Department of
Industry and Resources

EXPLANATORY NOTES

MENZIES
1:250 000 SHEET
WESTERN AUSTRALIA

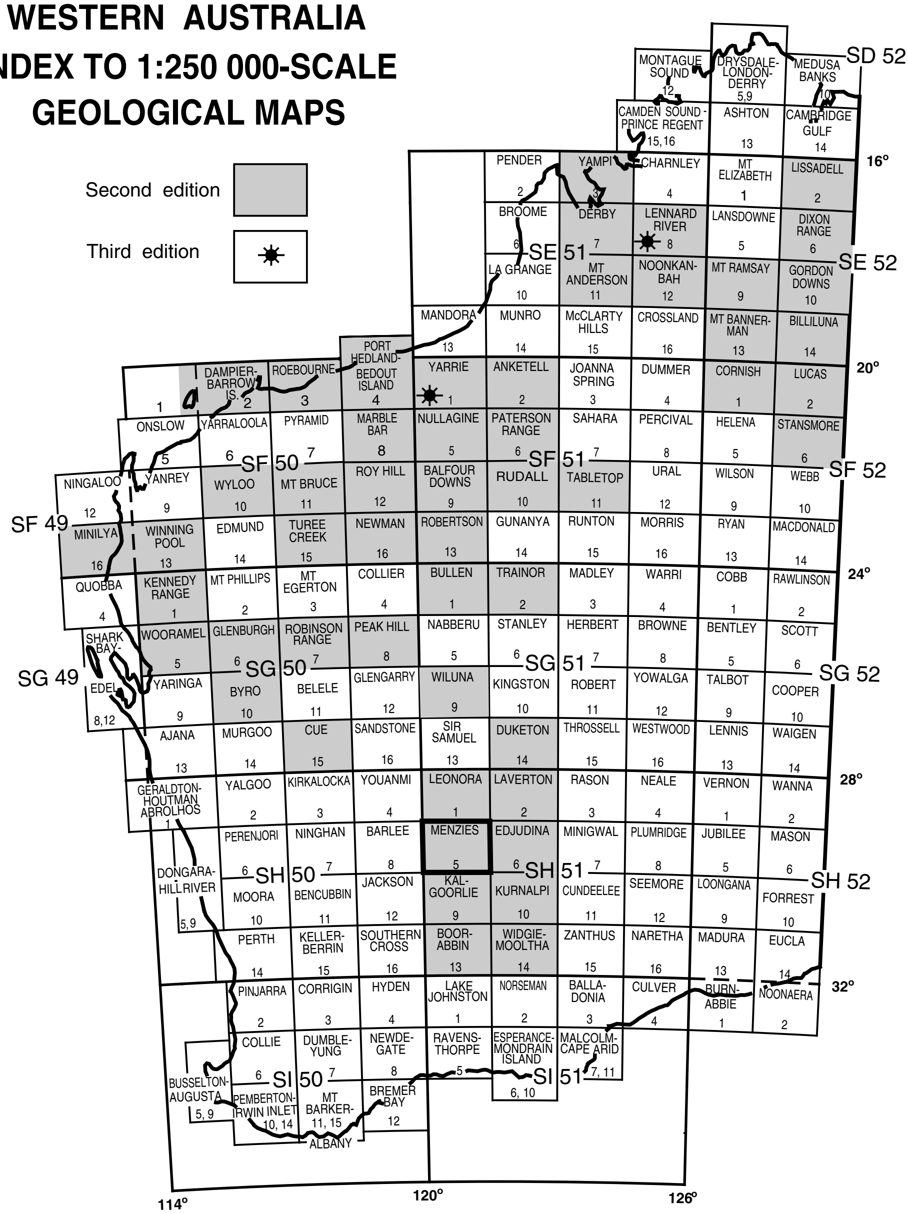
SECOND EDITION

1:250 000 GEOLOGICAL SERIES

SHEET SH 51-5 INTERNATIONAL INDEX

Geological Survey of Western Australia

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



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

MENZIES

WESTERN AUSTRALIA

SECOND EDITION

SHEET SH 51-5 INTERNATIONAL INDEX

by

S. WYCHE

Perth, Western Australia 2003

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Explanatory Notes on the Menzies 1:250 000 Geological Sheet, Western Australia (Second Edition)

by S. Wyche

INTRODUCTION

The MENZIES* 1:250 000 geological sheet (SH 51-5) is bounded by latitudes 29°00'S and 30°00'S, and longitudes 120°00'E and 121°30'E. The map sheet lies within the Eastern Goldfields region, and is named after the town of Menzies† in the southeast, about 130 km north-northwest of Kalgoorlie–Boulder (Fig. 1).

Access to the area is gained from Kalgoorlie–Boulder via the sealed Goldfields Highway (Fig. 2), and by formed roads from the towns of Leonora via Sturt Meadows Homestead to the north, Sandstone to the northwest, Southern Cross via the Evanston Mining Centre to the west, and Coolgardie via the Davyhurst Mining Centre to the south. The Kalgoorlie–Leonora railway line traverses the eastern part of the sheet area, passing through Menzies and Kookynie, a small mining settlement that lies about 20 km east of the Goldfields Highway near the eastern edge of the map sheet. Areas underlain by greenstones are readily accessible by station tracks and mineral-exploration grids, whereas access to areas underlain by granitoid rocks is more restricted, mainly via pastoral-station tracks.

MENZIES is sparsely populated — the Shire of Menzies had a population in 2001 of 353 (Department of Local and Regional Government, 2003). Apart from the small permanent populations at Menzies and Kookynie, there are a number of pastoral stations, mainly in the eastern part of the sheet area (Fig. 2), and several operating mines, also concentrated in the eastern part of the sheet area. Part of the Goongarrie National Park occupies the southeastern corner of the sheet.

PHYSIOGRAPHY, CLIMATE, AND VEGETATION

On MENZIES, greenstone belts form low ridges and areas of elevation. Relief is low (<200 m), with the highest points around Mount Morley (541 m above the Australian Height Datum), north of Riverina Homestead (Fig. 2). A north-trending chain of lakes and claypans in the southwestern part of MENZIES joins Lake Ballard in the centre. This system links with Lakes Goongarrie and Marmion in the east to form part of the Yindarlgooda Palaeoriver (Hocking and Cockbain, 1990). Away from areas of greenstone, sand- and loam-covered plateaus with breakaways are underlain by siliceous and ferruginous duricrust over granitic rock. West-northwesterly trending sand dunes are abundant in the central part of MENZIES, and developed locally over areas of granitoid rock in the western two-thirds of the sheet area.

* Capitalized names refer to standard 1:250 000 map sheets, unless otherwise indicated.
† Map Grid Australia (MGA) coordinates of localities on MENZIES mentioned in text are listed in the Appendix.

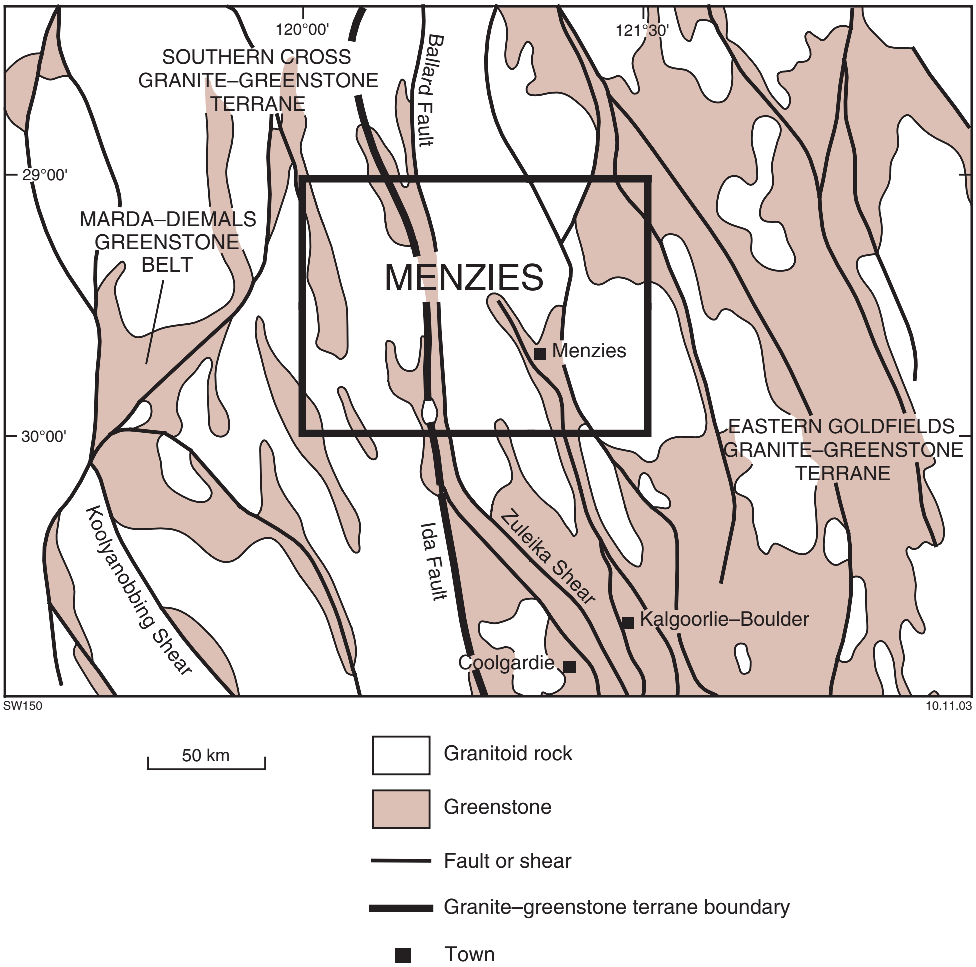

Figure 1. Regional geological setting of MENZIES (modified from Myers and Hocking, 1998)

The region has a semi-arid climate. Menzies township has an average annual rainfall of 251 mm (Commonwealth Bureau of Meteorology, 2003). Rainfall varies from year to year with the driest months typically from September to December. Summers are hot, with temperatures commonly greater than 40°C between December and February, and winters mild with occasional frosts. The average maximum temperature in July for Menzies is 17°C.

MENZIES lies mainly within the Austin Botanical District, or Murchison Region, of the Eremaean Province of Beard (1990). This region is characterized by extensive woodlands dominated by mulga (*Acacia aneura*) over a sparse, low shrub layer that may include acacia, cassia, and eucalypt species, with a ground layer of ephemeral herbs, and sparse perennial and annual grasses. Spinifex grass may grow in areas of extensive sandplain. The mulga scrub is very abundant in areas underlain by granitoid rocks, but a greater variety of vegetation is found in the greenstone belts. Eucalyptus trees replace mulga as the dominant tree type in the southwest, which lies in the Coolgardie Botanical District of the Southwestern Interzone of Beard (1990).

PREVIOUS INVESTIGATIONS

Early descriptions of the mining districts around Mulwarrie, Ularring, Mulline, Mount Ida, Menzies, Comet Vale, Niagara, Kookynie, and Tampa are provided by Gibson (1904, 1907), Feldtmann (1915, 1916), Jutson (1921a,b), and Woodward (1906). The first edition of MENZIES, published in 1971, complemented the explanatory notes of Kriewaldt (1970).

MENZIES was remapped at 1:100 000 scale during the late 1980s and 1990s by the Geological Survey of Western Australia (GSWA) and the Australian Geological Survey Organisation (now Geoscience Australia). Geological maps covering all the 1:100 000 sheets that constitute MENZIES were released during the 1990s. The 1:100 000-scale sheets include MELITA (Witt, 1994a), MENZIES 1:100 000 sheet (Swager, 1994), MULLINE and RIVERINA (Wyche, 1999), BALLARD (Rattenbury and Stewart, 2000), and MOUNT MASON (Duggan, 1995; Wyche and Duggan, 2003). The MELITA, MENZIES, MULLINE, and RIVERINA 1:100 000 maps have associated explanatory notes that have been used extensively in the writing of these explanatory notes. The 1:100 000-scale maps have been incorporated into a seamless map that forms part of the GSWA's East Yilgarn Geoscience Database (Groenewald et al.,

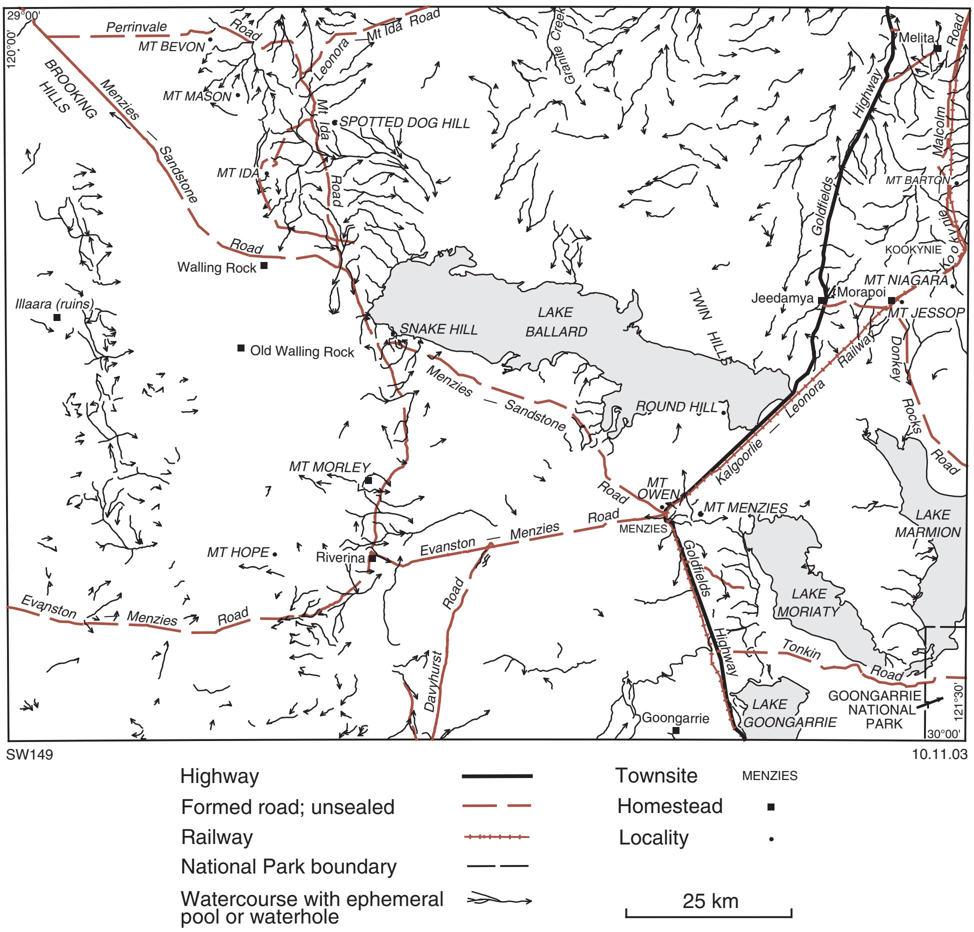

Figure 2. Principal localities, roads, and physiographic features on MENZIES

2000). The published 1:100 000 geological maps form the basis of this 1:250 000 map. Limited field checking resulting in reinterpretation of parts of the RIVERINA, BALLARD, and MOUNT MASON 1:100 000 map sheets was carried out by S. Wyche in 1996, 1999, and 2001.

A regional geochemical survey and regolith interpretation of MENZIES was completed by GSWA in 1994 (Kojan and Faulkner, 1994). Geoscience Australia has also published a regolith map of MENZIES (Churchward and Craig, 1995).

The northeastern part of MENZIES was included in a study of mineral deposits in the Leonora–Laverton area by Hallberg (1985), and the eastern part lies within the area embraced by the regional granitoid study of Witt and Davy (1997). Some of the greenstone belts on MENZIES have been investigated in studies of komatiite successions in the Eastern Goldfields (e.g. Hill et al., 2001), and there have also been studies of felsic volcanic rocks in the Melita Complex (e.g. Brown et al., 2001, 2002). Gold deposits in the Menzies district were documented by Witt (1993). The region has been extensively explored for gold, nickel, base metals, and diamonds (see **ECONOMIC GEOLOGY**). Statutory reports produced as a result of mineral exploration are available through the Western Australian mineral exploration (WAMEX) open-file system in the Department of Industry and Resources library.

NOMENCLATURE

All Archaean rocks on MENZIES have undergone low- to medium-grade metamorphism. Primary textures are commonly preserved, making it possible to identify the protolith. Thus, igneous or sedimentary rock names are used, with metamorphic terminology applied where rocks have been extensively recrystallized.

The term ‘komatiite’ here refers to ultramafic rocks with relict platy olivine-spinifex textures. Arndt and Nisbet (1982) used the term more broadly to describe ultrabasic extrusive rocks with more than 18% MgO. The term ‘komatiitic basalt’ is used to characterize basaltic rocks with relict pyroxene-spinifex texture, or which have been chemically analysed and shown to contain more than 10% MgO. Komatiitic basalts typically contain between 10% and 18% MgO (Cas and Wright, 1987).

REGIONAL GEOLOGICAL SETTING

Gee et al. (1981) divided the Archaean Yilgarn Craton into the Western Gneiss Terrain, and the Murchison, Southern Cross, and Eastern Goldfields Provinces. This arrangement and nomenclature has changed with the development of new structural models and better geochronological control. For example, various authors have applied terrane terminology to all or parts of the Yilgarn (e.g. Myers, 1990; Swager, 1997). According to the current scheme of Tyler and Hocking (2001), MENZIES lies in the central-eastern part of the Yilgarn Craton, and straddles the boundary between the Southern Cross and Eastern Goldfields Granite–Greenstone Terranes (Fig. 1). Swager et al. (1995) subdivided the Eastern Goldfields Granite–Greenstone Terrane (Province) into tectono-stratigraphic terranes bounded by major shear zones so that the eastern part of MENZIES lies within their Kalgoorlie Terrane. A large-scale regional structure, the Ida Fault (Figs 1, 3), marks the boundary between the Southern Cross and Eastern Goldfields Granite–Greenstone Terranes of Tyler and Hocking (2001), and the Kalgoorlie and Barlee Terranes of Swager et al. (1995).

Greenstones in the Southern Cross Granite–Greenstone Terrane differ from those in the Eastern Goldfields Granite–Greenstone Terrane in a number of ways: (1) they contain abundant banded iron-formation, whereas those in the Eastern Goldfields do not contain banded iron-formation in the Menzies region; (2) the Southern Cross greenstones contain little komatiite and associated ultramafic rocks, whereas the Eastern Goldfields greenstones contain thick sequences of various ultramafic rocks including abundant komatiite; (3) some Southern Cross greenstone belts have abundant quartzite and quartz-rich metasedimentary rocks at various levels within their successions, whereas clastic sedimentary rocks in the Eastern Goldfields are associated with felsic volcanic rocks, or are at the top of the succession in late sedimentary basins; and (4) felsic volcanic rocks in the Southern Cross Granite–Greenstone Terrane are typically much younger than the mafic-dominated

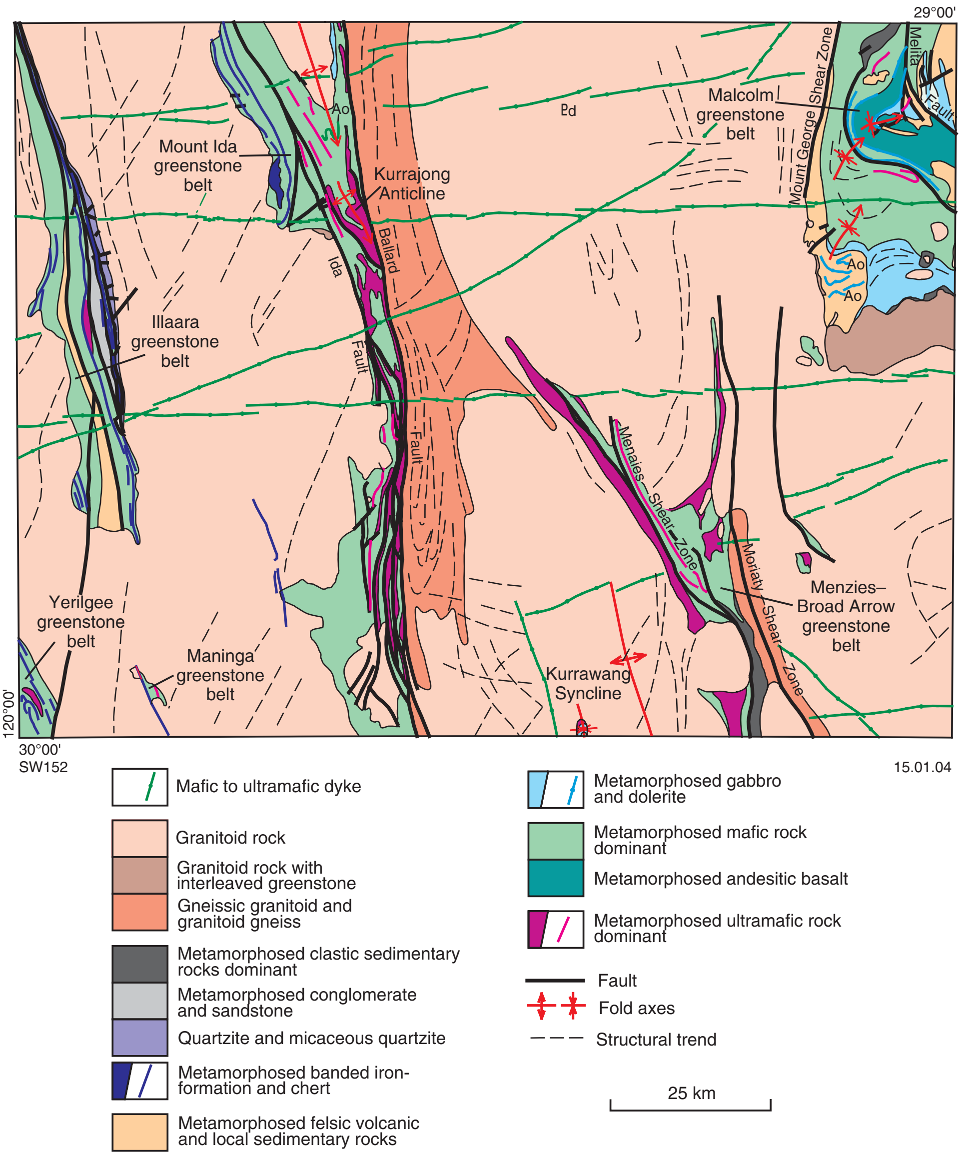

Figure 3. Simplified geological map of MENZIES

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Figure 4. Grey-scale image of total magnetic intensity for MENZIES (reproduced with the permission of Fugro Airborne Surveys Pty Ltd)

greenstones, whereas the felsic volcanic rocks in the Eastern Goldfields may be penecontemporaneous with the mafic greenstones.

Late, crosscutting dykes of probable Proterozoic age are only rarely exposed. Extensive Cainozoic regolith development has obscured much of the granite–greenstone geology.

PRECAMBRIAN GEOLOGY

Greenstones, which constitute less than 20% of the Archaean rocks on MENZIES, are typically preserved in narrow, commonly fault-bounded belts with the greater part of the sheet area occupied by granitoid rocks including granitoid gneiss. Greenstone belts in the eastern part of the sheet area, and the adjacent EDJUDINA (Chen, 1999) and KALGOORLIE (Wyche, 1998) sheets to the east and south respectively, are broader and less well defined.

Parts of seven of the greenstone belts of Griffin (1990a,b) are preserved on MENZIES. These include the Illaara, Yerilgee, Maninga, Mount Ida, Ora Banda, Menzies – Broad Arrow, and Malcolm greenstone belts (Fig. 3). The Ida Fault, the structure that coincides with the boundary between the Southern Cross and Eastern Goldfields Granite–Greenstone Terranes, is within and adjacent to the Mount Ida greenstone belt. Greenstones in the Southern Cross Granite–Greenstone Terrane to the west of the Ida Fault are probably substantially older than the c. 2700 Ma greenstones of the Eastern Goldfields Granite–Greenstone Terrane to the east of the fault (Nelson, 1997), and may be 3000 Ma (Chen et al., 2001b).

ARCHAEAN ROCK TYPES

Ultramafic rocks (*Au*, *Auk*, *Aup*, *Aur*, *Aux*)

Although ultramafic rocks are found in all the greenstone belts on MENZIES, they are most abundant in the Mount Ida and Menzies – Broad Arrow greenstone belts. Here they include cumulate rocks that, along with associated gabbro, pyroxenite, and dolerite, make up the Walter Williams Formation of Hill et al. (1995, 2001). All ultramafic rocks are metamorphosed to some degree and original mineralogy is rarely preserved. Alteration mineralogy commonly includes serpentine, tremolite–actinolite, chlorite, talc, carbonate minerals, and magnetite. However, relict igneous textures are commonly well preserved. Abundant magnetite in these rocks gives them a high magnetic susceptibility so that their distribution is clearly visible on total magnetic intensity images (Fig. 4).

Metamorphosed ultramafic rock that is undivided (*Au*) includes deeply weathered rocks whose protolith cannot be determined, and areas where there is a mixture of various ultramafic rock varieties such that individual units are too small to be distinguished at 1:250 000 scale. Deeply weathered ultramafic rocks are commonly altered to chlorite.

Metakomatiite with relict olivine-spinifex texture (*Auk*) is locally abundant on the eastern side of the central part of the Mount Ida greenstone belt between Mulline and the Forest Belle mine, and in the Menzies – Broad Arrow greenstone belt near Ghost Rocks and south of Menzies township. Although primary olivine is not preserved, platy olivine-spinifex texture is pseudomorphed by fine-grained tremolite–actinolite, talc, and serpentine. In some places, the texture is outlined by very fine grained magnetite. Pseudomorphs of tabular olivine crystals range from fine to very coarse, and may form sheaves or be randomly oriented.

Metamorphosed peridotite (*Aup*) includes all cumulate-textured rocks, and local areas of adcumulate-textured dunite; for example, south of Menzies township (Swager, 1994). However, most are meso- or orthocumulates that contain very fine grained, olivine-depleted, interstitial material (Hill et al., 1995, 2001). They are commonly altered to serpentinite or very fine grained, matted tremolite–actinolite, with the outlines of original olivine grains marked by very fine grained magnetite as in some metakomatiite. Ultramafic rocks are commonly capped by siliceous duricrust (*Rzu*) that preserves relict cumulate textures. Where extensive, these areas have been shown separately. A thick, very well preserved interval of peridotite containing ortho-, meso-, and adcumulate rocks, in association with gabbro, komatiite, basalt, and interflow metasedimentary rocks, outcrops in the Kurrajong Anticline in the Mount Ida greenstone belt (Hill et al., 2001).

Tremolite(–chlorite–talc) schist (*Aur*) is found in all greenstone belts, typically in or near shear zones. Fresh rock is light to dark green with light- to mid-brown weathered surfaces, and moderately to strongly deformed. The schist may be fine to coarse grained, with a foliation defined by green acicular tremolite–actinolite, but may also contain chlorite, talc, magnetite, and very fine plagioclase. Primary igneous textures are not preserved, but the composition suggests that these rocks are probably deformed and metamorphosed komatiites and peridotites. Where it contains small amounts of plagioclase, tremolite schist may be derived from komatiitic basalt (*Abk*, see below).

Metamorphosed medium- to coarse-grained pyroxenite (*Aux*) is typically associated with other ultramafic rock types, but is rarely sufficiently extensive to distinguish on MENZIES. However, there are distinctive metapyroxenite horizons at or near the bases of layered mafic sills in the northeast. They consist of very coarse (≤1 cm) grains of tremolitic amphibole, probably pseudomorphing clinopyroxene, with chlorite, talc, and fine, interstitial amphibole (Witt, 1994a).

Fine-grained mafic rocks (*Ab*, *Aba*, *Abg*, *Abi*, *Abk*, *Abs*, *Abv*)

Fine-grained mafic rocks are abundant in all greenstone belts on MENZIES. Undivided mafic rocks (*Ab*) are typically deeply weathered so that original compositions and textures cannot be determined, or are mixtures of mafic rock types that cannot be differentiated at 1:250 000 scale.

Although all greenstones are metamorphosed, amphibolite (*Aba*) is characterized by the presence of blue-green hornblende, with rare clinopyroxene (e.g. north of Blue Well). Tremolite–actinolite is present in places as a retrograde phase. The rocks are recrystallized, and plagioclase typically forms a fine-grained, granoblastic groundmass, although laths mimicking a relict igneous texture are preserved locally. Sphene and fine-grained opaque oxides such as ilmenite are common accessory minerals, and garnet and epidote are abundant locally. Amphibolite is commonly strongly foliated, and may be associated with ultramafic and metasedimentary schist. Areas of amphibolite are typically adjacent to granite–greenstone contacts, but most are too narrow or restricted to show at 1:250 000 scale. Larger areas of amphibolite are relatively common in the Menzies district (Swager, 1994). At the southern end of the Illaara greenstone belt, amphibolite contains intervals of layered rock containing medium- to dark-green amphibole, diopside, and locally abundant sphene and epidote (Wyche, 1999).

In areas of mafic rock interleaved with minor granitoid rock (*Abg*), 2 km south of Lillydale Well and 1 km north of Ram Well, metabasalt and mafic gneiss have been intruded by veins of diorite and tonalite that are similar in composition to leucosomes in mafic gneiss (*Anm*). The veins are irregular, and locally dominate areas of outcrop with the mafic host forming angular clasts in a matrix of vein material. Contacts between host rocks and vein material are typically sharp, but locally gradational (Witt, 1994a).

Metamorphosed basaltic andesite and basalt (*Abi*) is abundant in northeastern MENZIES where it forms part of the Melita Complex (Witt, 1994a; Brown et al., 2002). Rocks are typically light grey-green, fine grained, and massive to pillowed. They contain plagioclase and tremolite–actinolite, and may contain chlorite, epidote and accessory sphene and leucoxene. Phenocrysts are rare, but the groundmass commonly contains fine-grained plagioclase microlites. Along with pillow structures, volcanic features preserved in these rocks include vesicles and larger gas cavities, hyaloclastite, and interbeds of reworked hyaloclastite.

Metamorphosed komatiitic basalt (*Abk*) is characterized by pyroxene-spinifex texture in which randomly oriented needles and sheaves of acicular pyroxene have been pseudomorphed by tremolite–actinolite. Fine-grained, interstitial plagioclase is typically subordinate to amphibole, and there is common accessory opaque oxide. Chlorite, possibly as a late retrograde phase, is present locally. Komatiitic basalt may be variolitic with leucocratic spheres and ovoids of albite-rich metabasalt. These are not primary features and may result from devitrification. Pillow structures are evident locally, for example at Snake Hill at the western end of Lake Ballard. Komatiitic basalt is probably present in all greenstone belts, but is more abundant in the Eastern Goldfields Granite–Greenstone Terrane.

Mafic schist with interleaved metasedimentary rocks (*Abs*) outcrops in a broad area of strong shearing north and south of Menzies township (Swager, 1994). These rocks also contain lenses and thin layers of ultramafic schist. The mafic rocks are extensively recrystallized with secondary epidote, which is very abundant in a 1–2 km-wide zone around the Jorgenson Monzogranite (*Agjo*). Fine-grained biotite is present locally, and is a prominent phase in the alteration zones around auriferous lodes.

Metabasalt (*Abv*) is typically a dark-green, fine-grained rock containing approximately equal proportions of actinolite and plagioclase with accessory opaque oxides, and common secondary leucoxene (Swager, 1994; Witt, 1994a; Wyche, 1999). Epidote is abundant locally, commonly as a result of saussuritization of plagioclase, and chlorite may also be present in areas of retrograde alteration. In places, plagioclase is preserved as fine laths. Quartz-filled vesicles and evidence of pillow structures such as fragments of pillow rims are common, but well-preserved pillow structures are rare. Flow-top breccias have been noted in the northeast (Witt, 1994a) where metabasalt and metamorphosed basaltic andesite form much of the mafic component of the Melita Complex. Although typically tholeiitic in composition, these rocks may include some intervals of metamorphosed komatiitic basalt (*Abk*). Metabasalt (*Abv*) is abundant in all greenstone belts and dominates greenstone successions in some greenstone belts west of the Ida Fault.

Medium- to coarse-grained mafic rocks (*Ao*, *Aod*, *Aofb*, *Aog*, *Aol*, *Aon*, *Aonv*, *Aogx*)

Medium- to coarse-grained mafic rocks form a substantial component of most greenstone successions on MENZIES. Undivided medium- to coarse-grained mafic rocks have no distinctive features, or are deeply weathered. Where fresh, they comprise plagioclase and amphibole (tremolite–actinolite or hornblende) with accessory opaque oxides with locally preserved relict ophitic to subophitic texture. Some outcrops may represent thicker parts of mafic flows.

Medium-grained mafic rock (*Aod*) is found in most greenstone belts, although outcrops are typically too small to show at 1:250 000 scale. They include metamorphosed dolerite and quartz dolerite, and typically preserve relict subophitic texture with tremolite–actinolite replacing clinopyroxene. In places, they grade into metamorphosed leucodolerite (*Aol*). Dolerite and leucodolerite sills intrude the felsic Melita Complex in the northeast (Witt, 1994a, 1995), where they commonly form parts of layered sills with a locally developed basal ultramafic layer. Plagioclase, olivine, and ilmenite may be present as early cumulus phases in these rocks. Tremolite–actinolite commonly pseudomorphs oikocrysts (≤1 cm) of clinopyroxene, and some dolerite contains tabular, coarse (typically ≤1 cm) plagioclase phenocrysts (e.g. west of the Kurnalpi Rockholes). Some chlorite aggregates in dolerites within layered mafic sills may pseudomorph orthopyroxene, but none of the primary mineral assemblage is preserved. Small amounts of quartz in some dolerite may be primary. In the Niagara district, the dolerite forms part of the Niagara Layered Complex of Witt (1994a).

The Forest Belle Gabbro (*Aofb*) is a distinctive, coarse- to very coarse grained metagabbro with very coarse ophitic texture. Tabular aggregates of plagioclase crystals, up to 5 cm across, are enclosed by very coarse oikocrysts of clinopyroxene, which have been pseudomorphed by pale- to dark-green, strongly pleochroic amphibole. Individual plagioclase grains are up to 5 mm long. The size of the oikocrysts is difficult to determine, but crystallographic continuity across several plagioclase grains indicated by reflections on cleavage planes suggests that they may exceed 5 cm across in places. Plagioclase typically makes up at least 50% of the rock, but may be more than 70%. The rock contains scattered, interstitial grains of opaque oxide up to 1 mm, and fine-grained epidote is a common minor secondary mineral constituent. The Forest Belle Gabbro is typically massive, but is strongly foliated near the contact with the Copperfield Monzogranite (*Agcf*) where it is cut by auriferous quartz veins.

Metamorphosed gabbro (*Aog*) is a coarse-grained mafic rock in which pyroxene has commonly been replaced by actinolitic amphibole or hornblende, but commonly preserves relict subophitic to ophitic textures. Igneous layering in which gabbro is pyroxene-rich at the stratigraphic base and contains various phases with quartz gabbro at or near the stratigraphic top, for example south of Menzies township and west of Lake Moriaty, indicates younging direction in some sills. These gabbros are similar to layered sills in the Ora Banda greenstone belt to the south on KALGOORLIE (Swager, 1994).

Metamorphosed leucogabbro and leucodolerite (*Aol*), where plagioclase forms more than 60% (and locally more than 80%) of the rock, are common in the northeastern part of MENZIES where they have a medium- to very coarse grained ophitic texture (Witt, 1994a). Here, cumulus plagioclase (1–10 mm) is enclosed by very large oikocrysts of tremolite–actinolite that has pseudomorphed clinopyroxene. Modal and grainsize layering is best developed in coarser grained rocks. Leucodolerite, including quartz leucodolerite, is a common component of layered mafic sills. Accessory minerals include apatite, opaque oxides (with leucoxene after ilmenite), and quartz. Epidote and sericite are the most common alteration minerals. Fine- to medium-grained, commonly recrystallized leucogabbro, associated with cumulate-textured rocks including norite and gabbronorite near the Niagara Mining Centre, contains up to 30% quartz, and strongly pleochroic, green, Fe-rich, clinopyroxene (hedenbergite). The leucogabbro probably represents a fractionated layer within a large mafic intrusion, the Niagara Layered Complex of Witt (1994a).

Metamorphosed norite and gabbronorite (*Aon*) outcrops in the vicinity of the Niagara Mining Centre (Witt, 1994a). Rocks are typically fine to medium grained (≤2 mm), equigranular, and preserve mesocumulate to adcumulate textures. Orthopyroxene (probably hypersthene) is mainly a cumulus phase, but is locally interstitial to tabular or lath-shaped plagioclase grains. Augite is also present as a cumulus phase, but more commonly forms oikocrysts up to 5 mm across. Large, poikilitic grains (≤1 cm) of dark amphibole locally enclose pyroxene grains suggesting that they may be primary oikocrysts in some instances. Metamorphosed norite and gabbronorite intrude felsic volcanic rocks in the western part of the Niagara Mining Centre. Along with other metamorphosed intrusive mafic rock types such as leucogabbro (*Aol*) and dolerite (*Aod*), these rocks are probably parts of an extensive, dismembered and poorly outcropping layered mafic intrusion, the Niagara Layered Complex of Witt (1994a). Although largely obscured by regolith cover and extensively intruded by granitoids, this feature is evident on aeromagnetic images (Fig. 4).

Metamorphosed olivine gabbronorite (*Aonv*) near Mount Melita is a dark, medium-grained rock that occurs near the base of a layered sill (Witt, 1994a). The rock preserves orthocumulate to mesocumulate textures with cumulus olivine and plagioclase and intercumulus augite that forms oikocrysts up to 1 cm across. Orthopyroxene, probably hypersthene, forms cumulus and intercumulus phases. The rock contains intercumulus biotite and ilmenite, and secondary magnetite. Fine, disseminated, pyrrhotite and chalcopyrite are found in intercumulus positions, and within olivine grains.

Metamorphosed pyroxene-rich gabbro (*Aogx*) in the Illaara greenstone belt includes a range of typically medium-grained (≤2 mm) gabbroic rocks with cumulus clinopyroxene and plagioclase. Although there is a range of compositions, the patchy exposure and extensive alteration and weathering make it difficult to distinguish the varieties at 1:250 000 scale. Some rocks contain coarse grains (≤5 mm) of altered orthopyroxene. Amphibole has partly replaced pyroxene in places. Possible large oikocrysts of pyroxene are altered to amphibole and chlorite. Plagioclase content ranges from some 10% to about 50%. Secondary chlorite and epidote are abundant locally, and leucoxene after ilmenite is a common minor constituent.

Felsic rocks (*Af*, *Afi*, *Afp*, *Afs*, *Afv*, *Afx*)

Felsic rocks, including volcanic, volcaniclastic sedimentary, and fine-grained intrusive rocks, are abundant in the northeastern part of MENZIES, where they are components of the Melita Complex (Hallberg, 1985; Witt, 1994a; Morris and Witt, 1997; Brown et al., 2002). Felsic rocks of acid to intermediate composition are also found in weathered outcrop and exploration drillholes in the southern part of the Illaara greenstone belt.

Undivided, metamorphosed felsic volcanic and volcaniclastic rock (*Af*) is deeply weathered rock in which original volcanic or sedimentary features cannot be discerned. Such rocks are recognized as felsic because they contain quartz grains interpreted as a primary phase.

Metamorphosed feldspar porphyry of intermediate composition (*Afi*) has been mapped locally in the Illaara, Mount Ida, and Malcolm greenstone belts. In the Illaara greenstone belt (Wyche, 1999), these rocks are poorly exposed and commonly weathered. They contain saussuritized plagioclase phenocrysts up to 3 mm long in a fine-grained recrystallized, feldspathic groundmass containing quartz, amphibole, biotite, chlorite, epidote, and sphene. Primary textures have been largely obscured by metamorphism and weathering. Intermediate porphyry in the Mount Ida greenstone belt east of Mount Morley (Wyche, 1999) also contains plagioclase phenocrysts up to 3 mm. The main mafic component is pleochroic, olive- to light-green amphibole, commonly in clusters up to 3 mm across, constituting up to 25% of the rock. The fine, feldspathic groundmass also contains quartz, biotite, and sphene. North of the Niagara Mining Centre (Witt, 1994a), porphyritic intermediate rock contains abundant broken crystals of plagioclase, and subordinate subhedral, prismatic crystals of amphibole that have been pseudomorphed by fine-grained biotite. Weakly preserved bedding and the fragmental nature of this rock suggest that it was a pyroclastic or volcaniclastic deposit.

Metamorphosed quartz–feldspar porphyry (*Afp*) in the Mount Ida greenstone belt outcrops in an extensive, but poorly exposed, body that extends from about 3 km northwest of 51 Mile Well to at least as far as the Bottle Creek mine, where it can be seen in the walls of the openpit. It contains altered plagioclase phenocrysts up to 4 mm, and minor quartz phenocrysts up to 5 mm, in a fine-grained quartzofeldspathic groundmass. Aggregates of fine-grained biotite have replaced primary mafic minerals, and there are minor opaque oxide and tourmaline grains. The rock has a sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon age of 2700 ± 9 Ma (Nelson, 2002). Locally, strong deformation in the porphyry may be due to movement on the Ida Fault. Porphyry at the southern end of the Mount Ida greenstone belt in thin dykes or sills that are broadly parallel to the regional fabric is similar in character to that at Bottle Creek, but contains less biotite (Wyche, 1999).

Felsic schist (*Afs*) outcrops in close association with other felsic rock types in the northeastern part of MENZIES, where it forms part of the Melita Complex (Witt, 1994a). This biotite–quartz–feldspar schist outcrops along strike from, and is interbedded with, felsic volcanic rock (*Afv*). It is interleaved, and in faulted contact, with various mafic rock types including amphibolite, and basaltic and intrusive mafic rocks. The schist contains porphyroclasts of quartz and feldspar (≤5 mm), with quartz more abundant than feldspar, and sparse lithic clasts (≤1 cm). Bedding, indicated by variations in biotite content and the abundance and size of the porphyroclasts, indicates that these rocks are not intrusive, although the primary depositional environment is masked by deformation and recrystallization. Felsic schist in the Menzies – Broad Arrow greenstone belt (Swager, 1994) contains fine-grained muscovite, quartz, and feldspar with quartz porphyroclasts up to 4 mm. Clasts of fuchsite schist and andalusite porphyroblasts are present locally (see **Metamorphic rocks:** *Alu*). Strongly foliated felsic rock in the Ghost Rocks area contains quartz and feldspar porphyroclasts in a quartzofeldspathic groundmass. The protolith of this rock is unclear, but may have been felsic porphyry. It has a SHRIMP U–Pb zircon age of 2691 ± 6 Ma (Nelson, 1995).

Metamorphosed felsic volcanic rocks (*Afv*) outcrop extensively in northeastern MENZIES in the Melita Complex. These rocks include a wide range of lithotypes and depositional textures (Witt, 1994a; Brown et al., 2002). They are typically rhyolitic to dacitic in composition, commonly porphyritic, and variously bedded. Phenocrysts of quartz and feldspar are common, and amphibole, where present, is recrystallized and altered to finer grained aggregates of amphibole, biotite, and epidote. Accessory minerals include zircon, ilmenite, magnetite, sphene, and apatite, and pyrite and pyrrhotite in some rhyolite. Secondary chlorite and carbonate minerals are also locally abundant. Coherent rhyolite lava and shallow rhyolite sills have very fine grained, recrystallized quartzofeldspathic groundmass and locally preserve relict spherulites and perlitic textures. Abundant crystal fragments, the presence of lithic clasts, and bedding at various scales suggest a pyroclastic or locally reworked sedimentary depositional environment for many of these rocks. However, microscopic textures are poorly preserved owing to recrystallization and post-depositional alteration. Thus, possible primary pyroclastic features such as shards, pumice fragments, and evidence of welding are difficult to recognize. Some fine-grained metasedimentary rocks associated with volcaniclastic rocks of the Melita Complex preserve ripples and cross-beds suggesting a shallow-water depositional environment. SHRIMP U–Pb zircon dating of three samples of rhyolite from the Melita Complex gave an age of c. 2683 Ma (Brown et al., 2002). A sample of rhyolite from the southern part of the Melita Complex near Carpet Snake Soak gave a SHRIMP U–Pb zircon age of 2681 ± 4 Ma (Nelson, 1996, 1997).

Metamorphosed felsic breccia (*Afx*) of the Melita Complex (Witt, 1994a; Brown et al., 2002) is typically associated with finer grained, tuffaceous metasedimentary rocks (*Afv*). They comprise massive, poorly sorted, matrix-supported to clast-supported breccia with angular clasts dominated by rhyolite, but also contain local silicified shale and chert fragments, large pieces of basaltic andesite, and angular fragments of granite. The breccia contains fragments of quartz and feldspar crystals, and common biotite-rich aggregates, possibly derived from pumice fragments. Rhyolite clasts in the breccia are typically no larger than 10 cm but reach up to 30 cm near Mount Barton and farther north near the Melita railway siding. The quartzofeldspathic matrix is very fine grained to cryptocrystalline with abundant biotite, sericite, chlorite, and epidote. Breccia just to the east of Dead Horse Rocks contains blue-green amphibole in both the matrix and phenocryst phases. Younging direction is indicated by graded bedding in some finer grained intervals, which also contain rare accretionary lapilli.

Metasedimentary rocks (*As*, *Ash*, *Asp*, *Ast*, *Astq*, *Asw*, *Acc*, *Aci*)

Metasedimentary rocks are present in all greenstone belts, but are more abundant in some. There is also a distinct change in the nature of the metasedimentary rocks from east to west, with immature volcaniclastic metasedimentary rocks dominant in the Eastern Goldfields Granite–Greenstone Terrane, and chemical and more compositionally mature clastic sedimentary rocks dominant in the Southern Cross Granite–Greenstone Terrane.

Undivided metasedimentary rocks (*As*) are either deeply weathered, or contain a mix of lithotypes that cannot be distinguished at 1:250 000 scale. These rocks may include sandstone, wacke, shale and siltstone, but are commonly strongly foliated so that original textural and bedding features are obscured. Schistosity in deformed metasedimentary rocks is typically defined by metamorphic muscovite and biotite.

Metamorphosed shale and siltstone (*Ash*) are common as interflow sedimentary units in all greenstone belts, but are typically too thin to show at 1:250 000 scale. They are commonly deformed, but thin bedding is preserved locally. Dark, fine-grained carbonaceous, commonly silicified slate is widespread east and southeast of Menzies township (Swager, 1994). In the Illaara greenstone belt, poorly exposed fine-grained metasedimentary rocks that include shale, siltstone and chert outcrop extensively at the southern end of the sandstone and conglomerate unit in the middle of the greenstone belt (*Asp*), and probably represent a facies within that unit.

Metamorphosed sandstone and conglomerate (*Asp*) have been mapped in the Menzies – Broad Arrow and Illaara greenstone belts. In the Menzies – Broad Arrow greenstone belt, east of the Goldfields Highway and north of Lake Goongarrie (Swager, 1994), deformed metaconglomerates are closely associated with, and grade into, deformed and metamorphosed wacke and arkose (*Asw*). Here, matrix-supported conglomerates contain elongate and flattened pebbles and boulders, up to 50 cm long. Clasts are mainly granitoid, but may also include metamorphosed mafic and metasedimentary rock types. The quartzofeldspathic matrix is typically strongly deformed, commonly to quartz–feldspar–biotite schist. Bedding and other sedimentary features are commonly masked by deformation and recrystallization. These rocks are probably equivalent to the late, clastic sedimentary sequences of Krapez et al. (2000).

In the Illaara greenstone belt (Wyche, 1999), metamorphosed conglomerate and sandstone are interbedded and grade into each other in a lensoid unit that can be traced for about 20 km along strike in the central-southern part of the greenstone belt. The metaconglomerate is characterized by rounded to well-rounded clasts of quartzite, up to 1 m across, with subordinate angular pebbles of chert and silicified metasedimentary rock. Quartzite in the clasts is strongly recrystallized and poorly sorted with grainsize up to 2 mm. The conglomerate is mainly matrix supported in poorly sorted, locally ferruginous lithic sandstone that is strongly recrystallized and commonly deformed. The associated lithic sandstone is similar in character to the conglomerate matrix, and locally contains rounded quartz pebbles and granules, and angular clasts of chert up to 1 cm. Even where they are relatively undeformed, bedding features are not very clear in these rocks, and so younging directions are not readily seen. The eastern side of the unit is commonly marked by a breccia with angular clasts of grey and white banded chert in a siliceous matrix that may mark a structural break with greenstones to the east.

Metasandstone (*Ast*) in a poorly outcropping unit in the western part of the Illaara greenstone belt is poorly sorted, fine- to medium-grained, angular to subrounded quartz sandstone with abundant interstitial sericite.

Medium- to coarse-grained quartzite and quartz–muscovite schist (*Astq*) outcrops along the eastern side of the Illaara greenstone belt where it attains a maximum thickness of about 900 m. Quartzite, with a strong layer-parallel cleavage that suggests thin- to medium-scale bedding, forms prominent ridges. Other sedimentary features such as cross-beds or ripple marks, if present, have been largely obscured. Although strongly recrystallized, the quartzite appears to have been formed from fine- to coarse-grained quartz arenite. Where original grain outlines are visible, they appear rounded and poorly sorted. Some beds contain dark bands of very fine grained tourmaline. Recessive units between the quartzite ridges outcrop poorly, but contain a range of metasedimentary rocks that include quartz–muscovite schist, cleaved sandstone that locally contains rounded vein-quartz or chert pebbles, chert (locally pyritic), and cleaved shale with locally developed andalusite porphyroblasts (e.g. at MGA 223185E 6744853N). Fuchsite, a chromian muscovite, locally imparts a pale-green colour to both the quartzite and quartz–mica schist. A SHRIMP study of detrital zircons from a sample of quartzite from the Illaara greenstone belt found several populations of zircon ranging in age from 3304 ± 8 to 3494 ± 10 Ma. Thus, 3304 ± 8 Ma is considered to be the maximum age of deposition for this rock (Nelson, 2000). However, comparison with detrital zircon data from similar rocks in nearby greenstone belts suggests a maximum depositional age younger than 3131 ± 3 Ma (Riganti, 2003; Wyche et al., in prep.)

Metamorphosed wacke and arkose (*Asw*) outcrops in association with, and grades into, conglomerate (*Asp*) in the Menzies – Broad Arrow greenstone belt. The rocks are strongly deformed and contain lithic fragments and medium- to coarse-grained quartz and feldspar in a foliated feldspar–quartz–biotite matrix. The strong deformation fabric commonly obscures bedding features.

Metamorphosed chert (*Acc*) and banded iron-formation (*Aci*) are abundant in greenstone belts west of the Ida Fault where they form prominent ridges. These siliceous metasedimentary rocks are finely laminated on a submillimetre to millimetre scale with thicker bedding units up to centimetre scale. Laminations are defined by various ratios of quartz, magnetite, hematite, and limonite. Red jasper is rare. Chert and banded iron-formation are typically recrystallized and, in areas of elevated metamorphic grade adjacent to granite–greenstone contacts, banded iron-formation may contain grunerite (e.g. west of Sowerline Well on the western side of the Mount Ida greenstone belt). Some chert units in the Illaara greenstone belt are associated with shale, including carbonaceous and pyritic shale, and probably represent silicified fine-grained metasedimentary rocks. A distinctive unit of brecciated chert that commonly outcrops along the eastern side of the prominent sandstone and conglomerate unit in the Illaara greenstone belt (*Asp*) may mark a major structural break. Tight to isoclinal and intrafolial folds in chert and banded iron-formation are probably due to regional deformation, but more chaotic folding may be the product of soft-sediment deformation.

Chert and banded iron-formation are rare east of the Ida Fault. Material from mineral-exploration drillholes suggests that a chert unit in the northern part of the Mount Ida greenstone belt, east of the Copperfield Monzogranite, is a strongly silicified, and locally ferruginized, black shale unit. Similarly, a distinctive chert ridge in the northeastern arm of the Menzies – Broad Arrow greenstone belt near Round Hill (Swager, 1994) may be a silicified black shale or slate, like the unit (*Ash*) to the east and southeast of Menzies township.

Metamorphic rocks (*Alqm*, *Alu*)

All greenstones and most granitoid rocks on MENZIES have been metamorphosed to some degree. Metamorphic terminology has been applied where the protolith is unclear.

Quartz–mica schist (*Alqm*) in northeastern Menzies (Witt, 1994a), west of Paradise Well, and also near Twenty One Mile Well, is associated with metasedimentary rocks including chert and black shale. The schist typically consists of fine-grained quartz and muscovite, is chloritic, and may contain porphyroblasts of chloritoid and muscovite. Quartz porphyroclasts and lithic fragments are preserved in places.

Quartz–fuchsite and quartz–andalusite–fuchsite rock (*Alu*) are distinctive rock types that outcrop extensively east of Menzies township between Jowetts Well and Kings Dam, and in scattered, small outcrops to the north and south. They are found in contact zones between felsic and ultramafic rocks, and as clasts in the felsic schist (*Afs*) in this area (Swager, 1994). These rocks consist of various proportions of quartz, andalusite, and fuchsite, and have been described in detail by Martyn and Johnson (1986). The more fuchsite-rich rocks are a distinct bright-green colour. Andalusite, which forms coarse porphyroblasts up to 20 mm, may constitute more than 50% of the rock, and gives it a dull-brown colouration. Andalusite-rich rocks also contain abundant opaque sulfide and oxide minerals. Variations in andalusite content define a crude layering. The rocks have an unusual geochemical profile with a marked enrichment in SiO_2 or Al_2O_3 and Cr, with elements commonly correlating in ways that would be uncharacteristic in igneous rocks. Martyn and Johnson (1986) interpreted the quartz–andalusite–fuchsite rock to have been the result of intense, pre-deformation and pre-metamorphism alteration of komatiite or komatiite-derived sedimentary rocks.

Granitoid rocks and gneiss

Granitoid rocks range in composition from syenogranite to tonalite, with monzogranite the most abundant. SHRIMP geochronology on granitoids from both east and west of the Ida

Fault indicates that they were emplaced mainly between c. 2700 and c. 2660 Ma, but may be older than c. 2800 Ma, and are as young as c. 2621 Ma (e.g. Cassidy et al., 2002; Nelson, 1997, 2000, 2002, in prep.). A regional petrographic study that included granitoids on MENZIES was reported by Libby (1978). Witt and Davy (1997) included the eastern two-thirds of MENZIES in their regional study in which granitoid rocks in the southern part of the Eastern Goldfields Granite–Greenstone Terrane were characterized by their geochemistry and structural setting. More recently, Cassidy et al. (2002) classified granitoid rocks throughout the Yilgarn Craton on the basis of their geochemistry, and gathered a substantial amount of new SHRIMP geochronological data.

Gneissic granitoid rocks are found adjacent to the Mount Ida, Menzies – Broad Arrow, and Malcolm greenstone belts. Although no ages have been obtained for any of the gneissic rocks on MENZIES, their compositions, distribution, and textures suggest that they are strongly deformed varieties of the typical inter-greenstone belt granitoids.

Gneiss (Ang, Anm)

Although strongly deformed rocks outcrop in many parts of MENZIES, rocks mapped as gneiss are those with well-developed gneissic layering.

Granitoid gneiss (*Ang*) outcrops extensively on the eastern side of the Mount Ida greenstone belt, east of the Ballard Fault (Fig. 3), where it grades into gneissic granitoid (*Agn*) with decreasing strain to the east, away from the granite–greenstone contact and major fault zones. The best exposures of granitoid gneiss and gneissic granitoid outcrop within about 5 km of the granite–greenstone contact, particularly in the northern part of the greenstone belt. The eastern and southern extents of these deformed rocks are evident on aeromagnetic images (Fig. 4), which also suggest that they have undergone complex polyphase folding.

The granitoid gneiss (Williams et al., 1993; Wyche, 1999) is a fine- to coarse-grained quartz–feldspar–biotite rock characterized by compositional banding defined by variations in grainsize and relative abundance of biotite. The gneiss is mainly granodioritic to monzogranitic in composition, with original composition commonly difficult to determine because of cataclastic grainsize reduction of the protolith. The rocks typically contain various proportions of quartz, K-feldspar, plagioclase, and biotite. Accessory minerals may include opaque oxides, zircon, apatite, garnet, and sphene. Secondary minerals may include sericite, muscovite, epidote, sphene, and chlorite. The gneiss contains concordant slivers of amphibolite and mafic schist up to 2 m thick. Banding is on a scale of millimetres to tens of centimetres, and there is a common shallow-plunging mineral lineation. Some bands contain feldspar porphyroclasts up to 5 cm across, but pressure shadows around these grains do not give clear shear sense. Some of the numerous quartz and pegmatite veins that cut the gneiss at various angles are tightly folded, but the lack of any clear shear sense suggests a very strong compressional component to the last stages of deformation. They are probably similar in age to the c. 2685 Ma Wilbah gneiss on the LEONORA 1:250 000 sheet to the north (Black, L. P., pers. comm. to Champion, D. C., Stop 6 in Williams et al., 1993). Patches of granitoid gneiss in northeastern MENZIES (e.g. near Quartz Well) are similar in character to those described above, but are extensively intruded by monzogranite.

Mafic gneiss (*Anm*), in scattered outcrops in the Niagara area west of Kookynie township, near Mount Jessop, and east of Ivanhoe Bore (Witt, 1994a), is clinopyroxene–hornblende–plagioclase rock which typically has a gneissic banding, but may also be massive or patchy. Accessory minerals may include biotite, cummingtonite–grunerite, ilmenite, quartz, K-feldspar, sphene, and zircon. The gneiss is mainly granoblastic and fine grained, with millimetre- to centimetre-scale compositional banding defined by dark, hornblende-rich and light, pyroxene-rich layers and, to a lesser extent, variations in grainsize. Thin bands, lenses, and irregular patches of leucosome are also common. The banding and leucosomes are commonly folded or complexly deformed.

Granitoid rocks (Ag, Agb, Agcf, Agcs, Agcv, Agck, Agda, Agg, Aggl, Aggo, Agjo, Agm, Agmf, Agmy, Agn, Agot, Agul, Agy)

Granitoid rocks occupy large parts of MENZIES, but are typically concealed by Cainozoic cover, or are deeply weathered. Individual plutons are difficult to distinguish, but have been mapped where they have distinct petrographic characteristics, form in a distinctive intrusive setting (e.g. a pluton within a greenstone belt), or are clear on aeromagnetic images.

Undivided granitoid rock (*Ag*) is either too deeply weathered for identification, or in exposed areas that have not been visited or sampled. Weathered granite in breakaways is commonly capped by a siliceous duricrust that preserves the original texture. Most undivided granitoid is syenogranitic to granodioritic in composition, with monzogranite dominant.

Granitoid rock interleaved with subordinate greenstones (*Agb*) is common along some granite–greenstone contacts. These rocks are typically foliated, and contain abundant slices of greenstone from the adjacent greenstones. The granitoid rocks are typically similar in character to adjacent granitoids so that granitoids in the extensive area of interleaving south of Mount Jessop are dominantly granodioritic. Although not always clear, the interleaving is more likely tectonic than intrusive (Witt, 1994a).

The Copperfield Monzogranite (*Agcf*) is a distinctive, strongly deformed, biotite monzogranite (Rattenbury, M. S., Stop 5 in Williams et al., 1993), characterized by pervasive mineral lineation defined by trains of biotite and recrystallized quartz grains. Both K-feldspar and plagioclase form part of a fine-grained, quartzofeldspathic groundmass, although some coarser feldspar phenocrysts are preserved. Accessory minerals include garnet, opaque oxides, and apatite. Chlorite, muscovite, and epidote are secondary minerals. The Copperfield Monzogranite forms an extensive body in the northern part of the Mount Ida greenstone belt. The lineation is consistently shallow south plunging, and there is a weak foliation that is folded around an antiformal hinge at the southern end of the granite exposure. Attempts to date the Copperfield Monzogranite using the SHRIMP have been unsuccessful due to a lack of suitable minerals.

The Carpet Snake Syenogranite (*Agcs*), west of Dead Horse Rocks, is a biotite–muscovite syenogranite with coarse (≤6 cm) K-feldspar phenocrysts. Secondary minerals include carbonate, epidote, and fluorite. The granite is massive to weakly deformed, and extensively interleaved with greenstones (*Agb*) along its eastern contact (Witt, 1994a).

The Comet Vale Monzogranite (*Agcv*) is poorly exposed, massive, porphyritic monzogranite that intrudes the Menzies – Broad Arrow greenstone belt north of Lake Goongarrie (Swager, 1994). The fine- to medium-grained quartzofeldspathic groundmass contains phenocrysts of K-feldspar, zoned plagioclase, quartz, and aggregates of biotite. Although mainly undeformed, this monzogranite is strongly foliated on its eastern and northeastern side, where a major D_3 shear zone is interpreted within the greenstone belt.

The Clark Well Monzogranite (*Agck*) is a small, undeformed monzogranite intrusion in the central part of the Mount Ida greenstone belt south of Mount Morley (Wyche, 1999). It is a fine- to coarse-grained, weakly recrystallized, weakly seriate biotite monzogranite with vaguely zoned plagioclase and minor apatite, magnetite, zircon, and fluorite. Secondary minerals include chlorite, epidote, sphene, and muscovite. Nelson (1996) reported a

SHRIMP U–Pb zircon age of 2640 ± 8 Ma for the Clark Well Monzogranite, and this age has been used to constrain the last movement on the Ida Fault (e.g. Nelson, 1997).

The Dairy Monzogranite (*Agda*), which outcrops on the eastern edge of MENZIES and extends onto EDJUDINA (Chen, 1999), is an equigranular biotite monzogranite with accessory magnetite, apatite, and zircon (Witt and Davy, 1997).

Areas of monzogranite, granodiorite, tonalite, and diorite (*Agg*) outcrop near the Twin Hills Mining Centre, and around the Niagara Mining Centre, in the east of MENZIES; and at Day Rock in the west. In the Twin Hills area (Witt, 1994a), the rocks are broadly banded, with banding defined by composition and grainsize variation reflecting multiple intrusive episodes. Medium-grained biotite monzogranite is the major igneous phase, but has been extensively intruded by subparallel dykes of fine- to medium-grained syenogranite and monzogranite, and dykes of seriate to weakly porphyritic granodiorite. The granodiorite phase contains biotite and minor hornblende, and local xenoliths of monzogranite. In the Niagara area, this composite unit is similar to the material at Twin Hills, but with less-distinct banding. Day Rock is an outcrop of coarsely porphyritic granodiorite with coarse, tabular phenocrysts of K-feldspar (≤5 cm) in a medium-grained groundmass that contains biotite and hornblende, opaque oxide, and coarse sphene. There is also minor apatite, epidote, sericite, and zircon. A weak foliation is defined by alignment of mafic minerals. The SHRIMP U–Pb zircon crystallization age of granodiorite at Day Rock is 2676 ± 5 Ma (Nelson, 2000).

The Galah Monzogranite (*Aggl*) outcrops south of Jeedamya Homestead, where it contains primary muscovite and biotite, and secondary carbonate, epidote, and fluorite (Witt, 1994a).

The Goongarrie Monzogranite (*Aggo*), in southeastern MENZIES around the Goongarrie Homestead, is a seriate to sparsely porphyritic biotite monzogranite with K-feldspar phenocrysts up to 1.5 cm, and rare, small, biotite-rich enclaves (Witt, 1994b).

The Jorgenson Monzogranite (*Agjo*) outcrops between Menzies township and Lake Ballard (Swager, 1994). It is very strongly deformed along granite–greenstone contacts where it may be interleaved with amphibolite, and quartzofeldspathic schist that is locally garnetiferous. The monzogranite includes medium- to coarse-grained biotite syenogranite west of Jorgenson Tank.

Undivided monzogranite (*Agm*) is typical biotite monzogranite that may contain primary opaque oxides, apatite, muscovite, sphene, and zircon; and secondary carbonate, epidote, sericite, and rare fluorite. Composition may range from syenogranite to granodiorite, but monzogranite is by far the dominant rock type. Monzogranite may be fine to coarse grained, and equigranular to porphyritic. It is typically recrystallized, and massive to moderately deformed. Strongly deformed monzogranite (*Agmf*) has been distinguished where the tectonic fabric is very pronounced.

Monzogranite west of, and intruding, the Ida Fault is typical of the low-Ca granitoid group of Cassidy et al. (2002), with compositions ranging from syenogranite to monzogranite, little deformation, and relatively common minor fluorite. A sample of porphyritic biotite syenogranite from Hospital Rocks gave the youngest U–Pb SHRIMP zircon age obtained for a granitoid on MENZIES, of 2621 ± 5 Ma (Nelson, in prep.). However, a sample of monzogranite from Tower Hill, north of MENZIES near Leonora, has a SHRIMP U–Pb zircon age of 2753 ± 6 Ma (Fletcher et al., 2001), indicating that it is substantially older than most other granitoid rocks in the region.

The Mystery Monzogranite (*Agmy*) is a weakly seriate, fine- to medium-grained, massive biotite monzogranite intrusion in the southern part of the Mount Ida greenstone belt that probably postdates the major regional deformation (Wyche, 1999).

Gneissic granitoid rock (*Agn*) on the eastern side of the Mount Ida greenstone belt represents less strongly deformed granitoid gneiss (*Ang*) in which gneissic banding is only locally developed. The gneissic granitoid probably ranges in composition from granodiorite to monzogranite, but composition is difficult to determine owing to cataclastic grainsize reduction of the protolith.

The Oliver Twist Granodiorite (*Agot*) is a small, elongate pluton about 6 km east of Menzies township that ranges in composition from granodiorite to plagioclase-rich monzogranite (Swager, 1994). It is a weakly porphyritic biotite- and hornblende-bearing rock with minor opaque oxides and sphene, and common secondary epidote. Granite–greenstone contacts are strongly deformed.

The Ularring Monzogranite (*Agul*) is a large, ovoid pluton within the southern part of the Mount Ida greenstone belt that cuts across structures in the Ida Fault zone (Wyche, 1999). It is a fine- to coarse-grained, weakly seriate, biotite monzogranite that contains minor opaque oxides, muscovite, and rare apatite. Secondary minerals include epidote, chlorite, and rare fluorite. Although weakly recrystallized, the Ularring Monzogranite is mainly undeformed, cut only by several north-northeasterly trending faults with displacements up to 500 m and locally filled by quartz. These structures represent the last clear tectonic activity in the region prior to the emplacement of Proterozoic mafic and ultramafic dykes. The SHRIMP U–Pb zircon age of 2632 ± 4 Ma (Nelson, 2000) of the Ularring Monzogranite supports the c. 2640 Ma age of the last movement on the Ida Fault given by the age of the Clark Well Monzogranite.

Syenogranite to alkali-feldspar granite (*Agy*) forms common small intrusions west and northwest of Kookynie township (Witt, 1994a). They are typically undeformed, and show little evidence of recrystallization. Medium grained and equigranular, these rocks range in composition from monzogranite to alkali-feldspar granite. They contain biotite, opaque oxides, apatite, zircon, and fluorite. Numerous felsic dykes intrude similar rocks near the Mulga Plum mine.

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

Pegmatite (*p*) and quartz (*q*) veins are common on MENZIES, particularly at granite–greenstone contacts, but most are too small to show at 1:250 000 scale. Prominent veins of milky quartz are commonly associated with late, brittle structures, for example the north-northeasterly trending faults that cut the Ularring Monzogranite (*Agul*). These crosscutting quartz veins may be associated with pegmatite veins. Pegmatite veins in ultramafic schist near Wonder Well in the Mount Ida greenstone belt are associated with beryl (emerald) mineralization (Garstone, 1981).

PROTEROZOIC ROCK TYPES

Mafic dykes (*Ꭼdy*)

The region has also been intruded by a number of mainly east-northeasterly trending mafic and ultramafic dykes. Of probable Proterozoic age (Hallberg, 1987), they rarely outcrop but are readily recognized as positive and negative features on aeromagnetic images (Figs 3, 4). Individual dykes may differ in composition and character but most are unavailable for sampling. An outcropping dyke near the Mystery mine in the Mount Ida greenstone belt is medium grained with calcic plagioclase, subordinate clinopyroxene, and minor serpentinized olivine and opaque oxides (Wyche, 1999).

GREENSTONE STRATIGRAPHY

The western part of MENZIES lies in the Southern Cross Granite–Greenstone Terrane and the eastern part, east of the Ida Fault, lies within the Eastern Goldfields Granite–Greenstone Terrane (Fig. 1; Tyler and Hocking, 2001). Although different workers have presented local greenstone stratigraphies, there is no formal stratigraphy for either terrane.

Southern Cross Granite–Greenstone Terrane

Although there is no published regional stratigraphy for the Southern Cross Granite–Greenstone Terrane, recent mapping in the central Yilgarn Craton has described local greenstone belt stratigraphy based on correlation of banded iron-formation units. The best-preserved greenstone succession is in the Marda–Diemals greenstone belt west of MENZIES (Fig. 1). Here, Chen et al. (2001b, 2003) have described a lower greenstone succession that is dominated by mafic rocks with subordinate ultramafic and metasedimentary rocks including prominent, ridge-forming units of banded iron-formation. The age of the lower succession is poorly constrained but is probably about 3000 Ma. The lower succession is unconformably overlain in the Marda–Diemals greenstone belt by an upper c. 2730 Ma metamorphosed felsic and volcanic succession. Rocks similar to those of the Marda–Diemals lower succession are found in all greenstone belts in the Southern Cross Granite–Greenstone Terrane. However, the c. 2730 Ma upper succession is restricted to the Marda–Diemals greenstone belt. Felsic volcanic rocks that unconformably overlie greenstones of the lower succession in other greenstone belts are not necessarily the same age as those in the Marda–Diemals greenstone belt.

On MENZIES, greenstones of the Southern Cross Granite–Greenstone Terrane are found in the Illaara, Maninga and Yerilgee greenstone belts, and in the western part of the Mount Ida greenstone belt.

Illaara greenstone belt

The Illaara greenstone belt extends from the northwest of MENZIES over a strike length of about 80 km in the western part of the sheet area. Although poorly exposed for the most part, the stratigraphy in this greenstone belt differs markedly from most other greenstone belts in the region in that it contains substantial amounts of quartzite and quartz-rich metasedimentary rocks. There are very few unequivocal younging indicators in the greenstone belt, but rare cross-beds and some graded bedding in metasedimentary units suggest younging to the west.

At the lower or eastern contact, monzogranite is intrusive and locally tectonized. A generalized stratigraphy of the Illaara greenstone belt (Fig. 5) shows that it comprises a succession with quartzite and quartz-rich metasedimentary rocks, up to about 900 m thick, at the base. A strongly deformed contact between the quartzite and an overlying interval of mafic, ultramafic, and metasedimentary rocks including banded iron-formation, chert, and shale may represent a structural break. A zone of strong deformation containing mafic and ultramafic schist, chert breccia, and large, discontinuous blocks of chert and banded iron-formation marks the top of this package. This zone may also represent a structural discontinuity. In the central part of the greenstone belt (Fig. 3), this interval is overlain by

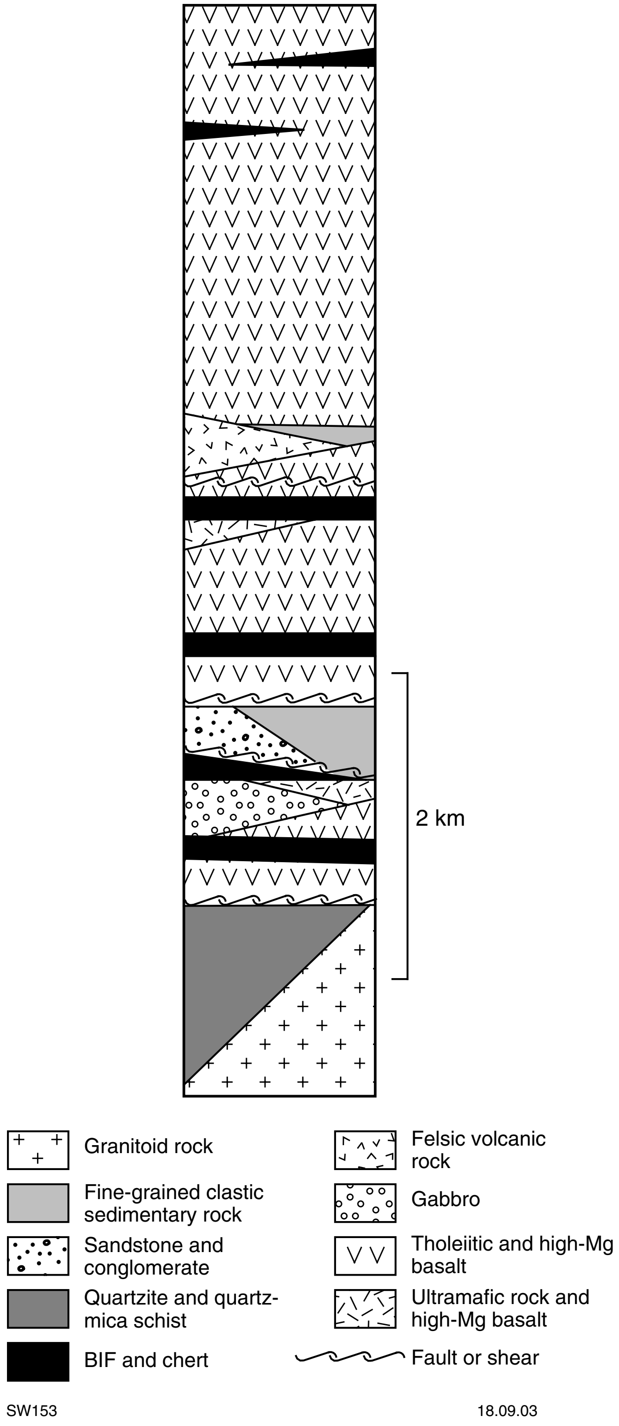

Figure 5. Generalized stratigraphy of the Illaara greenstone belt

a thick lens of quartz-rich metasedimentary rocks, including sandstone and conglomerate, that may have been structurally thickened. The stratigraphy above the conglomeratic metasedimentary unit is poorly constrained owing to a lack of continuous outcrop, but the succession includes basalt, ultramafic rocks, banded iron-formation, chert and some poorly exposed felsic rocks associated with a unit of fine-grained, recrystallized quartzite and shale. The upper part of the succession comprises a thick unit of mainly tholeiitic basalt that contains thin intervals of banded iron-formation and ferruginous chert. Granite–greenstone contacts in the northwest are strongly deformed. Contacts in the southwest and south are less well exposed but granitoid rocks are not strongly deformed, and are, at least locally, intrusive into greenstones.

Although there are no direct geochronological data for the Illaara greenstone belt, SHRIMP detrital zircon studies of quartzite from this greenstone belt and the adjacent Maynard Hills greenstone belt to the north suggest a maximum depositional age for the lowermost quartzite of c. 3131 Ma. The detrital zircon studies of quartzite in the Illaara and Maynard Hills greenstone belts suggest that these rocks may be related to quartzite and conglomerate in the western part of the Yilgarn Craton (Wyche et al., in prep.). Similar quartzite has been noted locally at the base of the succession in the Marda–Diemals greenstone belt but no SHRIMP data have been obtained from these exposures (Chen et al., 2001b).

Yerilgee greenstone belt

The poorly exposed Yerilgee greenstone belt crosses the southwestern corner of MENZIES where it comprises a folded and deformed succession containing banded iron-formation, ultramafic schist, and weathered mafic rock. No clear succession has been established for this greenstone belt. However, outcrop patterns in adjacent areas suggest that a lower mafic interval with thin intercalations of ultramafic rock, including komatiite, is overlain by a succession of banded iron-formation and chert interlayered with ultramafic rock, gabbro, dolerite, and basalt (Wyche, 1998; Greenfield, 2001; Chen and Wyche, 2003).

Maninga greenstone belt

The Maninga greenstone belt is exposed in some deeply weathered outcrops of ultramafic, mafic and metasedimentary rocks, including chert and banded iron-formation, in the southwestern part of MENZIES where it is extensively intruded by granitoid rocks. Aeromagnetic data suggest that the Maninga greenstone belt extends south onto KALGOORLIE (Wyche, 1998).

Mount Ida greenstone belt

The Ida Fault, which marks the boundary between the Southern Cross and Eastern Goldfields Granite–Greenstone Terranes is probably a complex structure represented by deformation throughout the Mount Ida greenstone belt, particularly the eastern part, and into the gneissic rocks to the east. The western part of the greenstone belt (Fig. 3) is characterized by the presence of a rock association, typical of the Southern Cross Granite–Greenstone Terrane, that comprises abundant metabasalt including komatiitic basalt, banded iron-formation, and subordinate ultramafic rocks and metagabbro. No younging indicators have been reported. The Ballard Fault, at the eastern contact between greenstones and gneissic and granitoid rocks, is probably the northern extension of the Zuleika Shear on KALGOORLIE (Wyche, 1998).

The most extensive area of greenstones of the Southern Cross Granite–Greenstone Terrane in the Mount Ida greenstone belt is in the north, in the poorly exposed area around Mount

Mason. Here, shallow to steep, east-dipping units of banded iron-formation, with intercalated mafic rocks, is structurally overlain by a very poorly exposed succession that appears to be dominated by metamorphosed mafic volcanic rocks, but includes gabbroic and ultramafic rocks. The eastern boundary of the Southern Cross Granite–Greenstone Terrane is unclear as the western trace of the Ida Fault is difficult to determine owing to the poor exposure. It is probably a composite of a number of faults and shear zones within the Mount Ida greenstone belt, with related movement on the Ballard Fault, and in the gneissic area to the east. Northwest of Corbett Well, units of banded iron-formation are deformed in what may be a fault splay from the Ida Fault.

In the centre of the sheet area, the western part of the Mount Ida greenstone belt has been extensively intruded by monzogranite, and most of the greenstones of the Southern Cross Granite–Greenstone Terrane may have been removed. In the south, west of Riverina Homestead, a prominent photolineament coincides with a magnetic lineament and a zone of deformation that contains abundant ultramafic and Mg-rich rocks. West of the lineament, a deformed and metamorphosed ridge of banded iron-formation lies west of a thick succession of dominantly tholeiitic metabasalt with subordinate metagabbro and thin metasedimentary intervals. This lineament may mark the eastern limit of the Southern Cross Granite–Greenstone Terrane.

Eastern Goldfields Granite–Greenstone Terrane

The Eastern Goldfields Granite–Greenstone Terrane has been divided into a number of tectono-stratigraphic terranes so that the area between the Ida Fault and the Moriaty Shear Zone forms part of the Kalgoorlie Terrane, and the area east of the Moriaty Shear Zone, including the Melita Complex, forms part of the Gindalbie Terrane (Fig. 3; Swager et al., 1995; Witt, 1995; Swager, 1997).

According to Hill et al. (1995, 2001), a regionally extensive ultramafic unit, the Walter Williams Formation, extends from the Siberia area northwest of Kalgoorlie in the Ora Banda greenstone belt, along the Menzies – Broad Arrow greenstone belt, and across to the Mount Ida greenstone belt. Swager et al. (1995) and Swager (1997) correlated the Walter Williams Formation with the major komatiite unit in the Kalgoorlie and Kambalda regions to produce a regional stratigraphy for a fault-bounded succession extending from Menzies to Norseman that they called the Kalgoorlie Terrane. In their stratigraphy, the regional komatiite unit lies between basalt formations, and the mafic–ultramafic sequence is overlain by felsic volcanic and volcaniclastic rocks. More recent work, including new SHRIMP geochronology, supports the overall stratigraphic framework established for the Kalgoorlie Terrane, and indicates complex relationships between rock types from different tectonic settings in areas farther to the east (Krapez et al., 2000; Brown et al., 2001).

Mount Ida greenstone belt

The eastern part of the Mount Ida greenstone belt is dominated by metamorphosed mafic and ultramafic volcanic rocks that are typical of the Kalgoorlie Terrane succession of Swager et al. (1995). The prominent komatiitic units in this greenstone belt have been folded and faulted, and the original stratigraphic succession has been extensively disrupted. However, where good sections are preserved, for example in the Kurrajong Anticline (Fig. 3), the ultramafic rocks are very similar in character to, and have been correlated with, those to the southeast to form the Walter Williams Formation of Hill et al. (1995, 2001). The ultramafic rocks are underlain and overlain by mafic volcanic and intrusive rocks, including tholeiitic and komatiitic basalts, like those described for the Kalgoorlie Terrane succession to the south in the Ora Banda greenstone belt (Witt, 1994b; Wyche and Witt, 1994). Although locally intruded by felsic porphyry, there are no felsic volcanic rocks in this greenstone belt.

Ora Banda greenstone belt

Metagabbro and tremolite–chlorite schist, at the northern end of the Kurrawang Syncline in the Ora Banda greenstone belt, outcrop on the southeastern edge of MENZIES (Fig. 3). The tremolite–chlorite schist is probably Wongi Basalt of the Ora Banda succession of Wyche and Witt (1994).

Menzies – Broad Arrow greenstone belt

On MENZIES, the Menzies – Broad Arrow greenstone belt extends from Comet Vale in the southeast, north to the Menzies township, where it divides into an eastern arm that runs north to meet Lake Ballard at Round Hill, and a western arm that includes the Ghost Rocks area. Swager (1994) divided the greenstone belt into western and eastern tectono-stratigraphic domains separated by the Menzies Shear Zone (Fig. 3).

The western domain, which is continuous along the western side of the Menzies – Broad Arrow greenstone belt and includes the Ghost Rocks area, contains a major ultramafic unit, the Walter Williams Formation of Hill et al., (1995, 2001). Underlying and overlying basaltic units similar to those in the Ora Banda greenstone belt are exposed locally near Comet Vale, and in the Ghost Rocks area. Textures in komatiites and differentiation in mafic sills indicate that the sequence youngs overall to the east, although the situation in the Ghost Rocks area is complicated by a possible sheared syncline–anticline pair (Swager, 1994). A sheared felsic porphyritic rock within the succession at Ghost Rocks, possibly derived from a volcanic or volcaniclastic protolith, has a SHRIMP U–Pb zircon age of 2691 ± 6 Ma (Nelson, 1995). However, this rock may be a later felsic intrusive.

In the eastern domain, east of the Menzies Shear Zone, structural complexity and strong deformation and metamorphism of the rocks does not allow detailed breakdown of stratigraphy (Swager, 1994). The major rock types in the domain include metamorphosed ultramafic rocks including komatiite; metamorphosed mafic intrusive and extrusive rocks including abundant komatiitic basalt; and metasedimentary rocks, particularly fine-grained varieties that may have been shale or chert units. Strong deformation and poor exposure precludes close examination of field relationships in the abundant clastic metasedimentary rocks, including polymictic conglomerate, that lie immediately east of the Menzies Shear Zone in the south. However, they are probably equivalent to similar rocks in late, clastic basins elsewhere in the Eastern Goldfields Granite–Greenstone Terrane as described by Krapez et al. (2000).

Malcolm greenstone belt

Part of the Malcolm greenstone belt occupies the northeastern corner of MENZIES where it contains predominantly bimodal metavolcanic and associated metasedimentary rocks of the Melita Complex (Hallberg, 1985; Witt, 1994a; Morris and Witt, 1997; Brown et al., 2002), and layered mafic intrusive rocks. Stratigraphy in the area is complicated by multiple episodes of deformation.

There has been no detailed stratigraphy described for the Melita Complex. However, measured sections by Brown et al. (2002) show it to be a bimodal succession, probably more than 3000 m thick, with a mafic-dominated lower part, and a felsic-dominated upper part. The lower part contains basalt and basaltic andesite lavas, including pillow basalts, hyaloclastite, pillow breccia, and minor rhyolitic to dacitic lavas that are enriched in rare earth and high-field-strength elements. The upper part comprises felsic volcaniclastic rocks, shale and sandstone, and high-silica rhyolite lava, with interbeds of mafic lava. Textures in fine-grained sedimentary rocks such as ripples and cross-beds indicate shallow-water deposition. However, locally emergent conditions are indicated by shard-rich material and accretionary lapilli. Coarse breccias and sandstones lack evidence of hot emplacement, suggesting that they may be debris flows or large-volume proximal turbidites that represent reworked rhyolite lava and pyroclastic deposits. SHRIMP U–Pb zircon data indicate a depositional age of c. 2683 Ma for the Melita Complex (Nelson, 1996; Brown et al., 2002).

The Melita Complex has been extensively intruded by layered dolerite and leucodolerite dykes and sills that are up to 400 m thick (Witt, 1994a, 1995). They are not compositionally equivalent to mafic rocks of the Melita Complex, but are similar to a poorly exposed and structurally dismembered, layered mafic–ultramafic body to the south in the Niagara district that Witt (1994a) called the Niagara Layered Complex (Fig. 3).

STRUCTURE

The Southern Cross and Eastern Goldfields Granite–Greenstone Terranes are juxtaposed along the Ida Fault, a regional-scale structure that, although extensively intruded by granitoid rock, can be traced using rock relationships, geophysical and Landsat imagery, and air photographs for more than 500 km from north to south across the eastern part of the Yilgarn Craton (Fig. 1).

The structural histories of the Southern Cross and Eastern Goldfields Granite–Greenstone Terranes have common elements, with both terranes showing evidence of an early north–south shortening event followed by a protracted period of east–west to east-northeast – west-southwest compression (Table 1). Absolute timing of various deformation events is poorly constrained, and some events in the Southern Cross Granite–Greenstone Terrane may pre-date similar styles of deformation in the Eastern Goldfields (Greenfield et al., 2000).

IDA FAULT

On Menzies, the Ida Fault trace is taken to be the westernmost of the package of faults that disrupt and dismember the greenstones in the Mount Ida greenstone belt (Fig. 3). However, the fault is probably a complex zone that involves ductile deformation within the greenstone belt, along the Ballard Fault (Rattenbury, M. S., Stop 4 in Williams et al., 1993), and in the granitoid gneiss to the east. A deep-crustal seismic traverse showed the Ida Fault to be a gently east-dipping structure that can be traced to a depth of 25–30 km (Swager et al., 1997). The seismic data suggest normal displacement on the Ida Fault, but it may have a long and complex history that included episodes of tectonic inversion. Where mineral lineations are preserved in the gneissic rocks, they are typically shallow plunging (Embry, 1999; Wyche, 1999) near the granite–greenstone contact, with more steeply plunging mineral lineations in gneiss away from the contact (Rattenbury, M. S., Stop 4 in Williams et al., 1993). There are no unequivocal shear-sense indicators in either the greenstones or the adjacent granitoid gneiss. However, both sinistral (Rattenbury, M. S., Stop 4 in Williams et al., 1993) and dextral (Embry, 1999) senses of movement have been interpreted for the Ballard Fault. The complex layer-parallel faulting within the greenstone belt indicated by repetition of ultramafic units, tight folding within the granitoid gneiss,

Table 1. Summary of the geological history of the MENZIES region

Age (Ma)	*Southern Cross Granite–Greenstone Terrane*	*Eastern Goldfields Granite–Greenstone Terrane*
<c. 3130 Ma	Deposition of lower greenstone succession	
	North–south compression: easterly trending reverse faulting, layer-parallel foliation, and tight to isoclinal folding (D_1)	
>2730 Ma	East–west shortening: early upright folding (D_2); granitoid intrusion after c. 2800 Ma	Granitoid intrusion after c. 2750 Ma
c. 2730 Ma	Deposition of felsic and clastic sedimentary successions to the west (Marda–Diemals greenstone belt)	
<2730 Ma	Continued east–west shortening: intrusion and deformation of granitoid rocks; development of gneissosity	
c. 2700 Ma		Deposition of regional komatiite formation
c. 2680 Ma	Continued east–west shortening; intrusion of granitoid rocks	Eruption of the Melita Complex and deposition of associated sedimentary rocks; granitoid intrusion; extensional deformation
<2680 Ma	Continued east–west shortening increasingly partitioned into regional faults and shear zones; reorientation of earlier (D_2) structures; intrusion of granitoid rocks	Shortening in various orientations: sequence repetition, thrusting and recumbent folding (D_1); widespread granitoid intrusion
		East–west shortening: upright folding; reverse faulting (D_2); widespread granitoid intrusion
c. 2650 Ma		Deposition of clastic sedimentary rocks
<2650 Ma		East–west shortening: continued upright folding; reverse faulting (D_2); regional-scale shear zones active (D_3)
	Intrusion of low-Ca granitoid rocks	Intrusion of low-Ca granitoid rocks
c. 2635 Ma	Intrusion of monzogranite into the Ida Fault	Intrusion of monzogranite into the Ida Fault
<2635 Ma	East-northeast – west-southwest shortening to produce north-northeasterly and southeasterly trending brittle structures	East-northeast – west-southwest shortening: north-northeasterly and southeasterly trending brittle structures (D_4)
	Intrusion of dominantly easterly trending mafic and ultramafic dykes	Intrusion of dominantly easterly trending mafic and ultramafic dykes

and steeply plunging mineral lineations in some granitoid gneiss, suggest substantial reverse movement across the fault zone.

SOUTHERN CROSS GRANITE–GREENSTONE TERRANE

There have been relatively few studies of the deformation history of the Southern Cross Granite–Greenstone Terrane. Dalstra et al. (1999) and Chen et al. (2001a,b) have described deformation for the central part of the Southern Cross Granite–Greenstone Terrane, in which a north–south compressional event that produced tight to isoclinal folds and reverse faults was followed by a protracted period of east–west compression.

There is no unequivocal evidence of the early thrusting and folding event (D_1) of Dalstra et al. (1999) and Chen et al. (2001b) on MENZIES. The best exposed and most complete sections of greenstones are preserved in the Illaara greenstone belt and the northern part of the Mount Ida greenstone belt. Although banded iron-formation in these areas contains small-scale isoclinal and intrafolial folds that may have formed during D_1 deformation, the meso- and large-scale refolded folds that have been noted in greenstone belts to the west have not been recognized

In greenstone belts to the west of MENZIES, D_2 east–west shortening produced large-scale, northerly trending upright folds. Precise timing of this deformation is difficult to determine, and there may have been several stages of approximately coaxial deformation. For example, there is local evidence of pre-2730 Ma D_2 folding in the Marda–Diemals greenstone belt to the west (Chen et al., 2001b, 2003); widespread, locally preserved, commonly northerly trending gneissosity, typically found in granitoid rocks older than c. 2700 Ma (e.g. Nelson, 2002), may also be related to east–west shortening; and widespread granitoid rocks emplaced between c. 2690 and c. 2650 Ma commonly preserve a northerly trending foliation (Chen et al., 2001b). Folding attributed to D_2 is apparent in the Yerilgee greenstone belt in the southwest (Wyche, 1999), but is better displayed in the Yerilgee greenstone belt to the west on the LAKE GILES 1:100 000 sheet (Greenfield, 2001). Upright D_2 folds are not evident in the Southern Cross greenstones elsewhere on MENZIES where the major east–west shortening episode may have been accommodated by movement on strike-parallel shear zones in the Illaara and Mount Ida greenstone belts.

Continued east–west shortening in the granites and greenstones to the west resulted in the impingement of granitoids into the greenstone belts as large, rigid blocks that realigned earlier structures to produce regional-scale arcuate structures bounded by major D_3 shear zones. Later (D_3) upright folding tightened earlier structures, or overprinted those that had been realigned during the granitoid impingement. The age of this deformation is not well constrained, but it was probably active until at least c. 2655 Ma (Chen et al., 2001a,b). The arcuate structures are not present in the Southern Cross Granite–Greenstone Terrane on MENZIES where the continuing east–west compression was probably accommodated by sustained movement on the faults in the Illaara and Mount Ida greenstone belts as suggested above for the D_2 deformation.

North-northeasterly trending aeromagnetic lineaments, some of which coincide with quartz veins, and less prominent east-southeasterly lineaments, are common in both the Southern Cross and Eastern Goldfields Granite–Greenstone Terranes (Fig. 4). The lineaments represent fractures and faults that cut across granitoids, locally offset greenstones, and post-date all structures except fractures associated with the late mafic and ultramafic dykes. They are brittle structures that indicate late east-northeast – west-southwest shortening. The absolute age of these structures is uncertain (Swager et al., 1995; Chen et al., 2001b), but they pre-date the Proterozoic dykes.

EASTERN GOLDFIELDS GRANITE–GREENSTONE TERRANE

Numerous local studies and regional reviews of the deformation history in the Eastern Goldfields Granite–Greenstone Terrane have failed to produce a consensus as to the sequence and timing of deformation events. Regional deformation studies in the Eastern Goldfields (e.g. Archibald et al., 1978; Platt et al., 1978; Swager et al., 1995; Swager, 1997; Weinberg et al., 2003) have long recognized four main phases of deformation — a poorly understood D_1 thrust stacking and recumbent folding event; east-northeast–west-southwest shortening that is characterized by upright folds (D_2) and regional-scale shear zones (D_3); and a D_4 regional shortening episode that produced conjugate brittle faults and fractures as described above for the Southern Cross Granite–Greenstone Terrane. The nature of the early (D_1) deformation has been interpreted variously as extensional (e.g. Passchier, 1994); compressional (e.g. Swager et al., 1995); or involving combinations of extension and compression (e.g. Williams and Currie, 1993). Post-D_1 and post-D_2 extensional events have also been proposed (e.g. Swager, 1997). The accumulating body of SHRIMP geochronological data on granitoid rocks in the region (e.g. Nelson, 1997; Cassidy et al., 2002) suggests that it is likely that D_1 coincided with granitoid plutonism (e.g. Swager, 1997; Weinberg et al., 2003). However, granitoid intrusion persisted throughout the major period of deformation, ceasing prior to the late brittle deformation (Table 1).

Evidence of the earliest thrusting and extensional deformation (D_1) on MENZIES is largely circumstantial, with the suggestion that many regional-scale faults and shear zones had a long history (Swager, 1994; Wyche, 1999). Refolded folds within the granitoid gneiss (Figs 3, 4) on the eastern side of, and structural repetitions within, the Mount Ida greenstone belt indicate a complex history, much of which may have taken place during D_2–D_3 shortening. Elsewhere in the Mount Ida greenstone belt, an early (D_1) deformation is indicated by the folding of foliation in the Copperfield Monzogranite around a D_2 fold hinge, probably a northern extension of the Kurrajong Anticline (Fig. 3). The granite–greenstone contact is strongly deformed but the fabric intensity dissipates rapidly in the greenstones, indicating ductile deformation localized near the contact (Rattenbury, M. S., Stop 5 in Williams et al., 1993). Witt (1994a) noted that interleaving of granite and greenstone in the southern part of the Malcolm greenstone belt has been folded. He attributed the interleaving to D_1. Isoclinal folds in the same area that have been folded were also attributed to D_1. In the northeastern part of the Malcolm greenstone belt, interpreted early folds and faults that have been folded are probably also D_1 structures (Witt, 1994a). As these structures are found within the Melita Complex, they indicate that D_1 was active after c. 2683 Ma.

The progressive D_2–D_3 east–west shortening produced folds that various authors have assigned on the basis of overprinting relationships (e.g. Witt, 1994a; Swager et al., 1995). Regional-scale folds assigned to D_2 include the Kurrawang Syncline and the Goongarrie – Mount Pleasant Anticline (Fig. 3), which are mainly on KALGOORLIE (Wyche, 1998). Swager (1994) also interpreted smaller scale D_2 folds within the Menzies – Broad Arrow greenstone belt. These structures include a syncline–anticline pair in the Ghost Rocks succession, and another fold pair near Kings Dam. Although the folded foliation in the Copperfield Monzogranite in the north of the Mount Ida greenstone belt is attributed to D_1, the strongly developed, shallow south-plunging mineral lineation in the monzogranite is parallel to a D_2 fold hinge, which is parallel to, but slightly displaced from, the D_2 Kurrajong Anticline fold hinge (Fig. 3). D_2 folding deformed clastic sedimentary rocks that were deposited at c. 2655 Ma (Krapez et al., 2000).

During continued east–west shortening, D_2–D_3 strain was increasingly partitioned into developing regional-scale faults and shear zones, some of which may have been active during earlier stages of the deformation. The Moriaty and Mount George Shear Zones are part of a complex structural domain between the Menzies – Broad Arrow and the Malcolm greenstone belts (Fig. 3). They form the boundary between the Kalgoorlie and Gindalbie Terranes of Witt (1995). Williams et al. (1989) and Witt (1994) regarded the Mount George Shear Zone as a D_3 structure, whereas Passchier (1994) regarded it as a terrane boundary whose most significant movement took place during D_1, but which was probably later reactivated. The complexity of the structural history of the Mount George Shear Zone is indicated by description of sinistral movement in the Leonora area by Williams et al. (1989); description of dextral movement in northeastern MENZIES by Witt (1994a); interpretation of east-directed normal movement by Passchier (1994); and interpretation, based on deep-crustal seismic evidence, of an east-dipping listric structure by Blewett et al. (2002). A poorly outcropping, strongly magnetized granitoid body in northeastern MENZIES (Fig. 4) appears to indicate at least late-stage sinistral movement on the Mount George Shear Zone.

The D_3 faults and shear zones commonly show evidence of both compressional and transcurrent movement consistent with transpressional movement. They typically follow granite–greenstone contacts, but may lie within greenstone belts, in some cases forming boundaries between tectono-stratigraphic domains (e.g. the Menzies Shear Zone). The best estimate of the age of cessation of major movement is provided by the ages of undeformed granites that intrude the Ida Fault. SHRIMP U–Pb zircon ages have been obtained for two such granites — the Clark Well Monzogranite at 2640 ± 8 Ma (Nelson, 1996), and the Ularring Monzogranite at 2632 ± 4 Ma (Nelson, 2000).

The last deformation in the region, prior to the emplacement of the mafic and ultramafic dykes, is represented by the conjugate fracture sets described above for the Southern Cross Granite–Greenstone Terrane. These structures cut across all granitoids, with north-northeasterly trending faults showing dextral displacements of up to 500 m where they cut the c. 2632 Ma Ularring Monzogranite.

METAMORPHISM

Binns et al. (1976) described metamorphic patterns in the central and eastern Yilgarn Craton, showing that metamorphism in the region ranges from very low grade (prehnite–pumpellyite facies) to relatively high grade (upper amphibolite facies). High-grade rocks are typically found adjacent to granite–greenstone contacts, with grade decreasing towards the centres of greenstone belts. Subsequent regional studies in the Southern Cross (Ahmat, 1986) and Eastern Goldfields Granite–Greenstone Terranes (Mikucki and Roberts, in prep.) have been consistent with Binns et al. (1976), but have refined the detailed patterns of metamorphic-grade distribution.

Limited data indicate that pressures attained during metamorphism in the Yilgarn Craton were relatively low, with maximum pressures in greenstones typically around 400 MPa, and maximum temperatures up to 550° C. During metamorphism, temperatures are elevated in clockwise P–T–t path in a relatively low pressure environment (Ridley, 1993; Ridley et al., 1997; Dalstra et al., 1999). In both the Southern Cross and Eastern Goldfields Granite–Greenstone Terranes, peak metamorphism is broadly coincident with the last major period of granitoid intrusion during D_2–D_3 (Swager, 1997; Chen et al., 2001b). In some of the larger greenstone belts, an early, very low grade, low-strain metamorphic event is preserved in the centre of the greenstone belts, and overprinted by the later, granite-related metamorphism (e.g. Dalstra et al., 1999).

Widespread low-grade, retrograde metamorphism is indicated by talc–carbonate alteration of ultramafic rocks; saussuritization of plagioclase; chloritic alteration of amphiboles and biotite; alteration of ilmenite to leucoxene; and late growth of quartz and epidote minerals.

Metamorphic patterns on MENZIES are similar to those described above. Greenstone belts west of the Ida Fault are generally not well exposed. However, mineral assemblages in the Illaara greenstone belt (Wyche, 1999) include development of grunerite in banded iron-formation; clinopyroxene, biotite, dark blue-green hornblende, and tremolite–actinolite in metamorphosed felsic and mafic rocks; and biotite, andalusite, cordierite, and orthoamphibole in pelitic rocks. These assemblages suggest metamorphism in the high-temperature, low-pressure amphibolite facies as reported by Ahmat (1986). In the Mount Ida greenstone belt, garnet or clinopyroxene in some mafic rocks, and olivine in some ultramafic rocks (with retrograde serpentine alteration), also suggest local amphibolite-facies conditions (Wyche, 1999). Farther east, the presence of kyanite, andalusite, chloritoid, staurolite, biotite, and garnet in the pelitic and mafic rocks of the Menzies – Broad Arrow greenstone belt indicates metamorphism in the middle to upper amphibolite facies (Swager, 1994).

In the Malcolm greenstone belt, Witt (1994a) identified a high-grade metamorphic zone, and a relatively low grade metamorphic zone. The high-grade zone is restricted to the granite–greenstone contact in the southern part of the greenstone belt around the Niagara Mining Centre, and the interleaved granitoids and greenstones farther south. The zone is typically 100 m to 1 km wide, but structural repetition has locally increased the width to 6 km. In the high-grade zone, mafic gneiss is locally interleaved with amphibolite and foliated granitoids. Iron-rich rocks contain grunerite and hedenbergite. Metamorphic conditions resulted in the generation of local, small-volume, dioritic partial melts from mafic rocks, and pegmatitic segregations from pelitic rocks. The low-grade zone, mainly greenschist or lower amphibolite facies, of Witt (1994a) occupies most of the rest of the greenstone belt. Local preservation of amphibolite along the western side of the greenstone belt indicates elevated metamorphic grades along this contact.

Common overgrowth of metamorphic minerals over deformation fabrics in all greenstone belts suggests that peak metamorphic conditions persisted late into the major D_2–D_3 compressional deformation (Witt, 1994a; Swager, 1994; Wyche, 1999).

PHANEROZOIC GEOLOGY

SANDSTONE OF UNCERTAIN AGE (*st*)

A low rise of deeply weathered sandstone west of Blue Well consists of poorly sorted, fine- to coarse-grained, angular quartz in a clay matrix. This outcrop may be part of a silcrete profile.

CAINOZOIC GEOLOGY

More than 75% of MENZIES is covered by Cainozoic regolith, and much of the exposed rock is deeply weathered. The classification system used is that of Hocking et al. (2001), which is based on the Residual–Erosional–Depositional (RED) scheme of Anand et al. (1993). A detailed description of regolith materials, processes, and evolution of the Yilgarn Craton is presented in Anand and Paine (2002).

Relict units (*Rd*, *Rf*, *Rgp$_g$*, *Rk*, *Rz*, *Rzu*)

Undivided duricrust (*Rd*) may be either siliceous or ferruginous, and occurs predominantly in areas underlain by granitoid rocks. Many areas of duricrust are covered by a thin layer of yellow sand with clay, silt, and nodular or pisolitic laterite gravel (*Sl*). Such areas are generally apparent on Landsat images as they are more ferruginous than typical eolian sandplain, and may be bounded by breakaways. Ferruginous duricrust (*Rf*), including laterite (Anand and Paine, 2002), is nodular, pisolitic or massive, and most common over areas of greenstone. There are extensive areas of ferruginous duricrust, mainly over mafic rocks, in all greenstone belts on MENZIES. Quartzofeldspathic sand over granitoid rock (Rgp_g) is red-yellow sand with scattered, typically weathered, granite outcrops, commonly with areas of quartz scree. Calcrete (*Rk*) forms over both granites and greenstones, and is commonly associated with drainage, but most areas are too small to show at 1:250 000 scale. Siliceous duricrust (*Rz*), including silcrete (Anand and Paine, 2002), is common over granite, and is best exposed in breakaways where it commonly preserves a granular texture. However, most areas of siliceous duricrust are too small to be shown at the map scale or have been included with undivided duricrust. Silica caprock over ultramafic rock (*Rzu*) is a distinctive brown siliceous unit that commonly preserves relict igneous textures in ultramafic cumulates.

Depositional units (*C*, *Cf*, *W*, *Wc*, *Wf*, *Wq*, *A*, A_p, L_d, L_l, L_m, *S*, *Sl*)

Undivided colluvium (*C*) includes proximal deposits of coarse to fine talus on steep to gently sloping ground adjacent to outcrops and breakaways. Areas of colluvium dominated by ferruginous gravel and reworked duricrust (*Cf*) blanket deeply weathered greenstones in the Illaara and Mount Ida greenstone belts.

Sheetwash deposits cover gently sloping plains, typically adjacent to areas of drainage. Undivided sheetwash deposits (*W*) may comprise sand, silt, and clay. An area of clay-rich sheetwash (*Wc*) adjacent to outcrops of mafic rocks is shown in the Illaara greenstone belt. Ferruginous sheetwash (*Wf*) contains abundant fine, ferruginous gravel. Sheetwash dominated by quartz-rich debris (*Wq*) is common near granitoid outcrops, but generally not very extensive. However, there is a broad sheet of this material near the Boudie Rat mine.

Alluvium (*A*) comprises clay, silt and gravel in active drainage channels, and may include broader areas with braided channel patterns. Isolated claypans (A_p), away from major lacustrine systems, fill with water during major rainfall events.

Drainage on MENZIES flows into a series of salt lakes, including Lake Ballard, Lake Moriaty, Lake Goongarrie and Lake Marmion (Fig. 2), that together constitute the western end of the south-southeasterly flowing Yindarlgooda Palaeoriver (Hocking and Cockbain, 1990). Lakes (L_l) contain silt, mud and sand deposits, with a veneer of halite, gypsum, or both. Sand dunes adjacent to playa lakes (L_d) may contain sand, silt, and evaporitic minerals. They are active systems and are not densely vegetated. More stable, and typically more densely vegetated, areas adjacent to lakes contain mixed alluvial, eolian, and lacustrine deposits (L_m).

Sandplain deposits (*S*), characterized by yellow sand, form extensive sheets over areas of granitoid rocks. This material may be residual in part, but probably contains a substantial eolian component. Sandplain with minor silt and clay that commonly contains a component of nodular or pisolitic laterite gravel (*Sl*) overlies areas of duricrust. The sand is yellow to reddish yellow and may have both residual and eolian components. These areas have been interpreted mainly from Landsat images.

ECONOMIC GEOLOGY

Gold is the only mineral commodity with any significant recorded production from MENZIES. Silver has been a common byproduct of gold mining in this area. Resources of various mineral deposits are available through the Department of Industry and Resources (DoIR) mines and mineral deposits information database (MINEDEX), which can be accessed via the Department's website (www.doir.wa.gov.au/MINEDEX2/).

GOLD

Early descriptions, commonly including maps, plans, and production data, of mines and mining districts on MENZIES, are contained in various GSWA reports and bulletins of the era. For the Mount Ida greenstone belt, these include Gibson (1904, 1907) and Feldtmann (1915, 1916); for the Malcolm greenstone belt, Jutson (1921a); and for the Menzies – Broad Arrow greenstone belt, Jutson (1921b) and Woodward (1906). Early descriptions of a number of gold deposits were also given in Maitland (1919). Detailed descriptions of all deposits in the Menzies – Broad Arrow greenstone belt with a recorded production of more than 5 kg were presented by Witt (1993), and Hallberg (1985) discussed controls on mineralization for some deposits in the Malcolm greenstone belt. Legge et al. (1990) described the geology of the Bottle Creek deposit in the Mount Ida greenstone belt. The recorded gold production data for deposits in all mining districts in Western Australia until about 1950 is presented in Department of Mines (1954). There are no current, accurate, detailed production data that cover the whole MENZIES sheet area.

Most of the gold production on MENZIES has come from the greenstones of the Eastern Goldfields Granite–Greenstone Terrane, with the Malcolm and Menzies – Broad Arrow greenstone belts the most richly endowed.

Apart from alluvial deposits in the Tampa Mining Centre, all the gold mined in the Malcolm greenstone belt has been from epigenetic, vein- and lode-style deposits that formed late in the deformation history. Major host rocks include granitoid rocks, metasedimentary, and metamorphosed mafic and felsic volcanic rocks in the Kookynie Mining Centre; mafic intrusive rocks in the Desdemona and Niagara Mining Centres; and metamorphosed felsic volcanic rocks in the Tampa Mining Centre (Witt, 1994a).

In the Menzies – Broad Arrow greenstone belt, the greatest gold production has come from the Menzies Mining Centre, with many deposits in structures parallel or subparallel to the schistosity associated with the Menzies Shear Zone. Most deposits are hosted in greenstones that include metamorphosed mafic, ultramafic, and metasedimentary rocks (Witt, 1993; Swager, 1994). Farther south, in the Comet Vale Mining Centre, mineralization appears to be related to late structures, formed during emplacement of the Comet Vale Monzogranite, that overprint the regional fabric at a high angle (Witt, 1993; Swager, 1994).

In the Mount Ida greenstone belt, most gold deposits lie in the strongly deformed greenstones in the eastern part of the greenstone belt, between the Ida and Ballard Faults. The greatest historical production has come from mines in the southern part of the greenstone belt, in the Riverina and Mulline districts (Department of Mines, 1954). The substantial deposits in the Mulline Mining Centre that lie west of the main area of deformation may be hosted in minor splay structures from the Ida Fault, or in late structures developed during emplacement of the nearby Ularring Monzogranite. Gold in the Mount Ida greenstone belt is typically hosted in quartz veins and lodes that are parallel or subparallel to the regional structure (Gibson, 1907; Feldtmann, 1915). However, Legge et al. (1990) interpreted the host rock of the Bottle Creek deposit as a volcanic-related exhalative unit of graphitic shale, chert, and felsic rock.

The only historical gold workings in greenstone belts to the west of the Mount Ida greenstone belt are in the Illaara greenstone belt. They include a trench at Lawrence Find and a line of shallow workings at Metzke Find. Mineralization appears to have been hosted by quartz veins, parallel to the regional foliation, in mafic rocks. There is no recorded production from either locality.

NICKEL

The abundant ultramafic rocks in the Mount Ida and Menzies – Broad Arrow greenstone belts on MENZIES have been correlated with the nickeliferous ultramafic succession in the Kambalda area (Swager et al., 1995). They are similar in character to ultramafic rocks that host major nickel deposits in the north of the Eastern Goldfields (Hill et al., 2001). Although no economic nickel sulfide deposits have been found, several subeconomic lateritic nickel deposits have been identified south of Menzies township, and near Ghost Rocks.

BASE METALS

Major exploration programs in search of base metal sulfide mineralization in the Melita Complex in the 1970s failed to locate any economic mineralization.

Copper minerals including chalcopyrite, bornite, azurite, and malachite are commonly associated with gold mineralization. Marston (1979) reported that 7.55 t of cupreous ore was mined from the Forest Belle gold mine in 1961, and there many other reported copper occurrences (e.g. Marston, 1979; Kriewaldt, 1970).

IRON

Although there is an early report of a very high grade iron assay (97% Fe_2O_3) from near Mount Mason (Talbot, 1912), ridges of banded iron-formation are typically thin with common chert horizons. There has been no major iron exploration on MENZIES.

GEMSTONES

Gem-quality emeralds have been mined from near Wonder Well where northeasterly trending pegmatites cut northerly trending ultramafic schist (Garstone, 1981). Chrysoprase commonly forms in silica caprock over ultramafic rocks, and has been extracted locally.

There have been a number of regional diamond-exploration surveys over parts of MENZIES. They have included regional aeromagnetic surveys and soil, stream and lake-bed sampling programs, but no indications of diamonds have been reported.

INDUSTRIAL MINERALS

Localities with various industrial commodities and minerals including clay, sand, gravel, slate, kaolin, gypsum, and talc have been identified on MENZIES, but there are few published resources.

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Appendix

Gazetteer of localities

Locality	*MGA coordinates*	
	Easting	*Northing*
Blue Well	264800	6730200
Bottle Creek mine	252900	6768400
Boudie Rat mine	257200	6786200
Carpet Snake Soak	334000	6747000
Comet Vale Mining Centre	319500	6684500
Corbett Well	254300	6758600
Day Rock	211800	6742600
Dead Horse Rocks	333400	6750200
Forest Belle mine	257000	6787000
Ghost Rocks	296000	6728200
Goongarrie Homestead	311600	6681200
Hospital Rocks	221400	6696500
Ivanhoe Bore	329400	6756000
Jeedamya Homestead	332700	6746000
Jorgenson Tank	317000	6721000
Jowetts Well	315000	6712900
Kings Dam	317800	6708300
Kookynie township	353700	6753800
Kurnalpi Rockholes	338400	6752800
Lawrence Find	221200	6711600
Lillydale Well	339800	6739600
Melita railway siding	352700	6785500
Menzies township	309300	6713500
Metzke Find	214600	6758000
Mount Barton	352300	6764500
Mount Ida Mining Centre	257000	6785000
Mount Jessop	344700	6746600
Mount Mason	243400	6775900
Mount Morley	264000	6716700
Mulga Plum	335200	6745000
Mulline Mining Centre	260000	6702000
Mulwarrie Mining Centre	264000	6680000
Niagara Mining Centre	346000	6749000
Paradise Well	343600	6787400
Quartz Well	308600	6779800
Riverina Homestead	264800	6706200
Ram Well	335500	6742500
Round Hill	318000	6729100
Snake Hill	267700	6740200
Sowerline Well	253000	6703100
Tampa Mining Centre	350000	6767500
Twenty One Mile Well	333000	6737700
Twin Hills Mining Centre	317000	6740600
Ularring Mining Centre	259000	6695000
Wonder Well	265000	6710600

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WYCHE
MENZIES, WESTERN AUSTRALIA, SECOND EDITION
EXPLANATORY NOTES

MENZIES

AUSTRALIA 1:250 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SH 51-5

SYMBOLS

Geological boundary
- exposed
- concealed
- concealed, interpreted from aeromagnetic data

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

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

Bedding, showing strike and dip
- inclined
- vertical
- trend of bedding

Igneous layering, showing strike and dip
- inclined

Way-up indicator
- igneous layering
- pillow structure
- sedimentary structure
- graded bedding

Metamorphic foliation, showing strike and dip
- inclined
- vertical
- trend of foliation

Mineral lineation, showing trend and plunge
- inclined
- horizontal

Axis of crenulation, showing trend and plunge
- inclined

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

Aeromagnetic lineament

Airphoto or satellite lineament
- fracture pattern in granitoid rock

Isotopic age determination site with identification number — 169078

Highway

Formed road; unsealed

Track

Railway, with siding — Melita

Woodline, abandoned

Powerline

Landing ground

Townsite
- population less than 1 000 — Menzies

Homestead — Riverina

Locality — Butterfly

Building

Yard — Yard

Microwave repeater station

National Park boundary

Horizontal control; major, minor

Sand dune

Watercourse with ephemeral pool or waterhole

Gnamma hole, rockhole — Gnamma hole, Rockhole

Soak — Soak

Pipeline — pipeline

Bore, well — Bore, Well

Windpump

Dam, tank — Dam, Tank

Abandoned, position doubtful — (abd) (PD)

Mineral field boundary

Mineral field district boundary

Mining centre — COMET VALE

Mining locality — COPPERFIELD

Deposit or occurrence — Ulysses

Battery or treatment plant, abandoned

Subsurface data from drillhole, costean, or shallow shaft — Ab

MINERAL OCCURRENCES

MINERALIZATION STYLES*

- Porphyry, pegmatite, greisen, and skarn
- Orthomagmatic mafic and ultramafic
- Vein and hydrothermal
- Stratabound volcanic and sedimentary
- Stratabound sedimentary and/or sedimentary banded iron-formation
- Regolith hosted
- Undivided

MINERAL AND ROCK COMMODITY GROUPS

- Precious mineral
- Precious metal
- Steel industry metal
- Specialty metal
- Base metal
- Iron
- Industrial mineral
- Construction material

MINERAL AND ROCK COMMODITIES

Commodity is gold unless otherwise indicated on the map

Beryl	Brl
Basalt	Bas
Clay	Cy
Copper	Cu
Emerald	Emer
Fluorite	Fl
Gold	Au
Gravel	Gvl
Gypsum	Gp
Iron	Fe
Kaolin	Kln
Lithium	Li
Magnesite	Mgs
Molybdenum	Mo
Nickel	Ni
Prase	Pras
Sand	Sd
Slate	Sl
Talc	Tlc
Tungsten	W

Mineral occurrences are from the GSWA WAMIN database.
*Larger symbols represent mines or deposits also in the DoIR MINEDEX database.

REFERENCE

PHANEROZOIC — CAINOZOIC

Colluvial units
- *C* Gravel and debris as proximal talus; includes sand and silt; locally ferruginous
- *Cf* Ferruginous gravel and reworked duricrust

Sheetwash units
- *W* Clay, silt, and sand; locally ferruginous
- *Wc* Clay-rich sheetwash
- *Wf* Sheetwash deposits with abundant ferruginous grit
- *Wq* Sheetwash deposits with abundant quartz-vein debris

Alluvial units
- *A* Clay, silt, and gravel in drainage systems
- *Ap* Clay and silt in claypans

Lacustrine units
- *Ld* Dune and lake deposits; active systems within and adjacent to playa lakes
- *Ll* Saline playa lake deposits
- *Lm* Mixed dune, evaporite, and alluvial deposits adjacent to playa lakes

Sandplain units
- *S* Residual and eolian quartz sand
- *Sl* Yellow sand with minor ferruginous gravel, silt, and clay

Residual or relict units
- *Rd* Siliceous and ferruginous duricrust, undivided
- *Rf* Ferruginous duricrust; includes iron-cemented reworked products
- *Rgpg* Quartzofeldspathic sand over granitoid rock, with sparse granitoid outcrop
- *Rk* Calcrete
- *Rz* Siliceous duricrust
- *Rzu* Siliceous caprock over ultramafic rock

St — Sandstone and silcrete; coarse, angular, poorly sorted quartz in a clay-rich matrix; partly silicified

PROTEROZOIC

Pd — Mafic to ultramafic dykes; interpreted from aeromagnetic data where dashed

- q Quartz vein
- p Pegmatite vein

ARCHAEAN — YILGARN CRATON

- *c.* 2640 Ma[1] Agck **CLARK WELL MONZOGRANITE:** biotite monzogranite
- *c.* 2632 Ma[2] Agul **ULARRING MONZOGRANITE:** biotite monzogranite

- Ag Granitoid rock, undivided; includes deeply weathered rock and local silcrete
- Agb Granitoid rock interleaved with subordinate greenstone
- Agcf **COPPERFIELD MONZOGRANITE:** biotite monzogranite with prominent mineral lineation
- Agcs **CARPET SNAKE SYENOGRANITE:** biotite–muscovite syenogranite
- Agcv **COMET VALE MONZOGRANITE:** porphyritic biotite monzogranite
- Agda **DAIRY MONZOGRANITE:** biotite monzogranite
- Agg Granodiorite, monzogranite, tonalite, and diorite; *c.* 2676 Ma[3] at Day Rock
- Aggl **GALAH MONZOGRANITE:** biotite monzogranite
- Aggo **GOONGARRIE MONZOGRANITE:** biotite monzogranite
- Agjo **JORGENSON MONZOGRANITE:** biotite monzogranite
- Agm Monzogranite, massive to foliated; fine- to coarse-grained; *c.* 2621 Ma[5] at Hospital Rocks
- Agmf Strongly foliated monzogranite
- Agmy **MYSTERY MONZOGRANITE:** fine-grained biotite monzogranite
- Agn Gneissic granitoid rock; strongly foliated granitoid rock with local gneissic banding
- Agot **OLIVER TWIST GRANODIORITE:** biotite–hornblende granodiorite
- Agy Syenogranite to alkali-feldspar granite

- Ang Granitoid gneiss
- Anm Mafic gneiss

- Alqm Quartz–mica schist
- Alu Fuchsite–quartz and andalusite–fuchsite–quartz rock

- As Metamorphosed sedimentary rock, undivided
- Ash Metamorphosed shale and siltstone
- Asp Metamorphosed sandstone and conglomerate
- Ast Metamorphosed fine- and medium-grained sandstone
- <*c.* 3304 Ma[3] Astq Medium- to coarse-grained, quartz-rich sandstone; metamorphosed; common micaceous intervals; locally fuchsitic; local quartzite
- Asw Metamorphosed wacke and arkose
- Acc Banded chert and ferruginous chert; metamorphosed
- Aci Metamorphosed banded iron-formation and minor banded chert

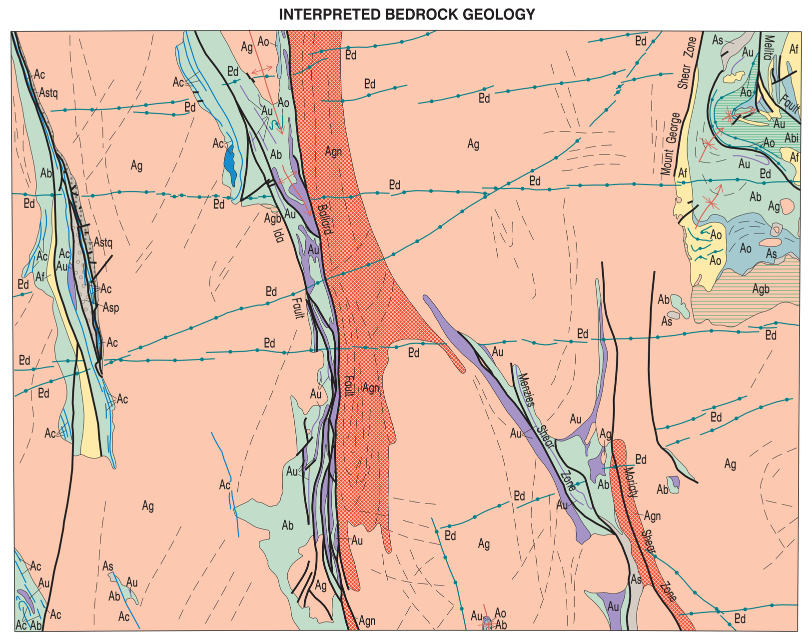
- Af Metamorphosed felsic volcanic and volcaniclastic rock, undivided
- Afi Metamorphosed feldspar porphyry of intermediate composition
- Afp Metamorphosed quartz–feldspar porphyry; *c.* 2700 Ma[3] from near 51 Mile Well
- Afs Felsic schist; *c.* 2691 Ma[4] at Ghost Rocks
- Afv Metamorphosed felsic volcanic rock; *c.* 2681 Ma[1] from near Carpet Snake Soak
- Afx Metamorphosed felsic breccia

- Ao Medium- and coarse-grained mafic rock; metamorphosed
- Aod Medium-grained mafic rock; metamorphosed
- Aofb **FOREST BELLE GABBRO:** coarse-grained gabbro with clinopyroxene olkocrysts; metamorphosed
- Aog Metagabbro
- Aol Leucogabbro and leucodolerite; metamorphosed
- Aon Norite and gabbronorite; metamorphosed
- Aonv Olivine gabbronorite; metamorphosed
- Aogx Pyroxene-rich gabbro; metamorphosed

- Ab Metamorphosed mafic rock, undivided; commonly weathered
- Aba Fine- to medium-grained amphibolite, foliated
- Abg Mafic rock interleaved with minor granitoid rock; metamorphosed; massive to strongly foliated; local amphibolite
- Abi Basaltic andesite and basalt; metamorphosed
- Abk Metamorphosed komatiitic basalt with pyroxene spinifex texture
- Abs Mafic schist with interleaved metasedimentary rocks
- Abv Metabasalt, massive to foliated

- Au Metamorphosed ultramafic rock, undivided; commonly weathered
- Auk Metakomatiite, with relic olivine spinifex texture
- Aup Peridotite; metamorphosed
- Aur Tremolite–chlorite(–talc) schist
- Aux Medium- to coarse-grained pyroxenite, metamorphosed; minor metagabbro

INTERPRETED BEDROCK GEOLOGY



Pd

- Ag Granitoid rock
- Agb Granitoid rock with interleaved greenstone
- Agn Gneissic granitoid and granitoid gneiss

YILGARN CRATON

- As Metamorphosed clastic sedimentary rocks dominant
- Asp Metamorphosed conglomerate and sandstone
- Astq Quartzite and micaceous quartzite
- Ac Metamorphosed banded iron-formation and chert

Af — Metamorphosed felsic volcanic and local sedimentary rocks

Ao — Metamorphosed gabbro and dolerite

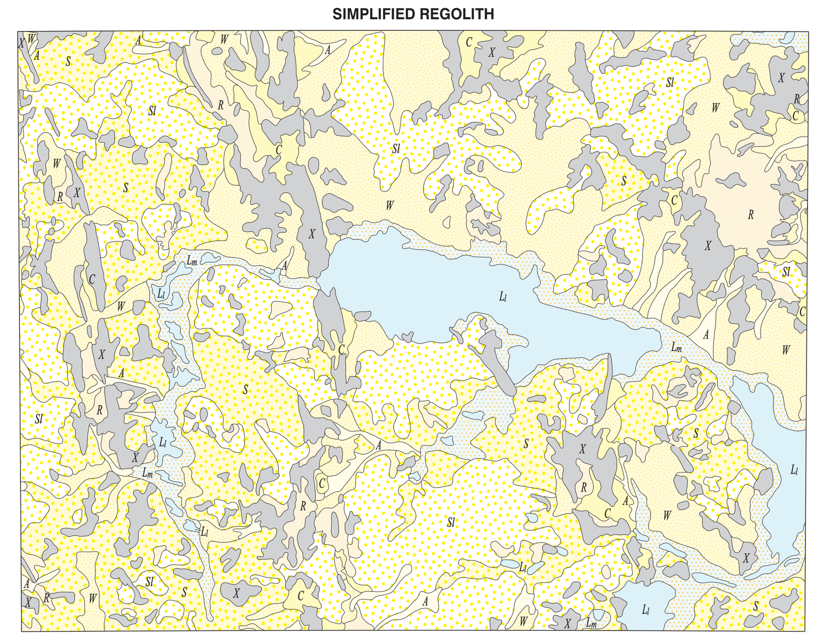
- Ab Metamorphosed mafic rock dominant
- Abi Metamorphosed andesitic basalt

Au — Metamorphosed ultramafic rock dominant

- Fault
- Fold axes
- Structural trend

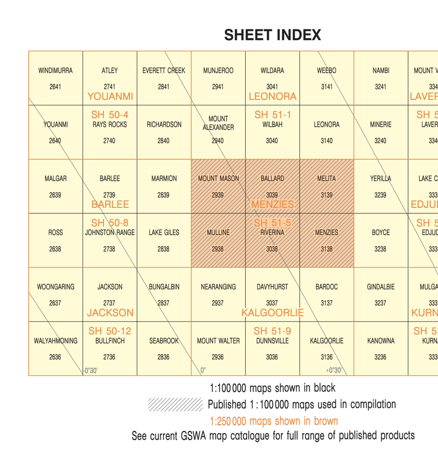
For further details, refer to main reference

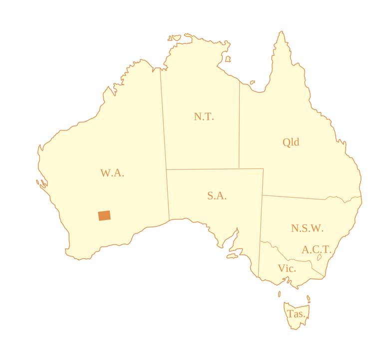
SIMPLIFIED REGOLITH



- *C* Colluvium
- *W* Sheetwash
- *A* Alluvium
- *Ll* Playa deposits
- *Lm* Mixed playa deposits
- *S* Sandplain, residual and eolian
- *Sl* Sandplain over duricrust
- *R* Residual units
- *X* Exposed and weathered rock, and associated eluvium

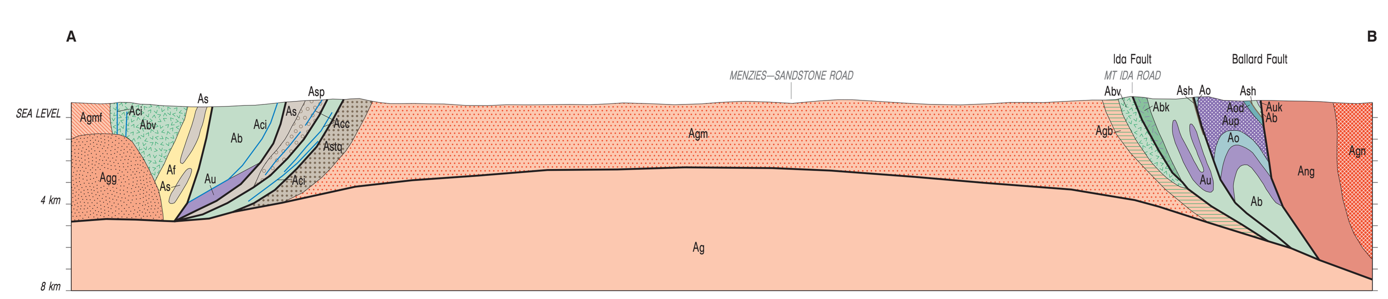
SHEET INDEX

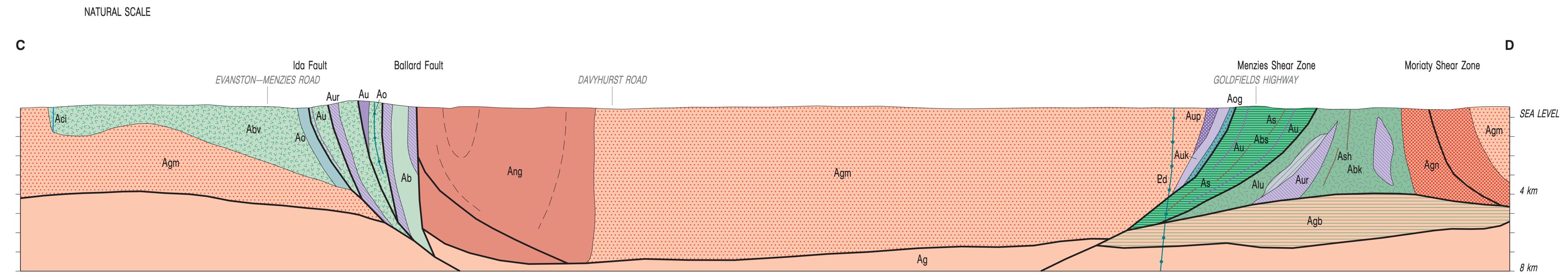




DIAGRAMMATIC SECTIONS

NATURAL SCALE





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Geology by S. Wyche 1996, 2001

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Geochronology by:
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(3) D. R. Nelson, GSWA Record 2002/2, p. 240–243.
(4) D. R. Nelson, GSWA Record 1995/3, p. 154–157.
(5) D. R. Nelson, in prep., GSWA Record 2003/2.

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Cartography by P. Taylor

Topography from the Department of Land Administration Sheet SH 51-5, with modifications from geological field survey

Mineralization and rock comodity information from non-confidiental data held in the WAMIN database, GSWA, at 27 June 2003. Data points filtered for clarity on the plotted product; full set of data points available in digital data

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SCALE 1:250 000

5000 Metres — 0 — 5 — 10 — 15 — 20 — 25 Kilometres

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

Grid lines indicate 20 000 metre interval of the Map Grid Australia Zone 51

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

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

MENZIES

SHEET SH 51-5 SECOND EDITION 2003

Version 1 – June 2003