across), with minor muscovite and sericite(–clay), and accessory feldspar and opaque minerals. Subrounded quartz grains are commonly recrystallized with a reaction margin. Muscovite is typically aligned along bedding planes. Sericite and clay minerals are more common in weathered sandstone (e.g. at MGA 791603E 6819819N), and some may have been derived from altered feldspar. At higher stratigraphic levels, quartzofeldspathic sandstone (*Ass*) is ferruginous and commonly permeated by iron oxides (e.g. at MGA 790800E 6807500N).

In the Mount Elvire greenstone belt, metamorphosed, fine-grained sandstone and pebbly sandstone (*Ass*), including minor siltstone and shale, contain cross-bedding (e.g. at MGA 759100E 6758500N) and graded bedding (e.g. at MGA 761600E 6758650N). The sandstone is pale grey to purplish-brown, and is composed of quartz and plagioclase in a mica–chlorite matrix. The pebbly sandstone contains up to 30% chert and vein-quartz clasts (2–5 cm across). Metamorphosed shale and siltstone in this area contain coarse andalusite porphyroblasts that are commonly 3–5 mm, but up to 20 mm long.

Quartzite with local micaceous and ferruginous intercalations (*Asq*) outcrops mainly in the eastern part of RICHARDSON, in the Illaara and Maynard Hills greenstone belts. In the Illaara greenstone belt, quartzite overlies quartz-rich sandstone (*Ass*) in the eastern limb of the Richardson Syncline, but is not preserved in the western limb, possibly due to granite intrusion or faulting. The quartzite is white, pale green (locally fuchsitic), and less commonly, whitish-grey and pinkish. It is fine to coarse grained and massive to well bedded. Individual beds range from less than 1 mm up to 15 cm in thickness. Steeply west-dipping bedding is defined by quartz grain-size variation, or by concentration and preferred alignment of muscovite. Apart from bedding, sedimentary structures are rarely preserved (e.g. ripple marks at MGA 790640E 6822578N). The quartzite is commonly foliated, with foliation subparallel to the bedding. A bedding–cleavage intersection lineation plunges moderately (20–30°) to the south (e.g. at MGA 791503E 6817220N). SHRIMP (Sensitive High-Resolution Ion MicroProbe) U–Pb zircon dating on detrital zircons from quartzite in the Illaara greenstone belt on RICHARDSON (GSWA 178064; Nelson, in prep.) and to the south (Nelson, 2000) has yielded maximum depositional ages of c. 3500 Ma and c. 3300 Ma respectively.

In thin section, the quartzite is composed predominantly of quartz (>95%), with minor muscovite, fuchsite, and accessory plagioclase, and iron oxides. Quartz grains are typically subrounded in less deformed quartzite, and are flattened and aligned along foliation in strongly deformed quartzite. Most quartz grains are clean, and some contain deformation lamellae. Although quartz grains are commonly recrystallized, grain-size variation within bedding probably reflects depositional sorting. Very fine grained fuchsite and iron oxides are commonly disseminated within or between quartz grains, locally giving the quartzite a pale green or pinkish colour. Muscovite in micaceous quartzite is mainly aligned parallel to bedding, but with locally folded aggregates (e.g. at MGA 792655E 6805482N).

A thick unit of massive to well-bedded quartzite (*Asq*) in the Maynard Hills greenstone belt is exposed near the northern edge of RICHARDSON (MGA 777600E 6844000N). The same unit extends northwards to EVERETT CREEK, and has been described in detail by Riganti (2003). SHRIMP U–Pb zircon dating on detrital zircons from quartzite in the Maynard Hills greenstone belt to the north on EVERETT CREEK has yielded a maximum depositional age of 3131 ± 3 Ma for the quartzite (Nelson, 2002). In the Bulgar Hill area on MARMION, a prominent ridge (10–30 m wide) is composed of quartzite with minor cherty bands. The fine- to medium-grained quartzite is white to greyish-white. Cross-bedding indicates that this unit youngs to the west (e.g. at MGA 756600E 6784800N).

Metamorphosed banded iron-formation (*Aci*) and chert (*Ac*) occur at various stratigraphic levels and are intercalated with many rock types, particularly gabbro sills. They are ridge-forming units with elevations up to 100 m above surrounding areas (e.g. Mount Forrest). Banded iron-formation may change into chert along strike, reflecting variation in iron content. Individual units of banded iron-formation and chert are typically less than 30 m thick, but may be up to 500 m thick. Both banded iron-formation and chert are laminated at millimetre to centimetre scale, and locally contain ripple marks (e.g. at MGA 757000E 6779650N).

Metamorphosed chert (*Ac*) is typically well banded and comprises white, pale-grey, brown, and black bands down to less than 1 mm thick. Most chert units are ferruginous to some degree. In thin section, light-coloured bands consist mainly of microcrystalline and recrystallized quartz, whereas darker bands consist of iron oxides, cryptocrystalline quartz, and silica. A metamorphosed chert unit (at MGA 789257E 6822842N) contains thin bands of clinopyroxene and grunerite between quartz laminations.

Metamorphosed banded iron-formation (*Aci*) forms the most prominent magnetic anomalies on aeromagnetic images that outline large-scale fold structures (Fig. 6). It is blue or steel-grey to black and comprises alternating bands of iron-rich minerals and fine-grained quartz. Compared to banded chert in which quartz and silica are dominant, banded iron-formation is composed mainly of iron oxides (hematite, magnetite, and minor goethite). Red jaspilite is locally prominent, but has not been mapped separately.

Granitoid rocks (*Ag*, *Agb*, *Agf*, *Agm*, *Agmf*, *Agn*, *Ang*)

Granitoid rocks comprise approximately 75% of both MARMION and RICHARDSON (Fig. 5), but are typically poorly exposed. They occupy or underlie extensive areas between greenstone belts, and locally intrude greenstones. The granite–greenstone contacts are either sheared or intrusive, or both. Exposed granitoid rocks are mainly monzogranitic in composition, with subordinate granodiorite in the dark phase of granitoid gneiss. Strongly deformed varieties of granitoid rocks are most commonly found in large-scale shear zones, but some bodies of granitoid gneiss and gneissic granitoid rock appear to be unrelated to any major shear zones. All granitoids show evidence of metamorphic recrystallization.

Undivided granitoid rocks (*Ag*) include deeply weathered rocks and inaccessible exposures that are interpreted from aerial photographs and Landsat images, with no compositional and structural data. Deeply weathered and poorly exposed granitoid rocks typically have a relict granular texture, but their primary mineralogy cannot be ascertained. Weathered granitoid rocks may be capped by silcrete or kaolinite, in which only medium- to coarse-grained quartz remains as a primary constituent. Deep weathering may have obliterated the structural fabrics of some granitoid rocks within shear zones. Weathered granitoid rocks with a relict strong foliation (*Agf*) are typically found near major shear zones (e.g. at MGA 767600E 6738000N).

Monzogranite (*Agm*) is the most common granite type in areas away from granite–greenstone contacts and major shear zones. It is fine to coarse grained, and commonly equigranular, but locally porphyritic with K-feldspar phenocrysts up to 20 mm in size (e.g. at MGA 748353E 6792765N, and at MGA 748835E 6823604N). Monzogranite is typically biotite bearing and leucocratic to mesocratic depending upon biotite content. It is typically massive to weakly deformed, but may contain narrow high-strain zones (commonly less than 20 m wide) with a northerly trending foliation (e.g. at MGA 769250E 6813200N).

In thin section, monzogranite is composed of microcline, plagioclase, quartz, and biotite. Accessory minerals include muscovite, opaque oxides, sphene, apatite, and zircon. Plagioclase is commonly sericitized and zoned plagioclase grains are common. Quartz may be fractured in weakly deformed monzogranite, with some fractures filled by quartz veinlets (e.g. at MGA 748835E 6823604N). Biotite is the major mafic mineral in monzogranite, although hornblende is present locally. Biotite may be altered to chlorite, and ranges from less than 3% to 8% of the rock. A monzogranite sample from south of the Bulga Downs Homestead yielded a SHRIMP U–Pb zircon crystallization age of 2684 ± 8 Ma (Cassidy et al., 2002).

Strongly foliated monzogranite (*Agmf*) contains a pervasive foliation, and is found mainly along shear zones or granite–greenstone contacts. For example, at the southeastern end of the Yuinmery Shear Zone on MARMION, a pervasive northwest-trending foliation in strongly deformed monzogranite (*Agmf*) is defined by grain-size reduction, the preferred alignment of quartz and feldspar, and segregation of biotite from quartzofeldspathic minerals (e.g. at MGA 756200E 6755150N). Quartz is typically finer grained than feldspar. Strongly foliated monzogranite near Airstrip Well (previously called Mountain Well) yielded a SHRIMP U–Pb zircon crystallization age of 2683 ± 4 Ma (Nelson, 2001).

Strongly foliated monzogranite (*Agmf*) is locally well exposed along the western margin of the Mount Elvire greenstone belt on RICHARDSON (Fig. 5), and has a gradational boundary with less deformed to massive monzogranite (*Agm*) farther west. It is medium to coarse grained and locally porphyritic with K-feldspar phenocrysts up to 10 mm in size (e.g. at MGA 749243E 6823503N). Pegmatite dykes are locally abundant, and typically parallel to a northerly trending, pervasive foliation. Strongly foliated to gneissic monzogranite from about 2 km southeast of 1 Mile Well yielded a SHRIMP U–Pb zircon crystallization age of 2756 ± 11 Ma (Nelson, 2002). Strongly foliated monzogranite within the Edale Shear Zone (Fig. 5) contains a northerly trending foliation that is sinistrally displaced by a northwest-trending foliation (see **Structural geology**).

Granitoid rocks and interleaved minor mafic and ultramafic rocks that cannot be distinguished at 1:100 000 scale (*Agb*) are found in shear zones and near granite–greenstone contacts. For example, near the southern–middle edge of MARMION (around MGA 766800E 6735200N), weakly to strongly foliated monzogranite is interleaved with discontinuous lenses of strongly foliated basalt, amphibolite, and tremolite–chlorite schist. A north-northeast-trending foliation has dip angles ranging from 25° to 90° (vertical). About 3.5 km northwest of Ten Foot Well (around MGA 762122E 6805574N), massive to weakly foliated, medium- to coarse-grained monzogranite contains patches of amphibolite that are typically dark grey and recrystallized. Approximately 1.2 km west of Visitors Bore (around MGA 777300E 6833300N), strongly foliated monzogranite is interleaved with lenticular units of amphibolite and weathered ultramafic schist.

Granitoid gneiss (*Ang*) and gneissic granitoid rock (*Agn*) are mainly found near, or within, large-scale shear zones (e.g. Edale Shear Zone). However, there are also some isolated outcrops that are unrelated to any major shear zones (e.g. granitoid gneiss at Native Well). Quartzofeldspathic gneiss derived from granitoid rocks (*Ang*) is fine to coarse grained, and comprises alternating leucocratic and mesocratic bands of largely monzogranite to granodiorite. The compositional bands have sharp to diffuse contacts, and range from a few millimetres up to 30 cm wide.

Fine- to coarse-grained granitoid gneiss (*Ang*) in the eastern part of RICHARDSON is abundant in the Edale Shear Zone and the associated north-northeasterly trending splays (Fig. 5). The compositional banding in granitoid gneiss (Fig. 9) is defined by variations in biotite content, pegmatite dykes, and less commonly, aplite and schlieren lenses. Within the Edale Shear Zone, the gneissic banding and a coplanar foliation dip steeply to the west-southwest (e.g. at MGA 782300E 6826100N). Porphyroclasts of feldspar are commonly aligned along, or wrapped by, the foliation, but some (up to 25 mm long) overgrow the foliation (e.g. at MGA 779042E 6833245N). The granitoid gneiss along the north-northeasterly trending shear zones contains a gneissic banding and foliation parallel to the shear zones (e.g. at MGA 781700E 6810100N).

The medium- to coarse-grained granitoid gneiss in the northwestern part of MARMION contains alternating leucocratic and mesocratic compositional bands that are parallel to a northerly (350–005°) trending foliation. The gneiss contains at least two generations of pegmatite dykes: early dykes parallel to the gneissic banding, and later dykes that crosscut the banding. Both the gneissic banding and foliation are sinistrally displaced by a small-scale (20 cm wide), semi-ductile shear zone trending 345°. In thin section, both quartz and feldspar are slightly flattened and contain fractures that are sub-perpendicular to the foliation. Biotite is aligned parallel to the foliation. A sample of granitoid gneiss from within a broad area dominated by monzogranite near McLeod Rock gave a poorly constrained crystallization age of c. 2740 Ma (Cassidy et al., 2002). A foliated monzogranite dyke that

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Figure 9. Granitoid gneiss with compositional banding within the Edale Shear Zone (MGA 779054E 6833186N)

crosscuts the gneissosity at Native Well yielded a SHRIMP U–Pb zircon crystallization age of 2682 ± 4 Ma (Cassidy et al., 2002).

Gneissic granitoid rock (*Agn*) is a rock type transitional between strongly foliated monzogranite and granitoid gneiss, and it contains a pervasive foliation, and locally prominent compositional banding. It is most abundant along the Evanston Shear Zone and its northerly trending splays (Fig. 5). On the eastern side of the South Elvire greenstone belt on MARMION (around MGA 767400E 6735400N), gneissic granitoid rock contains a locally well-developed compositional banding. The mesocratic granodiorite phase contains up to 10% mafic minerals (biotite and hornblende), and has a SHRIMP U–Pb zircon crystallization age of 2686 ± 6 Ma (GSWA 168965; Nelson, 2001). The leucocratic monzogranite phase has a SHRIMP U–Pb zircon crystallization age of 2699 ± 6 Ma (GSWA 168964; Nelson, 2002). This may indicate that the granodiorite and monzogranite were intruded lit-par-lit and then compressed to form the foliation and accentuate the banding. Southwest of Cashmere Downs Homestead, (MGA 748300E 6789450N), an isolated outcrop of gneissic granitoid rock contains a steep, northerly trending gneissic banding and coplanar foliation.

Veins and dykes (*q*, *g*, *p*)

Quartz veins (*q*), ranging from less than 1 m up to 30 m wide, are widespread on MARMION and RICHARDSON. They are most abundant along major shear zones, and in east- to east-northeast-trending brittle fractures or faults. For example, numerous quartz veins within and adjacent to the Evanston Shear Zone in the eastern part of MARMION trend northeast, parallel to the main foliation in surrounding granitoid rocks. The most conspicuous quartz vein on RICHARDSON is exposed along a north-northeasterly trending shear zone, about 1 km east of Victory Bore (MGA 782200E 6819500N). The vein is 5–30 m wide, and forms prominent but discontinuous ridges that are up to 50 m above the surrounding plain, and extend about 12.5 km to the south. East- and east-northeast-trending quartz veins in both granitoid rocks (e.g. around MGA 754000E 6759700N, and 773000E 6771300N) and greenstones (e.g. at MGA 787800E 6801100N) are related to late brittle faulting and crosscut earlier structures.

Granitoid dykes (*g*) of mainly monzogranitic composition in greenstones adjacent to the contacts with granitoid rocks (e.g. at MGA 758600E 6791100N) are fine- to coarse grained and massive to moderately foliated, with foliation typically parallel to the granite–greenstone contacts. Pegmatite dykes (*p*) that are up to 10 m wide are late intrusions that crosscut greenstones (e.g. around MGA 783700E 6800500N). Granitoid gneiss and gneissic granitoid rock contain numerous pegmatite veins and dykes that cannot be shown at 1:100 000 scale.

Mafic dykes (*Edy*)

On MARMION and RICHARDSON, a number of prominent east- and northeast-trending magnetic lineaments that cut across greenstones, granitoid rocks, and all other structural trends (Figs 5 and 6) are interpreted as brittle fractures or faults filled by mafic dykes (*Edy*). No surface expression of these dykes is known on MARMION and RICHARDSON, but they are readily identified as pronounced linear anomalies on magnetic images. Similar magnetic anomalies in the areas to the north (e.g. on EVERETT CREEK, Riganti, 2003; and ATLEY, Chen, 2003a) correspond to exposures of medium- to coarse-grained gabbroic dykes. Hallberg (1987) suggested that cross-cutting mafic and ultramafic dykes in the Yilgarn Craton were emplaced between 2.4 Ga and 2.0 Ga, and post-date cratonization.

Stratigraphy

The lithostratigraphy of most greenstone belts on MARMION and RICHARDSON is not well constrained due to poor exposure and structural complexity. Stratigraphy in greenstone belts on MARMION and RICHARDSON is broadly similar to the lower greenstone succession of the Marda–Diemals greenstone belt (Chen and Wyche, 2001; Chen et al., 2003) in that they are dominated by mafic rocks with subordinate ultramafic rocks, and contain prominent ridge-forming units of chert and banded iron-formation at some stratigraphic levels. However, stratigraphy differs significantly in detail between individual greenstone belts. The upper greenstone succession in the Marda–Diemals area is absent from all greenstone belts on MARMION and RICHARDSON.

In the Illaara greenstone belt on RICHARDSON, the most complete stratigraphy is exposed in the Richardson Syncline (Fig. 5). The lower part consists of quartz-rich sandstone, with minor quartzite and quartz–muscovite schist, which is overlain by a major quartzite unit. A maximum depositional age of the major quartzite unit is indicated by a SHRIMP U–Pb zircon date of 3504 ± 8 Ma on detrital zircons (GSWA 178064; Nelson, in prep.). The middle part of the stratigraphy contains several horizons of ridge-forming banded iron-formation that are locally intercalated with mafic–ultramafic rocks. The upper part comprises a thick unit of tholeiitic basalt that is overlain by banded iron-formation and chert. Locally preserved pillow-lava structures (e.g. at MGA 789893E 6822713N, and 790522E 6819578N) indicate younging towards the core of the syncline. The uppermost greenstones include basalt, sandstone, komatiitic basalt, and gabbro that are intercalated with thin units of banded iron-formation and chert.

The Illaara greenstone belt extends to the southeast where it contains clastic sedimentary and felsic igneous units in the middle part of the greenstone succession (Wyche, in prep.). SHRIMP U–Pb zircon dating on detrital zircons from the lowermost exposed quartzite unit indicates a maximum depositional age of 3304 ± 8 Ma (GSWA 142999; Nelson, 2000; Wyche, in prep.).

The southern part of the Maynard Hills greenstone belt (Fig. 5) is locally exposed on RICHARDSON (around MGA 777800E 6843300N) where it consists of a basal quartzite unit overlain by strongly foliated mafic–ultramafic rocks with intercalated banded iron-formation. The Maynard Hills greenstone belt outcrops more extensively on EVERETT CREEK to the north (Riganti, 2003), where it comprises a strongly deformed and highly metamorphosed assemblage of sedimentary and mafic–ultramafic igneous rocks. Locally preserved cross-bedding indicates younging towards the west-southwest. A thick quartzite unit is exposed at the stratigraphic base and has a maximum depositional age of 3131 ± 3 Ma based on SHRIMP U–Pb zircon dating of detrital zircons (Nelson, 2002; Riganti, 2003).

The South Cook Well greenstone belt (Fig. 5) occupies an extensive area on MARMION and RICHARDSON, but no coherent stratigraphy has been established due to disruption by north-trending shear zones and faults. Exposed greenstones are dominated by gabbro, komatiitic (or high-Mg) basalt, tholeiitic basalt, and numerous horizons of banded iron-formation and chert, with subordinate ultramafic and clastic sedimentary rocks. Locally observed pillow-lava structures in pyroxene-spinifex-textured komatiitic basalt (at MGA 786252E 6791958N) indicate that the eastern part of the greenstone belt becomes younger towards the west.

The northern part of the Mount Elvire greenstone belt on RICHARDSON (Fig. 5) is complexly folded and faulted. Although there are a number of macroscopic folds in this area, none preserve a complete stratigraphic sequence as fold limbs are commonly faulted and truncated. Using major units of banded iron-formation and chert as markers, the composite lithostratigraphy for the greenstones exposed in these folds comprises a lower part dominated by tholeiitic basalt (around MGA 759000E 6717000N) that is metamorphosed into amphibolite to the east and overlain by ultramafic rocks to the west, with intercalated thin units of banded iron-formation and chert; a middle part characterized by ridge-forming banded iron-formation and chert that have a maximum thickness up to 500 m and are locally intruded by gabbro sills; and an upper part that consists mainly of basalt and gabbro, with intercalated banded iron-formation and chert horizons, and subordinate ultramafic rocks. Clastic sedimentary rocks exposed in the core of a syncline may represent the uppermost exposed greenstones in this area. The southern part of the Mount Elvire greenstone belt (on MARMION) is less extensive than the northern part, but contains a similar range of rock types in a complexly folded and faulted succession.

No lithostratigraphy has been established for the North Cook Well, Mount Marmion, and South Elvire greenstone belts.

Structural geology

An outline of the geological evolution of the MARMION–RICHARDSON region is presented in Table 1.

First deformation event (D_1)

Like other areas in the central Yilgarn Craton (e.g. Greenfield and Chen, 1999; Chen et al., 2001, 2003; Wyche et al., 2001; Riganti and Chen, 2002; Chen and Wyche, 2003), the earliest recognizable structures on MARMION and RICHARDSON are originally east-trending

Table 1. Geological evolution of MARMION and RICHARDSON

Age	*Deformation event*	*Geology*
<c. 3130 Ma		Deposition of greenstones
	D_1	North–south compression: layer-parallel foliation, thrust faults, and tight to isoclinal folds in greenstones
c. 2755–2680 Ma	D_2	East–west compression: north-trending upright and inclined folds in greenstones. Intrusion and deformation of granitoid rocks: north-trending gneissic banding and foliation Peak metamorphism
c. 2680–2655 Ma	D_3	Development of northwest- and northeast-trending ductile shear zones (Edale, Evanston, and Yuinmery Shear Zones) Intrusion and deformation of granitoid rocks Metamorphism along shear zones
	Post D_3	East-, east-northeast- and northeast-trending brittle faults and fractures Intrusion of mafic dykes

layer-parallel foliation, thrust faults, and tight to isoclinal folds that have been overprinted by D_2 structures. For example, in the South Elvire greenstone belt, a moderately south-dipping S_1 foliation in tremolite–chlorite(–talc) schist (at MGA 765700E 6734800N) is folded around the hinge of an F_2 anticline that was rotated into a north-easterly trend during D_3. In the Edale Shear Zone (MGA 782007E 6827104N), an originally east-trending S_1 foliation in tremolite–chlorite(–talc) schist and amphibolite is parallel to the bedding of banded iron-formation, and both are folded into a mesoscopic F_2 upright anticline that plunges 25° to the north-northwest. In the northern part of the Mount Elvire greenstone belt, about 1 km west of Goat Creek Bore (around MGA 756400E 6797300N), an interpreted layer-parallel D_1 thrust is folded around the hinge zone of an F_2 syncline that plunges 25–30° to the north, and separates the syncline from north-trending banded iron-formation and mafic–ultramafic rocks in the south. Small-scale, east-trending tight F_1 folds in banded iron-formation are refolded into north-trending F_2 folds (Fig. 10). Similar east-trending F_1 folds are found locally in the hinge zones of, and are overprinted by, F_2 macroscopic folds.

Second deformation event (D_2)

D_2 east–west shortening produced macroscopic folds with a weak axial-planar foliation in greenstones, and a northerly trending gneissic banding and foliation in granitoid rocks (Chen et al., 2001, 2003; Wyche et al., 2001; Riganti and Chen, 2002). On MARMION and RICHARDSON, north-trending F_2 macroscopic folds in the Illaara, Mount Elvire, and South Elvire greenstone belts (Fig. 5) are clearly outlined by major banded iron-formation units. They are upright to inclined folds, and have steeply dipping limbs that are commonly truncated by faults or shear zones. The fold hinges plunge gently to moderately towards the south or north.

The F_2 Richardson Syncline in the Illaara greenstone belt has a wavelength of approximately 4 km (Fig. 5), and is the largest fold on MARMION and RICHARDSON. The hinge zone contains numerous small-scale folds that plunge moderately (20–40°) to the south, parallel to the hinge of the macroscopic syncline. Bedding dips steeply to the east on the western limb, and to the west on the eastern limb. Small-scale, Z- and S-shaped asymmetric folds have been observed on the western and eastern limbs, respectively (e.g. at MGA 789562E 6822614N, and 790713E 6821444N). The western limb of the syncline is truncated by a north-northeasterly trending fault, along which mafic and ultramafic rocks are strongly foliated. In the core of the syncline, a northerly trending foliation is axial planar to the syncline.

In the northern part of the Mount Elvire greenstone belt on RICHARDSON, five macroscopic F_2 folds (Fig. 5) are outlined by banded iron-formation and chert, with fold axial traces trending north to north-northwest. Three synclines plunge gently to moderately towards the south; a fourth syncline and an anticline plunge moderately to the north. With the exception of the syncline in the east, all folds are inclined to isoclinal with both limbs dipping steeply to the east. The limbs of these folds are truncated by east-dipping reverse faults that may coalesce downwards with a moderately east-dipping detachment fault to form an imbricate fan (see cross section A–B on RICHARDSON).

A prominent north-trending D_2 high-strain zone of foliated monzogranite containing local gneissic granitoid rock is developed along the western margin of the Mount Elvire greenstone belt (Figs 4 and 5). The fine- to coarse-grained and moderately to strongly foliated monzogranite contains a steep to vertical, northerly (350–005°) trending foliation. Locally prominent pegmatite dykes (commonly 2–10 cm, up to 2 m wide) and quartz veins (1–5 cm wide) are typically parallel to the foliation and gneissic banding, and some have been strongly boudinaged (e.g. at MGA 755223E 6795139N). The northerly trending foliation is subparallel to the axial traces of large-scale folds in greenstones to the east, and locally contains a steep (60–85°), north-pitching mineral lineation. In thin section, quartz grains are typically flattened, and coarse feldspar grains or grain aggregates commonly form symmetrical porphyroclasts, with both quartz and feldspar grains aligned along the foliation (e.g. at MGA 755352E 6796865N). These structural features indicate that the north-trending D_2 high-strain zone is dominated by shortening with a minor reverse movement component indicated by the steeply pitching mineral lineation.

Third deformation event (D_3)

D_3 progressive and inhomogeneous east–west shortening produced northwest-trending sinistral and northeast-trending dextral shear zones that are linked by north-trending contractional zones to form regional-scale arcuate structures (Chen et al., 2001, 2003). The southeastern sections of the sinistral Edale and Yuinmery Shear Zones and the northeastern section of the dextral Evanston Shear Zone are exposed on MARMION and RICHARDSON (Figs 4 and 5).

The northwestern section of the Edale Shear Zone lies on EVERETT CREEK (Riganti, 2003) and ATLEY (Chen, 2003a), and extends to the north of Sandstone (Fig. 1). The southeastern section of the Edale Shear Zone on RICHARDSON is 3–5 km wide and trends 330–335° (Figs 4 and 5). It is composed mainly of strongly foliated monzogranite and granitoid gneiss, interleaved with thin units of metasedimentary and mafic–ultramafic rocks in the North Cook Well and Maynard Hills greenstone belts (Fig. 5). S–C fabrics are locally well developed in strongly foliated monzogranite (e.g. at MGA 777217E 6836817N). The S-plane trends 340–360° and locally contains a steeply (60–75°) plunging mineral lineation (e.g. at MGA 777362E 6833308N). It is sinistrally displaced by a C-plane that trends 325–335° and contains a gentle (3–20°) mineral lineation plunging to both northwest and southeast. Both S- and C-planes are subvertical or dip steeply mainly towards the west. In granitoid gneiss, the S-plane is typically parallel to the gneissic banding, and to pegmatite dykes that are locally boudinaged (e.g. at MGA 779653E 6833276N). Where the S-plane is rotated into parallelism with the C-plane, a third foliation (C'-plane; Berthé et al., 1979) develops and typically trends 310–320°, forming C–C' fabrics that indicate a sinistral shear sense (e.g. at MGA 779025E 6833284N; and 781686E 6826983N). Asymmetric porphyroclasts of feldspar (e.g. at MGA 784673E 6824819N), and S-shaped asymmetric folds in chert and pegmatite dykes also indicate a sinistral shear sense.

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Figure 10. F_1 tight folds are refolded into a north-trending F_2 open fold in banded iron-formation (at MGA 765300E 6738800N)

The northeast-trending Evanston Shear Zone on MARMION and RICHARDSON (Fig. 5) is a 1–3 km-wide high-strain zone that is poorly exposed and consists mainly of strongly foliated to gneissic granitoid rocks interleaved with minor greenstones. The deflection pattern of several northerly trending shear zones and faults against the northeastern section of the Evanston Shear Zone indicates dextral movement (Fig. 5). The middle section of the Evanston Shear Zone is marked by northeast-trending quartz veins on MARMION that are parallel to the shear zone. Locally observed S–C fabrics, asymmetric porphyroclasts of feldspar in gneissic granitoid rock, and Z-shaped asymmetric folds in banded chert (Fig. 11) indicate a dextral shear sense. The Evanston Shear Zone extends southwestwards to LAKE GILES (Greenfield, 2001) and JOHNSTON RANGE (Wyche et al., 2001), where it lies on the eastern margin of the Marda–Diemals greenstone belt. Here it contains various kinematic indicators, such as en echelon quartz veins and asymmetric feldspar porphyroclasts, that show a dextral shear sense (Chen et al., 2001).

The Edale and Evanston Shear Zones are linked by a north-trending contractional zone to form the regional-scale Edale–Evanston arcuate structure (Figs 4 and 5; Chen et al., 2001). In the contractional zone, the Richardson Syncline plunges moderately to the south, and the Edale and Evanston Shear Zones split into several discrete shear zones or faults in which kinematic indicators show flattening and reverse movement with a minor strike-slip component (Chen et al., 2001). For example, within the north-northeasterly trending shear zones that splay off the Edale Shear Zone, mainly symmetrical, flattened porphyroclasts of feldspar are aligned along foliation that is parallel to the axial traces of tight folds in granitoid gneiss, indicating compressional deformation. Local S–C fabrics and asymmetrical porphyroclasts indicate a sinistral shear component (e.g. at MGA 781888E 6810373N). In a north-trending shear zone that splays off the Evanston Shear Zone, a northerly (350–005°) trending foliation in gneissic granitoid rock wraps around flattened porphyroclasts of feldspar, and is subparallel to the axial traces of upright folds in greenstones (e.g. at MGA 781900E 6786400N). A steeply plunging to downdip mineral lineation and striation (e.g. at MGA 780120E 6777101N) is probably related to reverse movement, whereas Z-shaped asymmetrical folds in banded iron-formation and a gently plunging mineral lineation indicate a dextral movement.

To the northwest on RAYS ROCKS (Chen, 2003b), the Yuinmery Shear Zone contains well-developed S–C fabrics, numerous asymmetrical porphyroclasts, and locally developed small-scale restraining jogs that indicate sinistral shear (Chen et al., 2001, in prep.). On MARMION, where the southeastern section of the Yuinmery Shear Zone is terminated by the Mount Elvire and South Elvire greenstone belts (Figs 4 and 5), it is locally well exposed in strongly foliated monzogranite with a pervasive northwest-trending foliation (around MGA 756100E 6755000N). Asymmetrical porphyroclasts of feldspar (e.g. at MGA 756100E 6754950N) and S-shaped asymmetrical folds of gneissic banding (at MGA 754600E 6756550N), together with a gently plunging mineral lineation, indicate

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Figure 11. Z-shaped asymmetrical folds indicative of dextral shear in chert within the Evanston Shear Zone (MGA 769500E 6734950N)

a sinistral shear sense. In thin section, grain-size reduction is common along the foliation. Coarser quartz grains or grain aggregates are commonly fractured, and feldspar porphyroclasts have recrystallized tails that are composed mainly of fine-grained quartz (e.g. at MGA 757000E 6753450N).

A northeast-trending high-strain zone, up to 3 km wide, in fine- to medium-grained, strongly foliated monzogranite (around MGA 760600E 6793800N) truncates the northerly to north-northwesterly trending structures in the Mount Elvire greenstone belt on RICHARDSON (Fig. 5). S–C fabrics are locally observed in the high-strain zone (e.g. at MGA 758932E 6790938N; and 759685E 6795470N). The C-plane containing a gently plunging mineral lineation dips steeply to the northwest and dextrally displaces a northerly trending S-plane that is parallel to locally prominent pegmatite dykes. Asymmetrical porphyroclasts of feldspar with recrystallized tails (e.g. at MGA 759644E 6793372N) also indicate a dextral shear sense.

Post-D_3 deformation

Post-D_3 structures on MARMION and RICHARDSON include widespread east-, east-northeast- and northeast-trending brittle faults or fractures, some of which are filled by quartz veins (e.g. at MGA 773000E 6771300N) or mafic dykes (Fig. 5). These later structures crosscut F_2 folds and D_3 shear zones. Other post-D_3 structures include locally observed, east-trending, spaced foliation, and small-scale, open folds that are superimposed on S_3 foliation (e.g. at MGA 780051E 6833244N).

Timing of deformation events

The timing of various deformation events on MARMION and RICHARDSON is poorly constrained. On a regional scale, there are no constraints on the age of D_1 other than that it must have taken place prior to the emplacement of the Marda felsic volcanic complex to the south at c. 2730 Ma (Chen and Wyche, 2001; Chen et al., 2003). In the Marda–Diemals area, the earliest stage of D_2 pre-dates deposition of the Diemals Formation clastic sedimentary rocks (<c. 2730 Ma) that unconformably overlie the mafic-dominated lower greenstone succession (Chen and Wyche, 2001; Chen et al., 2003). Widespread granitoid gneiss and gneissic granitoid rocks in the MARMION–RICHARDSON and adjacent areas have SHRIMP U–Pb zircon ages ranging from c. 2755 Ma to c. 2680 Ma (Nelson, 2001, 2002; Cassidy et al., 2002). They typically contain a northerly trending gneissic banding and coplanar foliation (S_2) parallel to the axial traces of F_2 folds and may have been deformed in a high temperature state during or shortly after intrusion (D_2). Strongly deformed granitoid rocks in D_3 shear zones are as young as c. 2654 Ma (Nelson, 2001; Chen and Wyche, 2001).

Metamorphism

The first comprehensive study of metamorphic patterns and grade distribution in the central and eastern parts of the Yilgarn Craton was carried out by Binns et al. (1976). They recognized that the central parts of wide greenstone belts are characterized by low-grade, static-style metamorphism, whereas high-strain zones along granite–greenstone contacts are characterized by higher grade, dynamic-style metamorphism. The greenstone belts on MARMION and RICHARDSON were shown as medium- to high-grade metamorphic domains, ranging from low to high amphibolite facies (Binns et al., 1976). Ahmat (1986) refined the metamorphic patterns and grades of greenstone belts in the central Yilgarn Craton and showed the greenstone belts on MARMION and RICHARDSON as low- to medium-grade domains. Dalstra (1995) and Dalstra et al. (1999) described a detailed metamorphic study of greenstones in the Marda–Diemals greenstone belt to the south.

All Archaean granitoid and greenstone rocks on MARMION and RICHARDSON have been metamorphosed to greenschist or amphibolite facies. Most granitoid rocks exhibit evidence of only low-grade metamorphism. The metamorphic grade of greenstones decreases towards the centres of greenstone belts, with amphibolite mainly in the areas close to granite–greenstone contacts, particularly along the eastern margins of the Mount Elvire, South Elvire, and Illaara greenstone belts. Amphibolite is typically strongly foliated and contains S_2 and, locally, S_3 foliations that are defined by the preferred alignment of hornblende, or by the segregation of hornblende and plagioclase (Fig. 12). Quartzite on the eastern margin of the Illaara greenstone belt contains aluminosilicate (mainly andalusite).

Greenschist-facies metamorphism has affected both low- and high-strain rocks. In low-strain rocks, primary igneous features, such as vesicles, varioles, and pillow-lava structures, are commonly preserved in metabasalt in which pyroxene is typically pseudomorphed by actinolite or chlorite, and clinochlore is locally observed (Fig. 13). High-strain rocks contain a pervasive foliation, and igneous features are rarely preserved. The metamorphic foliation is typically defined by actinolite, chlorite, and plagioclase in mafic rocks, and by tremolite, chlorite, and minor plagioclase in more magnesian rocks. In metasedimentary rocks within the southern part of the Mount Elvire greenstone belt, andalusite porphyroblasts contain a foliation that is parallel to the foliation in the matrix (Fig. 14).

Retrograde metamorphism in greenstones is shown by talc alteration of ultramafic schist, sericitization and saussuritization of feldspars, and the growth of late chlorite porphyroblasts (cf. Ahmat, 1986; Greenfield, 2001).

Cainozoic geology

MARMION and RICHARDSON are covered by extensive regolith. Regolith mapping has combined field observations with interpretation of aerial photographs and Landsat Thematic Mapper (TM5) imagery.

Regolith deposits were classified according to the scheme of Hocking et al. (2001) that extended the RED

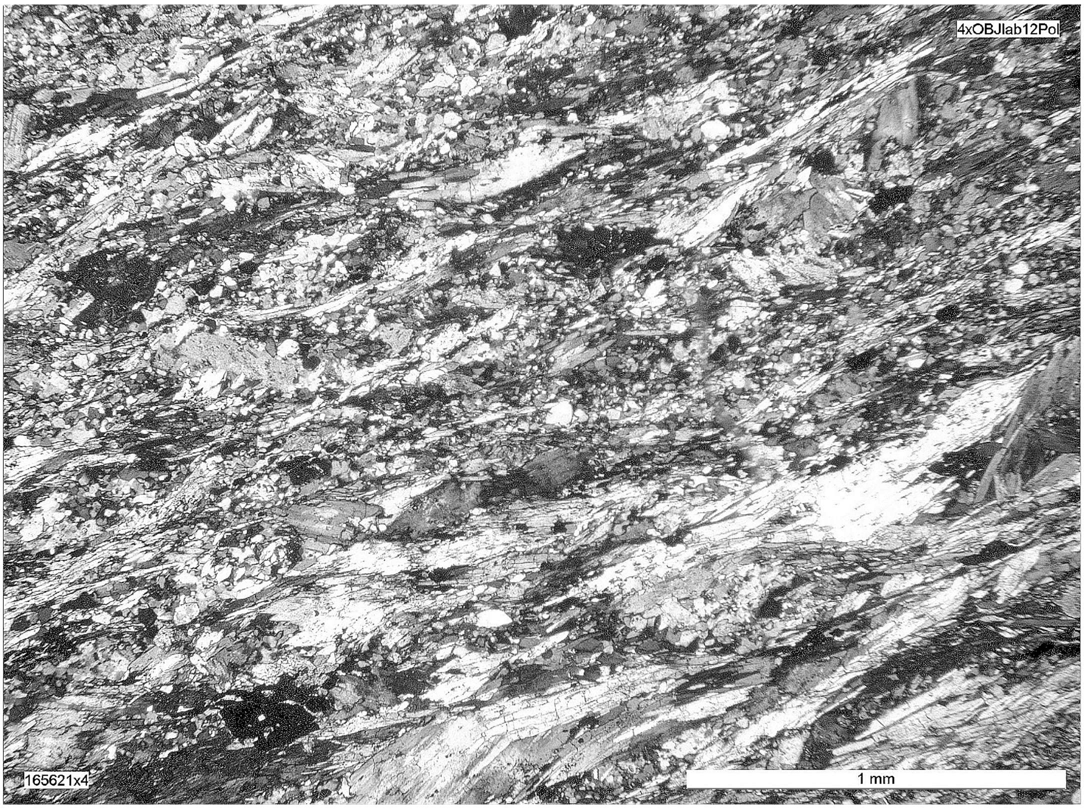

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Figure 12. Amphibolite with an S_2 foliation defined by preferred alignment of hornblende, plagioclase, and minor quartz (crossed nicols; GSWA 165621; at MGA 790457E 6820397N)

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Figure 13. Clinochlore porphyroblasts in fine-grained, massive basalt (plane-polarized light; GSWA 165342; at MGA 754647E 6818820N)

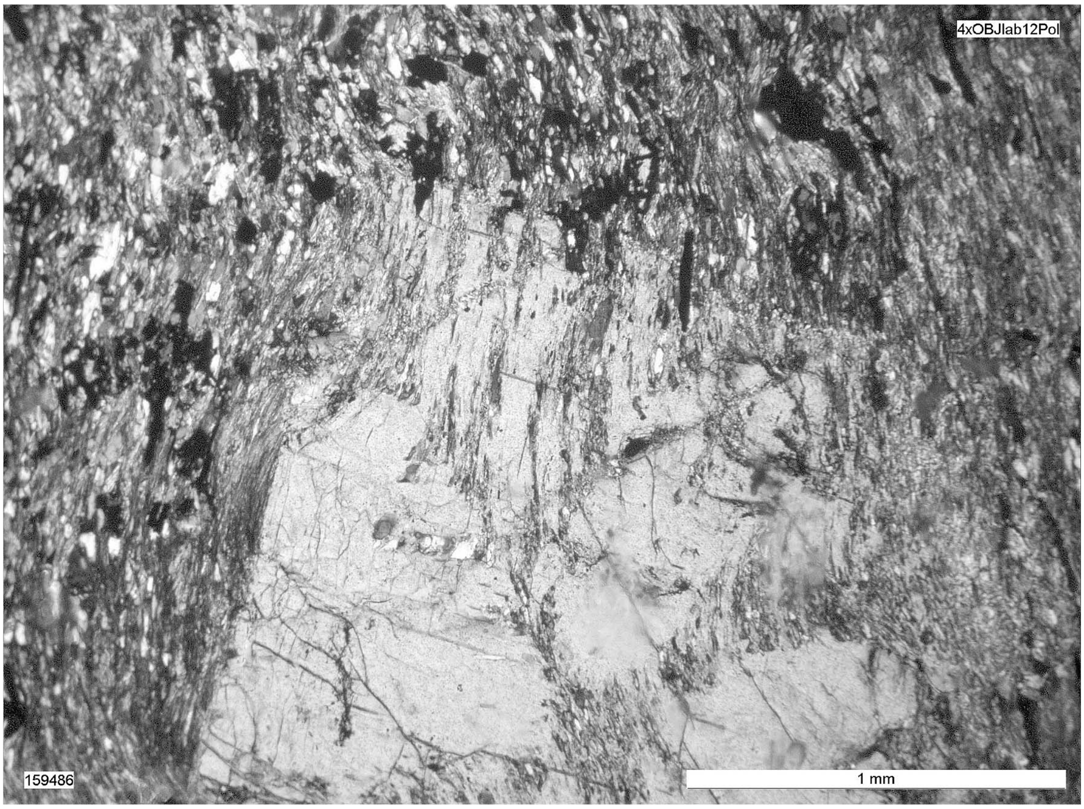

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Figure 14. Foliated andalusite porphyroblast in metapelite (crossed nicols; GSWA 159496; at MGA 761500E 6758650N)

(Residual–Erosional–Depositional) scheme of Anand et al. (1993). In these schemes, in addition to the erosional regime that is characterized by bedrock exposures, regolith deposits are broadly subdivided into two groups: residual or relict units represented by siliceous and ferruginous duricrust (R); and depositional units of colluvial (C), sheetwash (W), alluvial (A), and lacustrine (L) deposits. Sandplains (S) may be either depositional (eolian) or residual. For a review of regolith geology of the Yilgarn Craton, see Anand and Paine (2002).

Residual or relict units (*Rd*, *Rf*, *Rg*, Rgp_g, *Rk*, *Rz*, *Rzu*)

Undivided duricrust (*Rd*) is either siliceous or ferruginous, and is mainly derived from deeply weathered granitoid rocks. It is exposed above breakaways and on low hills, or is covered by a veneer of sand, silt, and clay, with locally abundant lateritic and siliceous pisoliths (*Sl*). Silcrete (*Rz*) is a siliceous duricrust over granitoid rocks.

Ferruginous duricrust and pisoliths (*Rf*) are derived from both granitoid rocks and greenstones, and typically show a dark-brown to black tone on aerial photographs. Light-brown silica caprock over ultramafic rocks (*Rzu*) is widespread in the northern part of the Mount Elvire greenstone belt and in the South Cook Well greenstone belt. It may contain a relict cumulate texture (after peridotite) or a strong foliation (after tremolite–chlorite–talc schist). White, massive to nodular calcrete (*Rk*) is commonly associated with drainage, although there are also patches of calcrete over greenstones and granite away from drainage.

Quartzofeldspathic sand over granitoid rocks (*Rg*) contains scattered, deeply weathered granitoid outcrops, with local silcrete. Adjacent to granite exposures and in the areas underlain by granitoid rocks, quartzofeldspathic sand with sparse granite outcrops (Rgp_g) is characterized by reddish-yellow sand that grades into sandplain, sandy sheetwash, and weathered to fresh granitoid rocks. White quartz-vein gravel is common in these areas.

Depositional units (*C*, *Cf*, *Cg*, Cgp_g, Clc_i, *Cq*, Cqm_q, *W*, *Wf*, *Wg*, *A*, A_c, A_d, A_f, A_p, L_l, L_d1, L_d2, L_m, *S*, *Sl*)

The depositional regime on MARMION and RICHARDSON is largely controlled by Lake Barlee, Lake Noondie (Fig. 2), and their associated drainage systems. In general, colluvial units are proximal to granitoid and greenstone outcrops, whereas sheetwash and lacustrine units represent distal deposits.

Undivided colluvium (*C*) includes proximal gravel, coarse talus, sand, and silt on sloping or undulating ground. Colluvium has been subdivided where it is dominated by a particular source material. Talus from banded iron-formation and chert (Clc_i) is widely distributed on slopes of, and in broad valleys between, prominent ridges, and grades downslope into ferruginous gravels (*Cf*), some of which contain reworked laterite. Adjacent to granite outcrops, detritus from granitoid rocks (*Cg*) includes granite or gneiss fragments with abundant quartzofeldspathic sand, silt, and subordinate silcrete and quartz-vein pebbles. Quartzofeldspathic colluvium (Cgp_g) contains granitic gravels, sand, silt, and subordinate quartz-vein clasts. Quartz-dominated talus adjacent to quartz veins (*Cq*) or derived from quartzite (Cqm_q) have also been distinguished.

Very gently sloping areas of sheetwash (*W*) are characterized by relatively distal deposits that consist of sand, silt, and clay material. Sheetwash derived from deeply weathered granitoid rock below breakaways (*Wg*) contains a higher proportion of quartzofeldspathic sand. Ferruginous sheetwash (*Wf*) is characterized by abundant fine, ferruginous grit.

Undivided alluvium along ephemeral channels and watercourses (*A*) contains sand, silt, and gravel that are locally cemented by calcareous material. Stream-channel alluvial deposits (A_c) have not been distinguished from undivided alluvium in most areas. Alluvium in braided drainage and broad alluvial flats (A_d) consists of unconsolidated clay, silt, sand, and gravel. Floodplain deposits (A_f) are dominated by clay and silt with various proportions of sand and gravel. Claypans (A_p) are ephemeral lacustrine deposits that contain a veneer of clay and silt.

The Lake Barlee playa lake system that forms part of the Raeside Palaeoriver (Hocking and Cockbain, 1990; van de Graaff et al., 1977) occupies much of MARMION, and the southeastern part of RICHARDSON. The Lake Noondie playa lake system lies mainly on EVERETT CREEK to the north and RAYS ROCKS to the west, and extends to the northwestern corner of RICHARDSON. Saline playa lake deposits (L_l) contain mud, silt, sand, and a veneer of halite and gypsum. Within and adjacent to the playa lakes, active dunes (L_d1) are barren to poorly vegetated, whereas more stabilized dunes (L_d2) are commonly vegetated. They both contain sand, silt, and evaporitic material. The areas immediately adjacent to the lakes have mixed alluvial, eolian, and lacustrine deposits (L_m).

Unconsolidated yellow sand in sandplains (*S*) covers extensive areas mainly underlain by granitoid rocks. Yellow to reddish yellow sand (*Sl*) over undivided duricrust (*Rd*) contains locally abundant ferruginous and siliceous pisoliths, and may represent a mixture of eolian and residual deposits.

Economic geology

All greenstone belts on MARMION and RICHARDSON have been explored to some extent for gold, nickel, and base metals by means of magnetic surveys, soil and stream sampling, and rotary air-blast (RAB), reverse circulation (RC), and diamond drilling. However, few significant mineral deposits have been discovered, and no mineral production has been recorded in the MARMION–RICHARDSON area. Open-file statutory mineral exploration reports (WAMEX database) and mines and mineral deposits information (MINEDEX database) are held at the Western Australian Department of Industry and Resources in Perth, and at the Kalgoorlie Regional Office of the Geological Survey of Western Australia, and are accessible online (www.doir.wa.gov.au).

The Paradise Bore oxide gold deposit is located on the western limb of the Richardson Syncline (MGA 789276E 6822391N). It has an inferred resource estimated at 400 000 tonnes grading 2.8 g/t gold, with contained gold of 1120 kg (Sipa Resources International NL, 2003). Gold mineralization is related to quartz veining along a strike-length of approximately 700 m. There are 18 continuous drillholes that have intersections averaging 2 m in thickness at 18 g/t gold (at 4 g/t gold cut-off; Sipa Resources International NL, 2002).

The Panhandle gold prospect (MGA 783012E 6788400N) covers a strike-length of 4 km of sulfidic banded iron-formation, with gossans in a black slate horizon along the contact between mafic volcanic breccia and overlying basalt (John, 1993).

The Mount Alfred copper prospect (at approximately MGA 791900E 6807700N) lies in a sequence of quartz–feldspar–chlorite schist, graphitic slate, chert, banded iron-formation, and mafic volcanic rock (Marston, 1979). Although results as high as 19% copper at surface and 6.5% copper at shallow depth were returned, the surface geochemical anomaly defined by Australian Selection Pty Ltd measured only 50 by 2 m. It was concluded after drilling that the copper occurrence was supergene in origin and of no economic significance (Marston, 1979; Monti, 1988).

The minor and poorly documented Lake Barlee gypsum deposit (Jones, 1994) is about 20 km east of Cashmere Downs Homestead (MGA 771400E 6792600N).

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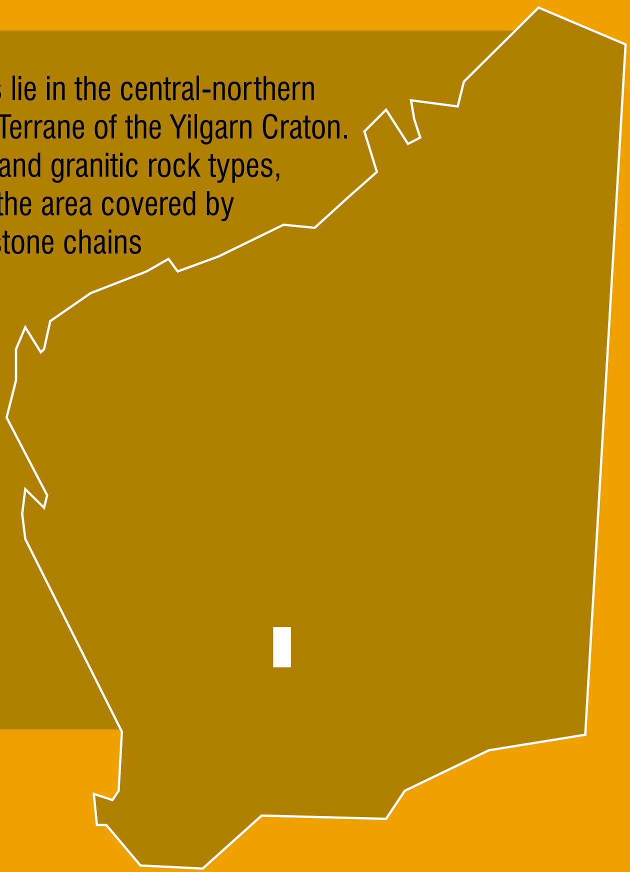
Appendix 1

Gazetteer of localities on MARMION and RICHARDSON

Locality	*Easting*	*Northing*
Airstrip Well	756200	6754900
Bulga Downs Homestead (on EVERETT CREEK)	768550	6844700
Bulgar Hill	756400	6787500
Cashmere Downs Homestead	750300	6792700
Churchill Bore	783200	6879200
Goat Creek Bore	757400	6797400
McLeod Rock	752700	6786200
Mount Alfred	792150	6803990
Mount Elvire	758200	6760300
Mount Elvire Homestead	752200	6748900
Mount Forrest	787800	6817150
Mount Marmion	776500	6752600
Mount Richardson	792000	6812150
Native Well	745600	6883900
North Panhandle Bore	781500	6887100
1 Mile Well	752700	6792300
Panhandle Well	782900	6782500
Paradise Bore	783100	6822500
Perrinvale Homestead (on MOUNT MASON)	211900	6786500
Ram Paddock Well	757800	6789700
Ten Foot Well	764500	6803100
The Stock Well	788600	6802200
Victory Bore	781100	6819400
Visitors Bore	778500	6833300

The MARMION and RICHARDSON 1:100 000 sheets lie in the central-northern part of the Southern Cross Granite–Greenstone Terrane of the Yilgarn Craton. These Notes describe the Archaean greenstone and granitic rock types, and the structural and metamorphic features of the area covered by these map sheets. Three narrow, arcuate greenstone chains run predominantly north–south. Their metamorphosed mafic rocks and banded iron-formation are interleaved with deformed granitoid rocks along complex shear zones of regional extent. Between the greenstone belts, very poorly exposed deformed granitoid rocks cover the greater part of the area. The Notes also contain brief descriptions of mineralization and the extensive Cainozoic regolith deposits, including the Lake Barlee playa-lake system.



These Explanatory Notes are published in digital format (PDF) and are available online at: www.doir.wa.gov.au/gswa.
This copy is provided for reference only. Laser-printed copies can be ordered from the Information Centre for the cost of printing and binding.

Further details of geological publications and maps produced by the Geological Survey of Western Australia can be obtained by contacting:

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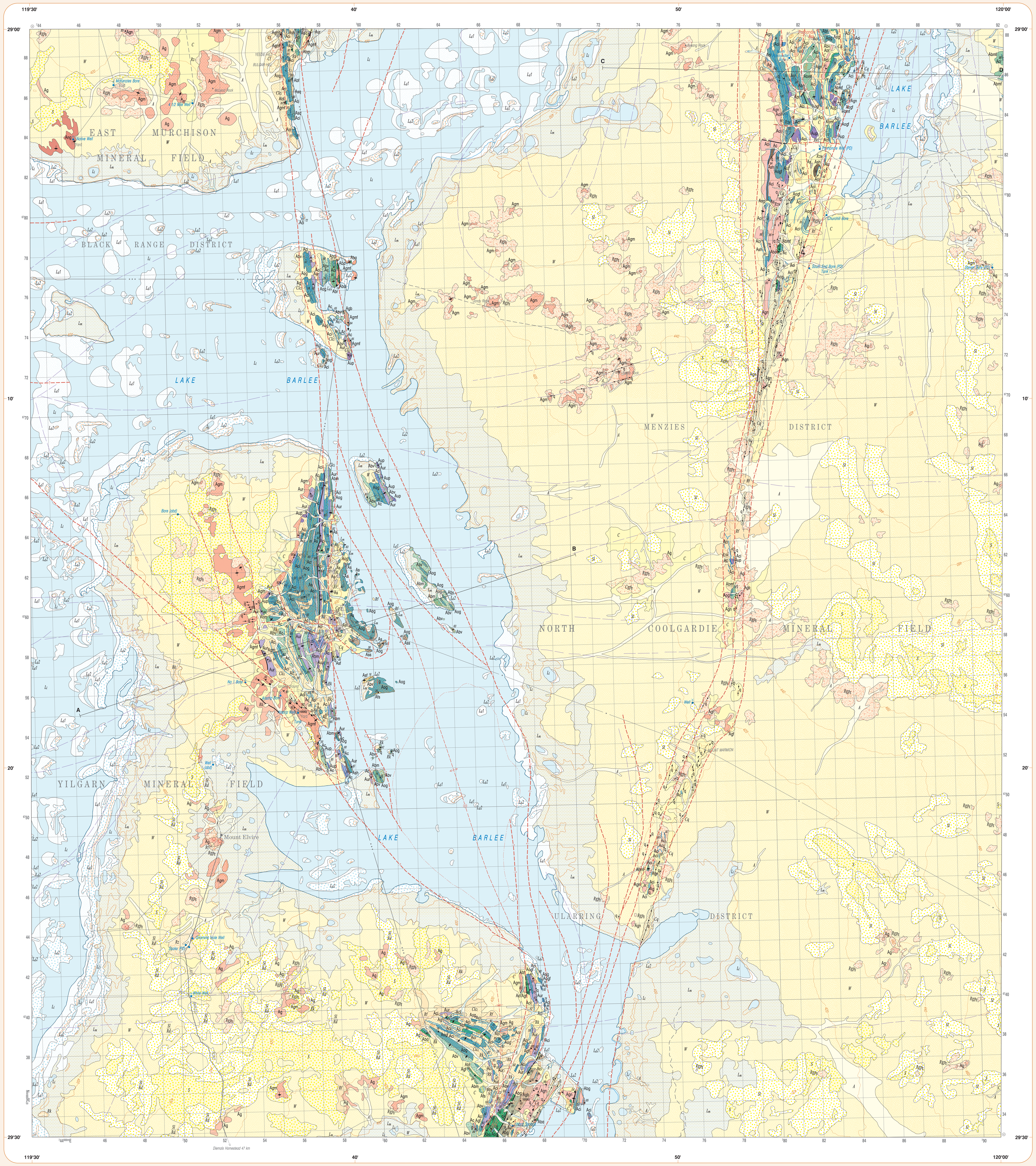


PHANEROZOIC — CAINOZOIC

Colluvial units

C Gravel and debris as proximal talus; includes sand and silt, locally ferruginous
Cf Ferruginous gravel and reworked laterite
Cgg Granitic gravel, with sand and silt
Ctc Talus from banded iron-formation and chert
Cq Quartz-vein debris

Sheetwash unit

W Clay, silt, and sand; locally ferruginous

Alluvial unit

A Clay, silt, sand, and gravel in channels and on floodplains

Lacustrine units

Ls Saline playa deposits; mainly gypsiferous evaporite
Ld Dune and lake deposits; active systems within and adjacent to playa lakes; nonvegetated or poorly vegetated
La Mixed dune, evaporite, and alluvial deposits adjacent to playa lakes

Lacustrine unit

Ld2 Stabilized dunes within and adjacent to playa lakes; typically vegetated

Sandplain units

S Residual and eolian sand
Sl Yellow sand with minor pisolitic laterite, silt, and clay

Residual units

Rd Siliceous and ferruginous duricrust, undivided
Rf Lateritic duricrust; includes lateritic nodules
Rgpq Quartzofeldspathic sand over granitoid rock, with sparse granitoid outcrop
Rk Calcrete
Rz Silcrete
Rzu Silica caprock over ultramafic rocks

ARCHAEAN — YILGARN CRATON

q Quartz vein
g Granitoid dyke

c. 2683 Ma[1]
c. 2696 Ma[1]

Ag Granitoid rock, undivided; includes deeply weathered rock
Agb Granitoid rock, interleaved with minor basaltic rock; both typically foliated
Agf Strongly foliated granitoid rock
Agm Monzogranite; typically biotite-bearing
Agmf Strongly foliated monzogranite
Agn Gneissic granitoid; locally migmatitic
Ang Granitoid gneiss; banded orthogneiss

As Metasedimentary rock, undivided; typically deeply weathered
Asf Foliated clastic sedimentary rock
Ash Shale; metamorphosed; includes mica-schist
Asq Quartz-rich metasedimentary rock; mainly quartzite
Ass Sandstone with minor siltstone and pebbly sandstone; metamorphosed
Ac Banded chert and ferruginous banded chert; includes minor banded iron-formation and quartzite; metamorphosed
Aci Banded iron-formation and banded chert; minor jaspilite; metamorphosed

Afs Strongly foliated felsic volcanic rock
Afv Fine-grained felsic volcanic rock; metamorphosed

Ao Medium- and coarse-grained mafic rock; typically deeply weathered; metamorphosed
Aog Metagabbro; medium- to coarse-grained mafic rock; includes metamorphosed quartz gabbro
Aogf Strongly foliated metagabbro

Ab Fine-grained mafic rock; mainly metabasalt; typically deeply weathered
Aba Amphibolite; fine- to medium-grained; commonly foliated
Abf Strongly foliated metabasalt; local amphibolite
Abg Mafic rock interleaved with minor foliated granitoid rock
Abm High-Mg basalt with pyroxene-spinifex and/or variolitic textures; metamorphosed
Abmf Strongly foliated high-Mg basalt; metamorphosed
Abr Strongly foliated tremolite- and chlorite-rich rock; probably after high-Mg basalt
Abt Mafic tuff; metamorphosed
Abv Metabasalt; massive to weakly foliated

Au Ultramafic rock; typically deeply weathered; metamorphosed
Aup Metaperidotite; typically serpentinized
Aur Tremolite-chlorite(-talc) schist

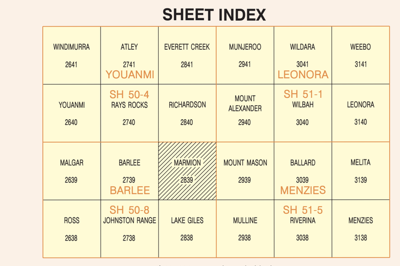
Geological boundary
exposed
concealed, interpreted from aeromagnetic data
Structural symbols are labelled according to the sequence of deformation events, where known
Fault or shear
exposed
concealed
concealed, interpreted from aeromagnetic data
Strongly foliated rock
Fold, showing axial trace and generalized plunge direction
anticline; exposed, concealed
syncline; exposed, concealed
Small-scale fold axis, showing trend and plunge
anticline
syncline
Bedding, showing strike and dip
inclined
vertical
Igneous layering, showing strike and dip
inclined
Way-up indicator
pillow structure
graded bedding
cross-bedding
Foliation, showing strike and dip
inclined
vertical
Gneissic banding, showing strike and dip
inclined
vertical
Mineral lineation, showing trend and plunge
inclined
Bedding–cleavage intersection lineation, showing trend and plunge
inclined
Aeromagnetic lineament
Isotopic age determination site with identification number

Formed road
Track
Fence, generally with track
Homestead
Yard
Horizontal control; major
Breakaway
Sand dune
Contour line, 20 metre interval

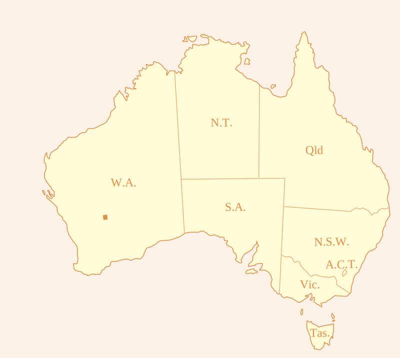
Watercourse
Soak, spring
Bore, well
Windpump
Tank
Abandoned
Position doubtful

Mineral field boundary
Mineral field district boundary
Mine abandoned
Prospect
Subsurface data from drillhole, costean, shallow shaft, or pit
Mineral occurrence
Gold

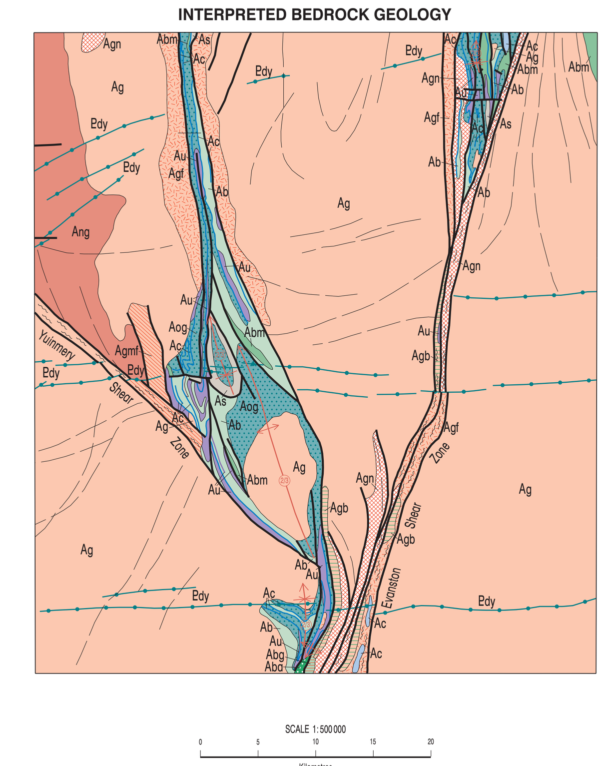
SHEET INDEX



1:100 000 maps shown in black
1:250 000 maps shown in brown



INTERPRETED BEDROCK GEOLOGY



Pdy Mafic dyke

Ag Granitoid rock
Agb Granitoid rock interleaved with minor mafic rock
Agf Strongly foliated granitoid rock
Agmf Strongly foliated monzogranite
Agn Gneissic granitoid rock
Ang Granitoid gneiss

As Metasedimentary rock
Ac Metamorphosed banded iron-formation and chert

Aog Metagabbro dominant

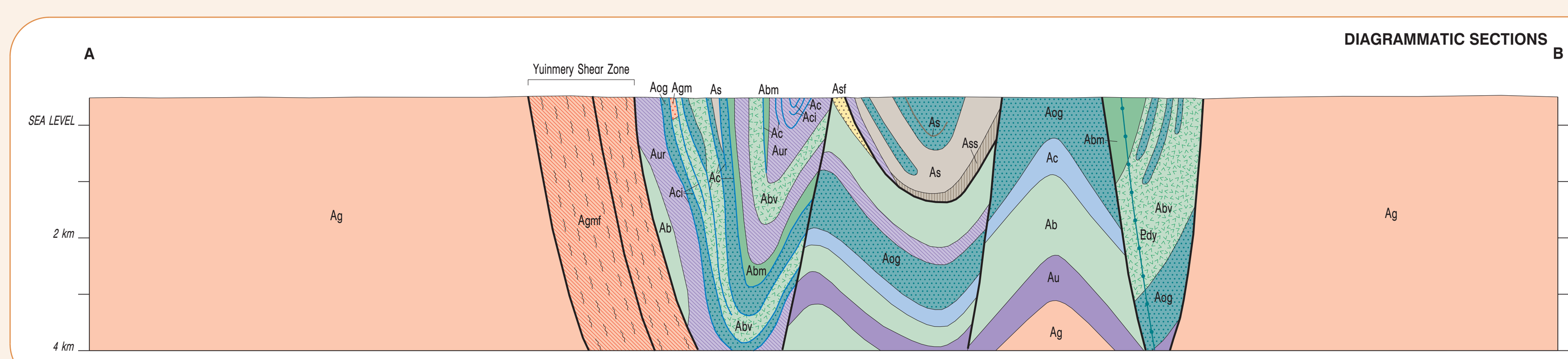
Ab Metabasalt dominant
Aba Amphibolite
Abg Mafic rock interleaved with granitoid rock
Abm High-Mg basalt

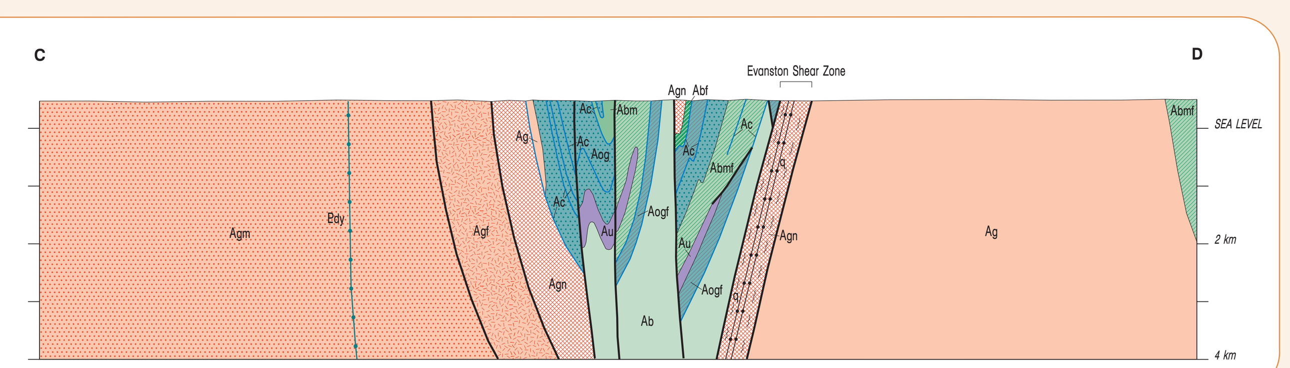
Au Ultramafic rock

YILGARN CRATON

Structural trend

DIAGRAMMATIC SECTIONS





Geology by S. F. Chen and J. Greenfield 1999

Geochronology by:

(1) D. R. Nelson, in prep., GSWA Record 2001/2

Edited by N. Tetlaw and C. Brien

Cartography by A. Francois and K. Greenberg

Topography from the Department of Land Administration Sheet SH 50-8, 2839, with modifications from geological field survey

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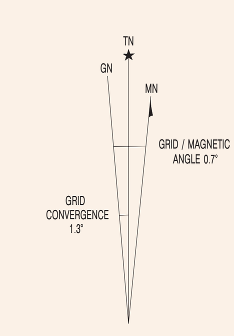


True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 2001 and moves easterly by about 0.1° in 1.2 years.

Department of Industry and Resources

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

JIM LIMERICK
DIRECTOR GENERAL

Geological Survey of Western Australia

TIM GRIFFIN
DIRECTOR

SCALE 1:100 000

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

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

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

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

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

MARMION

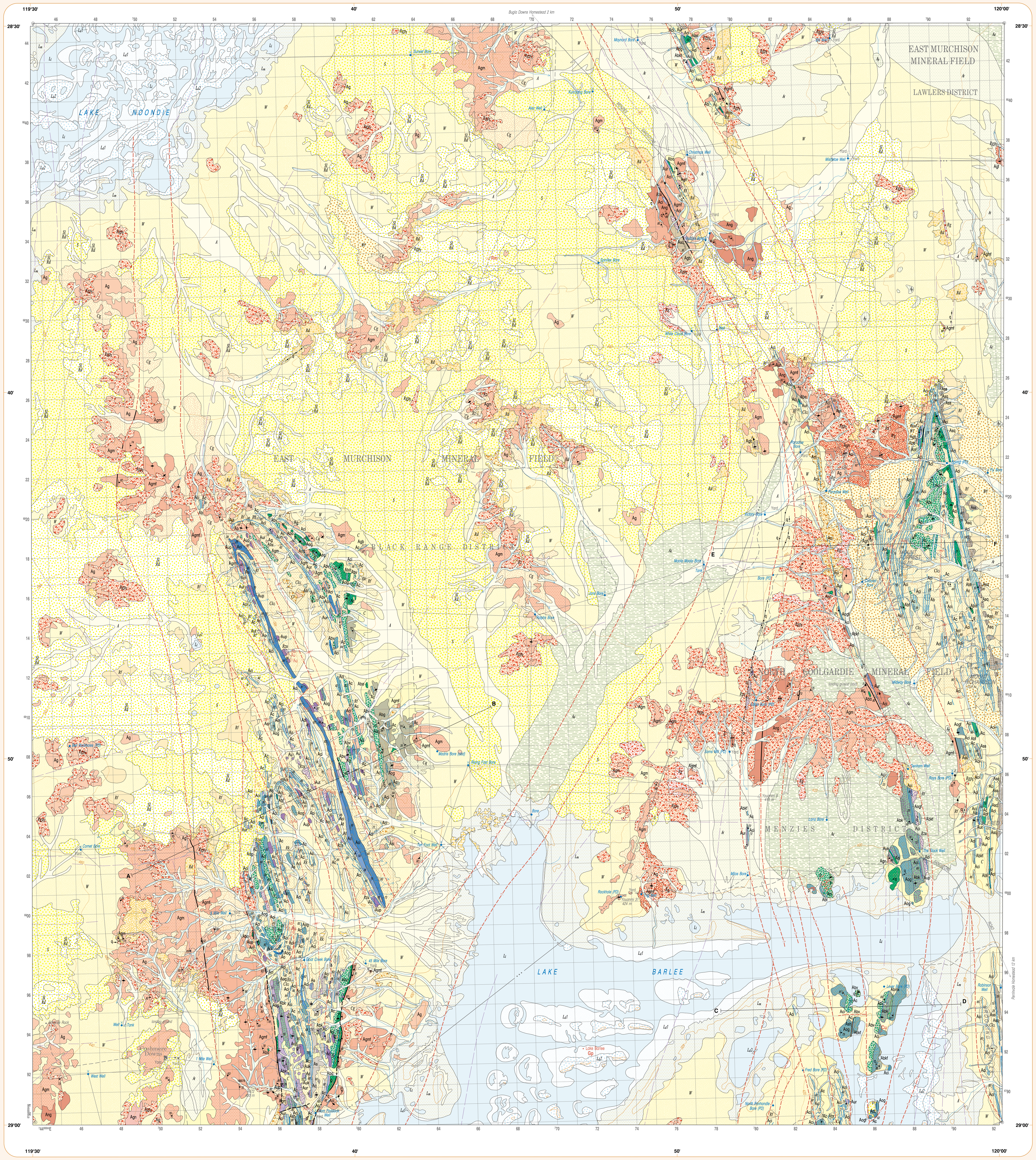
SHEET 2839 **FIRST EDITION 2001**
Version 1.1 — July 2003

AUSTRALIA 1 : 100 000 GEOLOGICAL SERIES

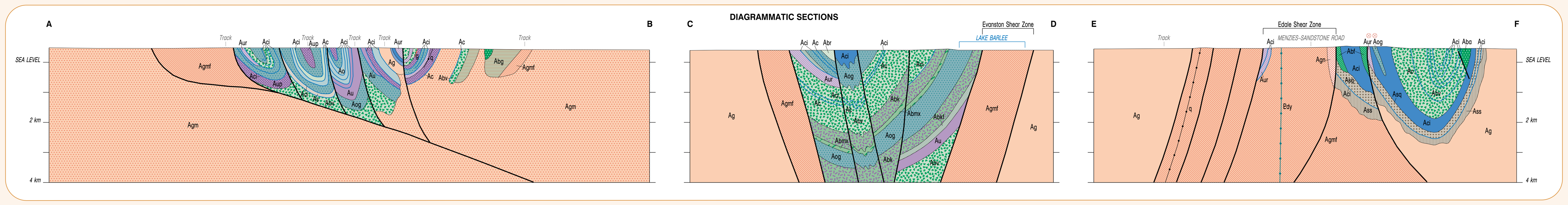
RICHARDSON

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 2840



DIAGRAMMATIC SECTIONS



PHANEROZOIC

CAINOZOIC

Colluvial units

- *C* Gravel and debris as proximal talus; includes sand and silt; locally ferruginous
- *Cf* Ferruginous gravel and reworked ferruginous duricrust
- *Cg* Granitic gravel, with sand and silt
- Clc_i Talus from banded iron-formation and chert; locally cemented
- *Cq* Quartz-vein debris
- Cqm_q Talus from quartzite

Sheetwash units

- *W* Clay, silt, and sand; locally ferruginous
- *Wf* Clay, silt, and sand with ferruginous grit
- *Wg* Silt and sand derived from granitoid rock

Alluvial units

- *A* Clay, silt, sand, and gravel in drainage systems
- A_c Deposits in stream channel and adjacent overbanks
- A_d Clay, silt, and sand as braided swales within floodplain
- A_f Floodplain
- A_p Clay and silt in claypans

Lacustrine units

- L_l Saline playa lake deposits
- L_d1 Clay, silt, and sand as dune and lake deposits; active systems within and adjacent to playa lakes; non-vegetated or poorly vegetated
- L_m Clay, silt, and sand as mixed dune, evaporite, and alluvial deposits adjacent to playa lakes

Lacustrine unit

- L_d2 Stabilized sand dunes within and adjacent to playa lakes; typically vegetated

Sandplain units

- *S* Residual and eolian sand
- *Sl* Yellow sand with minor pisolitic laterite, ferruginized silcrete, silt, and clay

Relict units

- *Rd* Siliceous and ferruginous duricrust
- *Rf* Ferruginous duricrust; includes ferruginous pisoliths
- *Rg* Quartzofeldspathic sand over granitoid rock
- Rgp_g Quartzofeldspathic sand and quartz gravel over granitic rock, with sparse granitoid outcrop
- *Rk* Calcrete
- *Rz* Silcrete
- *Rzu* Silica caprock over ultramafic rock

PROTEROZOIC

- Ꝑdy Mafic dyke (Section and Interpreted bedrock geology)

- q Quartz vein
- g Granitoid dyke, massive to foliated
- p Pegmatite dyke

ARCHAEAN

YILGARN CRATON

- Ag Granitoid rock, undivided; includes deeply weathered rock
- Agb Granitoid rock interleaved with minor mafic and ultramafic rocks; massive to strongly foliated
- Agf Strongly foliated granitoid rock; typically deeply weathered
- Agm Monzogranite, massive to weakly foliated; fine to coarse grained
- c. 2756 Ma[1] Agmf Strongly foliated monzogranite; fine to coarse grained
- Agn Gneissic granitoid rock; fine to coarse grained; strongly foliated granitoid rock with local gneissic banding

- Ang Granitoid gneiss; banded quartz–feldspar–biotite orthogneiss

- As Metasedimentary rock, undivided; mainly siltstone and shale; typically deeply weathered
- Ash Shale, metamorphosed; includes minor metamorphosed siltstone and mica schist
- Asq Quartzite, locally with micaceous and ferruginous intercalations
- Ass Sandstone with minor siltstone and pebbly sandstone; metamorphosed
- Ac Banded chert and ferruginous chert; includes minor banded iron-formation and quartzite; metamorphosed
- Aci Metamorphosed banded iron-formation and minor banded chert

- Af Fine-grained, felsic volcanic rock, undivided; metamorphosed; typically deeply weathered

- Ao Metamorphosed, medium- to coarse-grained mafic rock, undivided; typically deeply weathered
- Aog Metagabbro, medium to coarse grained; includes metamorphosed quartz gabbro
- Aogf Strongly foliated metagabbro; medium to coarse grained

- Ab Metamorphosed, fine-grained mafic rock, undivided; typically deeply weathered
- Aba Fine- to medium-grained amphibolite, strongly foliated
- Abf Strongly foliated metabasalt; local amphibolite
- Abg Mafic rock interleaved with minor granitoid rock; metamorphosed; massive to strongly foliated; local amphibolite
- Abk Komatiitic basalt with pyroxene-spinifex and/or variolitic textures; metamorphosed
- Abkf Strongly foliated komatiitic basalt; metamorphosed
- Abmx Brecciated high-Mg basalt; metamorphosed
- Abr Strongly foliated tremolite- and chlorite-rich rock; probably after high-Mg basalt
- Abt Mafic tuff; metamorphosed
- Abv Fine-grained, massive to weakly foliated metabasalt

- Au Metamorphosed ultramafic rock, undivided; typically deeply weathered
- Auk Metakomatiite; with relict olivine spinifex texture
- Aup Metamorphosed peridotite, locally serpentinized
- Aur Tremolite–chlorite(–talc) schist
- Aut Talc–tremolite(–chlorite) schist
- Auxf Strongly foliated, medium- to coarse-grained pyroxenite; metamorphosed

Geological boundary
- exposed

Fault or shear
- exposed
- concealed
- concealed, interpreted from aeromagnetic data

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

Small-scale fold axis, showing trend and plunge
- anticline — 23

Bedding, showing strike and dip
- inclined — 60
- vertical

Foliation, showing strike and dip
- inclined — 10
- vertical

Gneissic banding, showing strike and dip
- inclined — 84
- vertical

Mineral lineation, showing trend and plunge
- inclined — 5

Bedding–cleavage intersection lineation, showing trend and plunge
- inclined — 30

Lineation, unspecified, showing trend and plunge
- inclined — 71

Fracture or joint, showing strike and dip
- inclined — 82

Aeromagnetic lineament

Isotopic age determination site with identification number — 169076

Formed road

Track

Fence, generally with track

Homestead — Cashmere Downs

Building

Yard — Yard

Horizontal control; major, minor

Breakaway

Contour line, 20 metre interval — 480

Watercourse with ephemeral pool or waterhole

Rockhole — Rockhole

Spring — Spring

Bore, well — Bore, Well

Windpump

Tank — Tank

Abandoned — (abd)

Position doubtful — (PD)

Mineral field boundary

Mineral field district boundary

Mine

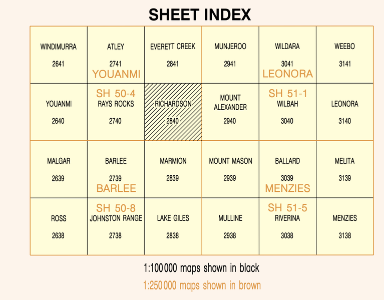
Quarry

Prospect — Perenjori

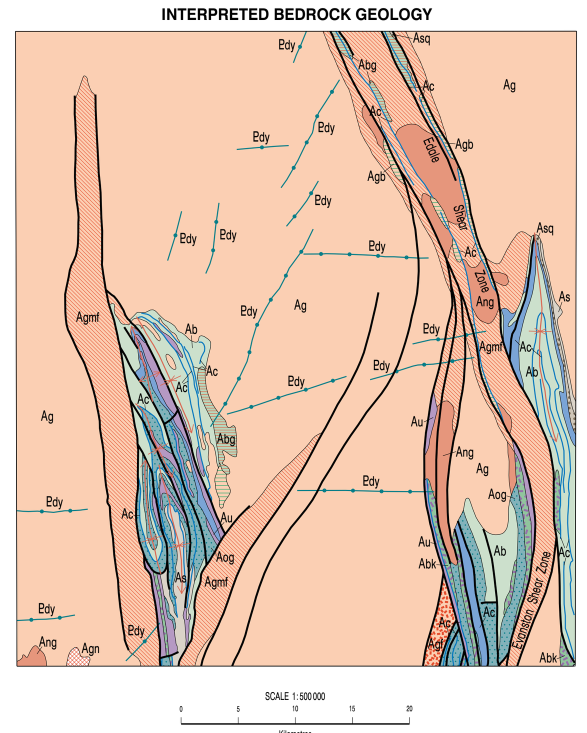
Subsurface data from drillhole, costean, shallow shaft, or pit — Ag

Mineral and rock commodities
- Copper — Cu
- Gold — Au
- Gypsum — Gp
- Lead — Pb
- Road material — Rm
- Zinc — Zn

SHEET INDEX



INTERPRETED BEDROCK GEOLOGY



YILGARN CRATON

- Ꝑdy Mafic dyke

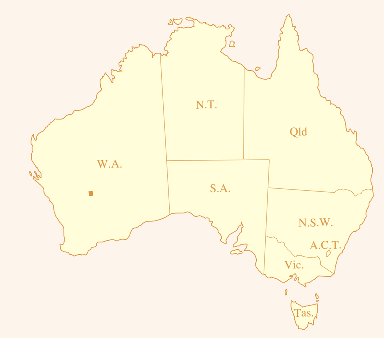
- Ag Granitoid rock
- Agb Granitoid rock with minor mafic and ultramafic rocks
- Agf Strongly foliated granitoid rock
- Agmf Foliated granitoid rock, dominantly monzogranite
- Agn Gneissic granitoid rock
- Ang Granitoid gneiss

- As Metamorphosed clastic sedimentary rock dominant
- Asq Quartzite
- Ac Metamorphosed banded iron-formation and chert

- Aog Metagabbro dominant

- Ab Metabasalt dominant
- Abg Mafic and ultramafic rocks with minor granitoid rock; metamorphosed
- Abk Metamorphosed komatiitic basalt

- Au Metamorphosed ultramafic rock dominant



Department of Mineral and Petroleum Resources

Geological Survey of Western Australia

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SCALE 1:100 000

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

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

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

GDA

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

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

Geology by S. F. Chen and J. Greenfield 2000

Geochronology by:
(1) D. R. Nelson, 2002, Record 2002/2, p. 237–239.

Edited by F. Eddison and G. Loan

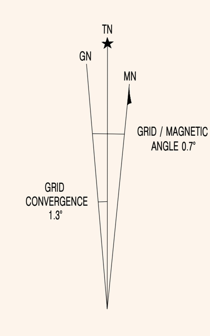
Cartography by A. Francois and K. Greenberg

Topography from the Department of Land Administration Sheet SH 50-04, 2840, with modifications from geological field survey

Published by the Geological Survey of Western Australia. Digital and hard copies of this map are available from the Information Centre, Department of Mineral and Petroleum Resources, 100 Plain Street, East Perth, WA, 6004. Phone (08) 9222 3459, Fax (08) 9222 3444
Web www.mpr.wa.gov.au Email geological_survey@mpr.wa.gov.au

Plotted by the Geological Survey of Western Australia

The recommended reference for this map is:
CHEN, S. F., and GREENFIELD, J., 2002, Richardson, W.A. Sheet 2840: Western Australia Geological Survey, 1:100 000 Geological Series



True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 2002 and moves easterly by about 0.1° in 1.2 years.

RICHARDSON

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