EXPLANATORY NOTES

GEOLOGY OF THE MENZIES 1:100 000 SHEET

(and adjacent Ghost Rocks area)

by C.P. SWAGER

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

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C. P. Swager

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ACTING DIRECTOR GENERAL
L. C. Ranford

DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
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Cover photograph:
Banded quartz–andalusite rock (1km southeast of Jowett Well) resulting from the regional metamorphism of early alteration assemblages associated with felsic volcanism. The brown bands (2 mm – 2 cm wide) are dominated by andalusite, which forms coarse, highly poikilitic grains enclosing numerous quartz grains.

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Geology of the Menzies 1:100 000 sheet (and adjacent Ghost Rocks area)

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Abstract

The MENZIES 1:100 000 sheet contains one major greenstone belt and two small greenstone inliers within extensive granitoids.

The major greenstone belt is divided into two domains separated by the Menzies Shear. The western domain consists of an east-facing greenstone sequence on the eastern limb of the regional, north-northwest-trending Goongarrie–Mt Pleasant Anticline (F_2). This greenstone sequence is the continuation of the Ora Banda stratigraphy. The sequence can be traced along strike onto the adjacent RIVERINA 1:100 000 sheet, where in the Ghost Rocks area it is deformed in a syncline–anticline fold pair. The anticline has strongly foliated monzogranite in its core.

The eastern domain contains a narrow and strongly foliated basalt–sedimentary–ultramafic schist association. Coarse clastic rocks, including conglomerate, dominate in the south of MENZIES and appear gradational, with all other rock types interleaved, to a basalt-dominated sequence in the north which is continuous onto the RIVERINA sheet.

East of this association the upright King Dam Anticline (F_2) is outlined by felsic volcaniclastic marker beds with quartz–andalusite assemblages along the contact with underlying ultramafic schist. The south-plunging anticline is bound to the east by the granitoid gneisses of the Moriaty Shear Zone, and becomes very strongly attenuated to the south. Northwards the anticline is disrupted by post-D_2 granitoid intrusions (Jorgenson Monzogranite, Oliver Twist Granodiorite). East of Menzies, basalts overlying the felsic marker beds, appear to have been thrust from south to north onto the Jorgenson Monzogranite.

The late tectonic Comet Vale Monzogranite intruded the greenstone belt across the two domains.

Metamorphic grade increases from south to north from middle greenschist to middle amphibolite facies around Menzies. Two small isolated greenstone inliers in the central map area consist of amphibolite-facies basalt and gabbro with pyroxenite.

Gold has been mined at several centres (Menzies, Yunndaga, Comet Vale) in both domains of the greenstone belt.

KEYWORDS: Regional geology, economic geology, MENZIES (SH51-5-3138), RIVERINA (SH51-5-3038), Ghost Rocks area.

Introduction

The MENZIES* 1:100 000 map sheet (SH51-5-3138) occupies the southeastern corner of the MENZIES 1:250 000 sheet. The first edition of the MENZIES 1:250 000 geological map sheet (Kriewaldt, 1970) was prepared and published before the intensive nickel and gold exploration in the 1970s and 1980s respectively.

Early publications include descriptions of the gold mines and their geology around Menzies township (Woodward, 1906) and around Comet Vale (Jutson, 1921). Detailed studies of host rocks, alteration assemblages, and structural setting of all major gold mines are described by Witt (1993). Several aspects of greenstone geology on MENZIES have been the subject of detailed studies including andalusite–fuchsite–quartz rocks east of Menzies township (Martyn and Johnson, 1986) and ultramafic flows (komatiite), particularly around Comet Vale (Hill et al., 1987).

This report describes regional setting, petrography, stratigraphy, and structure of Archaean rocks on MENZIES and the adjacent Ghost Rocks area on the RIVERINA 1:100 000 sheet (SH51-5-3038).

* Map sheet names are printed in capitals, to avoid confusion with identical place names.

Access, physiography, and Cainozoic geology

The Kalgoorlie–Meekatharra Highway (No. 91) and Kalgoorlie–Leonora Railway traverse the western half of MENZIES. Formed, but unsealed, roads on MENZIES include the Tonkin Road (Mulgabbie road) in the southern half, the Riverina and Mt Ida–Sandstone roads from Menzies, and the Jeedamya–Mulgabbie road in the northeast corner. Numerous pastoral and mining tracks provide access to the western half of MENZIES, whereas the eastern half is mainly accessible along fencelines. Sheep farming is based on Jeedamya Station in the northeastern and eastern parts of the sheet area, and Goongarrie Station in the southwest.

The physiography reflects to a large extent the underlying geology. Greenstone areas are characterized by low rolling hills with open acacia and eucalypt, which rapidly decrease to the north. Southeast of the Menzies township, isolated laterite mesas dominate the landscape. Areas underlain by granitoid are generally flatter, with lateritic plateaus and sandy plains, interrupted by low inselbergs of granitoid. Large greenstone lenses situated northeast of Alexandra Bore are entirely surrounded by granitoid, and form distinct ranges of low hills. Large salt lakes, such as Lake Ballard in the northwest, Lake Marmion in the east and Lake Goongarrie in the south, are surrounded and connected by areas of sand and silt dunes, with low stunted mulga growth.

Kriewaldt (1970) recognized many types of Cainozoic deposits on the Menzies 1:250 000 sheet, but on the 1:100 000 sheet only seven types are distinguished.

Laterite (*Czl*) and deeply weathered rocks form plateaus and more subdued areas of reworked products, including pisolitic soils. A prominent, relatively high plateau of laterite and a silica cap is developed over dunite and peridotite at the western boundary of the greenstone belt. The distinctive cap rock has locally preserved original textures (*Czl/Aud*).

Colluvium occurs as reddish-brown, ferruginous, sandy clay and fine sand (*Czc*), and fine- to medium-grained quartzo-feldspathic sand (*Czg*) derived by weathering and erosion of granitoid. Scattered small pebbles, granitoid-derived, may be present in the quartz-feldspathic sand (*Czg*).

Plains and dunes of yellow sand (*Czs*) cover extensive areas, for example north of Comet Vale, as sheets of variable thickness, with a scattering of small pisolitic pebbles.

Salt lakes (playas) and claypans (*Czts*) contain interbedded clay and sand with evaporite minerals (halite, gypsum), and are surrounded by stabilized dunes of sand, silt, and gypsum (*Cztd*) which were blown from the dried-out playas.

Quaternary alluvium (*Qa*) in present-day drainage channels and flood plains consists of unconsolidated clay, silt, sand, and pebbles.

Geological setting

Regional setting

MENZIES lies in the central part of the Norseman–Wiluna Belt within the Eastern Goldfields Province of the Archaean Yilgarn Craton (Gee, 1979; Griffin, 1990) (Fig. 1). The Norseman–Wiluna Belt has been interpreted as a rift developed on sialic basement and an older greenstone sequence (Groves and Batt, 1984), and more recently as a marginal basin (Barley and Groves, 1988).

The main greenstone belt on MENZIES is the northern continuation of the central-eastern belt on BARDOC (Witt, 1987, 1990) (see Figs 1, 2). This belt appears to have an overall synformal geometry between two anticlinal granitoid 'domes', but in detail has a more complex structure (Witt,1990; see below). At Menzies township, the belt divides into a western section continuing northwestwards into the Ghost Rocks area on RIVERINA, and an eastern section striking northwards into the Twin Hills area on the MELITA 1:100 000 sheet (Fig. 2). As both these greenstone areas appear to terminate northwards, a geological description of the Ghost Rocks area has been included in this publication.

In the centre of the map area, isolated areas of greenstone are entirely surrounded by foliated granitoid.

Stratigraphy and regional structure

Two tectono-stratigraphic domains, characterized by internally coherent stratigraphic successions and separated by major faults or shear zones, are distinguished in the main greenstone belt (Fig. 2). The western domain is bounded by granitoid rocks to the west and the Menzies Shear Zone in the east. This domain has a well-established stratigraphy that can be traced southwards as the lateral equivalent of the 'Ora Banda sequence' established on BARDOC (Witt, 1987, 1990). This sequence continues northwestwards, and also occurs in a complex geometry at Ghost Rocks. The eastern domain, bounded by the Menzies Shear Zone and by granitoid gneiss of the Moriaty Shear Zone, shows a complex internal structure, and is strongly sheared and attenuated.

The major shear zones (Menzies Shear Zone, Moriaty Shear Zone) are defined by strongly foliated and lineated rocks, interleaving of rock types, and wedging out of stratigraphy. The Menzies Shear Zone can be traced southwards into the Bardoc Deformation Zone ('Bardoc tectonic zone': Witt, 1987), and is a major structural break that probably separates original depositional basins. The Moriaty Shear Zone is at least 500 m and possibly up to 1 km wide, and largely consists of granitoid gneiss with interleaved amphibolite and ultramafic schist layers/lenses.

In the following sections the stratigraphic successions and overall structure in the two domains and the isolated greenstones northeast of Alexandra Bore are described in some detail. A more comprehensive discussion of the structure is given under 'Structural Geology'. Although

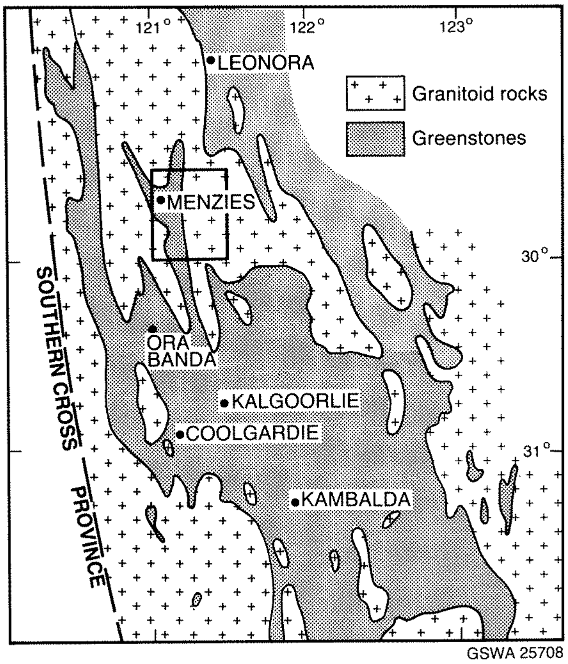

Figure 1. Location of MENZIES 1:100 000 sheet in Eastern Goldfields Province

all rock types are metamorphosed, the prefix meta- is omitted because good textural preservation allows recognition of the original rock type.

Western domain

The stratigraphy of the western domain is the northern continuation of the well-established Ora Banda sequence on BARDOC (Witt, 1987, 1990). Nearly all mafic extrusive units of this sequence are represented on MENZIES, though with a much reduced thickness. The entire sequence youngs eastward, as deduced from textures in komatiite flows and trends of differentiated layering in gabbro sills.

The lowermost unit on MENZIES, fine feldspar-phyric basalt, is only found in the Comet Vale area. It is overlain by prominent olivine cumulate (dunite, minor peridotite), mostly covered by silica cap rock and laterite, followed eastwards by a thick unit of komatiite flows. The contact between these two ultramafic units is characterized by shearing (i.e. talc–chlorite schist), local presence of sedimentary lenses and a narrow unit of pyroxenite, gabbro, and/or leucogabbro. The overall ultramafic sequence, which can be followed over a large strike length, has been studied in detail by Hill et al. (1987) and by Witt (1990) on BARDOC and DAVYHURST 1:100 000 sheet areas.

Units overlying the ultramafic rocks are only well exposed directly north of the Comet Vale Monzogranite. From west to east these are: pyroxene spinifex-textured ('high-Mg') basalt, locally pillowed basalt with dolerite sills, a distinctively layered gabbro sill, fine-grained massive basalt, coarse feldspar porphyritic basalt, and minor sedimentary rock. This sequence (Table 1; Fig. 5) can be directly correlated with the Ora Banda sequence described by Witt (1987, 1990).

Table 1. Stratigraphy of the Ora Banda sequence

	Kurrawang Formation
BLACK FLAG GROUP	Spargoville Formation Orinda Sill Pipeline Andesite Member Ora Banda Sill
ORA BANDA GROUP	Victorious Basalt Bent Tree Basalt Mt Pleasant Sill Mt Ellis Sill
LINGER AND DIE GROUP	Big Dick Basalt Siberia Komatiite Walter Williams Formation
POLE GROUP	Missouri Basalt Wongi Basalt

Source: Witt (1987, 1990)

Further northward only the ultramafic units and some gabbro remain, whereas all the overlying stratigraphy has been cut out against the Menzies Shear Zone. Outcrop is too poor to establish whether basalt underlying dunite is still present, although it is absent directly north of the Comet Vale Monzogranite. West of Menzies township, the ultramafic rocks are attenuated and interrupted, as suggested by aeromagnetics.

Further northwest along strike from MENZIES onto RIVERINA, no rocks of this western domain are exposed until the Ghost Rocks area. Here, a complex syncline–anticline fold pair is present (Figs 3, 4; see 'Structural Geology'), instead of the simple, though attenuated, east-younging sequence on MENZIES.

The core of the anticline is occupied by the pervasively foliated Ghost Rocks granitoid gneiss, probably derived from monzogranite, and shows an intermediate southeast-plunging mineral lineation. The southwestern granite–greenstone contact cuts locally across layering in the komatiite on the west-younging limb of the syncline. To the northeast of the foliated granitoid, a distinctive basalt–dolerite/gabbro sequence (Fig. 3) is less intensely deformed, except for the immediate contact zone. This sequence can be correlated with the Wongi and Missouri Basalts of the Ora Banda sequence (Witt 1990) (Table 1; Fig. 4). Pyroxene spinifex-textured basalt is separated from overlying massive basalt by a narrow, but persistent, unit of (felsic epiclastic) sedimentary rocks that was intruded by a dolerite/gabbro sill of quite constant thickness.

Eastern domain

The eastern domain has a more complex structure and stratigraphy than the western domain. Correlation along

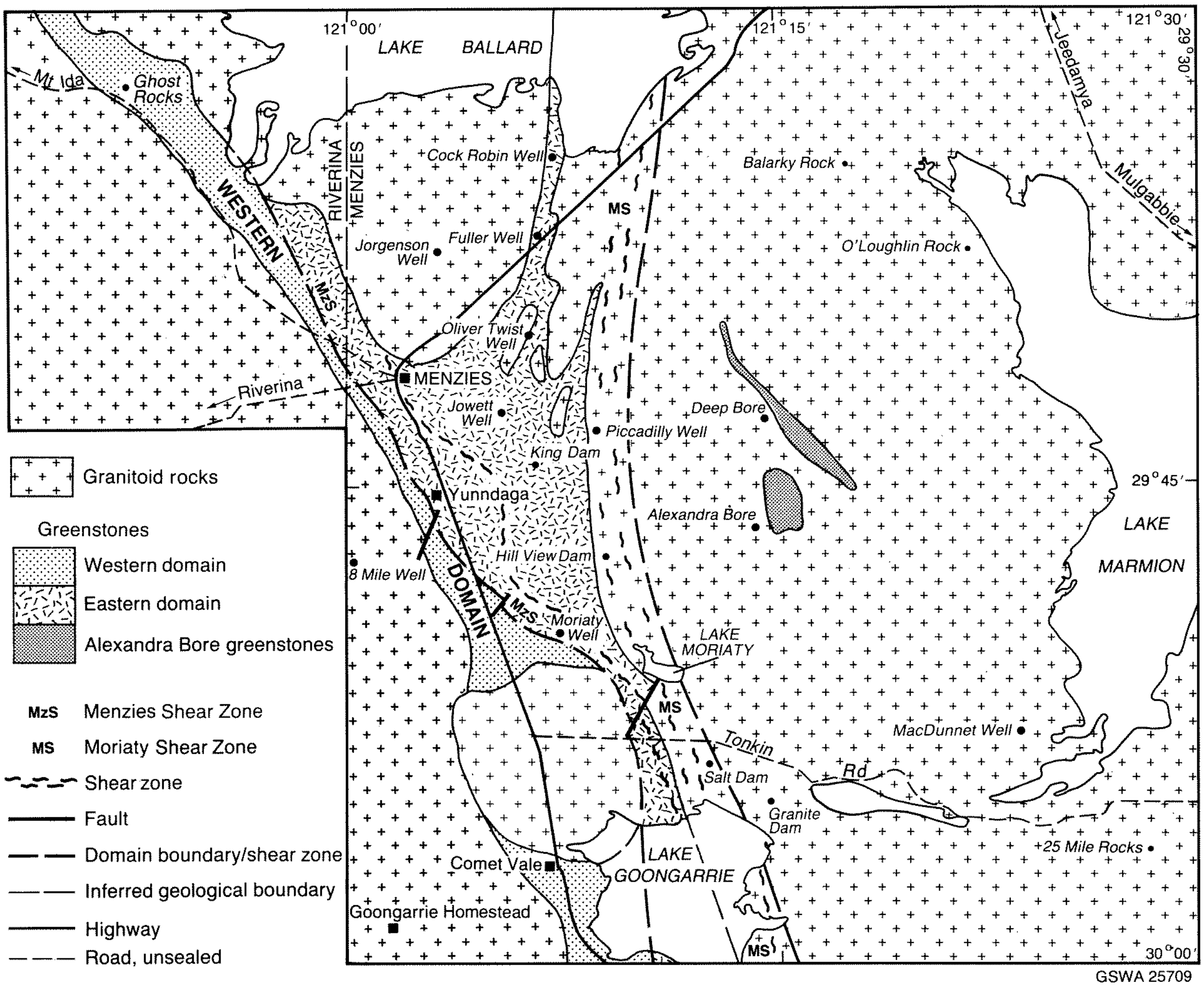

Figure 2. Main geological units and locality names on MENZIES and in the Ghost Rocks area on the RIVERINA 1:100 000 sheet. The Menzies greenstone belt is divided into western and eastern tectono-stratigraphic domains

strike is more difficult, and several changes in stratigraphy and/or structure are observed from south to north.

In the southern half of MENZIES, a distinctive sequence of predominantly quartzo-feldspathic clastic rocks, including matrix-supported polymictic conglomerate, occurs east of the Menzies Shear Zone. This sequence contains a well-developed upright foliation, and may be westward younging, although opposite younging directions also appear to be present. Along their western boundary, the high-strain rocks of the Menzies Shear Zone include tremolite–chlorite schist, slate and gabbro lenses, as well as coarse quartzo-feldspathic schist possibly derived as structural ‘slices’ from the Comet Vale Monzogranite. The eastern boundary is defined by the first occurrence of prominent silicified slate and chert bands.

Northwards along strike, a distinctive, well-foliated basalt and sedimentary rock association has economic importance as a host sequence for the gold mineralization in the Menzies area (Witt, 1993; see ‘Economic Geology’). Narrow tremolite and talc–chlorite schist lenses are present in both sedimentary rocks and basalt. The sedimentary layers usually form distinct zones up to several 100 m wide, and consist of fine- to coarse-grained, locally conglomeratic, clastic rocks that are possibly the lateral equivalents of the clastic rocks to the south. This could imply a major facies change from south to north, with increasing mafic volcanic components northward. Alternatively, the strongly sheared contacts within this package of rocks may also imply tectonic interleaving along the Menzies Shear Zone. The eastern boundary of this association, which continues along strike onto RIVERINA, is shown on Figure 2 as a shear zone.

East of the basalt–sedimentary association, a complex anticline, intruded by granite, dominates the outcrop pattern. The structure, the King Dam Anticline (Fig. 5), is outlined by a thin quartz (–feldspar)–muscovite schist that contains scattered fuchsite clasts at its contact with underlying ultramafic schist. Remarkable quartz–fuchsite–andalusite rocks are locally developed along the

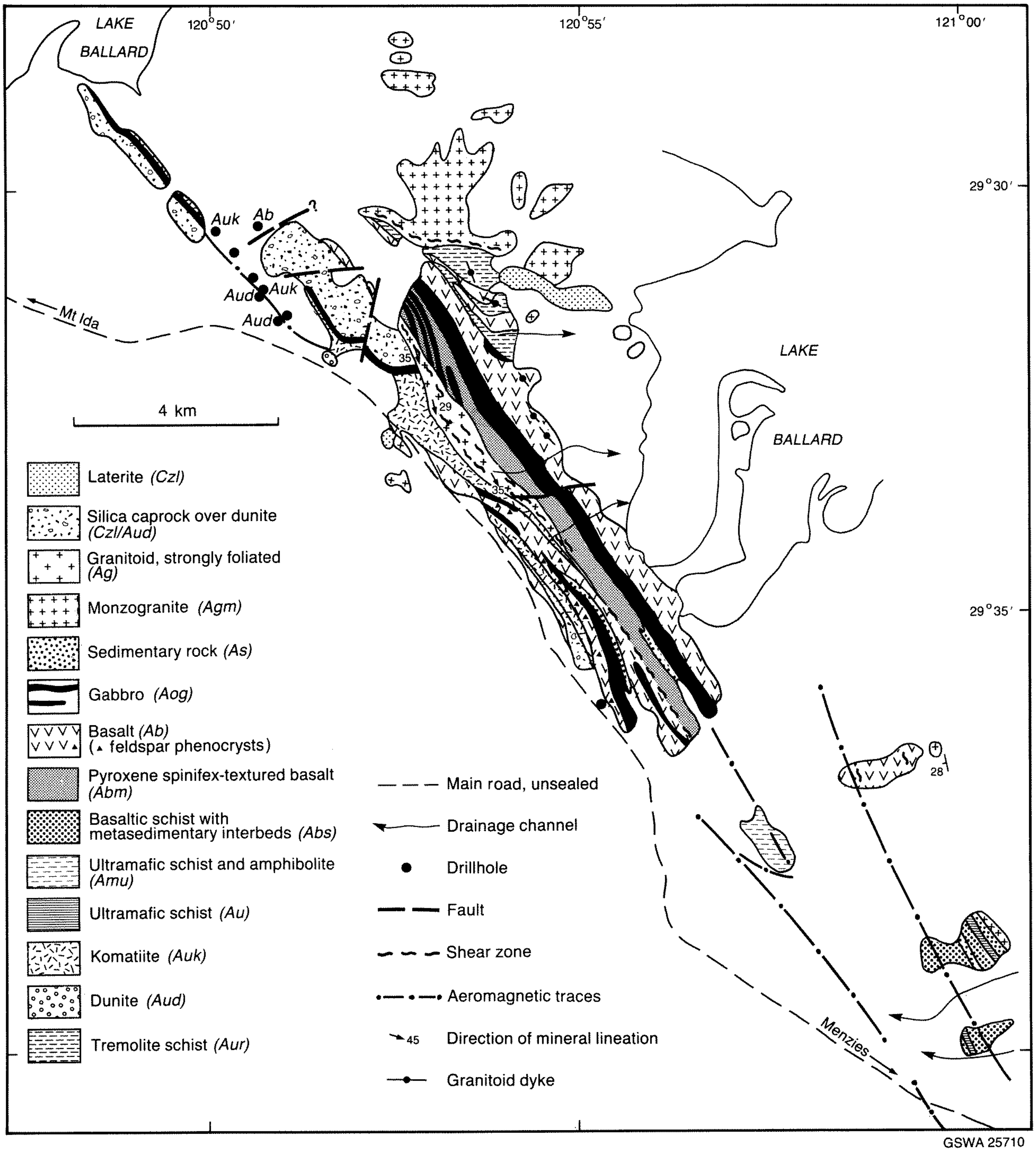

Figure 3. Outcrop map of the Ghost Rocks area on RIVERINA, bordering the northwestern part of MENZIES

contact, particularly south of Jowett Well. Upwards the quartz-phyric felsic schist contains more grey slate, and is capped in many areas by a prominent cherty layer. Although no way-up indicators were found, the sequence is suggested to represent the original stratigraphy (see also Martyn and Johnson, 1986).

The quartz-phyric felsic schist is overlain by two basalt units (ocellar-textured and massive). The contact is strongly deformed, as illustrated in the Mount Menzies area, where the massive basalt is sheared out against quartz–muscovite schist (see 'Structural Geology'; Fig. 10). In the Broughtonville area, only 'high-Mg' basalt overlies quartz–muscovite schist. The original relationship between the tremolite schist to quartz–muscovite schist sequence and the overlying basalts is not known. Its origin could be either depositional, with some substantial later movement, or tectonic, implying major displacement. All mafic and ultramafic rocks are intruded by numerous feldspar (–quartz), and more rarely plagioclase–amphibole,

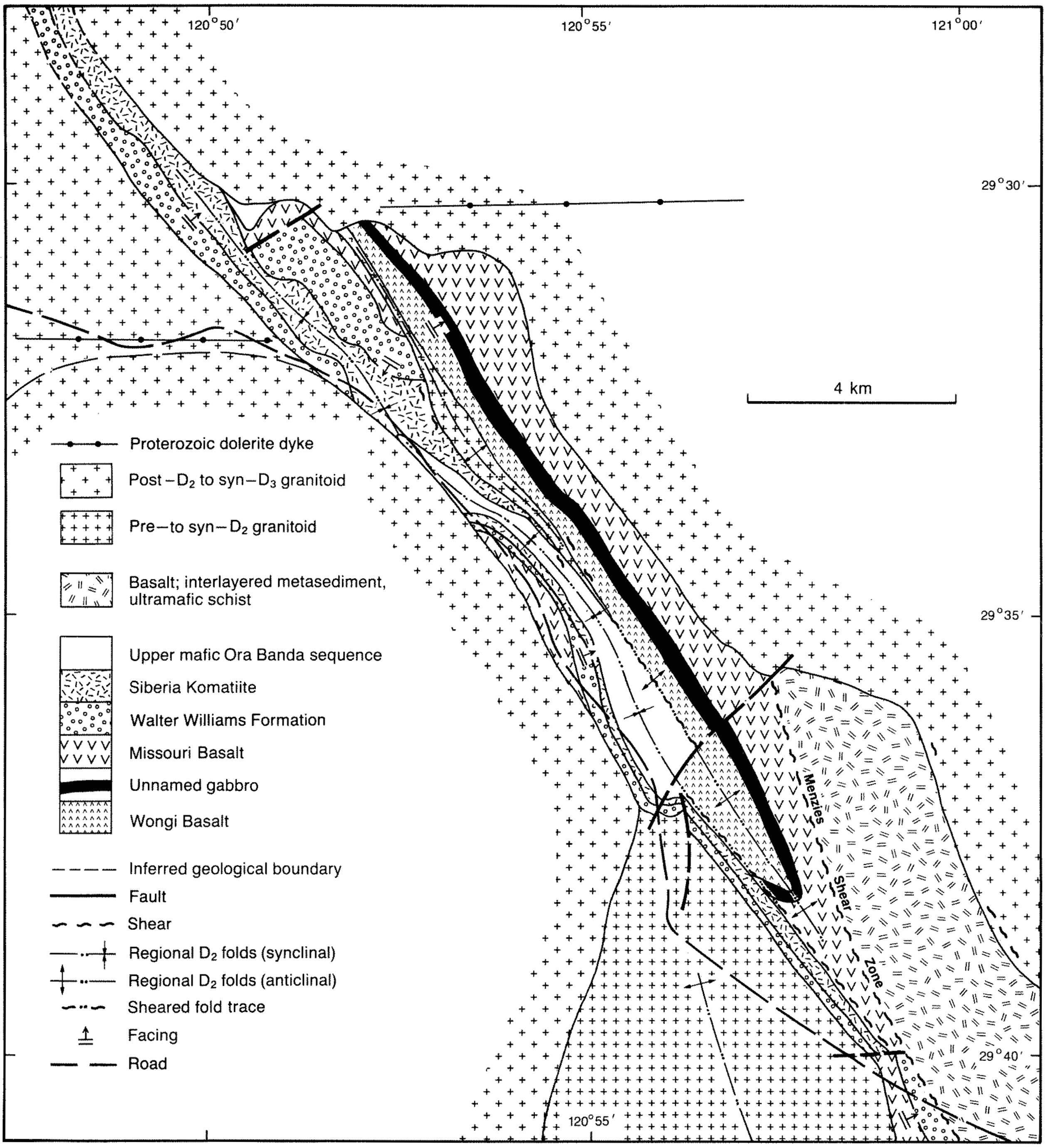

Figure 4. Interpretation map of the Ghost Rocks area, showing correlation of units with the Ora Banda sequence (Witt, 1990)

porphyry dykes and sills. A small hornblende lamprophyre ('spessartite') dyke was found 1.5 km east of the Blowfly mine.

The King Dam Anticline is flanked by two synformal structures that are not regional in extent (Fig. 5), and are interpreted to have developed as the result of granitoid intrusion after the formation of the anticline.

Northwards in the Fuller Well–Cock Robin Well area, the sequence is squeezed into a very narrow belt between granitoid plutons (Fig. 2). At the northernmost outcrop, a sheared-through, south-plunging antiform is outlined by a layered chert.

Southwards the strongly deformed sequence becomes increasingly attenuated between the Comet Vale Monzogranite and the Moriaty Shear Zone (Fig. 2).

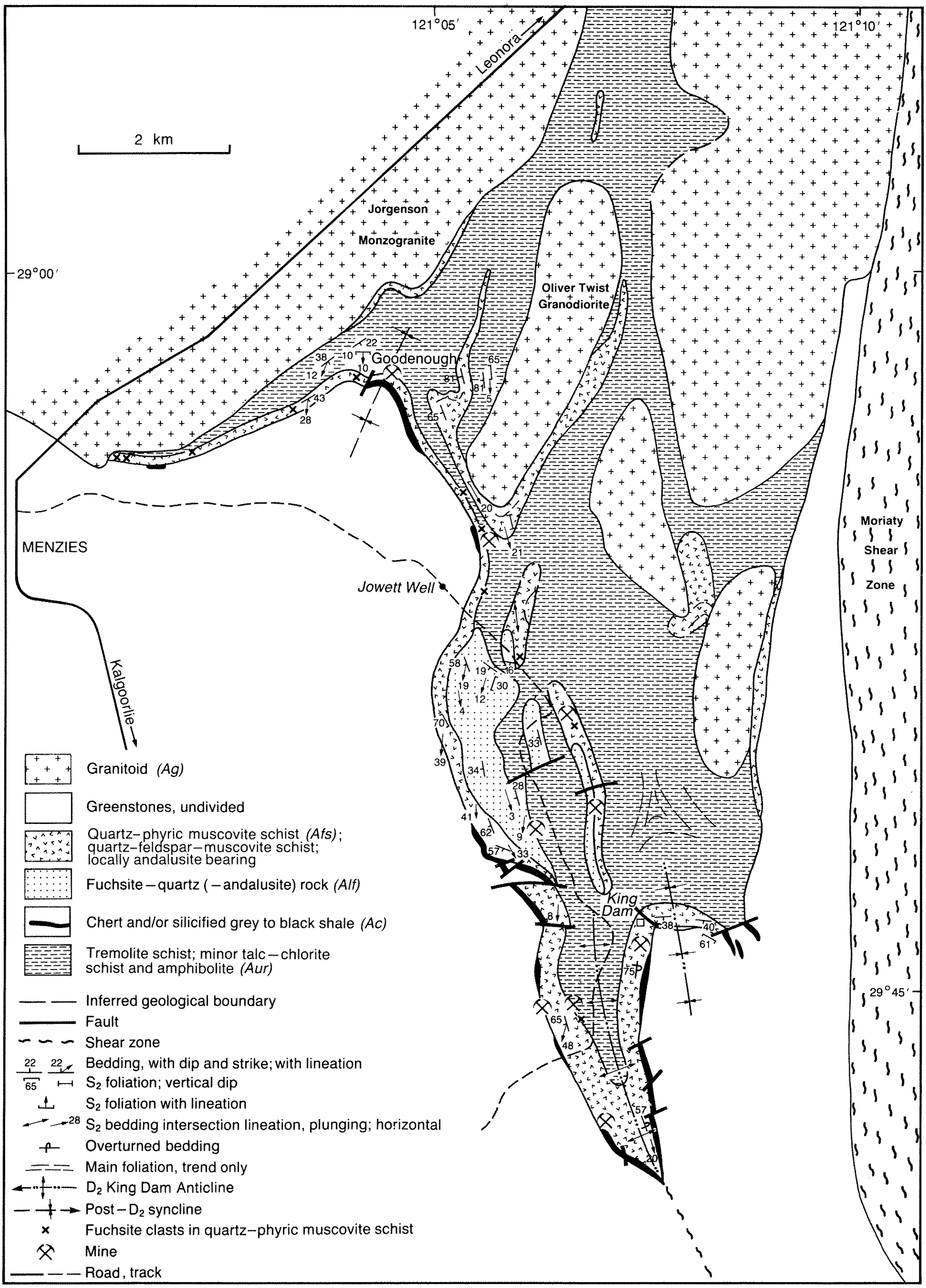

Figure 5. Distribution of quartz–fuchsite (–andalusite) rocks (*Alf, Als*) and quartz-phyric muscovite schist (*Asq*), highlighting the regional structure east of Menzies

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Between Lake Goongarrie and Lake Moriaty, the sequence shows sedimentary rocks containing numerous prominent 'chert' and silicified slate marker horizons, interleaved with basaltic schist, and minor dolerite and amphibolite, as well as tremolite–chlorite schist derived from komatiite (as indicated by locally preserved platy olivine spinifex textures).

Northwards from Lake Moriaty the sequence widens (Fig. 2), and a prominent amphibolite is bounded on either side by sedimentary rock, chert and thin ultramafic schist slivers. At one locality, 2 km northeast of Moriaty Well, ultramafic schist is overlain by quartz–andalusite mylonite, felsic schist with fuchsite clasts and interleaved quartz–muscovite schist, grey slate and ultramafic schist. This sequence is similar to the ultramafic schist to quartz–muscovite schist stratigraphy between Springfield and Jowett Well. Another characteristic feature is the presence of narrow bands of quartz-rich garnet–hornblende schist, both at this locality and near Goodenough mine.

Alexandra Bore greenstones

Two separate greenstone enclaves to the northeast of Alexandra Bore are entirely enclosed by granitoid rocks (Fig. 2). Wherever contacts are exposed, granitoid is strongly foliated, if only in a narrow zone. The northern belt consists of fine-grained amphibolite with some medium-grained layers/lenses, both presumably derived from basalt. It can be traced over a length of at least 12 km, and reaches a maximum width of approximately 1 km.

The southern belt reaches a maximum width of a little more than 2 km, and measures approximately 3.5 km along strike. The greenstones show a stratigraphy, from northwest to southeast, of coarse-grained tremolite rock (possibly derived from pyroxenite), medium-grained gabbro, and amphibolitic basalt. If the pyroxenite-derived rock is interpreted as the base of the gabbro, the succession youngs southwestwards. There are no obvious stratigraphic correlations with the major greenstone belt further west.

Petrography of the greenstones

Ultramafic rocks

Dunite *(Aud)* and peridotite *(Aup)*

Dunite is covered entirely by laterite and silica cap rock, forming prominent hills south and north of the Comet Vale Monzogranite, as well as in the Ghost Rocks area on RIVERINA. This distinctive unit can be traced over a large distance southwards onto BARDOC 1:100 000 sheet, and has been described in detail as the Walter Williams Formation by Hill et al. (1987) and Witt (1987, 1990). The rocks consist of serpentinized olivine adcumulate (Hill et al. 1987), that is overlain by siliceous laterite and jasperoidal silica (*Czl/Aud*), in which ghost textures are commonly preserved. The serpentinite, which outcrops predominantly at the upper contact, is an olivine orthocumulate layer, peridotite (*Aup*), rather than dunite. The formation was named by Hill et al. (1987) in honour of a prospector, who died of thirst and was buried along the old Menzies–Mt Ida road in the Ghost Rocks area. His grave is found close to the top of the formation.

Hill et al. (1987) described a distinctive coarse-grained, persistent, though thin (2–5 m), olivine harrisite layer just below the top of the formation, separating the main adcumulate body (*Aud*) from the thin overlying orthocumulate (*Aup*). The harrisitic layer, with its dendritic olivine crystals, is exposed at Comet Vale and in the Ghost Rocks area.

Pyroxenite and a variety of gabbroic rocks are present within the peridotite layer along the contact with overlying komatiite flows. The best exposed examples are due east of 8 Mile Well, at Yunndaga. On RIVERINA these gabbroic rocks occur along virtually the entire exposed contact in the Ghost Rocks area. Pyroxenite now consists of medium-grained tremolite/actinolite with scattered coarser phenocryst pseudomorphs. Gabbro is mostly medium grained and ophitic, with prismatic amphibole after pyroxene and sericitized or epidotized plagioclase. Minor pyroxene may be relict. Sphene occurs as anhedral rims on opaques and as euhedral crystals. Small aggregates of fine, even-grained quartz (1–3%) were recorded at several localities. Locally leucocratic gabbro encloses irregular fragments of more mafic, and finer grained, 'melagabbro' containing very fine-grained leucoxenated opaques. In thin section, boundaries between fragments and host are indistinct. At Yunndaga, and to a lesser extent in the Ghost Rocks area, the gabbro layer is thicker and becomes layered with a pyroxenitic base.

At Ghost Rocks a very distinctive porphyritic unit occurs within gabbro on the east limb of the syncline (see 'Petrography of the Ghost Rocks area'). The matrix consists of fine- to medium-grained orthopyroxene (partly replaced by amphibole), irregular fine- to medium-grained plagioclase, and very fine zoisite. Aggregates of medium-grained, long prismatic amphibole result in the porphyritic texture. In addition, irregular domains show complete epidote/zoisite replacement of plagioclase. Anhedral sphene, with or without opaque relicts, occurs throughout the rock. Witt (1990) described an identical gabbro unit from the Ora Banda area on BARDOC and DAVYHURST 1:100 000 sheets.

Both the harrisite and the gabbro layer are remarkably persistent, and present wherever the top of the Walter Williams Formation is exposed. Hill et al. (1987) noted that the formation is by far the most extensive olivine cumulate known in the Yilgarn Craton, and forms the base to an equally extensive ultramafic volcanic pile. They interpreted the Walter Williams Formation as the result of olivine accumulation and removal of liquid fractionate during outpouring of ultramafic lava.

The contact with overlying komatiite flows is marked by talc–chlorite schist, suggesting some movement along the lithological boundary. South of Happy Jack mine in the Comet Vale area, strongly deformed slices of fine-grained sedimentary rocks are also present along the contact. They are comparable to slivers of interflow sedimentary rocks found more commonly within komatiite.

Komatiite (*Auk*)

A thick package of komatiite flows, the equivalent of the Siberia Komatiite on BARDOC 1:100 000 sheet (Witt, 1987, 1990; see also Hill et al., 1987) overlies the Walter Williams Formation. The A- (spinifex olivine) and B- (cumulate olivine) zones of the totally serpentinized flows are recognizable in the southernmost exposures on either side of the highway and at the edge of Lake Goongarrie, and indicate an eastward-younging direction. Higher in the sequence, layers characterized by acicular clino-pyroxene textures indicate the presence of more mafic layers. Slivers of fine-grained, layered interflow sedimentary rocks are found east of Comet Vale, and in the southern Ghost Rocks area on RIVERINA. The rocks consist of very fine-grained, recrystallized plagioclase (?and quartz), with variable amounts of fine acicular tremolite in both matrix and veins.

Ultramafic schist (*Au*)

Ultramafic schist includes fine- to medium-grained tremolite(–chlorite) schist and fine-grained talc–chlorite–carbonate schist. No original textures are preserved, and precursor rocks cannot be confidently deduced. They occur within high-strain zones, commonly as lenses of variable dimensions, e.g. within granitoid gneiss southwest of Salt Dam and within basaltic schist (*Abs*) and metasedimentary rocks (*As*) in the Yunndaga area.

Lenses of ultramafic schist directly north of Lake Goongarrie contain locally undeformed domains with platy olivine spinifex textures, clearly indicating that they were derived from komatiite.

Tremolite schist (*Aur*)

Tremolite schist consists of fine- to medium-grained tremolite, with little or no interstitial plagioclase and/or chlorite. More complex assemblages are locally present. These include schists with a fine- to medium-grained talc–chlorite matrix, containing relicts of (early) medium-grained tremolite and overgrown by late stage tremolite prisms, either randomly oriented or with a weak preferred orientation. In many places hand specimens show a distinctly spaced main foliation defined by aligned tremolite, separating domains with unoriented amphibole.

Precursors for this lithology are komatiite, e.g. directly north of the Comet Vale Monzogranite. The major tremolite schist unit between Cock Robin mine and King Dam is probably derived from komatiite and high-Mg basalt, although undeformed precursors, including coarse-grained pyroxene spinifex ('stringy beef') textures south of Ant Bore, are not very common. Martyn and Johnson (1986) and Ashley and Martyn (1987) analysed some of these tremolite schists ('amphibole–chlorite schist') from the Jowett Well area, and found the high MgO contents indicative of both A- and B-zones of komatiite flows.

Mafic extrusive rocks

Basalt (*Ab*)

Massive, fine-grained basalt is found mainly in the Comet Vale area, both at the base of the greenstone succession and higher up (correlated respectively with Missouri Basalt and Bent Tree Basalt: see Table 1).

The 'footwall' basalt is mostly well foliated, and characterized, particularly towards the top, by fine- to medium-grained (up to 2 mm) phenocrysts or aggregates of plagioclase. In the Lady Margaret area, actinolite–plagioclase schist shows well-developed foliation defined by alignment of amphibole and shape-preferred orientation of plagioclase. This pervasive foliation is locally tightly folded. In less deformed domains, unoriented amphibole encloses interstitial plagioclase, epidote/zoisite, and irregular fine-grained sphene. Locally epidote/zoisite has replaced all plagioclase or even the entire rock; in such areas narrow veins are filled with sheaves of epidote/zoisite.

Narrow felsic porphyry sills, which have intruded the basalt, contain plagioclase and quartz phenocrysts, and are commonly quite strongly deformed. In the Lady Margaret area, leucogranite dykes and sills have also intruded both basaltic schist and felsic porphyry. This leucogranite is relatively little deformed and has no imposed pervasive fabric.

In the Ghost Rocks area, massive basalt occurs just below the overlying Walter Williams Formation on both limbs of the syncline, and as a major well-exposed unit along the entire northeast limb of the anticline.

Fine-grained, featureless basalt higher up in the Ora Banda sequence ('Bent Tree Basalt', Witt, 1987, 1990) is exposed north of the Comet Vale Monzogranite. Locally fine-grained plagioclase clots and/or phenocrysts are widely scattered throughout the rock. This basalt unit hosts several dolerite (*Ao*) and gabbro (*Aog*) sills ranging in width from several tens to several hundreds of metres. Minor fine- to medium-grained doleritic-textured layers and lenses are included in the basalt (*Ab*), and may represent central portions of thicker flows.

Ocellar-textured basalt (*Abo*) and pyroxene spinifex-textured basalt (*Abm*)

Two high-Mg basalt types (*Abo, Abm*) both contain ocellar and pyroxene spinifex textures, but are only distinguished by the main field characteristic. One type (*Abo*) contains widespread ocelli, whereas the other (*Abm*) shows predominantly fine- to coarse-grained acicular amphibole after pyroxene.

The ocellar-textured basalt (*Abo*) forms a distinct unit directly southeast of Menzies, separated from a more massive basalt to the north by a distinctive slate layer. Pyroxene spinifex-textured basalt (*Abm*) occurs as a thin, but persistent, unit above komatiite in the western domain (equivalent to Big Dick Basalt of the Ora Banda sequence;

Witt, 1987, 1990) (Table 1), and as a major unit in the Broughtonville area.

The ovoid, creamy to whitish ocelli appear locally more plagioclase rich than the matrix. Elsewhere, ocelli appear texturally identical to the groundmass. Remnants of pillow rims are found, but complete pillow structures are very rare. Locally ovoid aggregates of fine- to medium-grained plagioclase–epidote and quartz–epidote lie parallel to the foliation. They are distinct from the ocelli, and resemble amygdales.

The basalt matrix is dominated by prismatic amphibole (after pyroxene) with interstitial plagioclase. Variations of the matrix include the pyroxene spinifex and more doleritic texture in which fine- to medium-grained plagioclase prisms are surrounded by amphibole. Plagioclase is commonly recrystallized, and partly sericitized or replaced by epidote/zoisite. Fine-grained oxides, scattered throughout the matrix, are quite extensively leucoxenized.

Strong deformation of the basalt has resulted in formation of tremolite–chlorite–plagioclase schist, dominated by prismatic to acicular tremolite.

Basalt and hornblende schist (*Abs*)

Fine-grained basalt (*Abs*) interleaved with many sedimentary lenses/layers, as well as some narrow ultramafic schist layers, has locally preserved original textures, but contains major zones of shearing both along its western contact and within the sequence (e.g. Black Jack–Waterloo shear). Fine- to medium-grained amphibole prisms (60–70%) enclose randomly oriented, almost acicular plagioclase (20–25%) laths. Secondary epidote is a common minor phase (1–5%), in many cases clearly pseudomorphing plagioclase. Local massive epidotization, with 50% or more epidote/zoisite, is found in a wide zone (1–2 km) around the Jorgenson Monzogranite. At least locally, epidote forms small porphyroblasts that enclose the amphibole foliation. In such domains opaques (Fe–Ti oxide) are extensively altered to leucoxene and euhedral sphene crystals. Fine-grained biotite occurs only locally, but appears in equilibrium with amphibole. Biotite, however, is a prominent phase in the alteration zones of the gold-bearing lode systems (see 'Metamorphism') (Witt, 1993).

In strongly sheared domains, amphibole prisms lie within the main foliation, with interstitial plagioclase recrystallized into fine-grained granoblastic aggregates, and opaques and sphene arranged in trails.

Porphyritic basalt (*Abp*)

Basalt with medium- to coarse-grained, subhedral to euhedral plagioclase phenocrysts forms a distinctive, though narrow, unit at the top of the mafic succession in the western domain. This unit is equivalent to Victorious Basalt in the Ora Banda sequence (Witt, 1987, 1990). The only exposures are north of the Comet Vale Monzogranite, and further north the unit is cut out against the Menzies Shear Zone. In the Ghost Rocks area a similar narrow layer, including porphyritic doleritic-textured rock, occurs approximately in the centre of the syncline, and can also be considered as the equivalent unit.

The fine-grained matrix consists of amphibole prisms, plagioclase relics, epidote, minor biotite, small irregular (?Fe–Ti oxide) and elongate (?ilmenite) opaques. The plagioclase megacrysts and aggregates (5–30 mm) are extensively replaced by epidote/zoisite, and plagioclase relics are commonly sericitized. Locally large domains show epidotization of both megacrysts and matrix.

Basaltic amphibolite (*Aba*)

Fine- to medium-grained amphibolite in greenstone belts northeast of Alexandra Bore is probably derived from basalt and dolerite. Foliated domains show prismatic to acicular hornblende and fine-grained, polygonal granoblastic (recrystallized) plagioclase as main constituents. Fine-grained, locally euhedral, sphene is a prominent minor phase. Medium-grained zoisite is common in many areas, and may form massive layers or lenses parallel to the main foliation, with scattered fine-grained amphibole sheaves. Locally a ghost texture of unoriented plagioclase laths can still be recognized. In less deformed and altered domains, plagioclase laths, amphibole prisms, and fine-grained opaques are probably pseudomorphs after original igneous phases. Fine-grained garnet has been reported.

Amphibolite and mafic–ultramafic schist (*Ama, Amu*)

Pervasively foliated amphibolite (*Ama*) consists of fine- to medium-grained amphibole, fine-grained recrystallized plagioclase, and very fine elongate opaques and/or sphene. Amphibole commonly has a strong shape-preferred orientation that controls the overall fabric. Locally lath-shaped plagioclase, recognizable despite extensive recrystallization and/or sericite alteration, suggests a basaltic precursor. At several locations two amphiboles are present: an early, medium-grained, bluish yellow-green, pleochroic amphibole, and a later fine- to medium-grained, virtually colourless, acicular amphibole. Biotite is a minor phase and appears to be partly replaced by amphibole. Southeast of Cock Robin, thin biotite–plagioclase and zoisite-rich layers occur in feldspar-rich amphibolite.

The main foliation, or layering, is defined by an alteration of medium-grained amphibole and fine-grained plagioclase–quartz layers, and by the strong shape fabric of small opaque needles. Amphibole sheaves or curved crystals have locally grown across and enclosed this opaque fabric.

Garnet-bearing amphibolite, or quartz–hornblende schist, is found at three separate localities: 2 km north of Moriaty Well, 400 m northwest of Goodenough mine, and along the shore of Lake Ballard, west of Cock Robin mine. All three occurrences show very similar textures with a very strongly developed foliation, and are associated with strongly deformed to mylonitic felsic and siliceous schist. Most importantly, they appear much more quartz rich than the 'normal' amphibolite. For example, north of

Goodenough mine, medium-grained granoblastic quartz makes up 50% of rock volume, amphibole prisms approximately 35% and garnet up to 15%. Garnet occurs as anhedral, 'platy' grains (up to 1 cm long) parallel to the layering. The highly poikiloblastic garnet has enclosed the fine-grained opaques, plagioclase, quartz, and local fine-grained, prismatic colourless amphibole which is not present in the matrix.

The restricted occurrence of garnet amphibolite and garnet–hornblende–quartz schist in narrow layers and their quartz-rich composition, well-developed layering, and association with (strongly deformed) metasedimentary schist may indicate a sedimentary origin.

Variable carbonate alteration, accompanied by tourmaline, is quite extensive in the southernmost exposures.

In the area northeast of Menzies where amphibolite (*Ama*) is closely interleaved with tremolite schist (*Aur*) and some talc–chlorite schist (*Au*), the lithological code *Amu* is used on the map.

Mafic intrusives

Dolerite, pyroxene-phyric dolerite, and gabbro (*Ao*)

Narrow dolerite and pyroxene-phyric dolerite sills occur throughout the mafic extrusive rocks. They are commonly medium grained, with a 'spotted' texture of 3–4 mm prismatic amphibole (after pyroxene) in a partly recrystallized matrix of plagioclase. Distinct ophitic textures with prominent plagioclase laths are present in larger sills (gabbro). Porphyritic textures in the pyroxenitic rocks show variable amounts of larger (up to 20 mm) amphibole pseudomorphs of pyroxene scattered throughout a finer matrix of amphibole and plagioclase. These megacrysts are clearly poikilitic, enclosing small fragments of matrix. Skeletal leucoxene indicates the former presence of medium-grained Fe–Ti oxide. Fine-grained epidote and/or zoisite has resulted from metamorphic reconstitution of plagioclase.

Although some layering exists in the larger sills, it is commonly difficult to establish unequivocally a differentiation trend, and, therefore, a younging direction. In the greenstone enclave northeast of Alexandra Bore, a major dolerite/gabbro unit lies west of a coarse-grained tremolite (after pyroxene) rock (see later *Aox*) that may well represent a basal unit of a mafic sill.

Many narrow dolerite-textured lenses and layers in basalt are interpreted as part of thicker, and therefore coarser grained, flows. These are not indicated on the map sheet.

Gabbro (*Aog*)

Gabbro sills with well-defined layering or differentiation are mapped in the western domain. Two types of layering can be distinguished, very similar to layering displayed by two major sills in the Ora Banda sequence (Witt 1987, 1990).

The first type of layering, similar to that in the Mt Ellis Sill, is found in gabbro 2 km south of Yunndaga Siding, and overlying komatiite and high-Mg basalt (*Abm*). Three main zones are present:

(1) at the base a massive, coarse-grained pyroxenite-phyric to porphyritic dolerite;

(2) 'spotty' gabbro with subequant mafic spots (now amphibole after pyroxene) in leucogabbro groundmass; and

(3) gabbro, including quartz gabbro (Witt 1987).

The dolerite sills that occur further south at the same stratigraphic horizon show similar rock types, but with a less developed layering.

The second type of layering is found in a narrow sill to the northeast of the Comet Vale Monzogranite, entirely within massive basalt (*Ab*). The layers, and their comparison with units in the Mt Pleasant Sill in parentheses (Witt 1987, 1990), are from southwest to northeast:

(a) pyroxenitic gabbro and spotted gabbro (Unit 3);

(b) characteristic two-pyroxene gabbro (equant orthopyroxene and prismatic clinopyroxene; Unit 4);

(c) transitional to porphyritic gabbro with medium- to coarse-grained, chloritic, mafic patches (Units 5 and 6);

(d) 'flow-textured' gabbro, fine- to medium-grained with fine aligned plagioclase laths (Unit 7);

(e) quartz gabbro (Unit 9);

(f) medium-grained gabbro with long pyroxene and feldspar prisms; irregular size variations and small, more leucocratic domains present (Units 10 and 11).

The remarkable similarity in layering, as well as stratigraphic position, for the two gabbro types on MENZIES with the Mt Ellis and Mt Pleasant Sills on BARDOC 1:100 000 sheet (Witt 1987, 1990) suggest direct correlation. This does not necessarily imply that the sills are 'physically' connected, but that they are the result of the same intrusive events. For detailed petrography, geochemistry and petrogenetic considerations the reader is referred to papers by Witt (1987, 1990) and Witt et al. (1991).

Pyroxenite (*Aox*)

A distinctive, coarse-grained tremolite-rich rock in the greenstone enclave northeast of Alexandra Bore, is interpreted as a metapyroxenite. Unoriented, coarse-grained tremolite and its relics are surrounded and replaced by fine- to medium-grained tremolite and chlorite. This finer grained matrix is foliated close to the contacts with gabbro and granitoid. Fe–Ti oxide is leucoxenized and fine sphene crystals have grown locally. Scattered, poikilitic and highly irregular plagioclase locally show zoning, particularly within the rim.

Sedimentary rocks

Greywacke, arkose and biotite–feldspar–quartz schist (*Asg*) and polymictic conglomerate (*Asp*)

Well-foliated fine- to medium-grained greywacke and arkose, exposed north of Lake Goongarrie, consist of a fine-grained feldspar–quartz–biotite matrix in which larger clasts of quartz, feldspar and/or small rock fragments can be distinguished. Matrix minerals are variably recrystallized into finer grained aggregates, sericitized in the case of feldspar and/or locally boudinaged. Biotite is aligned parallel to the upright main foliation, and, in most of the area the rocks have developed into biotite–quartz–feldspar schist. Rock fragments include, in order of decreasing frequency, granitoid, felsic porphyry, grey to black slate, and greenschist.

Polymictic conglomerate (*Asp*) shows exactly the same features, and is only distinguished on the size of the clasts. These pebbles and boulders vary in size from 1 to 50 cm, and in shape from small elongate and flat to large and ovoid. The pebbles do not touch, i.e. the conglomerate is matrix supported. Granitoid pebbles are by far the most prominent, and the quartzo-feldspathic matrix is presumably largely granitoid derived.

Granitoid pebbles consist of unfoliated, biotite-bearing monzogranite. Both plagioclase and K-feldspar are altered (sericite, carbonate) and biotite is chloritized. Local late tourmaline has enclosed foliation trails. Quartz–mica schist fragments contain late-stage biotite porphyroblasts. Hornblende schist to amphibolite and carbonaceous slate to schist pebbles and fragments are commonly platy.

The well-developed foliation makes unequivocal recognition of sedimentary structures more difficult, although most, but not all, erosional contacts suggest a westwards younging sequence. Upright folding may be responsible for these opposite facing directions.

Towards the eastern tectonic contact of the coarse clastic association (*Asg–Asp*), very fine-grained slate is interlayered with coarser grained schist and greywacke. Locally extensive quartz veining and boudinage of coarser layers within slate occur, resulting in pseudo-conglomerate beds.

Grey slate and quartzo-feldspathic schist (*Asc*) and chert–silicified slate (*Ac*)

Fine-grained grey to black slate with interlayered fine- to medium-grained quartzo-feldspathic schist and siliceous marker beds form a much finer clastic sequence directly east of the coarse clastic association (*Asg–Asp*). Only the most prominent cherts and silicified slate beds (*Ac*) are shown on the map.

The fine-grained slate and schist association (*Asc–Ac*) sequence is strongly foliated, and interleaved on various scales with ultramafic schist, amphibolite and locally small granitoid gneiss slivers. Chert/silicified slate beds show isoclinal folding, (commonly steeply north- and south-plunging), and pervasive anastomosing foliation. These observations suggest a tectonically interleaved package of rocks.

Fine-grained slates locally show graded bedding, but with the closely spaced foliation and sharp contacts, it is difficult to unequivocally establish younging directions. Fine- to medium-grained biotitic quartz–feldspar schist is very similar to that described for the arkose–greywacke unit (*Asg*), and also contains typical coarse-grained feldspar and quartz clasts in a finer matrix. On a regional scale, however, the slate and schist association (*Asc–Ac*) is considerably finer grained and must represent a more distal depositional environment.

The chert beds (*Ac*) occur over the entire length of the exposed sequence, although, in detail, chert is not restricted to specific layers. In some breakaway exposures, partial silicification has preferentially occurred in fine-grained black slate, suggesting that most, if not all, chert is silicified slate or shale.

Grey to black slate (*Ash*) and grey-white banded chert (*Acw*)

Grey to black, fine-grained carbonaceous slate (*Ash*) is commonly silicified into coarsely banded grey-white 'chert' that outcrops well and provides excellent marker beds for mapping. Lateral changes from slate to chert are often observed. Slate lenses and layers occur as interflow units in mafic volcanic sequences.

A distinctive chert ridge (*Acw*), in a sheared-through macroscopic fold structure, occurs at the northernmost greenstone exposure at the edge of Lake Ballard. The chert varies from grey-white banded chert to layered, fine-grained, granular quartzite, and further to the south where two separate layers/lenses are exposed, it also includes very fine-grained, orange-reddish jasperoidal rock, similar to some of the silicified black slate. At several places chert is associated with feldspar-phyric quartzo-feldspathic schist. The origin of this chert is unknown, but may be primary. One float specimen of layered, fine- to medium-grained quartz–hematite rock (banded iron-formation) was found.

Metasedimentary rocks undivided (*As*)

Metasedimentary rocks occur as quite persistent layers and lenses within fine-grained basalt (*Abs*) in a zone from west of Menzies to south of Lady Harriet and Waterloo mines. All these rocks, including narrow ultramafic schist, are variably deformed and foliated within the Menzies Shear Zone.

A variety of metasedimentary rocks, including fine-grained slate, quartz-phyric quartz–muscovite schist, and biotite-rich quartzo-feldspathic schist with distinct clasts of granitoid (monzogranite and granodiorite) and locally ultramafic schist, make up this unit. The quartzo-feldspathic schists are directly comparable to the arkose–greywacke unit (*Asg*) and even polymictic conglomerate (*Asp*) north of Lake Goongarrie. Correlation of these clastic rock types implies either a major lateral facies change, with coarse clastic granitoid and minor greenschist debris becoming more and more interleaved with basalt and komatiite (ultramafic schist) flows, or tectonic interleaving of the coarse clastic rocks with the mafic and ultramafic volcanics.

In at least two localities, porphyritic schist with overall granodiorite to tonalite composition is of dubious origin. The schist could be derived from volcaniclastic sediments containing large clasts of plagioclase and quartz in a biotite–quartzo-feldspathic matrix, or from tonalitic porphyry sills.

Quartz-phyric schist (*Afs*) and fuchsite–quartz (–andalusite) rocks (*Alf, Als*)

Quartz-phyric schist (*Afs*), interbedded with feldspar-phyric layers and slate, and locally andalusite bearing, forms a narrow, but distinct unit, outlining the major structures in the area east and southeast of Menzies (Fig. 5; see 'Regional structure'). The unit is interpreted to overlie ultramafic schist, because at several localities along their contact the schist unit (*Afs*), contains small clasts of fuchsite schist that were probably derived from tremolite and/or talc–chlorite schist (Fig. 5). Furthermore, the unit shows more fine-grained slate higher in the sequence, and is overlain by a well-exposed chert marker bed, probably representing a silicified black slate. Furthermore, bedding–cleavage relationships indicate that the entire unit, though locally flat lying, lies on the west limb of a regional anticline. Martyn and Johnson (1986) also interpreted this sequence as upward younging, on the basis that increasing pyritic shale and chert are characteristic of the final stages in a felsic volcanic pile.

Fuchsite–quartz(–andalusite) rocks occur locally between the ultramafic and quartz-phyric schists, as well as within tremolite schist (Fig. 5). They form distinct outcropping ridges, particularly south of Jowett Well where the layering is very shallow dipping. The rocks are characterized by bright-green colours, and have a distinct accessory mineral assemblage (rutile, chromite) as well as geochemistry (Cr and Ni-rich: see Martyn and Johnson, 1986; Ashley and Martyn, 1987). Such alumino-silicate–quartz–fuchsite rocks are reported from a number of localities in the Eastern Goldfields (e.g. Purvis, 1984; Hallberg, 1985; Roth, 1988) and other Archaean greenstone belts (e.g. Schreyer et al., 1981; Kerrich et al., 1987). Their origin and setting are still subject of debate. Most interpretations involve early (synvolcanic or during early deformation) argillic-type high-temperature hydrothermal alteration, subsequently overprinted by regional metamorphism.

Interlayered quartz-phyric muscovite schist (*Afs*), ultramafic schist (*Aur*) and fuchsite–quartz–andalusite rock (*Alf*) are shown on the map as a separate unit (*Als*).

Quartz-phyric muscovite schist (Afs)

Quartz–muscovite schist shows a well-developed foliation defined by a preferred orientation of fine-grained muscovite, quartz, and feldspar. Typically ovoid, medium- to coarse-grained (1–4 mm) quartz 'eyes' are scattered throughout the matrix. Feldspar occurs as fine-grained plagioclase within a recrystallized quartz–muscovite matrix, and as small clasts (0.5–1 mm) and locally newly grown metamorphic porphyroblasts that have enclosed trails of quartz continuous with the main foliation. Fine-grained biotite, locally replaced by white mica, is found in feldspar-bearing layers.

Clasts of fuchsite schist (up to 10 cm, but commonly smaller) are found along or close to the contact with the underlying ultramafic schist (Fig. 5). The clasts consist almost entirely of fuchsite, with considerable amounts of very fine rutile (up to 1%) and locally medium-grained andalusite. In many cases, fuchsitic clasts are strongly flattened parallel to the main foliation, but still form highly distinctive bright-green patches.

Andalusite forms small porphyroblasts (up to 2 mm, but locally up to 10 mm). Microstructural observations indicate that andalusite grew after formation of the regional foliation, but before regional deformation had ceased (see 'Metamorphism'). Accessory minerals include tourmaline, which forms late-stage sheaves; very minor rutile; and, at one locality, multiply zoned zircon.

Grey to black slates become increasingly common higher in the sequence. The upper contact with overlying basaltic rocks is marked by a cherty layer, that may be partly original chert but is at least partly silicified slate. The interleaving of the unit with slate, the variable feldspar content, and the occurrence of fuchsite clasts suggest that the quartz-phyric muscovite schist is sedimentary in origin.

Fuchsite–quartz (–andalusite) rocks (Alf)

The remarkable fuchsite–quartz (–andalusite) rocks form a distinctive association that appears restricted to felsic–ultramafic schist contact zones (Fig. 5). This certainly holds true for the main body which forms pronounced ridges between Jowett Well and King Dam. Similar, but much thinner, fuchsite–quartz layers within ultramafic schist also appear associated with felsic schist layers, e.g. 1 km east of Emu mining centre. Other, smaller occurrences include:

(a) just west of Goodenough mine, in the hinge of the open synform;

(b) 1 km east of Goodenough mine;

(c) 500 m north of Cock Robin mine, on the shores of Lake Ballard;

(d) 400 m east of King Dam; and

(e) approximately 1.5 km north of Moriaty Well.

The quartz-rich rocks mostly have a distinctive bright-green colour, due to the commonly pervasive distribution of fuchsite, and also include dull brownish-grey, fine but irregularly banded quartz–andalusite rock. Quartz and fuchsite are generally fine grained, though andalusite varies in grain size from fine to coarse (up to 20 mm), highly poikiloblastic porphyroblasts. Rutile occurs as ubiquitous, very fine prisms, commonly arranged in prominent trails, that also include very fine chrome spinel (Ashley and Martyn, 1987). The typically high amounts of rutile and chrome spinel in all fuchsite–quartz rocks are illustrated by chemical analyses presented by Martyn and Johnson (1986; TiO_2 0.5–1.9%; Cr 2450 ppm–1.46%). Tourmaline is a common accessory, and locally occurs in quite massive lenses. Most minerals, including fuchsite, andalusite, rutile and tourmaline (chrome dravite) contain small, but significant, amounts of Cr_2O_3 (Ashley and Martyn, 1987).

Local chert and quartz–muscovite schist occurs within the fuchsite–quartz rocks. The bedding–cleavage intersection lineation in these interbedded chert–schist layers is parallel to the prominent linear fabric in the quartz–fuchsite rocks.

A variety of microstructures is observed in the fuchsite–quartz rocks. In the least deformed domains, irregular, ovoid patterns of very fine fuchsite surround fine-grained, polygonal granoblastic quartz. Irregular concentrations of very fine rutile(–chromite) may be independent of this pattern, but elsewhere show a similar ovoid distribution. The layering is defined by interbedded quartz-rich layers, fuchsite bands, and rutile(–chrome spinel) trails. However, irregular quartz- and fuchsite-rich patterns, crosscut by various narrow quartz veins, are locally developed.

At one locality, the common granoblastic quartz–fuchsite texture appears to postdate very fine-grained 'cherty' quartz with weakly orientated to random very fine fuchsite. The main foliation in this chert is outlined by thin, short trails of opaques that control two types of quartz microstructures:

(1) very fine grains, with weak shape-preferred orientation at right angles to the trails; and

(2) fine 'polygonal' grains, enclosing and partly controlled by trails.

Slightly larger chromite and rutile grains appear to be pulled apart in a direction at right angles to the opaque trails. Extension veins parallel to the trails in the polygonal quartz layers, as well as the elongate quartz in the 'cherty' domains, are all compatible with extension in the same direction.

Evidence for at least two foliations is common, particularly in the more fuchsitic rocks. The earlier foliation is defined by fuchsite–quartz banding, that in most cases is parallel to bedding, and locally appears to be a differentiated layering. This layering is overprinted by a second foliation, that forms a slaty cleavage in quartz-rich layers and a crenulation cleavage in fuchsite-rich layers.

Andalusite has grown across the early fabric. In many cases it has preferentially replaced fuchsite, and enclosed quartz as well as rutile(–chrome spinel) trails, thereby preserving the existing 'ovoid' or other textures. Locally, inclusion trails (the early fabric) are crenulated; outside the porphyroblast a closely spaced crenulation cleavage (the regional foliation) has formed. This would suggest that andalusite grew during formation of the second regional foliation. Andalusite–foliation relationships are described and discussed in more detail under 'Metamorphism'. In one specimen, relics of kyanite were found, suggesting that, at least locally, kyanite grew before andalusite.

At one location, 1.2 km southeast along the fence line from Jowett Well, two small outcropping ridges show quartz-phyric muscovite schist with numerous fuchsite clasts overlain by fuchsite–quartz(–andalusite) rock which, in turn, is overlain by a very distinctive, finely but irregularly banded quartz–andalusite rock. In thin section, the banding is defined by a quartz-rich and quartz–andalusite-rich layering, in which coarse-grained andalusite is highly poikiloblastic and is continuous across quartz-rich bands. The fine-grained polygonal grano-blastic quartz shows a weak crystallographic-preferred orientation, suggesting a possible tectonic origin for the original quartz–fuchsite layering.

A thin andalusite–quartz schist outcrops 1 km north of Moriaty Well. The rock consists of 75% quartz, with numerous fine trails of white mica and rutile, both with a very strong preferred orientation. Quartz is fine-grained and granoblastic, but elongate wherever mica seams are closer spaced. The bulk of the mica is replaced by andalusite, which forms medium-grained crystals that consist of 80% enclosed quartz. This strongly foliated schist separates talc–chlorite schist from fine-grained quartz–feldspar–muscovite schist with flattened fuchsite clasts.

At several localities small occurrences of (?)epidote are closely related to andalusite. For example, narrow bands of andalusite may laterally give way to epidote; elsewhere, medium-grained epidote is present within medium- to coarse-grained, highly poikiloblastic andalusite. Rarely kyanite is enclosed by andalusite and staurolite.

Biotite is present as a minor phase (east of King Dam) where it is spatially associated with, and enclosed by, andalusite. The fine- to locally medium-grained biotite is unoriented, and has grown over microfolds outlined by rutile trails within andalusite.

Locally feldspar-bearing schist occurs immediately adjacent to, or interleaved with, fuchsite–quartz rocks. For example, medium-grained feldspar is enclosed by medium-grained poikiloblastic andalusite in a thin layer immediately adjacent to finely banded quartz–andalusite rock. In the same layer andalusite encloses irregular epidote. Northeast of Cock Robin mine, the fuchsite–quartz rocks include schist with typical fine-grained, granoblastic quartz and very fine fuchsite, as well as very elongate feldspar crystals parallel to the layering. These plagioclase grains, though locally recrystallized, contain layering-parallel trails of fuchsite, rutile, opaques, and tourmaline. Such metamorphic feldspar is also observed in some felsic schists, where their inclusion trails distinguish them from earlier generation grains.

Martyn and Johnson (1986) and Ashley and Martyn (1987) interpreted the quartz–aluminosilicate–fuchsite (–rutile–chrome spinel) rocks to be derived from underlying komatiites by intense syn- to post-volcanic hydrothermal alteration, followed by regional metamorphism. Their main lines of evidence included:

(1) the stratiform nature of the fuchsite–quartz (–andalusite) assemblage (*Alf*) and its interleaving with cherts and quartz–muscovite schist, including those with fuchsite clasts;

(2) relatively immobile components such as Al_2O_3, TiO_2, V, Zr and Cr, though in variable absolute concentrations, have constant ratios suggesting residual enrichment; and

(3) the constancy of habit and (unusual) composition of chrome spinel in both fuchsite–quartz rocks and underlying komatiite. Chrome magnetite rims around already hydrothermally modified chrome spinel in antigorite–tremolite metakomatiite date alteration to pre-serpentinization (Ashley and Martyn, 1987).

Alteration characteristics suggest deep-level, acid epithermal-type processes, such as suggested for similar assemblages at Leonora/Malcolm (Roth, 1988) and in Zimbabwe (Kerrich et al., 1987). In these areas, as for the Jowett Well occurrence (Hallberg, 1987), alteration is envisaged to have occurred along major structures during early (thrust) deformation.

Evidence for large-scale thrusting at Jowett Well is, however, not convincing, even though interlayering of ultramafic schist and fuchsite–quartz rocks (*Alf*) is obvious. The quartz-phyric felsic schist (*Afs*) contains small flattened fuchsite clasts along its entire lower contact. Furthermore, fuchsite–quartz rocks are interleaved with quartz–muscovite schist of sedimentary origin and of generally low-strain states. Similar quartz–aluminosilicate assemblages elsewhere (e.g. north of Mt Monger, Kurnalpi, north of Kambalda) also occur in areas of low to intermediate strain entirely within felsic volcanic/ volcaniclastic successions (Swager, in press) suggesting that ultramafic or mafic rocks and early high-strain zones may not be essential requirements for their formation.

Intrusive porphyries

Intrusive felsic–intermediate porphyry (*Apq, Apa*)

The most common intrusive porphyry contains medium- to locally coarse-grained plagioclase and quartz phenocrysts in a finer grained feldspar–quartz–biotite matrix (*Apq*). It occurs as narrow (3–6 m) sills that are variably deformed, though contacts with greenstone host rocks are strongly sheared. As in many other areas in the Eastern Goldfields, minor gold mineralization is found locally along these sheared contacts, e.g. Sand Queen, Hill View. The matrix is recrystallized, with fine-grained, polygonal granoblastic quartz and feldspar (–sericite–zoisite), and aligned biotite flakes and/or aggregates. Where deformation and alteration are most intense, biotite is chloritized, plagioclase sericitized, and secondary carbonate becomes prominent. Fine-grained, elongate garnet (spessartine) was found in strongly foliated porphyry at three localities (eastern slope of Mt Menzies; 4 km southeast of Menzies township; Robinson Crusoe mine: W. K. Witt, pers. comm., 1989).

Plagioclase-rich (albite) porphyry sills and dykes (*Apa*) are restricted to ultramafic host rocks, and contain up to 90% albite, up to 15% fine- to medium-grained amphibole (tremolite), and some scattered quartz, opaques and/or chlorite. A matrix of fine-grained, irregular to polygonal granoblastic plagioclase encloses sub-euhedral phenocrysts, locally up to 1 cm long.

A remarkable albite habit is found in a plagioclase–amphibole rock north of Emu mine. Albite occurs as medium-grained, unoriented sheaves, built up of numerous irregular 'rods' and 'plates', that make up 80–85% of the rock, with the remainder fine- to medium-grained amphibole. A massive albitite occurs within basalt (*Abs*) approximately 3 km northwest of Menzies town. This rock consists of 95% fine- to medium-grained albite and 5% medium-grained prismatic epidote.

Hornblende lamprophyre (*Apl*) and diorite (*Apd*)

Only one small hornblende lamprophyre, or spessartite (Rock, 1984), dyke was found, approximately 1.4 km due east of Blowfly mine along a fence line. The spessartite contains medium-grained (1–3 mm) euhedral/ idiomorphic hornblende with numerous growth zones in a fine-grained matrix of hornblende, partly sericitized plagioclase (up to 50%), highly acicular apatite, and minor scattered opaques. Hornblende (locally replaced by tremolite) is the only porphyritic phase, varies from prismatic to acicular, and makes up 50% of the rock by volume. In handspecimen, irregular 'fragments' of more mafic composition 'float' within more leucocratic rock, suggesting a weakly fragmental texture. In thin section these distinctions appear largely gradational.

Two occurrences of diorite dykes (*Apd*) are found in the mafic–ultramafic rocks (*Aur, Amu*) underlying the felsic schist unit (*Asq*). Medium-grained subhedral hornblende and sericitized plagioclase phenocrysts are present in a finer grained matrix of plagioclase, hornblende, some quartz, and variable amounts of fine-grained biotite. Hornblende commonly shows growth zoning, and is prismatic to acicular, with up to 8 mm long crystals. Apatite and opaques are accessory phases. The western occurrence, within the contact zone along the Jorgenson Monzogranite, is strongly deformed, with a foliation formed by hornblende and biotite.

Diorite and lamprophyre have a similar mode of occurrence and are both porphyritic with zoned hornblende crystals. They may be genetically related.

Petrography of the Ghost Rocks area

Greenstones at Ghost Rocks (Figs 3, 4) are all part of the Ora Banda sequence (see 'Western domain'). They are mostly described with their equivalents on MENZIES. Here, attention 'is drawn to some rock occurrences and features not present on MENZIES.

Prominent, thin gabbro layers in the northernmost occurrences of the Wongi Basalt appear to contain layering with pyroxenite, quartz gabbro and medium-grained pyroxene sheaf-textured domains. The latter textures are very similar to those in the finer grained pyroxene spinifex-textured basalt. It is uncertain whether the gabbro layers represent intrusive sills or thicker, and therefore coarser and more differentiated flows.

The Wongi and Missouri Basalts (Figs 3, 4) are separated by thin metasedimentary rocks that were intruded by gabbro/dolerite. These metasedimentary rocks include grey slate and layered hornblende or biotite–quartz–feldspar schist, possibly derived from intermediate (andesitic) or contaminated felsic volcanic rocks. Towards the southeast, several layers of metasedimentary rocks are present within the top of the Wongi Basalt.

Greenstones overlying komatiite (i.e. Siberia Komatiite: Figs 3, 4) consist of basalt, coarse plagioclase-phyric basalt and dolerite, medium-grained gabbro with locally preserved slivers of basal perodotite, and (in the core of the syncline) narrow metasedimentary units. This sequence, though strongly foliated and structurally attenuated, nevertheless appears appreciably thinner than further south.

The strongly foliated and lineated granite (*Ag*) in the core of the proposed anticline is probably derived from K-feldspar-phyric biotite monzogranite.

Petrography and structure of the granitoids

Monzogranite is by far the dominant granitoid on MENZIES, with only minor granodiorite and tonalite. Several granite plutons can be interpreted in terms of the structural classification proposed by Witt and Swager (1989; Table 2). These distinctive plutons are given formal names. The general classification (*Ag*) is given where extensive weathering makes recognition of original rock type impossible, or where granitoid is covered by medium- to coarse-grained quartzo-feldspathic sand.

Monzogranite (*Agm*)

Monzogranite is characterized in handspecimen by K-feldspar megacrysts (1–4 cm) in a variably medium-grained matrix. K-feldspar (40–30%), plagioclase (30–35%), and quartz (25–35%) are present in approxi-mately equal amounts, and biotite (1–3%) is the only mafic phase. Narrow pegmatite dykes are common.

The K-feldspar grains vary from fine to coarse grained. The larger grains, as well as the megacrysts, enclose plagioclase and quartz, and show zones of perthite along their contact with plagioclase. Fine- to medium-grained plagioclase shows albite twinning, and is variably sericitized. Quartz commonly occurs as fine- to medium-grained aggregates formed by recrystallization of formerly much coarser grains. Biotite occurs as fine-grained single plates throughout the matrix and as medium-grained plates in small clusters or schlieren. These biotite clusters

Table 2. Regional deformation and granitoid emplacement history

	REGIONAL DEFORMATION HISTORY (a)	GRANITOID INTRUSION (b)
D_4	regional shortening, oblique N-striking faults; dextral (Kalgoorlie)	late-tectonic granitoid
D_3	continued, regional ENE–WSW shortening transcurrent faults NNW–trend; sinistral en–echelon folds Formation of syntectonic, clastic basins	post-D_2 to syn-D_3 granitoid
D_2	regional, upright folds NNW - strike	pre- to syn-D_2 granitoid
D_1	thrust stacking recumbent folding	?
	greenstone volcanism	

(a) Swager, 1989 ; Swager and Griffin, 1990
(b) Witt and Swager, 1989

contain locally higher concentrations of fine sphene and/or epidote–zoisite. Wherever chlorite has replaced biotite, it contains fine rutile needles. Sphene is locally a prominent phase, occurring as distinct euhedral crystals up to 1 mm long, and including grains enclosed by K-feldspar. Elsewhere, fine sphene still contains irregular leucoxene–opaque relics. Epidote and calcite are locally minor phases. Accessories include opaques (minor, leucoxenized), apatite, and multiply zoned zircon.

Five kilometres east of Alexandra Bore, fine-grained leucocratic dykes or sills show sharp, undeformed contacts with the main monzogranite, and are interpreted as co-magmatic phases. This monzogranite appears to have a marginally higher plagioclase:K-feldspar ratio, and contains up to 1% green hornblende within small biotite–epidote clusters. Ubiquitous zircons show clear, multiple, growth zones. Highly mafic (i.e. tonalitic) enclaves (40–35% hornblende, 40–35% biotite; 1% sphene, 2–3% opaques, 15–20% quartz–plagioclase–K-feldspar–epidote) occur in monzogranite without hornblende.

At Granite Dam, a weak, but well-developed, fabric is interpreted as a magmatic flow foliation, outlined mainly by the K-feldspar megacrysts and biotite schlieren. The foliation is better developed in locally finer grained and biotite-rich domains, in which plagioclase and quartz all show a weak shape-preferred orientation, but no crystallographic fabric. Fine- to medium-grained biotite (5%) has a very strong preferred orientation, and even epidote (1–2%) is elongate within the foliation. These more mafic domains occur as 'synplutonic' dykes; i.e. they are broken up and intruded by monzogranite, parallel to the foliation. Both monzogranite intrusions and more mafic monzogranite dykes are crosscut by the numerous pegmatite dykes.

The small greenstone enclaves northeast of Alexandra Bore are entirely surrounded by monzogranite, which shows a contact-parallel foliation independent of the orientation of the contact.

Goongarrie Monzogranite (*Agmg*)

The Goongarrie Monzogranite named after Goongarrie Station (Witt, 1990) contains a widely spaced foliation, and locally shows narrow shear zones, parallel to the regional fabric. As shown on BARDOC (Witt, 1990), this monzogranite occurs in the core of a regional F_2 anticline. The structural features suggest a pre- to syn-D_2 emplacement for this domal granitoid (Witt and Swager, 1989).

Jorgenson Monzogranite (*Agmj*)

The Jorgenson Monzogranite (herein named after Jorgenson Well 15 km north-northeast of Menzies) is characterized by a strong contact-parallel foliation with a steeply plunging mineral lineation. Some interleaving with amphibolite and felsic schist along the granitoid contact in the Fullers Well area may be intrusive, tectonic, or both. Locally very strongly foliated quartzo-feldspathic mica schist contains isolated fine- to medium-grained garnets, both as isolated grains and in lensoid domains parallel to the foliation. This schist may be tectonically derived from fine-grained leucogranite representing a marginal phase. Such garnet-bearing leucogranite was described in the contact zone of the Bali Monzogranite on DUNNSVILLE (Swager, 1990). The Jorgenson Monzogranite includes medium- to coarse-grained, weakly porphyritic biotite syenogranite, exposed 3 km east of Jorgenson Well.

Little deformation appears to have taken place within the bulk of the granitoid. Emplacement has influenced the geometry of the greenstone succession, but postdates the regional, upright F_2 folding (see 'Structural geology'). The structural features suggest a post-D_2 to syn-D_3 timing for emplacement of the Jorgenson Monzogranite 'diapir' (Witt and Swager, 1989).

Comet Vale Monzogranite (*Agmc*)

The poorly exposed Comet Vale Monzogranite (herein named after the abandoned town site at the southern border of the monzogranite) has slightly different, but distinctive, textural features in the limited fresh outcrop. It is characterized by a fine- to medium-grained feldspar–quartz matrix (up to 50%), in which medium- to coarse-grained K-feldspar, zoned plagioclase, rounded quartz grains and aggregates, and biotite aggregates occur. This porphyritic texture suggests relatively high-level emplacement.

The Comet Vale Monzogranite forms an almost circular outcrop pattern which is outlined largely by aeromagnetics (Fig. 6). From limited outcrop and drillchips along and across its southern contact, the monzogranite appears to be massive. Its emplacement was accommodated by various faults and shear zones (e.g. Lake View shear, Happy Jack shear, Lady Margaret shear), as well as zones of bulk shortening (small-scale refolding about east–west axes) within greenstones adjacent to the faults (Fig. 6).

Along the northeastern side of the pluton, strongly foliated monzogranite is exposed, and also in contact with the clastic metasedimentary rocks (*Asg*). The porphyritic texture of the monzogranite becomes enhanced in these shear zones. A narrow slice of similar foliated granitoid occurs 1 km northwest of Moriaty Well between porphyritic basalt (*Abp*) and ultramafic schist (*Au*), within the Menzies Shear Zone. The Comet Vale Monzogranite was thus apparently deformed (note sinistral displacement of isolated slice) in the major D_3 shear.

The overall structural relationships are similar to those of the late-tectonic (syn-D_3) granitoid of Witt and Swager (1989), that forcefully intruded the greenstones.

Tonalite (*Agt*)

Tonalite has only been found as dykes, although the granitoid pluton (*Ag*) between Blowfly mine and Piccadilly Well may well be largely tonalitic. This granitoid is poorly exposed, and strongly bleached and weathered so that its original composition cannot be determined. The only fresh exposure was found in a small (?)dyke at its southern end. This tonalite consists of medium-grained plagioclase

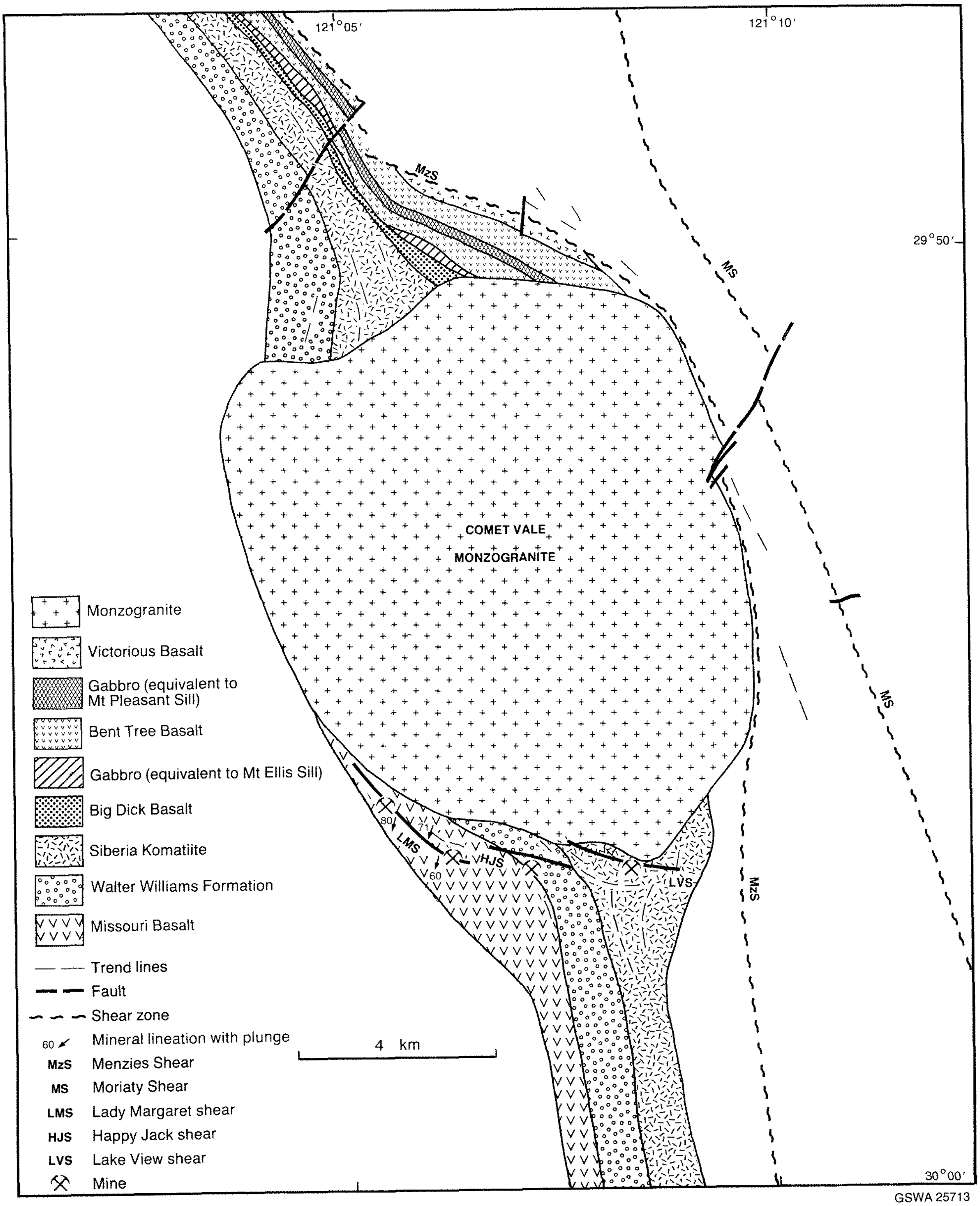


Figure 6. Greenstone structures around the Comet Vale Monzogranite, and correlation of greenstone units with the stratigraphy in the Ora Banda sequence of Witt (1990)

(60–65%) with locally preserved zoning, minor interstitial K-feldspar (<5%), interstitial quartz (25%) which is mostly recrystallized into granoblastic aggregates, and fine- to medium-grained amphibole (6–8%) with fine, acicular tremolite–actinolite overgrowths. Small amounts of biotite are found locally enclosed in plagioclase. Opaques, short prismatic apatite, and zoned zircon are the most prominent accessory phases.

A distinct plug of feldspar porphyry occurs to the west of this granitoid, and is separated from it by tremolite schist. This overall tonalitic rock which may be related to the larger granitoid pluton, is dominated by 1–3 mm plagioclase phenocrysts surrounded by fine-grained, partly altered, partly recrystallized plagioclase and regularly distributed fine quartz. Fine-grained biotite, as single grains and small concentrations, is locally associated with strongly pleochroic (colourless to bluish-green) hornblende (3–5%) present throughout the rock.

A major tonalite dyke exposed 1 km due south of Fullers Well is very similar in composition and texture to the dyke described above. Plagioclase is medium to, locally, coarse grained; shows widespread sericitization; and is commonly surrounded by a 'rim' of recrystallized plagioclase–quartz–hornblende. Quartz (15–20%) is largely interstitial to plagioclase, and fine- to medium-grained hornblende (5–10%) occurs throughout the rock. None of the these tonalite dykes show any strong deformation.

Oliver Twist Granodiorite (*Aggo*)

The elongate Oliver Twist Granodiorite north of Mt Menzies is poorly exposed along its southern and southeastern contacts, mainly as highly weathered rock. Its interpreted northern extent is less well constrained because detailed aeromagnetic coverage is not available.

The pluton consists of granodiorite transitional to plagioclase-rich monzogranite. Granodiorite from the Federal mine site is slightly porphyritic, with 70% phenocrysts (both feldspars) in a finer grained matrix. Medium- to coarse-grained plagioclase (35%) is extensively sericitized and epidotized, but in many cases still shows oscillatory zoning; quartz (30%) occurs as recrystallized aggregates outlining original magmatic grains. Dark-brown biotite occurs as fine-grained plates (3%) in the matrix and as prominent medium-grained crystals (5%), accompanied by subhedral hornblende (1%). Locally euhedral sphene is associated with the biotite–hornblende aggregates. Epidote (1%) is present throughout as a secondary phase, but is also present within plagioclase as euhedral, partly zoned, medium-grained crystals. Minor opaques include magnetite.

Pluton contacts are strongly foliated, and contain a well-developed mineral lineation. At the southern extremity of the pluton, this lineation plunges gently southwards; along its eastern contact zone, the lineation plunges obliquely southeast. Locally the foliation shows a distinct asymmetric fabric suggesting granitoid-up – greenstone-down movement. Relics of formerly medium- to coarse-grained feldspar (both plagioclase and K-feldspar) occur within the well-foliated/layered matrix of fine- to medium-grained, polygonal granoblastic feldspar and quartz, with its layers/lenses of biotite (5–6%). Secondary muscovite replaced both plagioclase and biotite.

The structural contact features are compatible with both a pre- to syn-D_2 timing (i.e. domal granitoid in core of anticline: see 'Structural geology') and post-D_2 to syn-D_3 timing (i.e. diapir granitoid, shouldering aside folded greenstone succession).

Granitoid gneiss (*Agn*)

Granitoid gneiss forms an approximately 4 km wide zone immediately east of the major greenstone belt (Fig. 2). Best exposure of the zone is north of Lake Goongarrie. Its extension beyond the weathered outcrops north of Piccadilly Well is unknown; its southern continuation on BARDOC can be interpreted only from aeromagnetics, but is not exposed (see 'Structural geology').

The gneiss is pervasively foliated, with a weak quartzo-feldspathic layering containing feldspar porphyroclasts of various sizes. A well-developed horizontal to gently north-plunging mineral lineation is characteristic (Fig. 7). Layers and lenses of tremolite schist, amphibolite, and locally massive gabbro are interleaved with the gneiss, and vary from narrow lenses (10 cm thick) to major layers up to several hundred metres wide and 1–2 km long. Some inter-leaving with strongly schistose metasedimentary rocks (*Asc*) and ultramafic schist (*Au*) occurs along the western contact.

In general, precursor granitoid textures can be inferred despite the intense deformation. The gneisses were derived largely from biotite monzogranite, though in some southwestern domains hornblende granodiorite was the precursor. K-feldspar megacrysts and larger plagioclase crystals are characterized by recrystallized tails adjacent to strongly undulose cores. Smaller original grains are more extensively recrystallized, with local development of relatively strain-free, polygonal, granoblastic domains. Quartz 'ribbons' are recrystallized into fine-grained aggregates of equant to barely elongate grains. Biotite (up to 3%), or hornblende, show a strong preferred orientation. Fine-grained opaques, leucoxene, and/or sphene also occur in fine trails.

The entire granitoid gneiss is interpreted as forming part of a major shear zone, the Moriaty Shear. Microstructures from various areas (pressure shadows and recrystallized tails on porphyroclasts; shear bands) indicate left lateral movement.

Metamorphism

Binns et al. (1976) in their review of the regional metamorphism in the Eastern Goldfields Province divided the greenstones into a medium-grade domain (upper greenschist to lower amphibolite facies) south of Menzies and high-grade domains (lower to upper amphibolite facies) northeast and northwest of Menzies. The change from low to medium metamorphic grade as defined by Binns et al. (1976) does not exactly coincide with, but lies just below, the greenschist–amphibolite facies boundary of Turner (1981) (see also Ahmat, 1986).

Distinctive andalusite-, garnet-, and locally chloritoid-bearing assemblages (Fig. 7) are diagnostic for medium-grade conditions, based on the metamorphic assemblages listed by Binns et al. (1976) and Ahmat (1986). Assemblages at the greenschist–amphibolite facies transition (e.g. epidote-bearing assemblages in metabasalt around Menzies) are included in the medium-grade domain. Andalusite is present as scattered crystals in quartz–muscovite and felsic schists (*Afs*) and as a prominent phase in the quartz–fuchsite–andalusite rocks (*Alf, Als*). Garnet occurs in thin quartz–hornblende schist layers/lenses within basaltic amphibolite (*Ama, Amu*), and, together with ?chloritoid, in hornblende–biotite alteration assemblages along gold-mineralized shear zones to the south of Menzies (Witt, 1993). These assemblages indicate peak temperature metamorphism at lower amphibolite facies but at relatively low pressures. Diopside and diopside–microcline assemblages in alteration zones to the northeast and northwest of Menzies (Fig. 7) (Witt, 1993) suggest middle amphibolite facies conditions.

Ashley and Martyn (1987) estimated that metamorphic conditions, based on co-existing assemblages in quartz–aluminosilicate rocks and ultramafic schist at Jowett Well are bracketed by the temperature and pressure limits of 400–525°C and less than 4 kb. They suggested a possible refinement of the temperature interval to 440–510°C using paragonite substitution in fuchsite (not taking into account any Cr and phengitic substitution in the white mica).

Staurolite and kyanite, both enclosed in andalusite, were observed in one handspecimen of quartz–fuchsite–andalusite schist east of King Dam. In the same rock, small biotite porphyroblasts are also enclosed by, or occur adjacent to, andalusite. Staurolite has been reported in medium- and high-grade pelitic rocks (Binns et al., 1976; Bickle and Archibald, 1984).

Reported occurrences of kyanite are restricted to the remarkable quartz–fuchsite–aluminosilicate rocks associated with or derived from felsic volcanic rocks (e.g. Hallberg, 1987) which in several examples are adjacent to ultramafic rocks (Purvis, 1984). This kyanite has been explained elsewhere as limited to ‘probably anomalous structural settings’ (Binns et al., 1976). The presence of kyanite enclosed within andalusite, however, merely suggests increasing temperature at low to intermediate pressures, or decreasing pressure at temperatures below the aluminosilicate triple point (ca. 500°C).

Foliation–porphyroblast relationships provide information about the relative timing of peak metamorphic conditions. Garnet porphyroblasts have grown across, and enclosed, the regional foliation. The internal fabric is outlined mainly by quartz-rich bands that are continuous with, and have the same textures as, quartz-rich bands in the matrix. These microstructures suggest garnet growth late during and/or after formation of the regional foliation.

Andalusite porphyroblasts show locally spectacular inclusion trail geometries (Fig. 8). Andalusite has enclosed distinct rutile trails which in most cases appear parallel to quartz-rich and quartz–fuchsite layering. This fabric (here designated S_0–S_1) is the oldest recognizable foliation, and is virtually parallel to bedding where thin chert–felsic schist is interlayered with the fuchsite–quartz rocks. Porphyroblast–foliation microstructures, illustrated in Figure 8, indicate that andalusite:

(1) postdates S_0–S_1;

(2) has grown both early and late during (micro)folding of S_0–S_1, and formation of a crenulation cleavage (i.e. upright D_2 folding with S_2 cleavage); and

(3) had largely stopped growing before later stage deformation.

The complex development of the regional foliation (S_2–S_3; see below) is apparent from Figure 8.

Structural geology

The major granite–greenstone structures are interpreted in terms of the deformation and granitoid emplacement histories outlined by Swager (1989) and Witt and Swager (1989) (Table 2). D_1 subhorizontal structures have not been identified, but post-D_2 shallow dipping shear zones have been recognized. The regional upright folds are interpreted as F_2 structures that developed further during continued D_3 regional shortening. The regional foliation is in most cases interpreted as a composite S_2–S_3 fabric. Major D_3 transcurrent faulting occurred in well-defined shear zones. These zones, however, probably have prolonged movement histories.

The main regional structures (i.e. shear zones, folds) on MENZIES, and their overall relationships with adjacent areas, are discussed below. The geometry of individual structures and/or areas is treated in more detail in a later section.

Regional structure

The regional structure is dominated by the Menzies–Bardoc–Boorara Shear Zone which separates two different tectono-stratigraphic domains (Fig. 2). This suggests that the Menzies Shear Zone follows, or may have developed from, an early, possibly syn-depositional, fault system, that was reactivated throughout the deformation history.

The trace of the Menzies Shear Zone is more or less defined by the eastern limit of the Ora Banda sequence. The actual zone of deformation, however, is much wider, as indicated by tectonic interleaving of rock units on a larger scale, for example, the amphibolitic basalt (*Abs*) – metasedimentary (*As*) – ultramafic schist (*Au*) association. This wide zone of shearing can be correlated with the Bardoc Deformation Zone and would include the greywacke (*Asg*) – polymictic conglomerate (*Asp*) sequence. The entire association can be interpreted as a

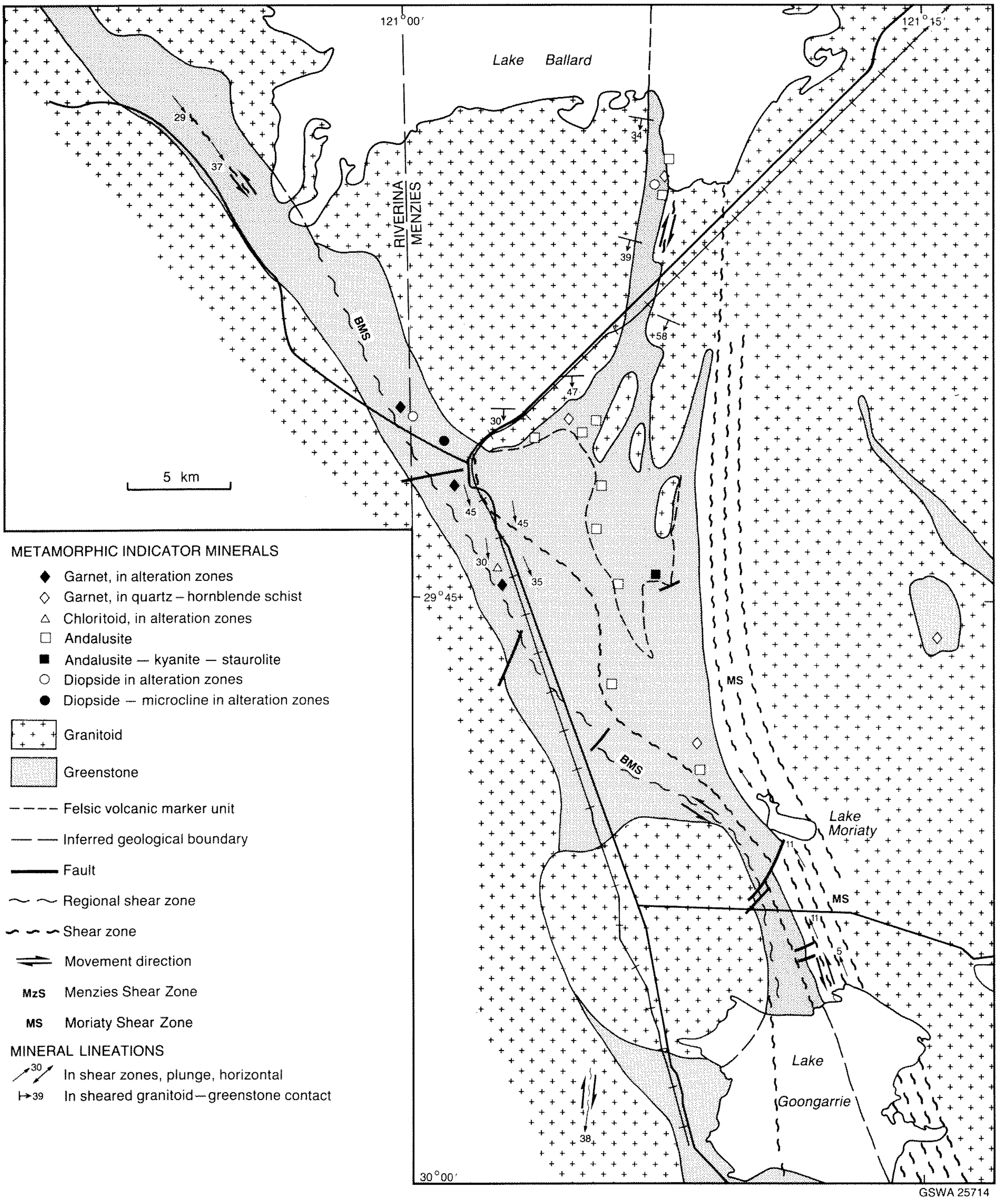


Figure 7. Mineral lineations, and inferred movement directions, in and along major shear zones, and distribution of metamorphic indicator minerals

separate tectono-stratigraphic domain (Fig. 9). A characteristic feature is the intermediate south- to southeast-plunging mineral lineation found in individual shear zones within and along the Menzies Shear Zone (Fig. 7). These lineations in the mineralized Menzies corridor and in the Ghost Rocks area indicate left-lateral and west-block-down movement, which is correlated with the main episode (D_3) of sinistral movement along the Menzies Shear Zone (Witt, 1990; Swager, 1989).

Figure 9 shows the main fold structures west of the Menzies Shear Zone. On MENZIES the Ora Banda sequence lies on the east limb of the regional Mt Pleasant–Goongarrie (F_2) anticline which is cored by the Goongarrie

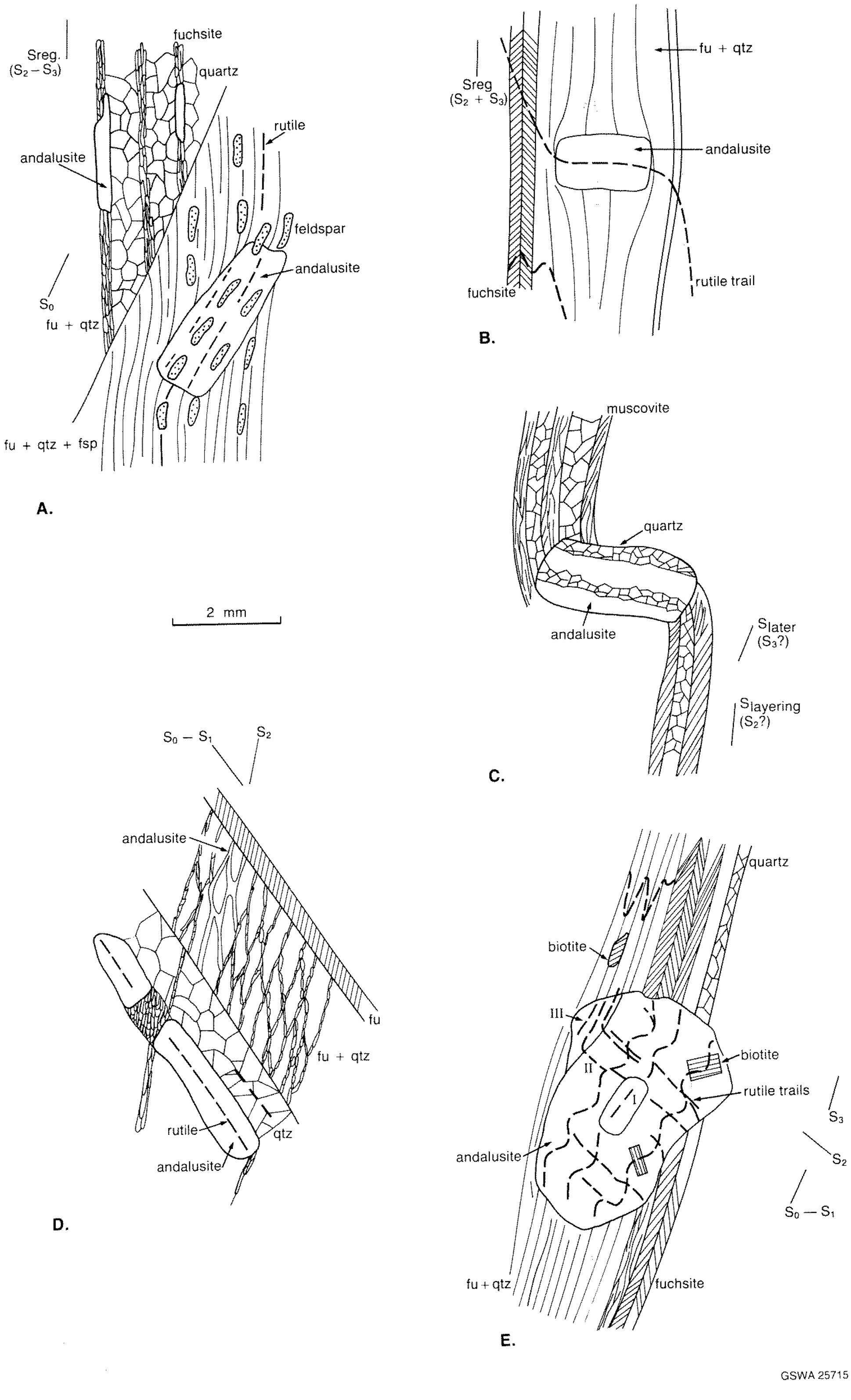


Figure 8. Examples of andalusite porphyroblast–foliation relationships

A, B. Andalusite-bearing muscovite–quartz–feldspar schist (*Afs*), with local fuchsite; Dunlop mine dump; GSWA samples 97198, 9197

C. Andalusite-bearing muscovite–quartz–feldspar schist (*Afs*), east of Cock Robin mine; GSWA sample 9766

D. Quartz–fuchsite–andalusite rock (*Alf*), east of Emu mine; GSWA sample 97616

E. Andalusite–biotite–fuchsite–quartz schist (*Alf*), east of King Dam; GSWA sample 97605

Note: fu — fuchsite, qtz — quartz, fsp – feldspar

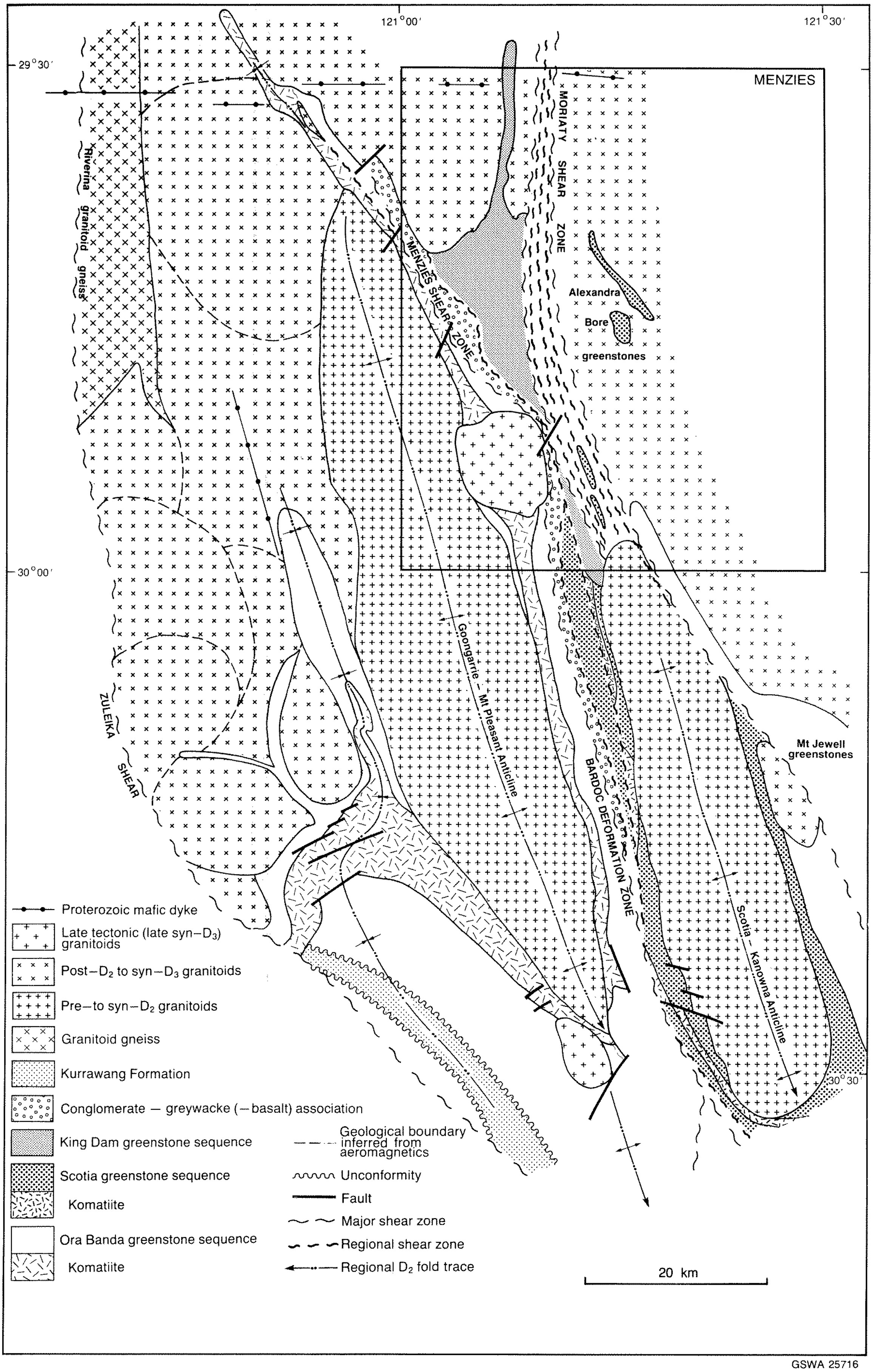


Figure 9. Regional tectono-stratigraphic interpretation of the MENZIES area

Monzogranite (Witt, 1990; Witt and Swager, 1989). North of the Comet Vale Monzogranite, successively older units are cut out against the Menzies Shear Zone, until southwest of Menzies township all units above the komatiite are absent.

The trace of the Menzies Shear Zone can be inferred from scattered outcrop on the adjacent RIVERINA sheet. The complex syncline–anticline structure of the Ora Banda sequence in the Ghost Rocks area (see p. 26) is less easily correlated with the simple anticline further south on MENZIES. A possible explanation involves the development of an asymmetrical fold pair on the east limb of the F_2 regional Mt Pleasant – Goongarrie Anticline. This interpretation appears to be supported by aeromagnetic trends between Ghost Rocks and Menzies, which suggest that the syncline–anticline fold pair dies out southwards along strike (Figs 3, 4). The pre- to syn-D_2 ('domal') Goongarrie Monzogranite has a distinct magnetic signature dominated by a northwesterly trend. South of Ghost Rocks this magnetic signature dies out against magnetically featureless granitoid with an approximately ovoid outline in plan. This latter granitoid is tentatively interpreted as a post-D_2 to syn-D_3 'diapir' (Witt and Swager, 1989).

East of the Menzies Shear Zone, stratigraphy and structure of the greenstones are distinctly different. This eastern domain with its complex internal structure is bounded to the east by the Moriaty Shear Zone, consisting of strongly foliated (gneissic) granitoid with interleaved amphibolite and ultramafic schist lenses. The Moriaty Shear Zone is characterized by a subhorizontal to very shallow north-plunging mineral lineation, and left-lateral displacement deduced from microstructural criteria (Fig. 7).

The dominant structure within this domain is the King Dam Anticline, which is interpreted as a regional F_2 fold (see p. 25). South of King Dam, the anticline is clearly outlined by a felsic schist unit (Fig. 5). North of King Dam the anticline is poorly defined because of later deformation associated with granitoid intrusion.

Two locally developed synclines on either side of the King Dam Anticline are interpreted as post-D_2 structures which resulted from granitoid emplacement (Fig. 5). Immediately east of King Dam, the felsic schist marker unit abruptly swings into an east–west orientation, appears to be discontinuous further eastwards, and then returns possibly to a northerly strike. Both bedding (S_1) and the axial planar S_2 foliation (see below) are rotated, indicating the post-D_2 development of this 'synclinal' structure that lacks an axial-plane foliation (see later). However, in mica-rich andalusite–quartz–fuchsite schist a new foliation has overprinted earlier fabrics.

Between Menzies township, Goodenough mine and Jowett Well an open synclinal structure is interpreted to result from emplacement of the Jorgenson Monzogranite (Figs 5, 10). This granitoid partly intruded into, and partly pushed aside, the western limb of the F_2 anticline. The highly deformed top of the felsic schist unit around this late stage syncline is interpreted as a shear zone, along which the doleritic- and ocellar-textured basalt units (*Ab–Abo*) moved relatively northwards. Between Menzies and Goodenough the shear movement is mostly reverse (thrust); however, between Goodenough and Jowett Well a dextral component is prominent (Fig. 10). Evidence for the northwards movement direction is inferred from:

(1) cutting out of slate and basalt units between Goodenough and Jowett Well (Fig. 10);

(2) the sigmoidal map trace of several intrusive porphyry dykes (Fig. 10); and

(3) microscopic shear criteria from highly foliated felsic porphyry.

Evidence for the post-F_2 timing of this movement includes the unchanged orientation of mineral lineations around the open syncline. The exact relationship of the rocks across this shear zone is not known, but there appears to be no simple stratigraphy of basalt overlying felsic schist. Even though movement in the Jowett Well area is relatively late, the shear zone itself may have had a longer history, and could possibly be an early (D_1) fault across which a mafic volcanic succession was repeated. A similar northwards reverse movement was found at the base of the east-striking felsic schist directly east of King Dam (Fig. 5). Total movement along this latter fault is probably small.

The timing relationships suggest that the northwards-directed movement postdates formation of the syncline, and, therefore, granitoid emplacement. The orientation of the reverse fault between Menzies and Goodenough is east-northeast, i.e. very close to the orientation of the principal plane of shortening during sinistral shear. Whether, and how, this movement can be related to D_3 sinistral wrenching between the Menzies Shear Zone and Moriaty Shear Zone is not clear.

In the southern half of the sheet, the structure in the eastern domain becomes strongly attenuated. This attenuation is at least partly due to emplacement of the Comet Vale Monzogranite, but may also be related to other regional structures. The eastern half contains rock types and assemblages typical of this domain further north, including garnet–quartz–hornblende schist and quartz–andalusite schist (between talc–chlorite schist and felsic schist with fuchsite clasts). Southwards the rock units become more and more attenuated, and interleaved with schist derived from sedimentary rocks. Directly north of Lake Goongarrie this complex, highly schistose package can be seen as part of the Moriaty Shear Zone. The coarse clastic sequence (*Asg, Asp*) directly to the west is also well foliated, but appears less strongly sheared.

Further southwards onto BARDOC, the clastic sequence (mapped as *Afv*: Witt, 1990) can be traced along the southwestern shores of Lake Goongarrie. The interleaved mafic–ultramafic–sedimentary schist association appears to be wedging out along strike.

The Moriaty Shear Zone, consisting of granitoid gneiss with interleaved greenstone layers/lenses, has a distinct aeromagnetic signature. Southwards the shear zone appears to be transitional into the Scotia–Kanowna Anticline (Fig. 9), a fold structure equivalent to the

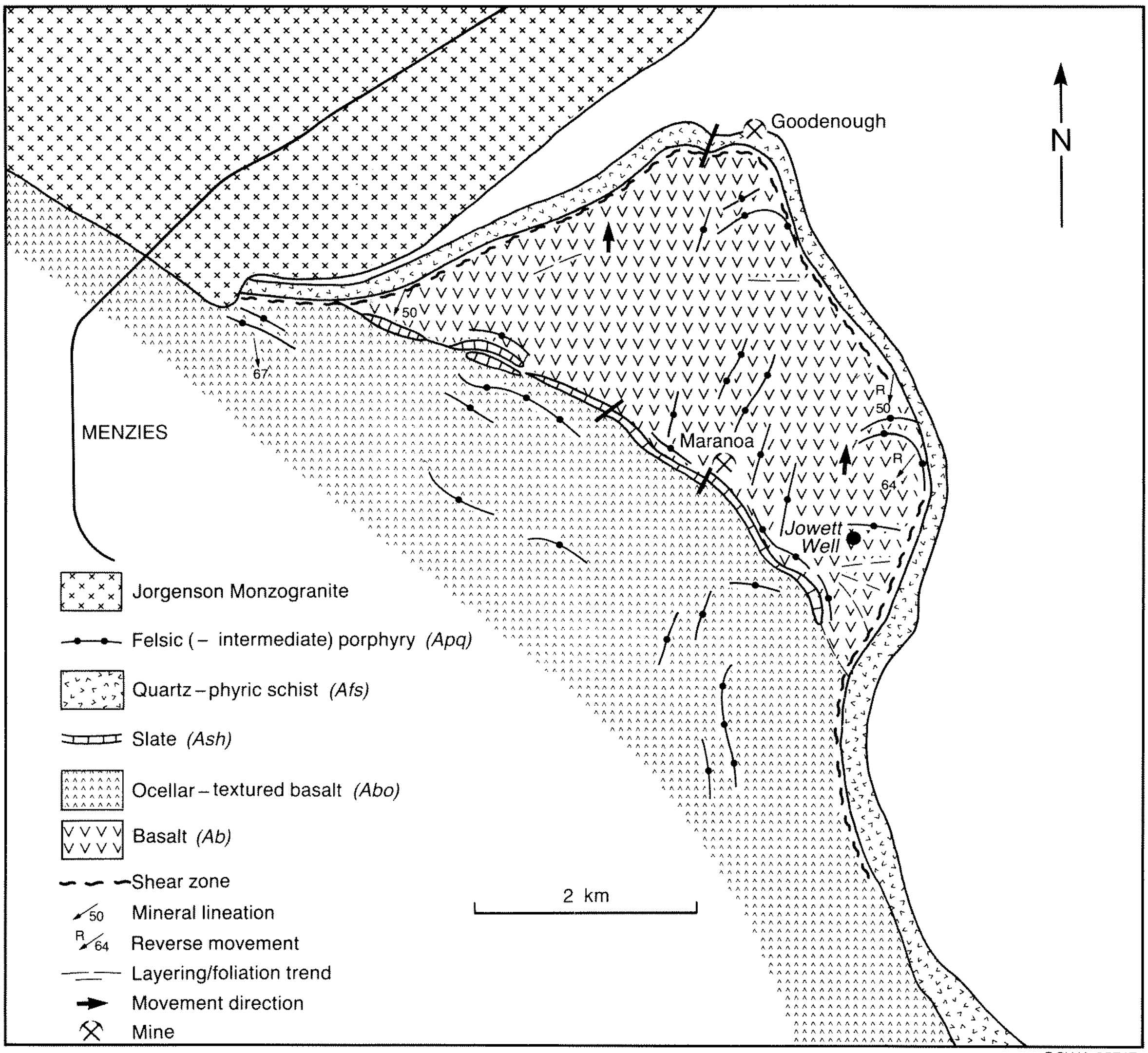


Figure 10. Structures around the open synformal structure between Menzies and Jowett Well

Mt Pleasant – Goongarrie (F_2) Anticline (Witt, 1990). Sinistral displacement along the shear is probably partitioned along the limbs of the anticline, most likely along granite–greenstone contacts. The Mt Jewell greenstones on the eastern limb of the Scotia–Kanowna Anticline, are cut out northwards along strike and do not reach MENZIES. Post-D_2 granitoids (?both diapiric and late tectonic) may be largely responsible for this.

The northern extent of the Moriaty Shear Zone is not clear from available aeromagnetics; the shear zone may well be largely overprinted by late granitoid intrusions.

King Dam Anticline

South of King Dam, the anticline is upright, with a slightly overturned eastern limb, and has an axial-planar foliation developed in felsic schist and grey slate (Fig. 5). Its attitude and orientation suggest the same timing as the regional upright F_2 folds to the south (e.g. Witt, 1990; Swager, 1989). Northwards the western limb of the anticline shows a consistent bedding (S_0) to S_2 relationship, irrespective of the highly variable dip. The intersection lineation (S_0–S_2) has a quite constant plunge orientation, though the plunge varies (Fig. 5). This lineation is a particularly strong fabric in fuchsite–quartz (–andalusite) schist.

East of King Dam the eastern limb of the anticline, (both bedding, S_0, and S_2, and their intersection lineation, S_0–S_2) is abruptly rotated over approximately 90°, probably as result of post-D_2 granitoid emplacement. Other indications for the presence of such granitoids include the foliation re-entrant geometry in tremolite schist northeast of King Dam and the flat-lying attitude of bedding and S_2 in the felsic schists southeast of Jowett Well. The re-entrant geometry, based on aerial photo interpretation of foliation trajectories in tremolite schist, is characteristic for multiple granitoid emplacement.

Further northwards the axial trace of the anticline is difficult to establish. One possible interpretation is that the anticlinal axial plane passes through the Oliver Twist

Granodiorite which can be interpreted as a pre- to syn-D_2 'domal' granitoid. Felsic schist is folded around its hinge with a well-developed south-plunging fold axis parallel to the common intersection lineation L_2. The overall geometry around the Oliver Twist Granodiorite, however, cannot be explained in terms of a simple anticline geometry. The Oliver Twist Granodiorite may be one of the post-D_2 granitoids that have distorted the folded greenstone sequence.

Ghost Rocks area

Structural interpretation of the greenstone geometry at Ghost Rocks, on the RIVERINA 1:100 000 sheet, is based on the recognition of the continued Ora Banda sequence. Hill et al. (1987) showed the presence of the Walter Williams Formation and overlying Siberia Komatiite (Figs 3, 4; Table 1), but did not comment on the overall geometry.

Figure 4 illustrates the presence of a very tight, partly sheared, syncline–anticline fold pair. The syncline is outlined by the opposite younging directions indicated by the Walter Williams Formation – Siberia Komatiite sequence. The contact of the eastern fold limb with the strongly foliated Ghost Rocks granitoid cuts across stratigraphy in the northwest. Further southeast, the contact deflects into parallellism with layering: even though both granitoid and komatiite become very thin, traces of foliated granitoid and tremolite schist (with 'flattened' platy olivine pseudomorphs) can be found all along strike. Interpretation of the Wongi and Missouri Basalt equivalents northeast of the granitic schist implies an anticline with the foliated granitoid in its core. Independent evidence for a northeast-younging direction from small-scale structures is ambiguous, although possible differentiation in thin gabbroic layers within the Wongi Basalt indicates the same direction. Both folds are interpreted as F_2 structures, that die out along strike.

The strongly foliated granitic schist, and narrow zones of tremolite schist on either side, are characterized by an intermediate (30–40°) southeast-plunging mineral lineation (Fig. 7). Microstructures in these schists (feldspar–foliation relations), S–C, fabrics and the asymmetry of outcrop-scale folds in tremolite schist are all compatible with sinistral (and southwest-block-down) movement.

Economic geology

Gold

Two prominent former gold-producing areas in the Menzies District of the North Coolgardie Mineral Field fall within the boundaries of MENZIES. Woodward (1906) and Jutson (1921) gave early descriptions of these two mining centres, respectively Menzies and Comet Vale (Fig. 11). Witt (1993) has documented host rock, structural control, and alteration of all gold mines in the district with a production greater than 5 kg. Here, only the regional tectono-stratigraphic setting of the gold-bearing domains (Fig. 11) is very briefly described, and the production statistics of major producing mines is presented in Table 3.

Table 3. Production statistics of selected gold mines on MENZIES

Mining centre/mine	*Ore treated (t)*	*Gold produced (kg)*	*Production period*
MENZIES			
Robinson Crusoe	39 790.29	1 235.90	1897–1909
Queensland Menzies, Wedderburn (First Hit)	50 212.98	2 505.63	1897–1909
Aspacia/Pandora	25 992.89	963.33	1897-1918
Warrior	12 394.56	224.87	1897–1944
Alpha	13 519.3	1556.87	1897–1939
Lady Shenton	171 198.85	5 836.91	1897–1942
Florence	11 061.25	289.27	1897–1911
Flying Fish	6 616.57	231.56	1901–1911
Friday (Balkis)	6 087.17	366.80	1897–1905
Yunndaga (Princess May, Princess Eva)	507 824.92	8 757.89	1897–1935
Goodenough	13 021.05	264.74	1897–1940/ 1981-1984
Maranoa	19 465.61	288.25	1898–1942
Kensington	1 561.44	49.62	1897–1907
Sunday Gift	817.4	43.79	1897-1913
Springfield	1 003.9	22.04	1900–1945
Emu	521.6	43.67	1903-1908
Spion Kopp	338.3	7.05	1936–1940
Queens Birthday, Pride of the Hills, Sun, Hills View	1 418.7	30.81	1906–1916
Menzies total		**25 604.35**	**up to 1988**
COMET VALE			
Sand Queen, Gladsome	253 154.00	5 959.84	1904–1948
Happy Jack	11 633.96	220.45	1901–1920
Lady Margaret	6 727.90	101.42	1897–1906
Lady Mack	363.17	5.41	1905-1906
King of the Hills, Lake View, Mount View, Long Tunnel	1 854.69	23.82	1899–1900 1913–1932

Sources: Annual Reports and Statistical Digests, Department of Mines, W.A.; Witt, 1993

The Menzies belt is the most productive area (>25 t of gold) and occurs within the highly sheared basalt (*Ab*) – sediment (*As*) – ultramafic schist (*Au*) sequence forming the eastern part of the Menzies Shear Zone. Numerous mines from St Albans in the north and Yunndaga (Princess May) in the south (Fig. 11) were developed on intermediate southeast-plunging shoots, parallel to a well-developed mineral lineation, within narrow individual shears. Host rocks include meta-sedimentary rock, ultramafic schist, and amphibolitic basalt, with gold contained in and adjacent to quartz–sulfide veins. Biotite(–garnet) alteration of the mafic rocks is characteristic (see Witt, 1993).

The second largest producing area is around Comet Vale, where several distinct mineralized structures can be

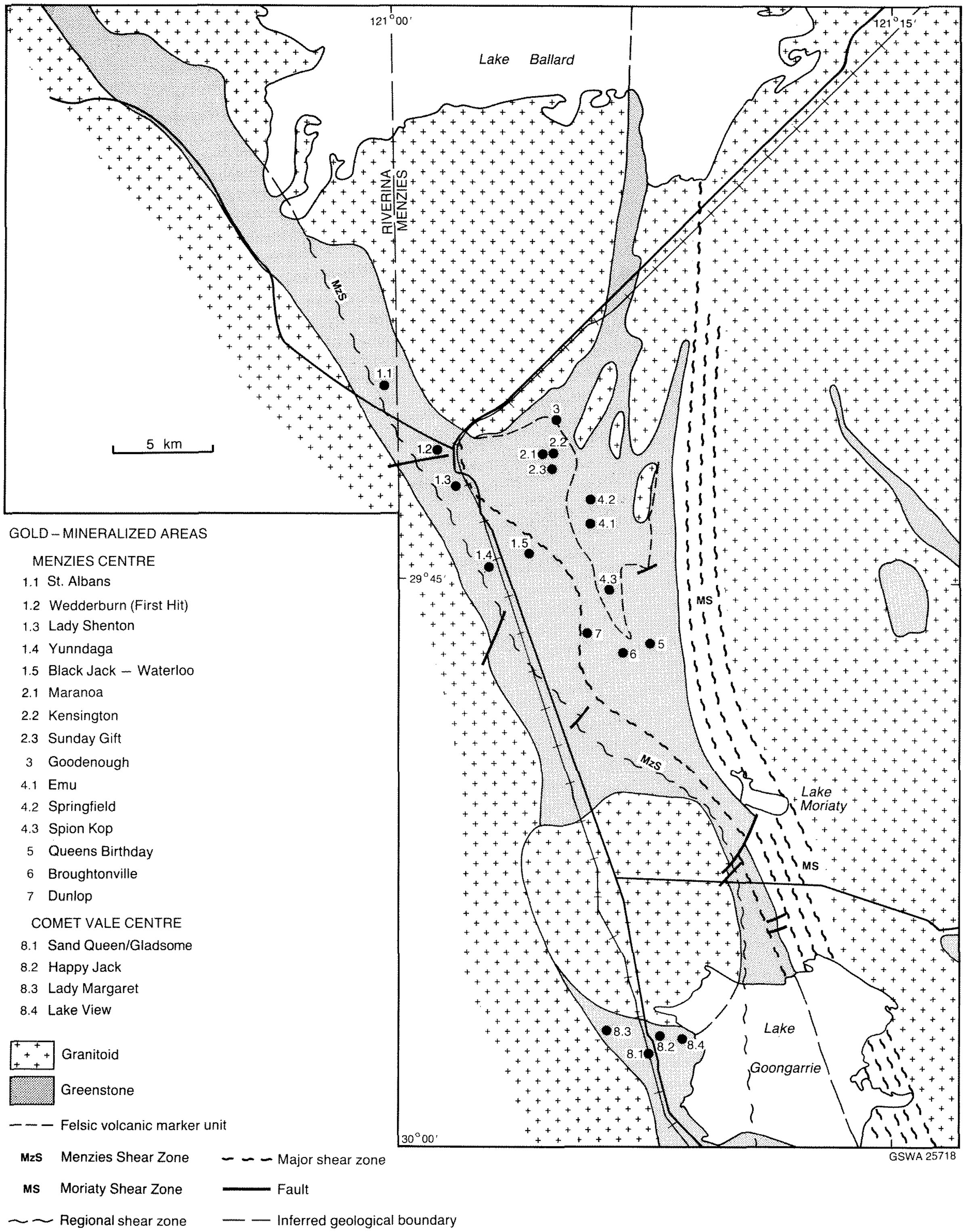


Figure 11. Prominent gold-producing mines on MENZIES

recognized (Fig. 6). The major producer is Sand Queen, with Gladsome mine directly to the north on the same lode. This lode structure is a steeply west-dipping quartz reef within felsic porphyry along its strongly sheared contact with basalt (*Ab*; Missouri Basalt). This bedding-parallel horizon lies just below the Missouri Basalt – Walter Williams Formation contact.

Other mineralized structures include the approximately east–west-striking Happy Jack and Lake View (from west to east, King of the Hills, Lake View, Long Tunnel mines) shear zones which are interpreted as accommodation faults formed during emplacement of the 'late tectonic' Comet Vale Monzogranite (Fig. 6). The two shear zones are developed largely in respectively the Walter Williams

Formation and Siberia Komatiite, and are characterized by talc–chlorite and tremolite schist. Jutson (1921) reported narrow porphyry dykes and widespread occurrence of crocoite in the Happy Jack mine. Only small amounts of gold were produced from the major quartz blows along the steeply south-dipping Lake View shear, with scheelite as a prominent accessory (Jutson, 1921).

All other mineralized areas are only small producers (Table 3; Fig. 11). Goodenough lodes occur in the hanging-wall of the shear zone between felsic schist (*Asq*) and basalt (*Ab*) (see 'Structural geology'; Fig. 10), and may include altered and mylonitized felsic porphyry (Witt, 1993). Maranoa and associated mines occur along subvertical, north-northeast-striking shears at a high angle to bedding (Fig. 10). Felsic porphyries are locally present along the shear zones, and may also be host rock together with silicified and biotitized amphibolitic basalt.

The Queen's Birthday lodes occur in narrow, but persistent shear zones along attenuated feldspar porphyry dykes in ocellar and pyroxene spinifex-textured basalt. Extensive biotite alteration resulted in biotite–amphibole schist. Broughtonville, for which no production data are available, has a similar host rock, alteration, and structure.

Several workings (Springfield, Emu, and Spion Kopp; see Table 3) were developed on narrow shear zones along and just below the contact between tremolite schist (*Aur*) and quartz-phyric muscovite schist (*Asq*)/quartz–andalusite–fuchsite rock (*Alf*). Dunlop mine is developed on andalusite-bearing quartzo-feldspathic, locally fuchsitic, schist (Fig. 8A, B) along a northwest-trending shear. No production figures are available.

Other minerals

Extensive exploration for nickel within the Walter Williams Formation and Siberia Komatiite (e.g. north of Comet Vale Monzogranite; Ghost Rocks) has not resulted in any major finds.

Chrysoprase (apple-green chalcedony) occurs, in association with ultramafic rocks, at Comet Vale (Simpson, 1952, p. 473) and near Emu Mine (PA 29/2845; 8 km southeast of Menzies) where, in 1969, 2939 kg was mined.

References

AHMAT, A. L., 1986, Metamorphic patterns in the greenstone belts of the Southern Cross Province, Western Australia: Western Australia Geological Survey, Report 19, Professional Papers, p. 1–21.

ASHLEY, P. M., and MARTYN, J. E., 1987, Chromium-bearing minerals from a metamorphosed hydrothermal alteration zone in the Archaean of Western Australia: Neues Jahrbuch fur Mineralogie, Abhandlungen, v. 157, p. 81–111.

BARLEY, M. E., and GROVES, D. I., 1988, Geological setting of gold mineralization in the Norseman–Wiluna Belt, Eastern Goldfields Province, Western Australia, *in* Western Australian Gold Deposits, Bicentennial Gold 88 Excursion Guide Book *edited by* D. I. GROVES, M. E. BARLEY, S. E. HO, and G. M. F. HOPKINS: University of Western Australia, Geology Department and University Extension, Publication, no. 14, p. 17–46.

BICKLE, M. J., and ARCHIBALD, N. S., 1984, Chloritoid and staurolite stability — implications for metamorphism in the Archaean Yilgarn Block, Western Australia: Journal of Metamorphic Geology, v. 2, p. 179–203.

BINNS, R. A., GUNTHROPE, R. J., and GROVES, D. I., 1976, Metamorphic patterns development of greenstone belts in the eastern Yilgarn Block, Western Australia, *in* The Early History of the Earth *edited by* B. F. WINDLEY: New York, John Wiley and Sons, p. 303–313.

GEE, R. D., 1979, Structure and tectonic style of the Western Australian shield: Tectonophysics, v. 58, p. 327–369.

GRIFFIN, T. J., 1990, Eastern Goldfields Province, *in* Geology and Mineral Resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 77–119.

GROVES, D. I., and BATT, W. D., 1984, Spatial and temporal variations of Archaean metallogenic associations in terms of evolution of granitoid–greenstone terrains with particular emphasis on the Western Australian shield, *in* Archaean geochemistry — the origin and evolution of the Archaean continental crust *edited by* A. KRONER, G. N. MANSON, and A. M. GOODWIN: Berlin, Springer-Verlag, p. 73–98.

HALLBERG, J. A., 1987, The nature and origin of some aluminous alteration assemblages of the Eastern Goldfields, *in* The Second Eastern Goldfields Field Conference, Kalgoorlie, Western Australia, Abstracts and Excursion Guide, *edited by* W. K. WITT and C. P. SWAGER: Geological Society of Australia (Western Australian Division), p. 27–29.

HILL, R. E. T., GOLE, M. J., and BARNES, S. J., 1987, Physical volcanology of komatiites: a field guide to komatiites between Kalgoorlie and Wiluna, Eastern Goldfields Province, Yilgarn Block, Western Australia: Geological Society of Australia (Western Australian Division), Excursion Guidebook no. 1.

JUTSON, J. T., 1921, The mining geology of Comet Vale and Goongarrie, North Coolgardie Goldfield: Western Australia Geological Survey, Bulletin 79.

KERRICH, R., FYFE, W. S., BARNETT, R. L., BLAIR, B. B., and WILLMORE, L. M., 1987, Corundum, Cr-muscovite rocks at O'Briens, Zimbabwe — the conjunction of hydrothermal desilicification and LIL-element enrichment–geochemical and isotopic evidence: Contributions to Mineralogy and Petrology, v. 95, p. 481–498.

KRIEWALDT, M., 1970, MENZIES, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes.

MARTYN, J. E., and JOHNSON, G. O., 1986, Geological setting and origin of fuchsite-bearing rocks near Menzies, Western Australia: Australian Journal of Earth Sciences, v. 33, p. 373–389.

PURVIS, A. C., 1984, Metamorphosed altered komatiites at Mount Martin, Western Australia — Archaean weathering products metamorphosed at the aluminosilicate triple point: Australian Journal of Earth Sciences, v. 31, p. 91–106.

ROCK, N. M. S., 1984, Nature and origin of calc-alkaline lamprophyres — minettes, vogesites, kersantites and spessartites: Royal Society of Edinburgh, Earth Sciences, Transactions, v. 74, p. 193–227.

ROTH, E., 1988, Petrogenesis of aluminosilicate-bearing assemblages in the Archaean greenstone terrains of Leonora and Malcolm Districts: University of Western Australia, B.Sc. (Hons.) thesis (unpublished).

SCHREYER, W., WERDING, G., and ABRAHAM, K., 1981, Corundum–fuchsite rocks in greenstone belts of Southern Africa — petrology, geochemistry and possible origin: Journal of Petrology, v. 22, p. 191—231.

SIMPSON, E. S., 1952, Minerals of Western Australia, Volume 3: Perth, Western Australia, Government Printer.

SWAGER, C. P., 1989, Structure of the Kalgoorlie greenstones — regional deformation history and implications for structural setting of gold deposits within the Golden Mile: Western Australia Geological Survey, Report 25, p. 59–84.

SWAGER, C. P., 1990, Geology of the DUNNSVILLE 1:100 000 sheet, Western Australia: Western Australia Geological Survey, Record 1990/2.

SWAGER, C. P., in press, KURNALPI, W.A.: Western Australia Geological Survey, 1:100 000 series Explanatory Notes.

SWAGER, C. P., and GRIFFIN, T. J., 1990, Geology of the Archaean Kalgoorlie Terrane — an explanatory note: Western Australia Geological Survey, Record 1990/12.

TURNER, F. J., 1981, Metamorphic petrology — mineralogical, field and tectonic aspects: New York, McGraw-Hill Book Co.

WITT, W. K., 1987, Stratigraphy and layered mafic/ultramafic intrusions of the Ora Banda sequence, Bardoc 1:100 000 sheet, Eastern Goldfields — An excursion guide, *in* The Second Eastern Goldfields Geological Field Conference, Kalgoorlie, Western Australia, Abstracts and Excursion Guide, *edited by* W. K. WITT and C. P. SWAGER: Geological Society of Australia (Western Australia Division), p. 69–83.

WITT, W. K., 1990, Geology of the BARDOC 1:100 000 sheet: Western Australia Geological Survey, Record 1990/14.

WITT, W. K., 1993, Gold deposits of the Menzies and Broad Arrow areas, Western Australia: Western Australia Geological Survey, Record 1992/13.

WITT, W. K., DAVY, R., and CHAPMAN, D. M., 1991, The Mount Pleasant Sill, Eastern Goldfields — Fe-rich granophyre in a layered high-Mg intrusion: Geological Survey Western Australia, Report 30, Professional Papers, p. 73–92.

WITT, W. K., and SWAGER, C. P., 1989, Structural setting and geochemistry of Archaean I-type granitoids in the Bardoc–Coolgardie area of the Eastern Goldfields Province, Western Australia: Precambrian Research, v. 44, p. 323–351.

WOODWARD, H. P., 1906, The auriferous deposits and mines of Menzies, North Coolgardie Goldfield: Western Australia Geological Survey, Bulletin 22.

Appendix 1

New plutonic names on MENZIES

Jorgenson Monzogranite

Lithology: K-feldspar-phyric monzogranite; with minor weakly porphyritic syenogranite; K-feldspar megacrysts up to 4 cm long in a medium- to coarse-grained matrix; biotite is only mafic mineral (1–3%).

Other characteristics: Characterized by strong contact-parallel foliation, and local presence of garnet-bearing leucocratic phase at contact.

Derivation of name: Named after Jorgenson Well 15 km north-northeast of Menzies township.

Comet Vale Monzogranite

Lithology: Porphyritic monzogranite with a fine- to medium-grained feldspar–quartz matrix and contains coarse-grained K-feldspar, zoned plagioclase, quartz grains/aggregates, and biotite aggregates.

Other characteristics: Poorly exposed along southern edge of the lake directly east of abandoned Comet Vale township, and in northeast part of the circular outcrop pattern. The Tonkin Road off the Kalgoorlie–Meekatharra Highway traverses the granitoid in east–west direction.

Derivation of name: Named after abandoned Comet Vale township 15 km south of Menzies; an old quarry for building stone is located north of township and east of highway.

Oliver Twist Granodiorite

Lithology: Granodiorite, transitional to plagioclase-rich monzogranite; biotite (6–8%) and minor hornblende (1%) are the mafic phases.

Other characteristics: Strongly foliated contacts with plunging mineral lineations. Best exposures at southern tip of body 500 m to 1 km east-northeast of Mt Menzies.

Derivation of name: Named after Oliver Twist Well, in centre of small granodiorite body, 5 km east-northeast of Menzies.

Appendix 2

Location of places referred to in text

	1:100 000 sheet (a)	AMG coordinates	
		N	E
Alexandra Bore		670545	32990
Ant Bore		672415	31790
Bardoc Mining Centre	BARDOC	664290	33560
Black Jack mine		670790	31340
Blowfly mine		671110	31635
Broughtonville mine		670360	31765
Cock Robin mine		672670	31815
Cock Robin well		672510	31805
Comet Vale Mining Centre		668595	31870
Dunlop mine		670475	31600
Eight Mile well		670045	30900
Emu mine		670945	31605
Fuller well		672070	31690
Ghost Rocks	RIVERINA	672850	31600
Gladsome mine		668465	31930
Goodenough mine		671540	31395
Goongarrie Station		668140	31125
Granite Dam		668965	33030
Happy Jack mine		668510	31945
Hills View mine		670590	31830
Jorgenson well		672945	31220
Jowett well		671270	31475
King Dam		670825	31750
Lady Harriet mine		671000	30990
Lady Margaret mine		668535	31720
Lake View mine		668525	32090
Maranoa mine		671210	31380
Menzies Mining Centre		671285	30940
Moriaty well		669680	32005
Mt Jewell	BARDOC	664440	35255
Mt Menzies		671370	31355
Oliver Twist well		671640	31675
Ora Banda Mining Centre	BARDOC	663780	31365
Piccadilly well		671025	32060
Pride of the Hills mine		670520	31885
Princess Eva mine		670740	31154
Princess May mine		670695	31170
Queen's Birthday mine		670485	31890
Robinson Crusoe mine		671370	30815
Salt Dam		669190	32750
Sand Queen mine		668435	31935
Springfield mine		671030	31575
Spion Kopp mine		670595	31710
St Albans mine	RIVERINA	671670	30540
Waterloo mine		670725	31370
Yunndaga siding		670740	31165

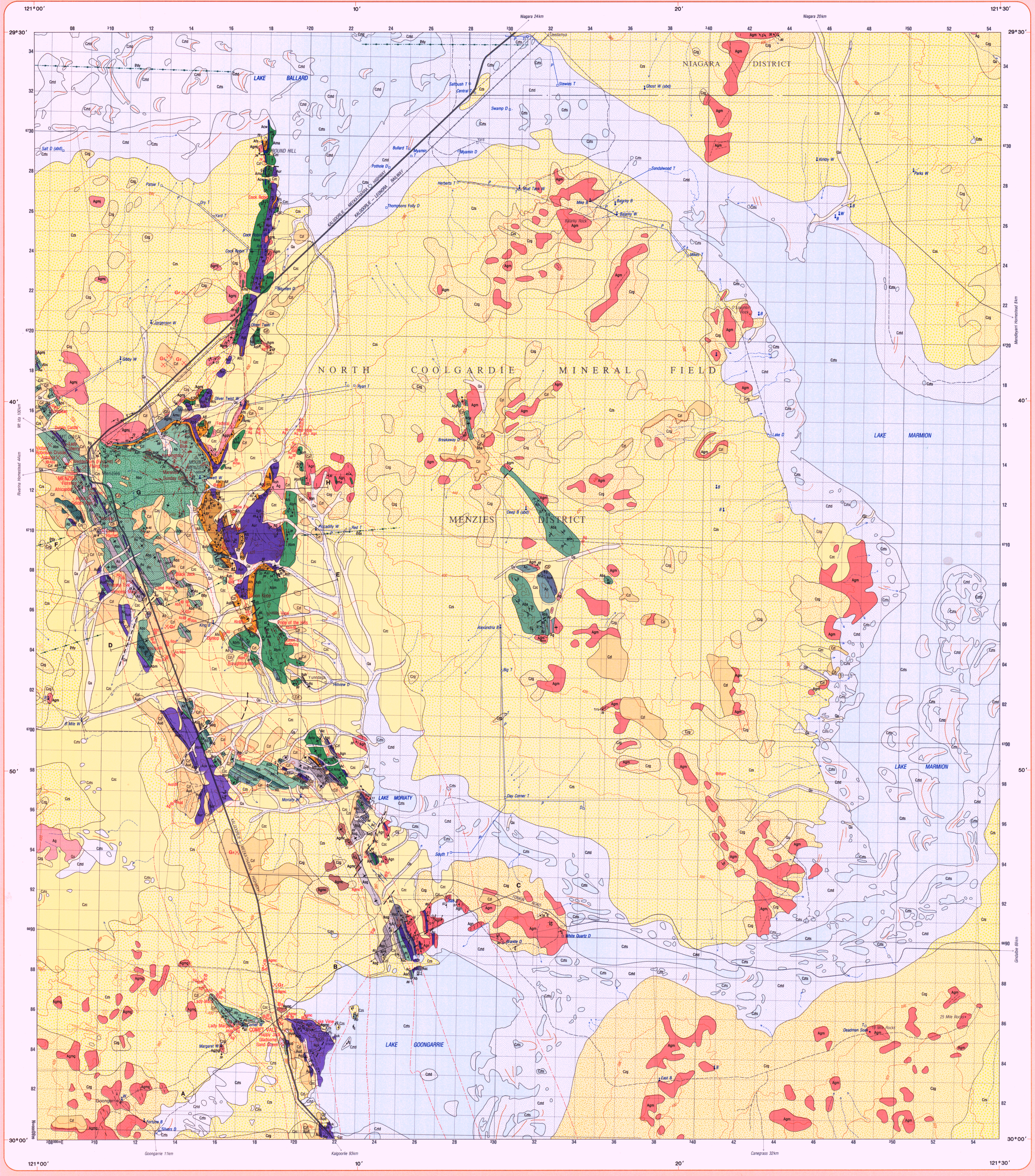
(a) All localities are on MENZIES, unless otherwise indicated

AUSTRALIA 1:100 000 GEOLOGICAL SERIES

MENZIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 3138



CAINOZOIC

- Qa — Alluvium — clay, silt, sand, and gravel in channels
- Czts — Evaporite interbedded with clay and sand in playas
- Cztd — Sand, silt and gypsum in stabilized dunes adjacent to playas
- Czc — Colluvium — gravel, sand as sheetwash and talus
- Czg — Quartzo-feldspathic sand over granitoid rock
- Czs — Sandplain — yellow sand, with limonitic pisoliths near base
- Czl — Laterite and reworked products, includes silicic cap on Aud

PROTEROZOIC

- Ƥdy — Mafic and ultramafic dykes — inferred from aeromagnetics

ARCHAEAN

Veins and dykes: p — pegmatite; g — granite; q — quartz

- Ag — Granitoid rock
  - Agm — Monzogranite; with K-feldspar megacrysts
  - Agmc — **COMET VALE MONZOGRANITE:** unfoliated, mostly discordant contact with greenstones; late-tectonic, syn-D_3 granitoid
  - Agmj — **JORGENSON MONZOGRANITE:** intense, contact-parallel foliation with steeply plunging mineral lineation; post-D_2 to syn-D_3 granitoid
  - Agmg — **GOONGARRIE MONZOGRANITE:** contains widely spaced regional foliation; forms core to regional (D_2) anticlines; domal, pre- to syn-D_2 granitoid
  - Aggo — **OLIVER TWIST GRANODIORITE:** contains minor monzogranite; strongly sheared contact with greenstone sequence
  - Agt — Tonalite
  - Agn — Granitoid gneiss; pervasively foliated, with horizontal to shallowly north-plunging mineral lineation; contains lenses of amphibolite and ultramafic schist on all scales

- Apq — Porphyry, felsic, sill or dyke; plagioclase and quartz phenocrysts
- Apa — Porphyry, acid to intermediate, sill or dyke; plagioclase and amphibole phenocrysts
- Apl — Hornblende lamprophyre (spessartite) dyke
- Apd — Diorite dyke

Apq unless otherwise indicated

- As — Sedimentary rock; may contain slate, and felsic and mafic schist
  - Ash — Grey to black slate, and grey-white banded chert; including clastic sedimentary rock within volcanic units
  - Asg — Greywacke and arkose; regularly layered; occurs as biotite-feldspar-quartz schist and minor slate
  - Asp — Conglomerate, polymictic; matrix-supported; pebbles and boulders consist of mainly granitoid rock, and minor mafic schist and slate
  - Asc — Grey to black slate and interlayered quartzo-feldspathic schist; including chert layers and lenses
  - Ac — Chert and silicified slate within Asc; locally mylonitic and intense intrafolial folding
  - Acw — Grey-white chert, finely layered or banded; locally quartz-hematite ''banded iron-formation''
  - Afs — Quartz-phyric muscovite schist; felsic volcaniclastic schist; locally andalusite-bearing and containing fuchsite clasts; interbedded with quartz-feldspar-muscovite schist, grey to black slate, and overlain by banded chert
  - Alf — Fuchsite-quartz and andalusite-quartz-fuchsite rock; massive, finely layered or complexly veined; locally interlayered with white chert and muscovite-quartz schist
  - Als — Fuchsite-quartz (-andalusite) rock with interlayered quartz-feldspar-muscovite schist and minor tremolite schist

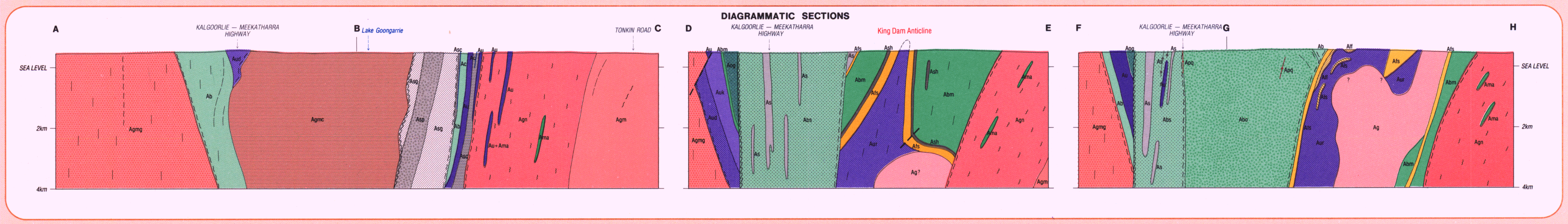
- Ao — Mafic intrusive rock; including dolerite, pyroxene-phyric dolerite, and gabbro
  - Aog — Gabbro, differentiated
  - Aox — Pyroxenite; occurs as coarse-grained tremolite rock

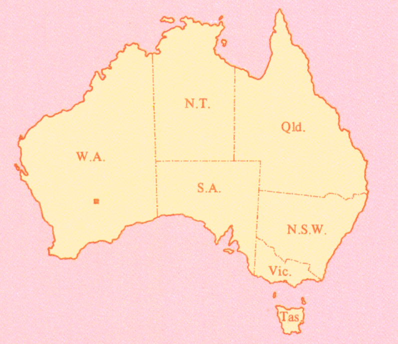
- Ab — Basalt; contains doleritic textured layers and lenses
  - Abo — Basalt with ocellar texture; plagioclase-tremolite/actinolite schist
  - Abm — Basalt with quenched pyroxene (-amphibole) texture; also ocellar-textured basalt with pillow structures; plagioclase-tremolite schist
  - Abs — Basalt and fine-grained hornblende schist; extensive interlayered sedimentary rock (As)
  - Abp — Basalt, porphyritic; medium- to coarse-grained plagioclase phenocrysts; locally extensive epidote
  - Aba — Amphibolite, locally basaltic or fine-grained doleritic texture preserved; local zoisite-rich layering
  - Ama — Amphibolite, pervasively foliated; locally garnetiferous and quartz-rich layers
  - Amu — Interleaved mafic and ultramafic schist; amphibolite, tremolite schist, talc-chlorite schist

- Au — Ultramafic schist; including talc-chlorite (-carbonate) schist and tremolite-chlorite schist
  - Auk — Komatiite; characterized by platy olivine spinifex texture; altered to tremolite-chlorite and serpentinite
  - Aud — Massive ultramafic rock; serpentinized dunite and peridotite (olivine cumulate)
  - Aup — Massive serpentinized peridotite (olivine cumulate); minor pyroxenite, gabbro and fine-grained sedimentary rock, and talc-chlorite schist
  - Aur — Tremolite schist; minor talc-chlorite (-carbonate) schist; local serpentinite lens; minor undeformed basalt (Abm)

Metamorphosed at greenschist-amphibolite transition facies and lower amphibolite facies

DIAGRAMMATIC SECTIONS





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

True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 1989 and moves westerly by 0.1° in about 20 years.

HON. JEFF CARR, M.L.A.
MINISTER FOR MINES
D.R. KELLY DIRECTOR GENERAL OF MINES

P.E. PLAYFORD
DIRECTOR, GEOLOGICAL SURVEY
OF WESTERN AUSTRALIA

SCALE 1:100 000

TRANSVERSE MERCATOR PROJECTION
Grid lines indicate 1000 metre interval of the Australian Map Grid Zone 51

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