GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 22

ARCHAEAN GEOLOGY OF THE MOUNT NARRYER REGION WESTERN AUSTRALIA

by
I. R. Williams and J. S. Myers

DEPARTMENT OF MINES
WESTERN AUSTRALIA

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State Printing Division
Perth 1987

52795-1

MINISTER FOR MINERALS AND ENERGY
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Cataloguing-in-publication entry

Williams, I. R. (Ian Robert), 1938-
Archaean geology of the Mount Narryer region, Western Australia.

Bibliography
ISBN 0 7309 0938 7.

1. Geology, Stratigraphic—Archaean. 2. Geology—Western Australia—Scrubby Range Region. I. Myers, J. S. (John Stuart), 1943- . II. Geological Survey of Western Australia. III. Title. (Series: Report (Geological Survey of Western Australia); 22).

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ISSN 0508-4741

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ARCHAEAN GEOLOGY OF THE MOUNT NARRYER REGION WESTERN AUSTRALIA

ABSTRACT

The Mount Narryer region contains a well-exposed complex of early Archaean gneisses, typical of the northern part of the Western Gneiss Terrain. The main components are: two groups of quartzo-feldspathic gneiss called the Meeberrie gneiss and Dugel gneiss, both derived from granites; fragments of a deformed and metamorphosed layered anorthosite-gabbro-ultramafic intrusion called the Manfred Complex; and metasedimentary rocks, mainly quartzites. The metamorphosed plutonic rocks formed between 3800 and 3400 Ma ago, while the metasedimentary rocks formed about 3300–3200 Ma ago. All these rocks were strongly deformed together and metamorphosed in granulite facies, perhaps about 3300–3200 Ma ago.

About 2700–2600 Ma ago there was a major episode of magmatic and tectonic activity which resulted in the emplacement of granite and gabbro (as sheets and plutons), intense deformation, and metamorphism in amphibolite facies.

In spite of this complex sequence of deformation and metamorphism, large areas of the quartzites are relatively little deformed and they preserve their sedimentary structures and stratigraphy. They also contain detrital zircons which mostly give U-Pb ages similar to the ages of the adjacent gneisses, but a few give ages of 4 200–4 100 Ma, far older than any known terrestrial rocks.

INTRODUCTION

The Mount Narryer region is situated 600 km north of Perth and 250 km north-northeast of Mullewa, adjacent to the Murchison River. Mount Narryer occurs in the northwestern part of the Western Gneiss Terrain, a belt of heterogeneous gneiss which forms the western margin of the Archaean Yilgarn Block (Fig. 1). The Western Gneiss Terrain mainly consists of high-grade metamorphic rocks derived from composite granitic intrusions, layered-basic intrusions, and quartz-rich sedimentary rocks, which were repeatedly deformed and metamorphosed more than 3000 Ma ago. Metavolcanic rocks have not been recognized in this gneiss terrain, in marked contrast to their abundance in the rest of the Yilgarn Block. The Western Gneiss Terrain is considered to be an extensively exposed example of the sialic basement upon which the mainly volcanic, greenstone sequences to the east were deposited between 3000 and 2600 Ma ago (Gee and others, 1981).

The main components of the gneiss complex at Mount Narryer are: two groups of quartzo-feldspathic gneiss; called the Meeberrie gneiss and Dugel gneiss; fragments of a deformed and metamorphosed layered-basic intrusion called the Manfred Complex; and metasedimentary rocks, mainly quartzites (Fig. 1). All these rocks were deformed and metamorphosed in granulite facies. They were then cut by sheets and dykes (now deformed and metamorphosed) of granite, gabbro and dolerite, and by younger dykes (undeformed) of aplite, pegmatite and dolerite.

The Mount Narryer region is of especial interest because it contains the oldest known rocks in Australia, and some of the oldest known rocks on Earth. The first age determinations showed the Rb-Sr whole-rock age of a group of granitic banded gneisses to be 3348 ± 43Ma (de Laeter and others, 1981a). This was followed by measurements of the Sm-Nd model ages of two of these samples as 3630 ± 40 and 3510 ± 50 Ma (de Laeter and others, 1981b), significantly older than any previously known ages from the Yilgarn Block. U-Pb studies by ion microprobe on detrital zircons, from quartzites adjacent to these banded gneisses, showed that most of the zircons formed between about 3750 and 3500 Ma (Froude and others, 1983). In addition, four zircons were analyzed which showed ages of 4200–4100 Ma, far older than any known terrestrial rocks.

The region was mapped, over a period of 5 months, between July 1981 and October 1982 (IRW), and further detailed mapping was carried out in the the northeastern part in October 1983 (JSM). A 1:25 000 scale map of the region is presented on Plate 1.

Mount Narryer (514 m) and Mount Dugel (461 m) form the highest points at the southern and northern ends of a low strike ridge, mainly of quartzites, 27 km long and 3 km wide. The ridge is rocky, steep-sided, and rises 200 m above the Murchison River flood plain. Mount Murchison (503m) forms a similar isolated ridge, 4.5 km long, to the south of the Murchison River. The rocks are less well exposed in the flatter ground away from

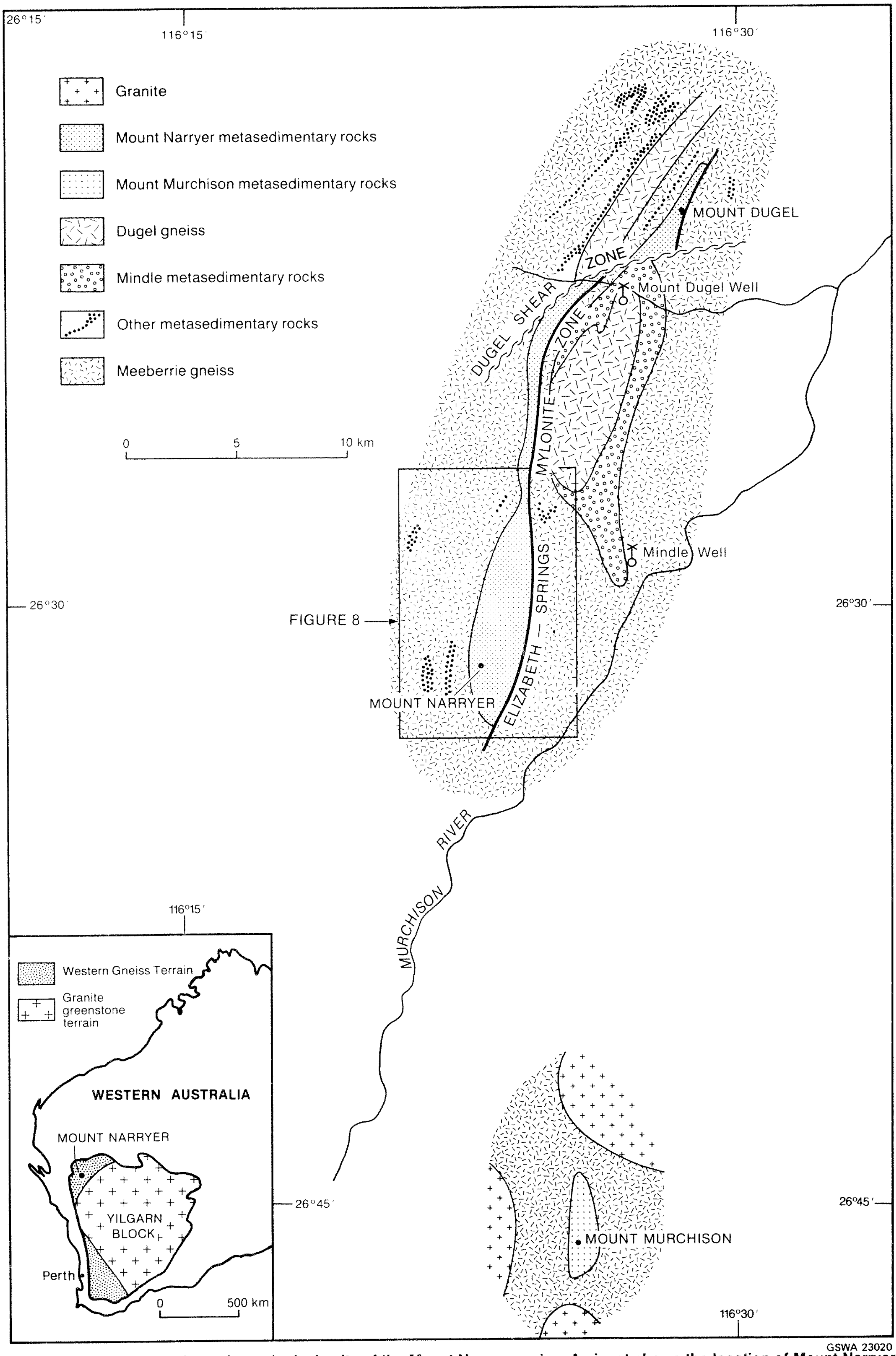

Figure 1. Map showing the main geological units of the Mount Narryer region. An inset shows the location of Mount Narryer in the Western Gneiss Terrain of the Yilgarn Block. The rectangle outlines the southern sector of the Mount Narryer metasedimentary rocks which is shown in more detail in Figure 8.

these ridges (Plate 1), except in the north where, to the west of Mount Dugel, banded gneisses are extensively exposed in rugged hills, formed from partly weathered bedrock below a laterite hardcap.

The broader regional setting of the Mount Narryer rocks is shown on the 1:250 000 Byro sheet and described in the associated explanatory notes (Williams and others, 1983), which also make reference to all previous work. An outline of the Archaean geology of the Mount Narryer region is given by Myers and Williams (1985). The geology of the whole Yilgarn Block, including the Western Gneiss Terrain, is summarized by Gee and others (1981).

Isotopic studies were carried out at WAIT in Perth and at the ANU in Canberra in conjunction with the mapping. Petrography was studied by W. G. Libby at the GSWA, and whole-rock chemical analyses were made by the Government Chemical Laboratories in Perth.

MANFRED COMPLEX

Fragments of a deformed and metamorphosed major layered-basic intrusion, called the Manfred Complex (Myers and Williams, 1985; Myers, in press), are abundant in the Dugel gneiss (Plate 1). They range in composition from ultramafic rocks to anorthosite, and in size from small fragments a few centimetres across (Fig. 2) to strips over 100 m thick and 1 km long. The rocks have given a Sm-Nd whole-rock isochron of 3680 ± 70 Ma and a Pb-Pb isochron of 3689 ± 146 Ma (Fletcher and others, in press); also zircons analyzed by ion microprobe show (Pb-Pb) ages of 3730 ± 6 Ma (Kinny and others, in press). The geochronology is summarized in Table 1. The Manfred Complex is the oldest known rock unit of the Mount Narryer region, the oldest known rock unit in Australia, and is almost as old as the oldest known rocks on Earth — the Isua Supracrustal rocks of Greenland (Moorbath, 1983).

The most distinctive rock type is leucogabbro (*MCax*) with coarse-grained relic igneous textures characterized by relic igneous plagioclase, mostly 2–5 cm in diameter (Fig. 3). Remnants of igneous feldspars are patchily preserved in some leucogabbros as large crystals of plagioclase (An_{75-95}), partly replaced by granular aggregates of finer grained metamorphic plagioclase. The feldspars occur in a matrix of metamorphic green hornblende (probably after igneous pyroxene) and clinopyroxene. Small zircon and apatite crystals are abundant in both igneous plagioclase and metamorphic hornblende. Allanite and epidote are locally abundant.

Most anorthosites (*MCax*) consist of metamorphic plagioclase, with an equigranular mosaic texture, and show macroscopic tectonic fabrics.

More than half the outcrop of the Manfred Complex consists of either metagabbro (*MCg*) or amphibolite, which is interpreted as metagabbro (*MCh, MChx*). Igneous textures and minerals (showing subophitic and corona structures) are locally preserved and consist of orthopyroxene, clinopyroxene, green and brown hornblende,

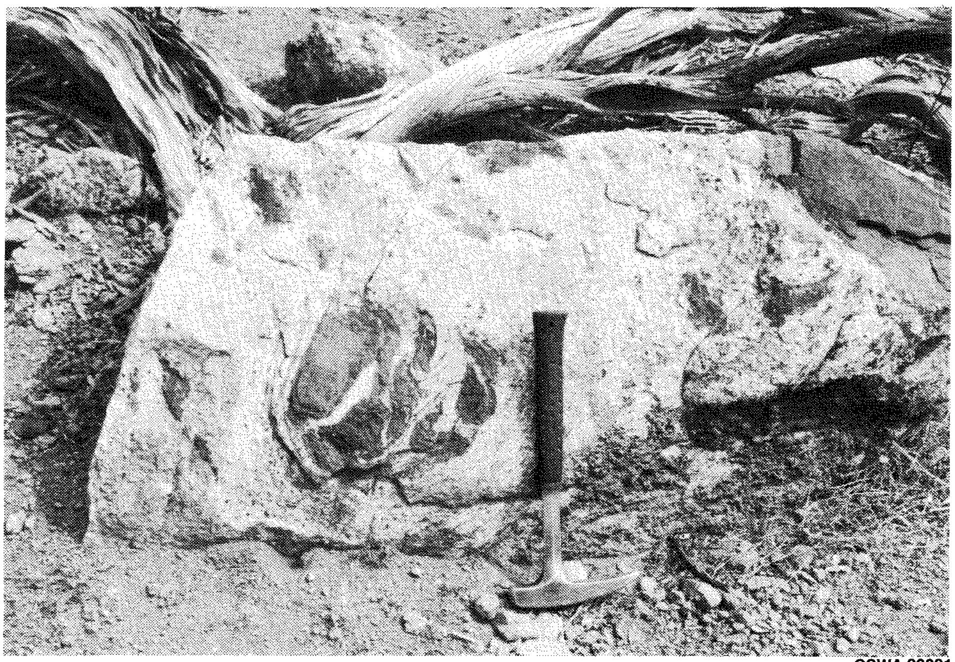

Figure 2. Fragments of amphibolite derived from Manfred Complex gabbro, in Dugel gneiss. (Length of hammer is 33 cm.)

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Figure 3. Fragments of Manfred Complex metaleucogabbro and isolated large, relic-plagioclase crystals in Dugel gneiss. (Diameter of compass mirror is 6.5 cm.)

plagioclase (An_{80-95}), and green spinel. The metagabbro, with igneous texture and some igneous minerals, occurs as large lenses within amphibolite. Complete gradations can be seen, associated with increasing deformation and recrystallization, between metagabbro and amphibolite with metamorphic textures. The amphibolite makes up over 90% of the gabbroic rocks. Most amphibolite consists of an equigranular mosaic of plagioclase (An_{45-55}), green hornblende and clinopyroxene, with macroscopic tectonic fabrics.

Ultramafic rocks form a minor but prominent part of the Manfred Complex (*MCp, MCpx*). They range in composition from dunite to peridotite and pyroxenite. Some have igneous textures and minerals which include olivine, orthopyroxene and minor chromite. But most are serpentinized and consist of talc, tremolite, serpentine, green hornblende, clinopyroxene, and magnetite.

Igneous layering, marked by either sharp or gradational variations in mineral content, occurs locally in the whole range of igneous rock types. Mineral and size-graded layering was seen in some ultramafic rocks and leucogabbros.

The primary igneous stratigraphy, thickness, and proportions of the various rock types of the Manfred Complex are unknown, because the rocks now occur as fragments in younger, strongly deformed Dugel gneiss.

Deformation of the Manfred Complex was heterogeneous; some rocks are undeformed whereas others are strongly deformed, and marked variations in deformation intensity occur between different fragments. Deformation of the associated gneiss is generally less heterogeneous but more intense than that of the Manfred Complex. Therefore, the complex appears to have been deformed before it was fragmented by the intrusion of the syenogranite, which became the Dugel gneiss. Fragments and strips of single rocks types, such as leucogabbro, gabbro and ultramafic rocks, occur in the gneiss as trains which can be followed discontinuously along strike for several kilometres. This suggests that the syenogranite (now Dugel gneiss) was intruded as sheets subparallel to the igneous layering.

Many rocks of the Manfred Complex are partly altered by a patchy, low-temperature metamorphism which post-dates all major ductile deformation. This metamorphism is characterized by the growth of chlorite, epidote, mica, carbonate, and prehnite. These minerals partly replace the older, coarser grained mineral assemblages.

The compositions and textures of rocks of the Manfred Complex are typical of a widespread group of anorthosites which appear to be restricted to the Archaean. The best exposed example of this group is the Fiskenaesset Complex (c. 3.0 Ga old) of West Greenland (Myers, 1985). The Manfred

Complex is the first example of this group of rocks to be found in Australia, and is the oldest known example of these rocks on Earth.

QUARTZO-FELDSPATHIC GNEISSES

Quartzo-feldspathic gneisses are the most abundant rocks of the region. They are moderately well exposed adjacent to ridges formed by metasedimentary rocks, but elsewhere the gneisses are poorly exposed and weathered, except in areas west of Mount Dugel and Mount Murchison (Fig. 1).

The quartzo-feldspathic gneisses are divided into two groups:

(a) Meeberrie gneiss (oldest) forming 87% of gneiss outcrop.

(b) Dugel gneiss (youngest) forming 13% of gneiss outcrop.

Their geochronology is summarized in Table 1, chemical analyses of the gneisses are given in Table 2, and their petrography is summarized in Table 3.

MEEBERRIE GNEISS

The largest unit of quartzo-feldspathic gneiss in the Mount Narryer region (Plate 1) is called Meeberrie gneiss (Myers and Williams, 1985); it is named after the station property of Meeberrie. It is a banded quartz-microcline-oligoclase-biotite gneiss *(Mgn)*, with a monzogranite or granodiorite composition (Table 2). The banding is clearly defined and is generally parallel to other lithologies. It is marked by variations in grain size, in the concentration of biotite, and by pegmatite veins. The banding is a characteristic feature of the Meeberrie gneiss in this region and is the result of intense deformation (Fig. 4). It is most pronounced adjacent to faulted and sheared contacts with metasedimentary rocks, where there is a reduction in both grain size and band thickness.

In areas where the gneiss is least deformed (marked *Mgng*), three main generations of pegmatite veins can be seen. The banding is poorly defined and discontinuous (nebulitic), and it outlines complex small-scale folds (Fig. 5).

The oldest, microscopic, tectonic fabric that can now be recognized is a strongly marked flaser or mylonitic fabric (Fig. 6). It is best preserved north of Mount Dugel Creek (Plate 1) where the gneiss (*Mgnl*) is least effected by subsequent recrystallization. Quartz ribbons occur up to 3 cm long in layers separated by granoblastic-elongate intergrowths of microcline and oligoclase. Few pegmatite veins are seen in the flaser gneiss, but it contains pods and lenses of cordierite and orthopyroxene-bearing pelitic rocks. These contain mineral assemblages in granulite facies, which formed in association with the flaser fabric.

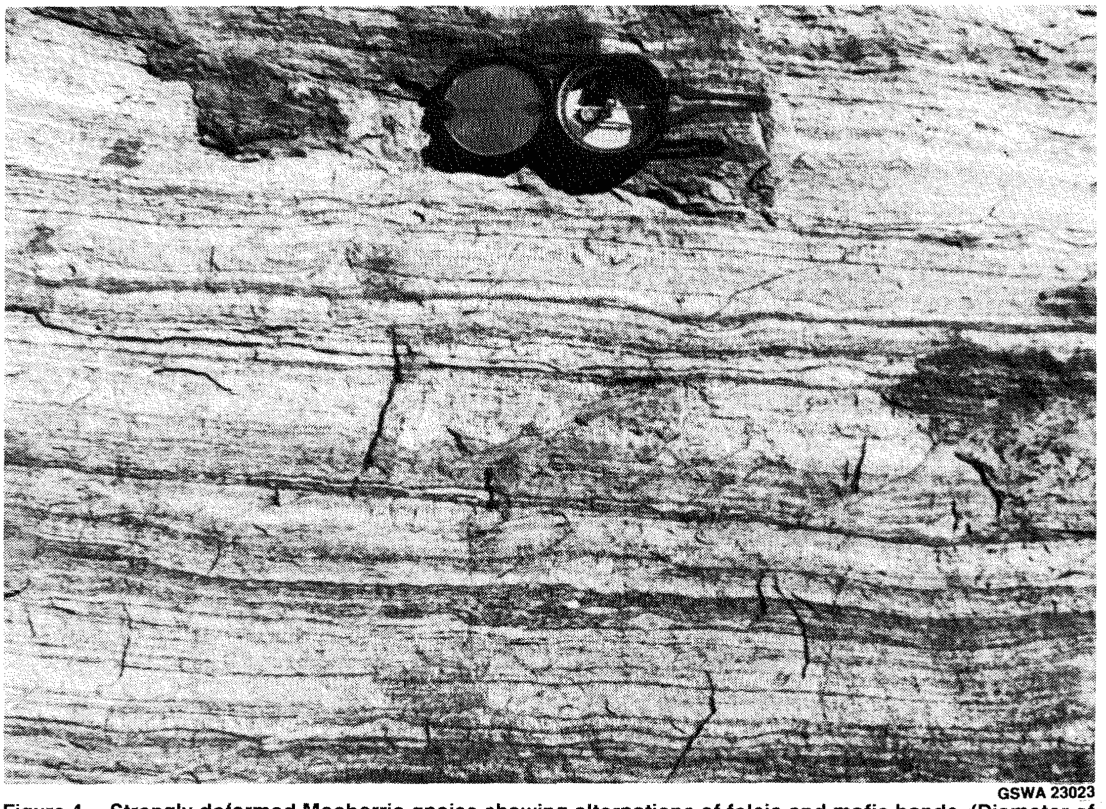

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Figure 4. Strongly deformed Meeberrie gneiss showing alternations of felsic and mafic bands. (Diameter of compass mirror is 6.5 cm.)

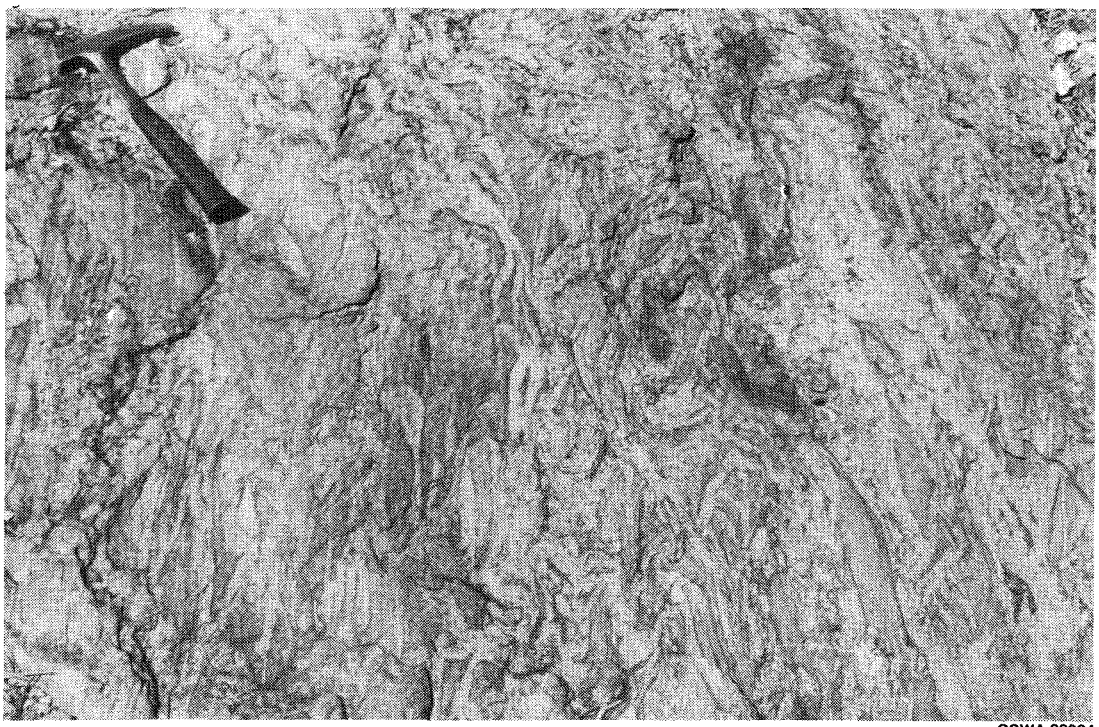

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Figure 5. Less strongly deformed Meeberrie gneiss showing a folded network of felsic veins in uniform biotite-bearing monzogranite. (Length of hammer is 33 cm.)

Southwards from Mount Dugel Creek, the pronounced flaser fabric is seen to be increasingly recrystallized and is replaced by amphibolite-facies mineral asemblages with granoblastic textures. The banding is enhanced by the injection of subparallel pegmatite veins. This recrystallization and pegmatite veining may be associated with the increasing abundance, southwards, of younger granitic veins and small plutons.

A similar, recrystallized, flaser fabric is seen in the Meeberrie gneiss west of Mount Murchison, where the gneiss is surrounded by younger Archaean granites.

DUGEL GNEISS

The Dugel gneiss (Myers and Williams, 1985) occurs east of the Mount Narryer metasedimentary rocks between Mount Dugel

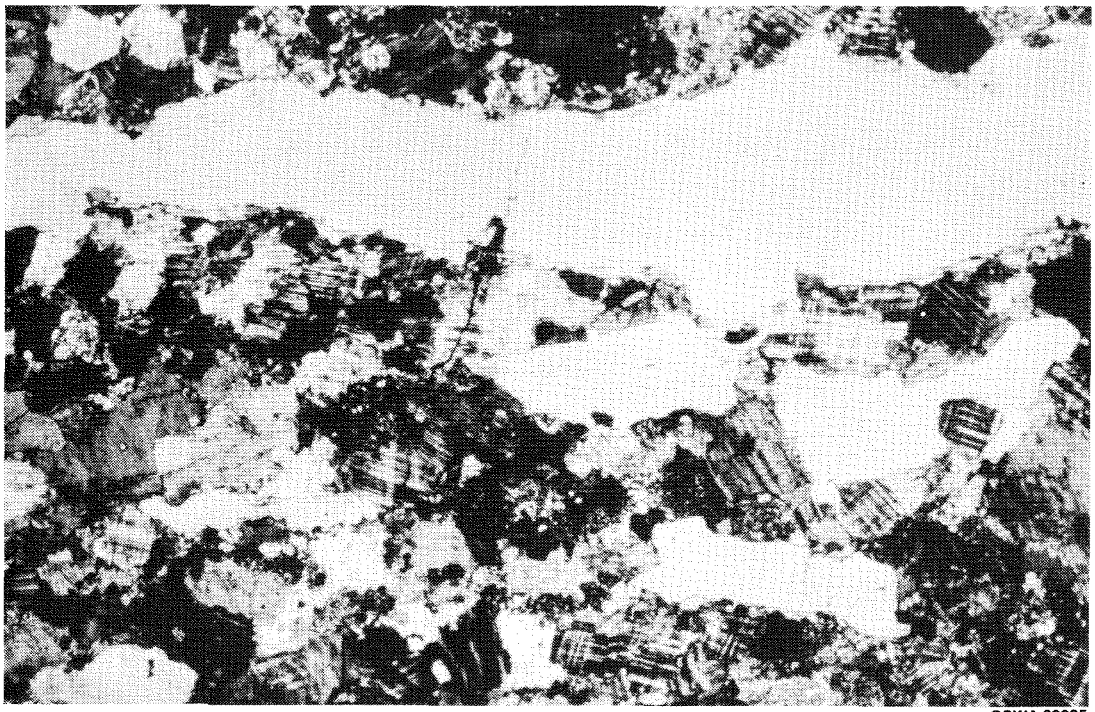

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Figure 6. Photomicrograph of Meeberrie gneiss showing D_2 flaser fabric. (Field of view is 8 mm wide.)

Well and Mindle Well (*Dgn*), and is interlayered with Meeberrie gneiss west of Mount Dugel (*Dgnf*). The gneiss is named after Mount Dugel Well. East of Mount Narryer the Dugel gneiss comprises quartz, plagioclase, microcline, biotite, and amphibole. It ranges from syenogranite to granodiorite in composition (Table 2).

East of Mount Narryer the gneiss (*Dgn*) shows discontinuous banding and contains irregularly distributed inclusions of the Manfred Complex. In areas where these inclusions are abundant, the gneiss is rich in amphiboles—cummingtonite and hornblende (Fig. 7). The gneiss has a strongly marked flaser or mylonitic fabric, similar to that in the Meeberrie gneiss. Both this fabric and the banding are locally destroyed by patchy recrystallization and partial melting, associated with subsequent high-grade metamorphism.

West of Mount Dugel, the Dugel gneiss contains less than 3% biotite and smaller amounts of muscovite and garnet (*Dgnf*, Table 3). The banding is marked by variations in composition and by subparallel pegmatite veins. The gneiss has the composition of syenogranite or monzogranite, and shows a pronounced flaser fabric, with little or no subsequent recrystallization. It contains many thin bands of quartzite and some lenses of pelitic gneiss.

A pegmatitic phase of the gneiss, characterized by bluish quartz, intrudes both the Meeberrie gneiss and Mindle metasedimentary rocks.

METASEDIMENTARY ROCKS

Narrow, linear belts of strongly deformed metasedimentary rocks are an important component of the Western Gneiss Terrain in the Mount Narryer region (Fig. 1). They are separated by tracts of banded Meeberrie gneiss and both are intruded by gneissic, foliated or undeformed granitoids and basic dykes of various ages.

MOUNT NARRYER METASEDIMENTARY ROCKS

The Mount Narryer metasedimentary rocks form a continuous steeply dipping belt, which crops out over a distance of 21 km and reaches a maximum width of 2.5 km near Mount Narryer (Fig. 1). These rocks form a north-trending range of low, rounded hills which rise 200 m above the surrounding quartzo-feldspathic gneisses. Mount Narryer (514 m) and Mount Dugel (461 m) are prominent peaks located near the southern and northern ends of the range, respectively.

The outcrop of the Mount Narryer metasedimentary rocks is divided into a northern and southern sector. The rocks in the northern sector, which includes Mount Dugel (Fig. 1), are strongly deformed. Different rock types can be distinguished (Plate 1) but deformation has obscured the original stratigraphic sequence. The rocks in the southern sector, which contains Mount Narryer, are less deformed. A primary stratigraphy is well preserved and the rocks are divided into five lithostratigraphic units (Fig. 8). The

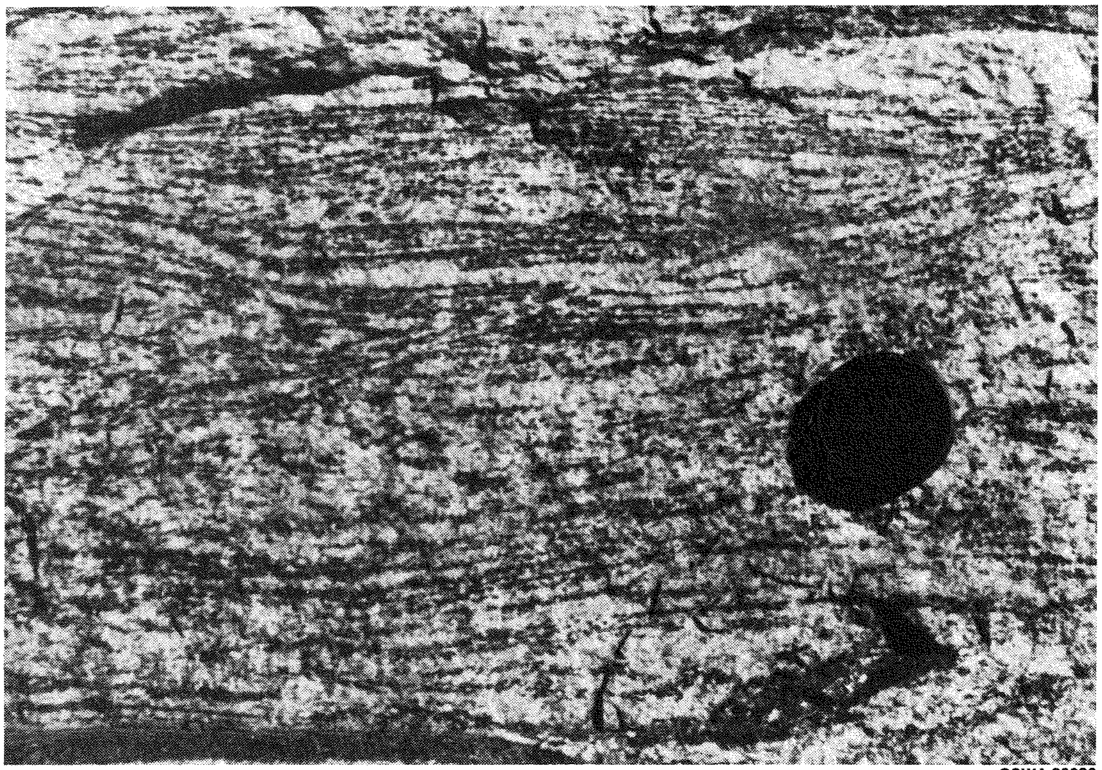

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Figure 7. Strongly deformed Dugel gneiss showing discontinuous quartzo-feldspathic and amphibole-rich bands. (Diameter of lens cap is 5.3 cm.)

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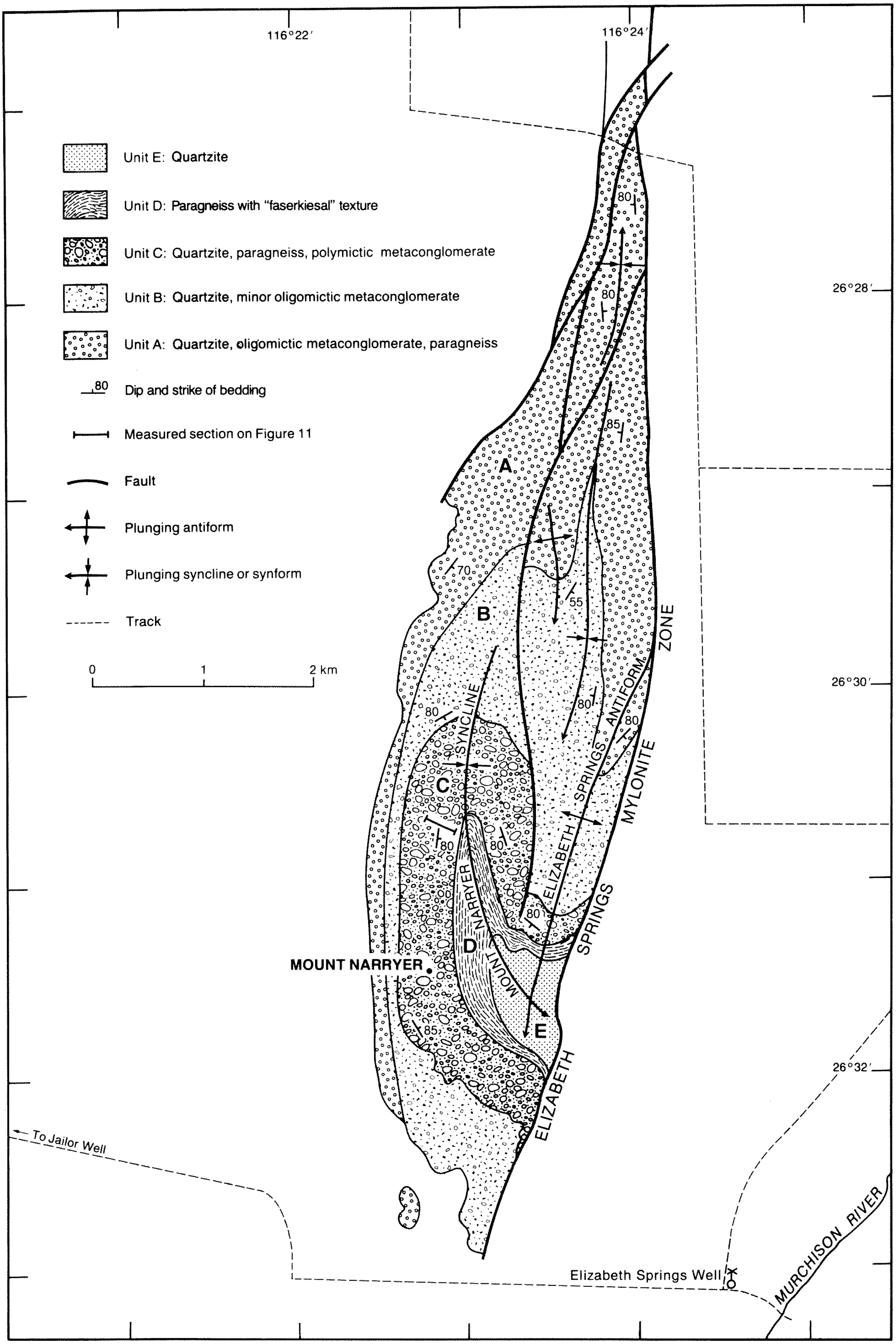

Figure 8. Map showing the lithostratigraphy of the southern sector of the Mount Narryer metasedimentary rocks.

boundary between the northern and southern sectors corresponds to a relatively abrupt change in deformation state and thickness of the metasedimentary rocks. North of this boundary the deformation has destroyed the distinctive bedding and sedimentary structures, which are characteristic of the southern sector around Mount Narryer.

Southern sector

The southern sector of the Mount Narryer metasedimentary rocks forms a range of hills, with a lozenge-shaped perimeter, 11 km long and up to 2.5 km wide (Fig. 8). Mount Narryer, the highest hill, lies on the western limb of the southeast-plunging Mount Narryer syncline (Fig. 8). The excellent exposure, well-preserved bedding, and other sedimentary structures, make possible the recognition of five lithostratigraphic units. These are informally designated, in upward succession, units A, B, C, D, and E (Fig. 8).

The units occur in a conformable sequence with a minimum thickness of 2250 m. The original thickness of the sequence is unknown, because the rocks are deformed, the top of the sequence is not exposed, and the base of the sequence is a zone of intense deformation and tectonic movement.

The eastern margin of the metasedimentary rocks is marked by the broad westward-dipping, Elizabeth Springs mylonite zone (up to 200 m wide) in which all five lithostratigraphic units are intensely deformed and are indistinguishable (Fig. 8).

The western margin of the metasedimentary rocks is poorly exposed, but is sharp and less sheared. Five kilometres north of Mount Narryer, the western contact between the metasedimentary rocks and Meeberrie gneiss is occupied by a large quartz vein, whereas just west of Mount Narryer the quartzites are in direct contact with the banded gneiss (Plate 1). The bedding planes in the quartzites are slightly oblique ($<15°$) to the gneiss contact. The banded gneiss has a strongly recrystallized flaser fabric. The adjacent quartzite, although appearing coarse grained in outcrop, shows (in thin section) a strongly recrystallized poikiloblastic texture with the large quartz grains enclosing strongly aligned sillimanite, clinopyroxene, amphibole, plagioclase, and microcline. This suggests that, before recrystallization, the rocks on both sides of this contact were intensely deformed together, and the contact may be a zone of tectonic dislocation.

The stratigraphy of the southern sector of the Narryer metasedimentary rocks is summarized in Table 4 and is described below:

Unit A: This is the lowest unit and is characterized by thick continuous beds of quartz-pebble metaconglomerate (*Ao*), Figure 9, interbedded with sillimanite-garnet quartzite (*Aq*),

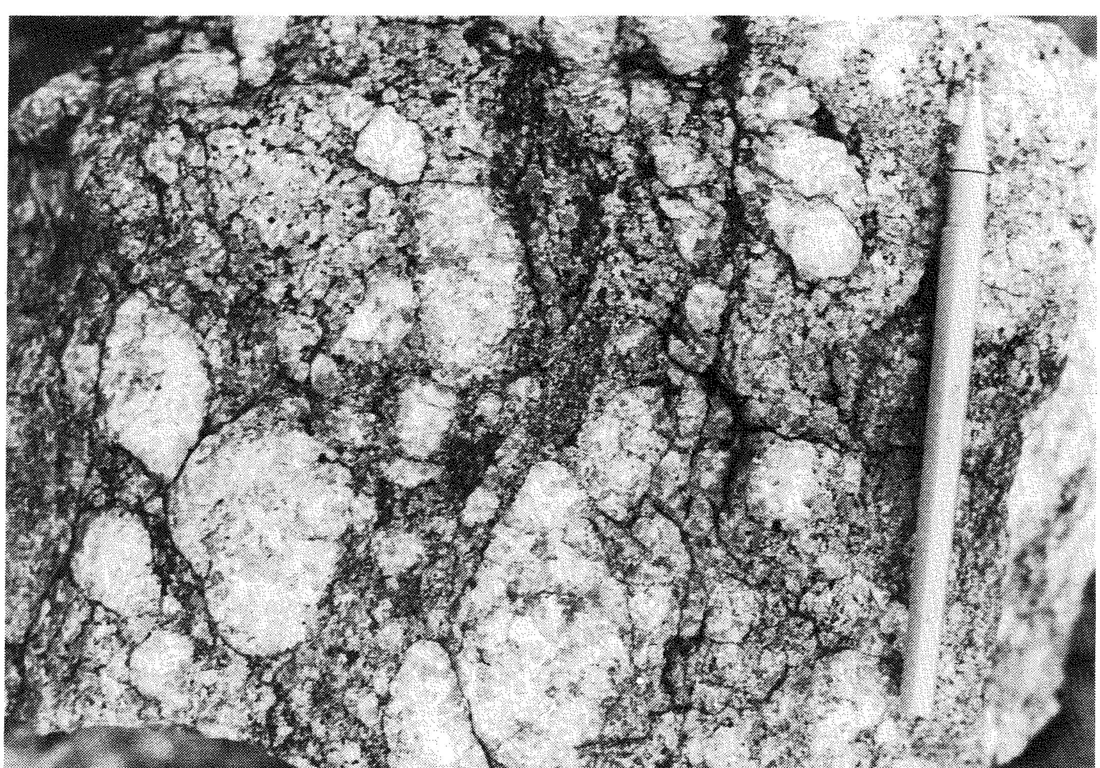

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Figure 9. Recrystallized quartz-pebble conglomerate; Mount Narryer metasedimentary rocks, southern sector, unit A. (Length of pen is 13.5 cm.)

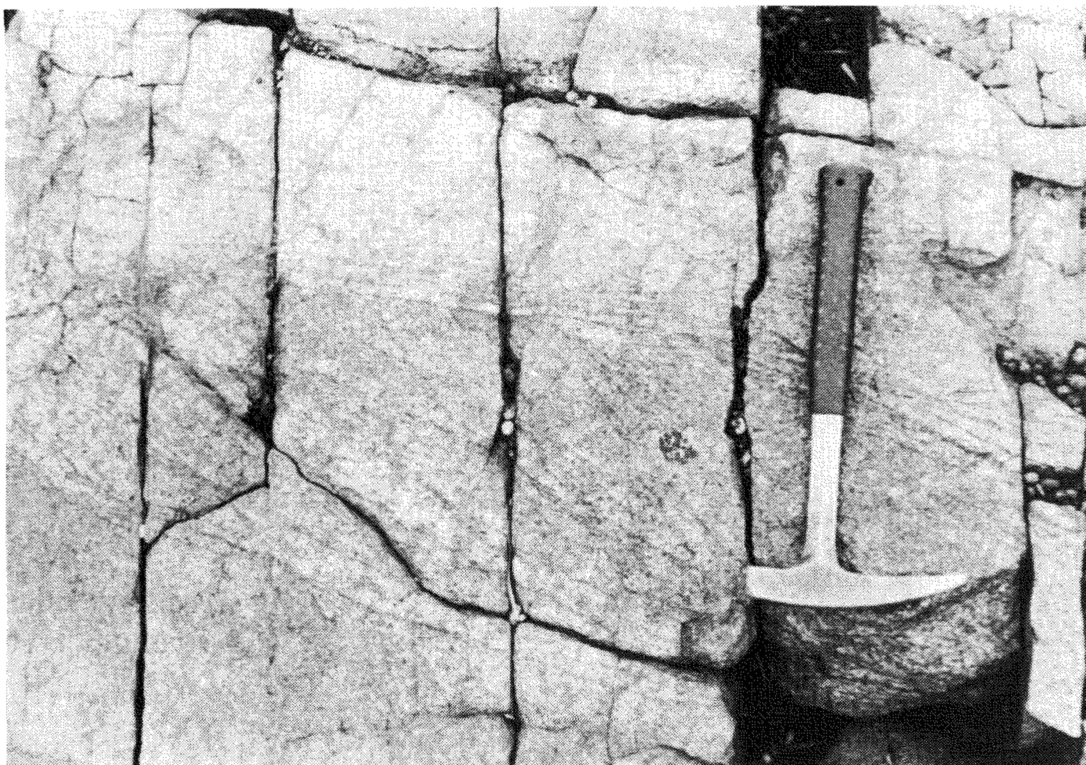

Figure 10. **Trough cross-bedding structures in sillimanite-garnet quartzite; Mount Narryer metasedimentary rocks, southern sector, unit A. A small pebble of garnet quartzite can be seen just left of the hammer shaft. (Length of hammer is 33 cm.)**

feldspathic quartzite (*Af*), clinopyroxene-amphibole quartzite (*Ap*), minor cordierite gneiss (*Ab*) and pods of banded calc-silicate gneiss (*Aa*).

Clinopyroxene-amphibole quartzite and associated calc-silicate gneiss locally occur in the lower parts of the unit. They are interlayered with and appear to pass laterally into predominantly feldspathic quartzite and cordierite gneiss. There is an upward increase in the ratio of aluminous sillimanite-garnet quartzite to feldspathic quartzite. The top of unit A in the Elizabeth Springs antiform (Fig. 8) is marked by a persistent bed of quartz-pebble metaconglomerate.

The sillimanite-garnet quartzite generally shows well-preserved trough cross-bedding structures where it is interbedded with the quartz-pebble metaconglomerate (Fig. 10). These may be single sets (up to 1.5 m thick), stacked small troughs, or festoon cross-beds individually between 200 mm and 800 mm thick. The cross-bedded structures are now marked by trains of red-brown garnets.

The feldspathic quartzites show a few large planar (tabular) cross-beds up to 2 m thick. Both the feldspathic and the clinopyroxene-amphibole quartzites show graded bedding. There is generally an upward decrease in clast size in graded beds of quartz-pebble metaconglomerate, between 100 mm to 3 m thick, interbedded with clinopyroxene-amphibole quartzite.

Unit B: This mainly comprises sillimanite-garnet-(cordierite) quartzite *(Bq)* with minor feldspathic quartzite *(Bf)* and lenses of quartz-pebble metaconglomerate *(Bo)*. Midway up the unit, a single large lens of pelitic gneiss, now represented by "faserkiesal" textured sillimanite gneiss *(Br)*, overlies cordierite-biotite-garnet-sillimanite gneiss *(Bb)*. The thickness of the unit varies from less than 100 m, west of Mount Narryer, to around 750 m in the hinge zone of the Mount Narryer syncline. The well-preserved sedimentary structures in the synclinal hinge zone suggest that the latter approximates the primary thickness. Shearing is restricted to discrete zones.

Unit B has yielded detrital zircons from a feldspathic quartzite near the base of the unit which gave U-Pb ages of 4200–4100 Ma (Froude and others, 1983).

The unit shows an upward decrease in the ratio of feldspar to aluminous minerals (sillimanite and cordierite). Traces of cross-bedding and graded bedding occur throughout the unit, with cross-bedding becoming more abundant towards the top.

Unit C: This unit makes up the highest ridges of the Mount Narryer range. It comprises almost equal portions of polymict metaconglomerate *(Cc)*, and medium- to coarse-grained garnet-sillimanite-cordierite quartzite and quartz-rich gneiss *(Cq)*.

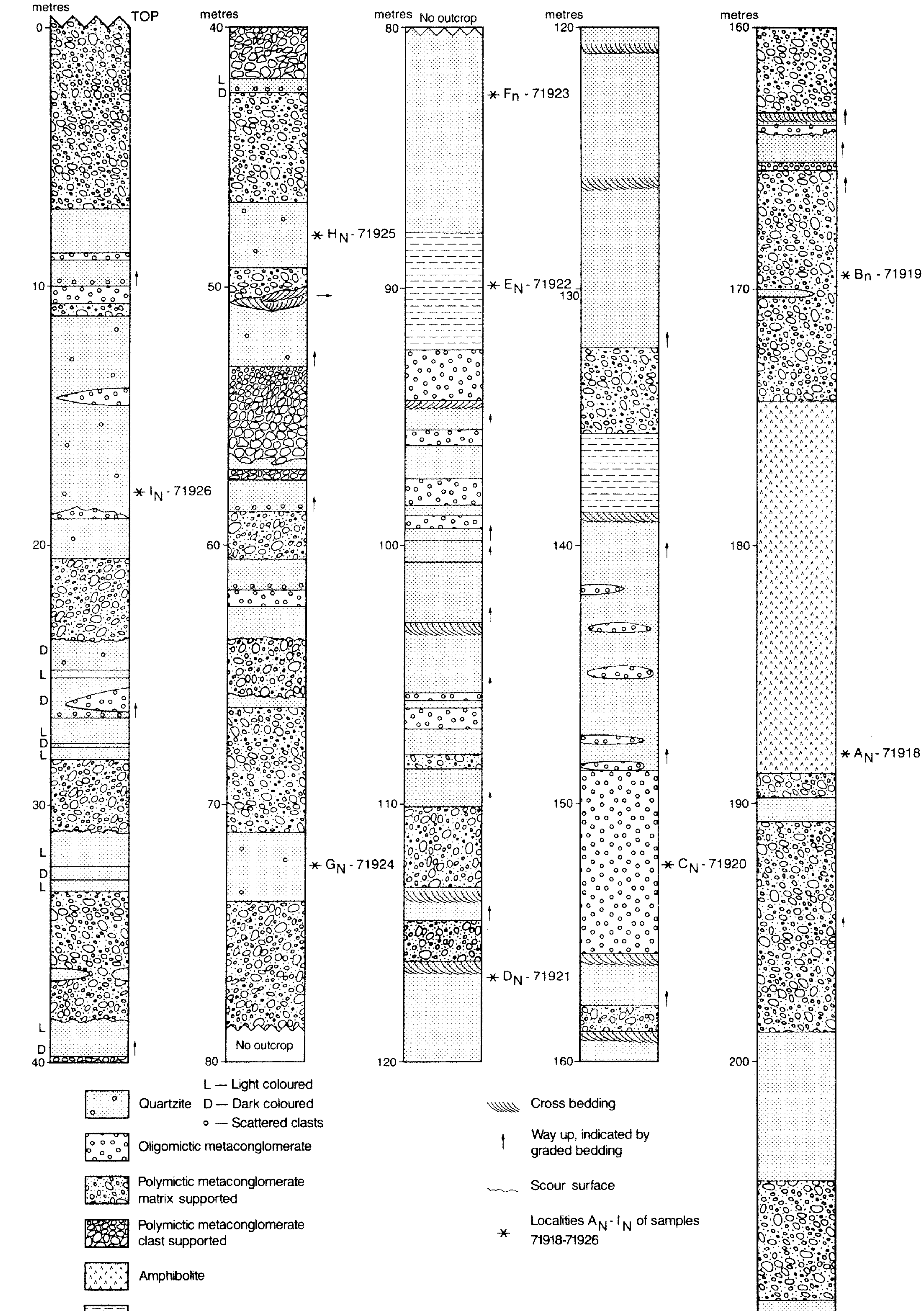

Figure 11. Measured stratigraphic section of part of unit C showing interbedded quartzites and metaconglomerates. Mount Narryer metasedimentary rocks, southern sector; located on Figure 8.

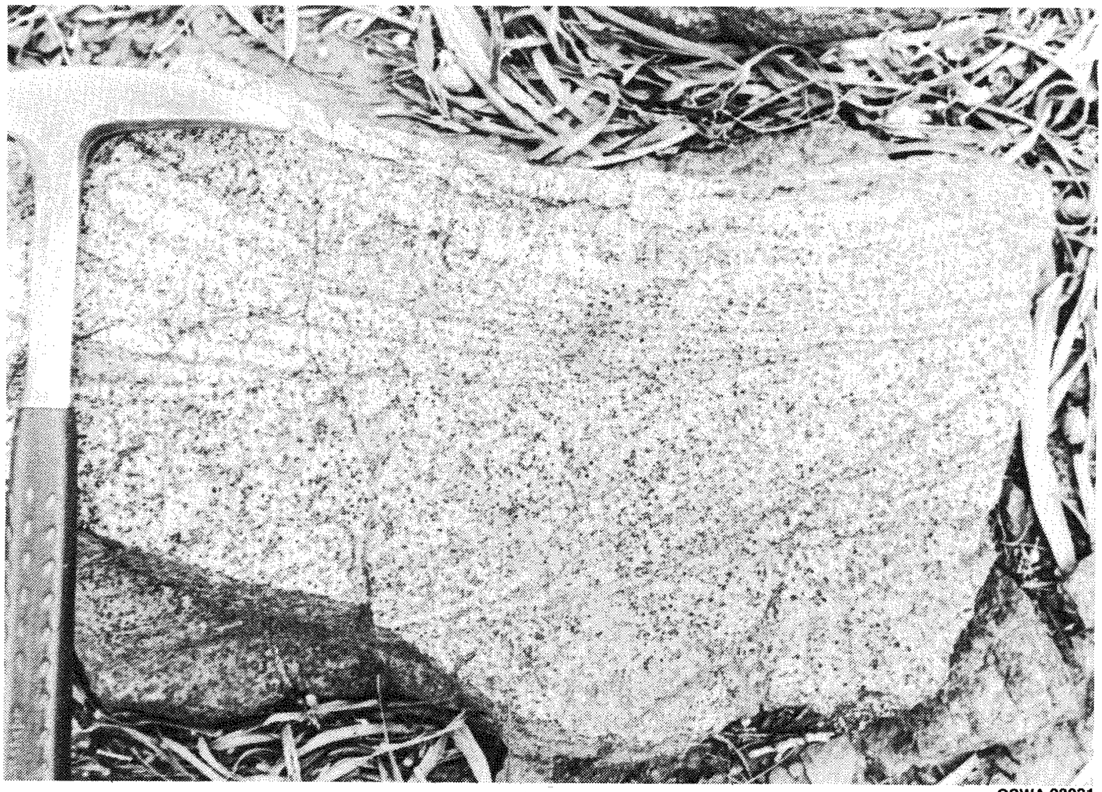

Figure 12. Trough cross-bedding in garnet-sillimanite-cordierite quartzite; Mount Narryer metasedimentary rocks, southern sector, unit C. (Length of metal head on hammer is 14 cm.)

Thin bands and lenses of dark cordierite-garnet-biotite-sillimanite gneiss and grunerite-plagioclase-quartz gneiss are minor components of the unit.

A detailed section of the unit (209 m thick, Fig. 11) was measured along a creek, 1.3 km north of Mount Narryer. In the section, quartzite and polymict metaconglomerate are interbedded on all scales ranging from beds less than 1 m thick up to 75 m thick. The maximum thickness of the unit is about 500 m. The basal bed is a thick (up to 80 m) lensoid polymict metaconglomerate.

The excellent exposure of the unit reveals an abundance and variety of sedimentary structures in spite of high-grade metamorphism. Trough cross-bedded quartzites, 100 mm to 3 m thick, are abundant between polymict metaconglomerate beds (Fig. 12). Some metaconglomerates are massive whereas others show upward-fining sequences, from coarse metaconglomerate to quartzite. Some of these were deposited in scoured channels cut into the underlying rocks. In many cases the metaconglomerate shows a chaotic internal structure of matrix-supported angular clasts (Fig. 13), whereas other metaconglomerates show reverse grading at the base and normal grading towards the top.

Unit C shows an overall upward increase in grain size. There is also a variation in the composition of clastic fragments towards the top of the

Figure 13. Polymict metaconglomerate showing angular, matrix-supported fragments of quartzite and banded quartz-magnetite rocks; Mount Narryer metasedimentary rocks, southern sector, unit C. (Length of hammer is 33 cm.)

GSWA 23033

Figure 14. White clots of quartz-fibrolite (faserkiesel texture) in quartz-sillimanite-biotite-garnet gneiss; Mount Narryer metasedimentary rocks, southern sector, unit D. (Length of hammer is 33 cm.)

unit; clasts of banded quartz-magnetite-grunerite-orthopyroxene iron-formation and banded chert increase whereas clasts of quartzite, vein quartz and biotite-garnet schist decrease.

Unit D: In marked contrast to the prominent hills of unit C, the more easily weathered unit D occupies a broad valley between the quartzites of units C and E. The unit is up to 250 m thick and consists entirely of quartz-sillimanite-biotite-garnet gneiss *(Dr)* with clots of quartz and fibrolitic sillimanite defining a "faserkiesal" texture (Fig. 14). The clots are metamorphic in origin and do not appear to be replacing primary structures such as clasts. The clots range in size from 40 to 140 mm, and are regularly spaced throughout the gneiss. The unit contains a relatively minor component of distinct clasts of quartzite and vein quartz. These are locally abundant near the base of the unit.

The rocks show a prominent axial-planar cleavage and minor transposition of bedding in the hinge zone of the Mount Narryer syncline. Associated with this axial-planar fabric are thin mylonite zones and the retrogressive development of muscovite (from sillimanite) and sericite.

Unit E: This occupies the core of the Mount Narryer syncline and comprises prominent outcrops of garnet-sillimanite quartzite which resembles similar quartzites in units A, B and C. It has a minimum thickness of 200 m; the upper part has been removed by erosion.

Unit E is intersected by two major fold axes: the older Mount Narryer syncline and the younger Elizabeth Springs antiform (Fig. 8). Both folds have a strong axial-planar fabric, and the intersection of this has produced "tombstone-like" slabs of lineated quartzite up to 4 m high in the weathered quartzite.

Northern sector

The northern sector of the Narryer metasedimentary rocks consists of quartzites (*Nq, Nf, Np*) with various proportions of sillimanite (fibrolite), muscovite (fuchsite), garnet, plagioclase, microcline, clinopyroxene, and amphibole (see Table 4). Quartzite *(Nr)* with "faserkiesal" texture (quartz-fibrolite clots) occurs locally in lenticular belts which, near Mount Dugel, may be the keels of synforms.

Intense shearing of the previously deformed quartzite has locally produced zones of quartz-sillimanite-muscovite schist *(Ns)*. Lenses of oligomict quartz-pebble metaconglomerate *(No)*, and pods of banded calc-silicate gneiss *(Na)* form minor components of the metasedimentary rocks. An unusual andalusite-corundum-chlorite rock *(Nl)*, which may represent a metamorphosed aluminous clay or bauxite, occurs 1.8 km southwest of Mount Dugel.

The quartzites show a mylonitic or flaser fabric, with crystalline sillimanite and mortar texture. Subsequent, more localized, shearing was accompanied by retrograde metamorphism, with the development of muscovite and sericite.

The metasedimentary rocks terminate to the east in the Elizabeth Springs mylonite zone. The Narryer metasedimentary rocks and the Elizabeth Springs mylonite zone are truncated by the Dugel shear zone (Williams and others, 1983) 3 km southwest of Mount Dugel. This shows a dextral movement of about 1 km and may be late Archaean in age.

Porphyritic and seriate, gneissic, biotite monzogranite intrudes the quartzites 4.5 km southwest of Mount Dugel Well.

MINDLE METASEDIMENTARY ROCKS

The Mindle metasedimentary rocks are a belt of poorly-banded, clinopyroxene-bearing quartzites *(Mp)* and orthopyroxene-bearing banded iron-formation *(Mi)*. They crop out discontinuously as thin bands in quartzo-feldspathic gneisses northeast of Mount Narryer, between Mindle and Mount Dugel Wells (Plate 1). Minor units of feldspathic quartzite *(Mf)*, biotite gneiss *(Mb)* and banded calc-silicate gneiss *(Ma)* also occur (Fig. 15). These metasedimentary rocks are separated from the Narryer metasedimentary rocks by a strip of highly deformed Meeberrie gneiss. Both the Meeberrie gneiss and the Mindle metasedimentary rocks are intruded by the Dugel gneiss.

The clinopyroxene-bearing quartzite is a brown-weathering, grey-green rock with a distinctive, speckled, cellular-weathered surface resulting from the preferential weathering of the clinopyroxene. The calc-silicate pods, which contain up to 90% clinopyroxene, have a similar rough-weathered surface. Petrographic data is summarized in Table 6.

Fabrics in the Mindle metasedimentary rocks range from granoblastic-elongate to flaser and mylonitic, indicating that deformation occurred during high-grade metamorphism.

The rocks show various amounts of low-grade recrystallization.

OTHER METASEDIMENTARY ROCKS IN THE VICINITY OF MOUNT NARRYER.

The Meeberrie and Dugel gneisses contain long, narrow strips of sillimanite-muscovite-garnet quartzite *(Wg)* and metamorphosed banded and granular iron-formation *(Wi)* together with pods and lenses of banded calc-silicate gneiss *(Wa)* and orthopyroxene-bearing cordierite gneiss *(Wg)*. The rocks are spatially distinct from the Narryer and Mindle metasedimentary rocks but are broadly similar in lithology.

GSWA 23034

Figure 15. Bands of light quartz-rich and dark (clinopyroxene-rich) rocks in strongly deformed calc-silicate gneiss; Mindle metasedimentary rocks. (Diameter of compass mirror is 6.5 cm.)

They mainly occur west of Mount Dugel as low hogback ridges (up to 7 km long and 300 m wide) of white-weathering highly deformed quartzite and dark-coloured metamorphosed banded iron-formation (Plate 1).

The ridges are separated by poorly exposed banded gneiss. Other examples occur near Gidgee Bore, 6 km northwest of Mount Narryer, as isolated exposures of polymict metaconglomerate *(Wc)* and garnet-sillimanite-cordierite quartzite, similar to those in the southern sector of the Narryer metasedimentary rocks.

Two types of banded or massive, granular, metamorphosed iron-formation occur in discrete linear bodies. The most widespread type consists of quartz-magnetite-hematite-grunerite rock. A subsidiary type is faintly banded and characterized by clinopyroxene, orthopyroxene, and amphiboles. They generally occur together with the clinopyroxene-bearing quartzites similar to the Mindle metasedimentary rocks. The main rock types are summarized in Table 7.

The metasedimentary rocks show a variety of tectonic and metamorphic fabrics. Textures range from granoblastic and granoblastic-elongate, in calc-silicate gneiss and orthopyroxene-bearing cordierite gneiss, to mortar and flaser structures in the quartzite. The adjacent gneisses have a pronounced mylonitic or flaser structure.

MOUNT MURCHISON METASEDIMENTARY ROCKS

The Mount Murchison metasedimentary rocks form an isolated belt of steeply dipping quartzites, 5 km long and 2 km wide, which lies east of the Murchison River 27 km south-southeast of Mount Narryer (Fig. 1 and Plate 1).

They are surrounded by strongly deformed banded gneiss which resembles the Meeberrie gneiss at Mount Narryer. A thin sheet of banded amphibolite occurs along the western margin of the quartzites.

The Mount Murchison metasedimentary rocks are coarse grained, glassy quartzites (*Rq*) with a metamorphic texture. They are either white, buff, brown or pale-green in colour. Sillimanite and minor biotite, muscovite, and fuchsite are aligned in a prominent foliation which trends north-south and dips steeply eastward. Graded bedding in thin lenses of quartz-pebble metaconglomerate shows that the beds are, locally, the right way up. A clinopyroxene-bearing quartzite (*Rp*) was mapped 1.8 km north of Mount Murchison. Petrographic data are given in Table 8.

The quartzites are intruded by dykes of foliated, or massive, biotite monzogranite and pegmatite.

Numerous stringers, lenses, pods, and angular xenoliths of metasedimentary rocks also occur in the gneisses west and east of Mount Murchison. The mesocratic, contorted gneiss (*Mgnm*), immediately west of Mount Murchison, contains many deformed and streaked-out small xenoliths of biotite-cordierite quartzite, together with a large enclave of cordierite-gedrite gneiss (*Wm*) metamorphosed banded iron-formation (*Wi*) and amphibolite. Pods of banded calc-silicate gneiss (*Wa*) occur in the leucocratic contorted gneiss (*Mgng*) further to the west. North-trending layers of banded quartz-magnetite-grunerite iron-formation occur in the gneisses (*Mgn*) both east and west of Mount Murchison. Two thin layers of quartz-biotite-muscovite-plagioclase gneiss (*Wb*) occur in banded quartzo-feldspathic gneiss 2 km northwest of Mount Murchison. Petrographic summaries are given in Table 8.

All these metasedimentary rocks are foliated, recrystallized, and show some retrogression from an earlier moderate- to high-metamorphic grade. The relation between these largely pelitic metasedimentary-rock enclaves in the gneiss and the coarse-grained arenaceous metasedimentary rocks of Mount Murchison is unknown.

INTRUSIONS INTO THE QUARTZO-FELDSPATHIC GNEISSES AND METASEDIMENTARY ROCKS

BASIC INTRUSIVE ROCKS

The quartzo-feldspathic gneisses and metasedimentary rocks contain basic intrusions which occur as dykes, sills, sheets, lensoid bodies, and podiform bodies. These intrusions are of various ages and range from strongly deformed bodies, with high-grade metamorphic mineral assemblages, to undeformed slightly altered dolerite, gabbro, and diorite dykes.

The earliest recognized basic intrusions include strongly deformed banded amphibolite, derived from dolerite and gabbro (*uh*), metapyroxenite (*ux*) and meta-anorthosite (*ua*). They form conformable lenses and pods in the banded quartzo-feldspathic gneisses and appear to be pre- or syn-tectonic to the flaser fabric which is prominent in the gneisses. They cross-cut the quartzites west of Mount Dugel. High-grade, strongly deformed, basic intrusions have not been found in the Narryer metasedimentary rocks.

The banded amphibolite and metapyroxenite are grey-green to dark grey-blue, brown weathered, and crop out in low rubbly mounds. North of Mount Dugel Creek they contain granulite-facies assemblages of orthopyroxene, clinopyroxene, brown hornblende, cummingtonite, and calcic plagioclase. But southwards these rocks, together with the quartzo-feldspathic gneisses and metasedimentary rocks, show increasing degrees of retrograde recrystallization in amphibolite facies.

Several small pods of pale greenish-cream to light-brown meta-anorthosite form low bouldery hills in the Meeberrie gneiss (*ua* on Plate 1). They contain oligoclase-andesine in contrast to the labradorite-bytownite of the meta-anorthosite pods of the Manfred Complex, but they are extensively altered to epidote, zoisite and clinozoisite; this may account for the more sodic nature of the feldspars.

The Narryer metasedimentary rocks are intruded by thin medium-grained amphibolite dykes (*da*). The dykes are deformed and some show a protomylonitic fabric; they tend to parallel the axial-planar fabric of the Mount Narryer syncline and Elizabeth Springs antiform. This northerly trend is also shown by similar amphibolite dykes in the gneisses. All these dykes post-date the strongly marked flaser fabric and guanulite-facies metamorphism. The field evidence suggests that they were intruded during the waning phases of relatively brittle deformation and amphibolite-facies metamorphism. A folded, large sheet of metagabbro with amphibolitic margins (*dag*), which intrudes Meeberrie gneiss 1.3 km west of Mount Narryer, may be coeval with these amphibolite dykes.

Clusters of small lenses and pods of strongly foliated serpentine, chlorite, and tremolite rock (after peridotite, *du*) intrude the Meeberrie gneiss and quartzites, west of Mount Dugel (Plate 1).

Fine-grained amphibolite (*dm*) lies just east and parallel to the Elizabeth Springs mylonite zone in which it is sheared and altered, from a labradorite-hornblende rock to a banded epidote-clinozoisite-quartz rock. The amphibolite crops out, discontinuously, from east of Mount Narryer to north of Mount Dugel where the amphibolite is least altered (Plate 1). A similiar amphibolite (metadolerite) also occurs along the western margin of the Mount Murchison Quartzite. All these amphibolites are intruded by both deformed (foliated and folded) and undeformed granitic and pegmatitic dykes.

Undeformed metagabbro and metadolerite dykes crop out in the area between Mindle Well and Mount Dugel Well, east of the Narryer metasedimentary rocks. They have northwest and northeast trends and are characterized by olivine-augite-labradorite assemblages (*do*). They are intruded by leucocratic garnet-bearing granodiorite dykes.

The youngest basic intrusions are dykes of gabbro, diorite and dolerite (*dg*) which trend east to east-northeast. They occur at irregular intervals throughout the Mount Narryer region and post-date all deformation including late shearing along the Elizabeth Springs mylonite zone.

Analyses of a selection of basic intrusive rocks are given in Table 2.

ACID INTRUSIVE ROCKS

The Mount Murchison metasedimentary rocks and adjacent quartzo-feldspathic gneisses are partly enclosed by granitic plutons. The abundance and size of these plutons decrease northwards. The oldest recognizable acid bodies are small and scattered, and comprise intensely deformed, folded, even-grained, augen granodiorite and monzogranite gneiss (*na*). These bodies show a mylonitic or flaser fabric and metamorphism, indicating some partial melting in upper amphibolite to granulite facies. They were probably intruded during the development of the D_2 flaser fabric and were folded and retrogressed during syn-D_3 amphibolite-facies metamorphism. Cross-cutting (but folded and strongly foliated) pegmatites in the quartzo-feldspathic gneisses may belong to this intrusive phase.

A second group of acid intrusions consists of gneissic, porphyritic, seriate or even-grained biotite monzogranite (*gg*) which intrudes both the Meeberrie gneiss and the Narryer metasedimentary rocks. These rocks locally preserve igneous textures and show a heterogeneous planar fabric, mainly comprising narrow mylonite zones and broader shear zones. The bodies show upper greenschist-facies dynamic metamorphism. Deformed tourmaline-bearing pegmatites in the Narryer metasedimentary rocks and foliated, discordant pegmatites in the Meeberrie gneiss probably belong to this same intrusive episode.

Small plutons and dykes of recrystallized, deformed, biotite monzogranite (*ge*) are abundant in the Meeberrie gneiss, just west of Mount Narryer, and similar bodies occur less abundantly to the north, in the area around Mount Dugel. A single pluton of this type also intrudes the Narryer metasedimentary rocks 1 km southeast of Mount Narryer.

The granitic plutons surrounding the Mount Murchison metasedimentary rocks consist of foliated, seriate, biotite monzogranite and syenogranite (*gbf*) and younger phases of massive, seriate, porphyritic or even-grained monzogranite and syenogranite (*gb*). These bodies are correlated with the large batholiths of the "Yilgarn cratonic granitoids" which lie southeast of Mount Murchison (Williams and others, 1983).

Foliated and unfoliated granitic and pegmatitic dykes intrude the Mount Murchison metasedimentary rocks. Many of the pegmatites are zoned and some granite dykes contain garnet. Alluvial beryl has been found west of Mount Murchison (Plate 1).

Detailed petrographic information is given in Table 9.

STRUCTURE

The quartzo-feldspathic gneisses and intercalated metasedimentary rocks of the Mount Narryer region have undergone heterogeneous polyphase deformation. Although regional correlation of the successive deformation episodes is made difficult by the scattered and, in some places, weathered nature of the outcrops, three major deformation episodes can be recognized. These are designated D_1, D_2 and D_3.

The D_1 episode formed the earliest gneissose banding in the Meeberrie gneisses and, possibly, in the Dugel gneiss. This banding is generally faint, and in some areas is discontinuous. It is expressed mainly by grain size and compositional variation, also pegmatite bands are not abundant. Intrafolial

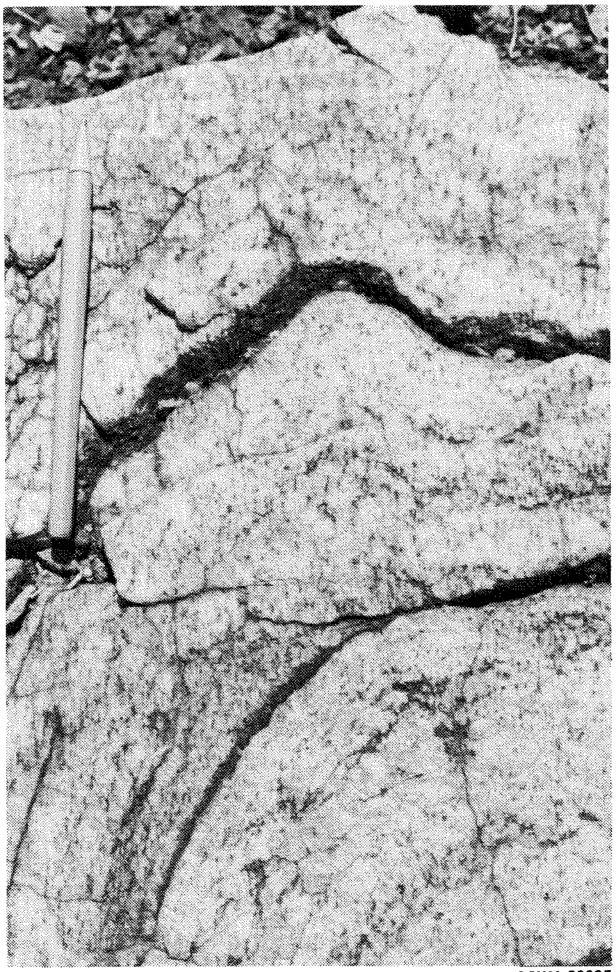

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Figure 16. D_1 banding in Meeberrie gneiss folded by D_2 deformation and crossed by D_2 cleavage, here forming a flaser fabric parallel to the D_2 fold axial surface. North-west of Mount Dugel. (Length of pen is 13.5 cm.)

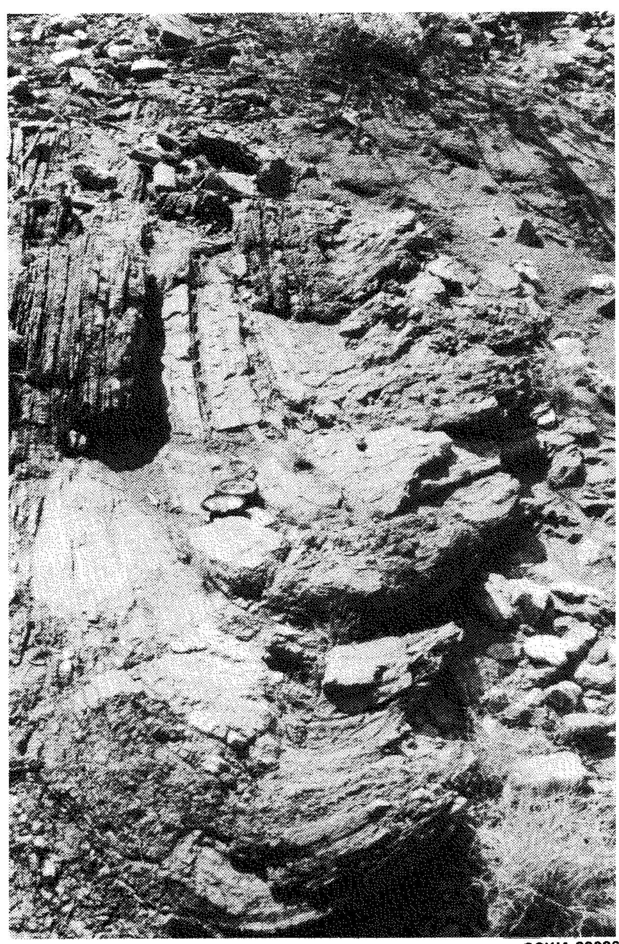
folds are found in a few places but no large-scale folds are recognized. The D_1 banding can only be clearly recognized in the hinge zones of large D_2 isoclinal folds northwest of Mount Dugel. These large folds are the product of the widespread and pervasive D_2 episode.

The D_2 deformation is characterized by a pronounced flaser fabric, which is axial planar to major D_2 isoclinal folds and to small parasitic folds on their attenuated limbs (Fig. 16). The isoclinal folds are steep, south-southwesterly plunging antiforms and synforms, which fold both the Meeberrie gneiss and interlayered metasedimentary rocks. Both the banding in the gneiss and axial planes of the large isoclines dip steeply west. The D_2 deformation occurred during granulite-facies metamorphism.

The D_2 flaser fabric is generally parallel or subparallel to pre-existing compositional banding in the gneisses, throughout the Mount Narryer region, and enhances the banding in the gneisses. This banding becomes more distinct and individual bands become thinner towards the contacts with metasedimentary rocks, where the original contact relations are obliterated.

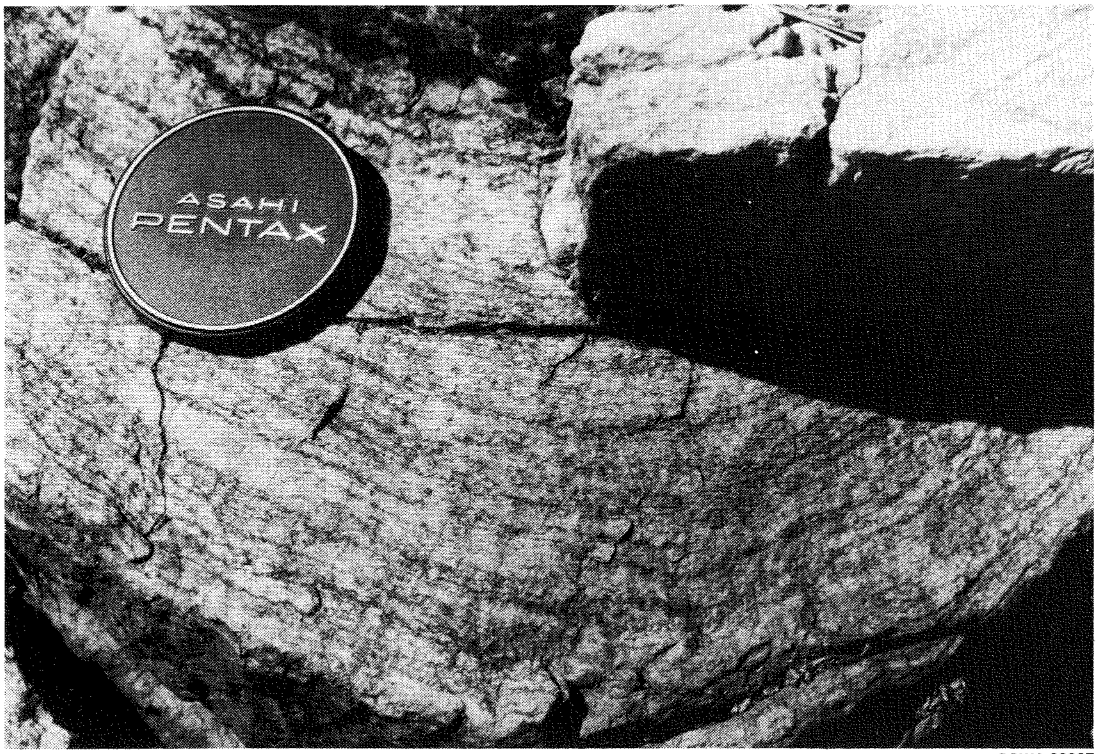
The northern sector of the Mount Narryer metasedimentary rocks shows the same pronounced flaser fabric. This has, however, been heterogeneously modified by later shearing and retrograde metamorphism, especially along contacts between the Narryer metasedimentary rocks and Meeberrie gneiss. The flaser fabric in these metasedimentary rocks can be traced southward into a coeval granoblastic-elongate fabric at Mount Narryer. There the fabric is axial planar to a major steep southeasterly plunging syncline, developed in well-preserved metasedimentary rocks. This fold structure, D_2, (the first in the metasedimentary rocks) is truncated by the Elizabeth Springs mylonite zone.

South of Mount Dugel Creek, the D_2 flaser fabric is increasingly recrystallized and the optically continuous quartz blades are replaced by a granoblastic quartz mosaic. This recrystallization corre-



GSWA 23036

Figure 17. D_2 flaser fabric parallel to D_1 banding in Meeberrie gneiss, folded by a D_3 fold; northeast of Mount Narryer. (Length of compass mirror is 6.5 cm.)



GSWA 23037

Figure 18. D_2 flaser fabric parallel to D_1 banding in Meeberrie gneiss crenulated by minor D_3 folds; northeast of Mount Narryer. (Diameter of lens cap is 5.3 cm.)

sponds to the increasing abundance of pegmatite veins which, in turn, may be related to increasing numbers of syn- and post-kinematic granitic plutons.

The D_2 flaser fabric and D_1 banding are folded by D_3 folds (Figs 17 and 18). Large-scale fold interference patterns are formed by the superposition of major D_2 and D_3 folds. Examples can be seen east of the Narryer metasedimentary rocks (Plate 1): in the Meeberrie gneiss, 6 km northwest of Mindle Well; further east, outlined by amphibolite of the Manfred Complex; and the whole outcrop of the Dugel gneiss south-southwest of Mount Dugel Well. The major D_2 and D_3 folds appear to have steep axial surfaces at a high angle to each other. The strike of D_2 structures is east-west whereas D_3 structures strike north-south. These fold interference structures are truncated by the Elizabeth Springs mylonite zone.

Small-scale s-folds and z-folds are abundant in the hinge zones of the large D_3 folds east of Mount Narryer. West of Mount Narryer, similar small-scale s-folds and z-folds occur in the Meeberrie gneiss, but they are not seen in association with large folds. The major Elizabeth Springs antiform at Mount Narryer, which refolds the Mount Narryer syncline, may also be the result of the D_3 deformation.

D_3 deformation is accompanied by a retrograde, amphibolite-facies to upper greenschist-facies metamorphism. D_3 fabrics tend to be concentrated in narrow zones which are, locally, shear or mylonite zones. The main fabric of the gneissic adamellite (*gg*), which intrudes the Narryer metasedimentary rocks, also appears to be the result of the D_3 episode.

Small-scale polyclinal folds occur just west of Mount Dugel in the Meeberrie gneiss (Fig. 19). They fold the D_2-D_3 fabrics but cannot be related to any larger scale fold event. Their brittle nature and lack of associated penetrative fabric suggest that they are later than the D_3 episode.

Mylonitic zones, ranging from several millimetres to hundreds of metres wide, occur throughout the Mount Narryer region. Many contain quartz veins and appear to have been repeatedly reactivated. Small folds and shear zones associated with the Elizabeth Springs mylonite zone show evidence of dextral movements. The microstructures and steep westward dip of this zone also suggest steep reverse faulting, or thrusting, of the metasedimentary sequence eastwards over the Meeberrie gneiss.

The Mount Narryer area is still seismically active. Recent fault scarps (such as the Mount Narryer faults, Plate 1) have been identified in alluvial areas adjacent to Mount Narryer (Williams, 1979). The strongest recorded earthquake on the Australian mainland (magnitude 7.1) occurred west of Mount Murchison in 1941

GSWA 23038

Figure 19. Post-D_3 fold of strongly deformed Meeberrie gneiss, just west of Mount Dugel. (Diameter of compass mirror is 6.5 cm.)

(Denham, 1976) on the southern extension of the Mount Narryer Fault (West) (Plate 1). The recent tectonic history of the area has been described in Williams (1979).

The deformation episodes and metamorphic history are summarized in Table 10.

METAMORPHISM

The quartzo-feldspathic gneisses and siliceous metasedimentary rocks show upper amphibolite- to granulite-facies mineral assemblages, which formed during the D_2 deformation. This is the first metamorphism recognized in the metasedimentary rocks. But the preservation of pre-D_2 banding in the Meeberrie gneiss, west of Mount Dugel, indicates that the gneisses have an earlier metamorphic history.

Upper amphibolite- to granulite-facies conditions are indicated by the widespread occurrence of sillimanite, cordierite and garnet (with the absence of primary muscovite) in the quartzites, together with orthopyroxene (eulite and hypersthene) in the metaconglomerate, cordierite gneiss, and banded iron-formations. Most of the gneisses do not contain mineral assemblages which are diagnostic of metamorphic grade. But incipient partial-melting textures and numerous enclaves of orthopyroxene-bearing metasedimentary rocks (with the same tectonic fabric as the enclosing gneiss) suggest that the gneisses were metamorphosed in upper amphibolite to granulite facies. The composition of a cordierite-garnet pair from quartzites in unit C, at Mount Narryer, was interpreted as showing metamorphic temperature and pressure conditions of 622°C at 550 MPa (Blight and Barley, 1981).

The D_3 deformation was accompanied by retrograde amphibolite-facies metamorphism. This is shown by the partial replacement of pyroxenes by amphiboles (hornblende, tremolite-actinolite), sillimanite by muscovite, and biotite by chlorite. However, the widespread partial preservation of high-grade minerals shows that this retrograde metamorphism was heterogeneous.

Syntectonic amphibolite-facies metamorphism during D_3 was followed by widespread low-grade recrystallization in low amphibolite-facies to greenschist-facies conditions. This is marked by the complete replacement of tectonic fabrics by fine-grained polygonal quartz mosaics in the gneisses, coarse-grained poikiloblastic quartz mosaics in the metasedimentary rocks, and saussuritization of feldspars. This recrystallization becomes increasingly evident south of Mount Dugel Creek and seems to correspond to the increasing abundance of younger intrusive granite plutons and dykes.

CONCLUSIONS

The rocks of the Mount Narryer region show a long and complex history of magmatic, sedimentary, tectonic, and metamorphic episodes which mainly occurred between 3800–2700 Ma ago. Most of the rocks were derived from already evolved magmas, which crystallized as monzogranite (Meeberrie gneiss) or syenogranite (Dugel gneiss), similar to younger granitic rocks. Layered-basic rocks form a second major component and comprise a cumulate sequence of anorthosite, leucogabbro, gabbro, and ultramafic rocks (the Manfred Complex). They show textures typical of a distinctive group of layered-basic intrusions, which appear to be restricted to the Archaean.

The Manfred Complex is the oldest known example of this group of rocks on Earth.

The supracrustal rocks are mainly quartz-rich clastics and do not appear to contain a volcanic component. The well-preserved Mount Narryer metasedimentary rocks are mainly metamorphosed conglomerates and sandstones, which show sedimentary sequences and structures similar to younger sedimentary rocks. They appear to have been laid down in a fluviatile environment (braided stream) in a region of, at least, moderate relief. Some poorly sorted matrix-supported conglomerate beds resemble debris flows.

In the metaconglomerates, clasts of metamorphosed banded iron-formation, chert, pelitic gneiss and quartzite indicate erosion of pre-existing sedimentary rocks. The absence of clasts of plutonic rocks, in the metaconglomerates, suggests that plutonic rocks were not exposed close to the area of deposition. However, the ages of detrital zircons in the quartzites are similar to ages obtained from the Meeberrie and Dugel gneisses (Froude and others, 1983). This suggests that these gneisses may have provided distal source rocks for the quartzites of the Narryer metasedimentary rocks.

The source of the 4200–4100 Ma zircons found in the same Narryer quartzites (Froude and others, 1983) is unknown. However, the source rock may yet be found in the Western Gneiss Terrain, perhaps in the vicinity of Mount Narryer.

TABLES 1 to 10

Reference geochronological footnotes to Tables and Plate 1

(1) Kinny and others, in press

(2) Fletcher and others, in press

(3) Froude and others, 1983

(4) de Laeter and others, 1985

(5) de Laeter and others, 1981a

(6) de Laeter and others, 1981b

(7) Kinny (1986)

(8) Kinny (1987)

TABLE 1. MOUNT NARRYER REGION: SUMMARY OF GEOCHRONOLOGY

	Sm-Nd model age (Ma)	*Sm-Nd whole-rock isochron (Ma)*	*U-Pb ion microprobe zircon age (Ma)*	*Pb-Pb whole-rock isochron (Ma)*	*Rb-Sr whole-rock isochron (Ma)*
Manfred Complex		3680±70 (1)	3730±6 (1)	3689±146 (2)	2690±155; I.R. 0.7012±0.0004 (2)
Meeberrie gneiss (*Mgn*)	3630±40 (5) 3710±30 (4) 3620±40 (4) Inclusion in gneiss: 3540±30 (4)		Zircon rims: 3296±4 (1) Zircon cores: 3678±6 (1)	3357±70 (4)	3348±43 I.R. 0.7037±0.0005 (6) 3302±65; I.R. 0.7004±0.0023 (4)
Dugel Gneiss (*Gnd*)	3510±50 (4) 3540±30 (5)		Zircon cores: 3381±22 (1)		
Augen monzo-granite (*na*)			3300 (7)		
Recryst-allized granite (*ge*)	3120±30 (4) 3070±40 (4)				2579±122 Ma I.R. 0.7143±0.0092 (4)
Meta-sedimentary rocks (collected from *Bf*)			Detrital zircon Narryer quartzite: few 4100-4200 Ma, most 3750-3500 Ma, some 3300 Ma(3)		

TABLE 2. CHEMICAL ANALYSES OF ROCK SAMPLES FROM THE MOUNT NARRYER REGION

	MANFRED COMPLEX		*MEEBERRIE GNEISS*				*DUGEL GNEISS*	*INTRUSIVE ROCKS*			*NARRYER METASEDIMENTARY ROCKS (NMR)*				
	Meta-leuco gabbro	*Meta-gabbro*						*Recrys-tallized biotite monzo-granite*	*Banded amphibolite (into Meeberrie Gneiss)*	*Amphi-bolite (into NMR)*	*Quartzite Unit B*	*Sillimanite-garnet-cordierite-feldspar gneiss Unit C*	*Matrix of meta-conglomerate Unit C*	*Sillimanite-cordierite-garnet gneiss Unit C*	*"Faserkiesal" gneiss Unit D*
Sample	*77239B*	*77229*	*69626*	*69627*	*71917*	*71287*	*77376*	*71901*	*71907*	*71906*	*71932*	*71931*	*71925*	*71924*	*71928*
SiO_2%	45.90	48.20	71.36	74.47	74.13	70.19	75.40	72.47	54.61	50.85	85.60	54.90	80.33	74.90	85.57
TiO_2	0.43	0.22	0.31	0.22	0.12	0.29	0.01	0.29	0.85	1.86	0.11	0.59	0.21	0.35	0.12
Al_2O_3	31.90	11.40	14.28	12.69	13.28	15.70	13.10	13.43	10.19	13.56	6.69	22.41	9.90	16.55	7.19
Fe_2O_3	0.40	2.00	0.81	0.59	0.61	0.89	<0.10	0.79	3.44	2.85	0.38	1.30	1.13	0.74	0.55
FeO	0.92	8.77	1.18	1.09	0.83	0.91	0.34	1.40	7.64	10.25	1.32	7.00	5.78	4.40	1.93
MnO	0.04	0.18	0.02	0.02	0.01	0.02	<0.01	0.02	0.20	0.20	0.04	0.11	0.23	0.13	0.06
MgO	0.57	15.80	0.59	0.33	0.30	0.48	0.04	0.33	7.87	6.21	1.27	3.60	1.06	1.28	0.45
CaO	15.65	9.94	2.31	1.23	1.41	3.44	1.10	1.39	9.80	10.24	2.34	1.25	0.12	0.04	0.02
Na_2O	1.72	0.83	4.26	3.19	3.34	4.84	2.58	2.91	2.38	2.06	0.20	0.35	0.03	0.04	0.11
K_2O	0.32	0.65	3.06	4.84	5.01	1.79	6.00	5.89	0.84	0.41	0.82	5.77	0.01	0.10	2.22
P_2O_5	0.04	0.03	0.08	0.08	0.09	0.16	0.03	0.11	0.18	0.18	0.05	0.07	0.10	0.09	0.06
CO_2	—	—	0.19	0.19	0.05	0.27	—	0.14	0.13	0.11	0.14	0.10	0.02	0.11	0.11
H_2O	0.99	1.82	0.49	0.49	0.46	0.62	0.34	0.51	1.38	1.58	0.64	1.76	0.30	0.63	0.77
TOTAL	**98.84**	**99.88**	**99.20**	**99.43**	**99.64**	**99.60**	**98.90**	**99.68**	**99.38**	**100.36**	**99.60**	**99.21**	**99.22**	**99.36**	**99.16**
Li ppm	—	—	7	5	30	9	—	14	0	24	21	65	10	17	10
Be	—	—	1	<1	2	1	—	1	1	<1	<1	2	1	1	<1
B	—	—	1	<1	1	<1	—	2	2	10	2	3	1	4	2
F	—	—	220	142	84	288	—	246	1018	334	348	362	15	46	26
Ba	317	91	1423	1081	536	613	4689	1370	306	155	45	836	<1	21	792
Rb	10	54	57	110	180	62	93	193	7	7	55	166	1	8	68
Sr	1818	75	307	117	93	334	254	115	152	215	21	38	1	1	25
Pb	32	<10	15	23	66	20	20	56	3	2	2	28	3	7	11
Th	26	<5	22	34	35	10	10	51	7	<5	13	10	25	24	7
U	4	<1	<1	3	10	<1	<1	3	<1	<1	2	1	6	<1	1
Zr	331	19	192	164	157	254	10	230	95	78	80	122	79	137	80
Nb	30	<5	<5	6	8	7	<5	9	8	8	<5	9	<5	12	<5
Y	21	6	5	19	10	13	5	15	24	21	18	20	23	29	15
La	81	21	73	87	30	38	82	74	31	25	15	23	40	39	20
Ce	128	<20	120	170	89	55	77	141	79	27	40	67	74	115	<20
Sc	<5	36	<5	<5	<5	<5	<5	<5	30	45	<5	29	14	8	7
V	22	140	14	5	6	8	<5	<5	189	414	15	160	73	62	26
Cr	<5	1197	<5	<5	<5	<5	<5	<5	624	226	81	536	213	271	106
Ni	26	470	4	4	3	1	10	2	206	65	18	183	49	73	30
Cu	22	31	37	33	33	29	27	26	45	65	34	36	39	30	38
Zn	17	63	46	37	30	35	<1	45	110	110	18	89	42	37	22
Ga	—	—	19	16	14	19	—	18	13	17	9	26	11	16	7
Sn	—	—	2	3	4	2	—	3	4	0	4	5	6	4	4

Analyses are by XRF or AAS by the Government Chemical Laboratories, Perth

TABLE 3. QUARTZO-FELDSPATHIC GNEISSES, MOUNT NARRYER REGION

Rock type	*Symbol*	*Description*	*Remarks*
DUGEL GNEISS	*Dgn*	Gneiss discontinuously banded, containing quartz, plagioclase (oligoclase to andesine), microcline, biotite, hornblende, minor cummingtonite; accessory magnetite, zircon, apatite, sphene, allanite; secondary amphibole, chlorite, sericite, saussurite. Syenogranite, monzogranite or granodiorite composition; strong flaser fabric reflected in quartz; early high-grade gneiss recrystallized to lower amphibolite facies.	Dugel gneiss intrudes Meeberrie gneiss and Mindle metasedimentary rocks; gneiss contains, in places, numerous xenoliths of the Manfred Complex; some partial melting associated with high-grade metamorphism; gneiss has distinctive pegmatite phase with dark bluish quartz. Sm-Nd model age of about 3500 Ma[4,5] Zircon age of about 3400 Ma.
	Dgnf	Gneiss banded, leucocratic, containing quartz, microcline, oligoclase, biotite, muscovite, garnet; accessory apatite, zircon, sphene; secondary chlorite; sericite; strong flaser fabric; syenogranite to monzogranite composition.	Interlayered with Meeberrie gneiss west of Mount Dugel; contains thin bands and pods of quartzite and pelitic gneiss; shows granulite-facies metamorphism. Restricted to area immediately west of Mount Murchison metasedimentary rocks, passes gradationally with increasing deformation to *Mgn* variety.
MEEBERRIE GNEISS	*Mgng*	Gneiss, discontinuous, nebulitic, banded, containing quartz, plagioclase, microcline, biotite; accessory zircon, apatite, allanite; secondary sericite, muscovite, chlorite; monzogranite to granodiorite composition; granulite facies retrograded to amphibolite facies.	
	Mgnm	Gneiss, same as *Mgng* but with numerous high-grade metasedimentary xenoliths.	A mesocratic gneiss with a higher biotite content.
	Mgn	Gneiss, well-banded, containing quartz, microcline, oligoclase, biotite; accessory zircon, apatite, sphene, allanite; secondary sericite, chlorite, carbonate; strongly recrystallized flaser fabric; monzogranite to granodiorite composition; granulite facies retrograded to lower amphibolite facies.	Widespread through Mount Narryer region. Sm-Nd model ages and zircon ages of about 3650 Ma[1,4,5] Rb-Sr whole rock age 3348 $\pm$ 43 Ma I.R. 0.7037 $\pm$ 0.0005[6]
	Mgnl	Gneiss, same as *Mgn* but with unrecrystallized flaser fabric.	Restricted to area west of Mount Dugel.

TABLE 4. MOUNT NARRYER METASEDIMENTARY ROCKS, SOUTHERN SECTOR.

Unit	*Symbol*	*Description*	*Metamorphic mineral assemblage*	*Sedimentary precursor*	*Remarks*
UNIT E (Uppermost unit) >300m thick	*Eq*	Quartzite, white, pale-brown, buff and pink, fine to medium grained; granoblastic, gneissic and mylonitic fabric; recrystallized	Quartz (95%), sillimanite (fibrolite), garnet, biotite; secondary muscovite, sericite	Quartz arenite with less than 10% matrix	Occupies core of Narryer syncline; top of unit not seen
UNIT D (Max. 250m thick)	*Dr*	Gneiss, blotchy white, grey-green to purplish-green; weathers red-brown with grey spots or ovoids up to 140 mm x 40 mm diameter; "faserkiesal" textured; scattered pebbles and large (up to 300 mm) cobbles of vein quartz and quartzite; some small lenses of polymict metaconglomerate towards base of unit	Quartz (85%) sillimanite (fibrolite), biotite, garnet, microcline, muscovite, plagioclase,cordierite abundant in basal part; secondary sericite, chlorite; accessory zircon, rutile, monazite, opaques	Quartz wacke and feldspathic wacke, some quartz arenite with clay matrix and very scattered pebbles and cobbles	A large lenticular body. The metamorphic "faserkiesal" texture consists of quartz-fibrolite intergrowths
UNIT C (Max. 500m thick)	*Cq*	Gneiss (quartz-rich) and quartzite, buff, brown to reddish-brown; cream with speckled brown, weathered surface; medium- to coarse-grained	Quartz (85-90%), garnet, sillimanite, cordierite, biotite; secondary sericite, chlorite; accessory magnetite, zircon, rutile, apatite	Quartz wacke to quartz arenite with clay matrix	Interbedded with polymict meta-conglomerate; trough cross-beds, picked out by biotite and garnet, are characteristic of the upper parts of the quartzite. Thick quartzite units contain minor unmapped metaconglomerate units contain unmapped quartzite bands
	Cc	Metaconglomerate, polymict, dark-grey, purple to red-maroon; clasts range from pebble to boulder size (<600 mm), matrix supported; clasts are banded quartz-magnetite rock, banded chert, quartzite, vein quartz, garnet rock, biotite-garnet schist; clasts subangular to subrounded	Matrix minerals are quartz, garnet, magnetite, grunerite, cordierite, sillimanite, biotite, gedrite, eulite; secondary sericite, chlorite, chloritoid; accessory zircon, apatite, monazite	Poorly sorted matrix-supported conglomerate; many debris-flow type Some minor clast-supported, poly-modal with poorly-sorted matrix type	Metaconglomerate occurs as lenses and stringers; some show gradation to overlying quartzite; thick metaconglomerate units contain unmapped quartzite bands
	Cb	Granofels and gneiss, dark grey and green-black fine grained; distinctive lilac-coloured garnets. Minor para-amphibolite grey-green medium to fine grained	Quartz (75-80%) cordierite, garnet, biotite, sillimanite; accessory zircon, grunerite, plagioclase (calcic), quartz, biotite, magnetite; accessory zircon, apatite	Silty quartz wacke, shale; para-amphibolite probably iron-rich silty quartz wacke, shale	Units occur as small, thin lenses and bands, interbedded with quartzite and metaconglomerate
UNIT B (Various thicknesses up to 700m)	*Bq*	Quartzite, buff, brown, grey and pinkish, fine to coarse grained	Quartz (95%), sillimanite (fibrolite), garnet; minor plagioclase, cordierite; secondary sericite, chlorite; accessory zircon, rutile	Quartz arenite	Contains minor trough cross-beds; is major component of unit B
	Bf	Quartzite, feldspathic, white, grey, grey-green, fine and medium grained	Quartz (60-85%), sillimanite (fibrolite), microcline, plagioclase, muscovite (fuchsite); secondary sericite, zoisite; accessory zircon	Feldspathic arenite to feldspathic wacke	Occurs as lenses in *Bq;* shows graded bedding; detrital zircon from this rock near base of unit B yielded U-Pb age up to 4200–4100 Ma[3]

TABLE 4. MOUNT NARRYER METASEDIMENTARY ROCKS, SOUTHERN SECTOR.

Unit	*Symbol*	*Description*	*Metamorphic mineral assemblage*	*Sedimentary precursor*	*Remarks*
UNIT B (Various thicknesses up to 700m)	*Bo*	Quartz-pebble metaconglomerate, oligomictic, grey, blue-grey, cream, mainly clast supported with some matrix supported; clasts subrounded to rounded	Matrix: quartz, biotite, garnet, sillimanite; secondary sericite, accessory zircon	Quartz-pebble conglomerate mainly clast supported with sandy clay matrix	Occurs as lenses and stringers in *Bq*
	Br	Gneiss (quartz-rich), blotchy, grey-white to grey-green, "faserkiesal" textures; poorly exposed	Quartz (85-90%) sillimanite (fibrolite), plagioclase, microcline; secondary sericite, saussurite; accessory zircon	Quartz wacke and feldspathic wacke	A single large lens midway through unit B; the "faserkiesal" texture is made up of quartz-fibrolite clots
	Bb	Gneiss and granofels, dark-grey to green-black, fine grained	Quartz (45-75%), cordierite, biotite, microcline, garnet, sillimanite, plagioclase (calcic), muscovite; secondary zoisite, pumpellyite; accessory zircon, monazite	Silty quartz wacke, silty shale	A single large lens stratigraphically below *Br*
UNIT A (lowermost unit) >500m thick	*Aq*	Quartzite, buff brown, cream, with speckled brown weathered surface; medium to coarse grained	Quartz (95%), sillimanite (fibrolite), garnet, biotite; secondary chlorite, sericite; accessory zircon, tourmaline	Quartz arenite	Contains trough and planar cross-beds
	Af	Gneiss, feldspathic quartz and quartz-rich white, pale-grey, buff, pale-green, green-grey, fine to medium grained	Quartz (50-85%), oligoclase-andesine, microcline, biotite, muscovite (fuchsite), minor amphibole, secondary epidote, sericite; accessory zircon, opaques	Feldspathic wacke, minor feldspathic arenite	Contains graded bedding; mostly occurs near the base of unit A
	Ap	Clinopyroxene quartzite, grey, greenish-grey, greenish-brown, medium grained; distinctive pitted or cellular-weathered surface	Quartz (85-90%) clinopyroxene (diopside-hedenbergite), amphibole, plagioclase (calcic), microcline, biotite; secondary clinozoisite, sericite; accessory opaques, sphene, apatite, zircon, tourmaline, pyrite	Calcareous quartz arenite and wacke	Interbedded with quartz-pebble metaconglomerate and calc-silicate gneiss near base of unit A. Plagioclase is bytownite-anorthite
	Aa	Calc-silicate gneiss, dark grey-green, black and brown weathering, banded; closely associated with blue-green faintly banded para-amphibolite	Clinopyroxene (max 80%), hornblende, quartz, bytownite, biotite; secondary epidote; accessory zircon, sphene, apatite. Amphibole dominates in para-amphibolite	Siliceous dolomite, very calcareous quartz wacke	Occurs in small pods and lenses near base of unit A
	Ao	Quartz-pebble metaconglomerate, oligomictic, grey-blue, cream, purplish; oligomictic clasts 5 mm to 100 mm diameter, of vein quartz, quartzite, minor garnet-quartz rock; clasts subrounded to rounded; clast and matrix supported	Matrix: quartz, biotite, garnet, microcline, sillimanite, grunerite; secondary sericite, epidote; accessory zircon, rutile, opaques, pyrite	Clast and matrix-supported quartz-pebble conglomerate with clay-sand matrix	Occurs interbedded with *Ap*, *Af*, and *Aq*
	Ab	Cordierite gneiss dark grey to grey-green medium-grained	Cordierite (50%), quartz, biotite, garnet, plagioclase, microcline, sillimanite; secondary chlorite; accessory opaques	Silty quartz wacke, shale	Occurs near base of unit A; interbedded with *Ap* and *Af*

TABLE 5: MOUNT NARRYER METASEDIMENTARY ROCKS, NORTHERN SECTOR

Rock type	*Symbol*	*Description*	*Metamorphic mineral assemblage*	*Sedimentary precursor*	*Remarks*
Sillimanite-muscovite-garnet quartzite	*Nq*	Buff, cream, pale-brown, fine, medium and coarse grained	Quartz, sillimanite, (fibrolite), muscovite, garnet; secondary sericite; accessory zircon	Quartz arenite	Intensity of deformation increases northwards; pervasive flaser fabric at Mount Dugel
Feldspathic quartzite	*Nf*	White, grey, grey-green, fine, medium and coarse grained	Quartz, sillimanite (fibrolite), muscovite (fuchsite) plagioclase, microcline; secondary sericite, saussurite; accessory zircon	Feldspathic arenite	Interbedded with *Nq*
Quartz-muscovite-sillimanite schist	*Ns*	White, grey,pale-brown, fine to medium grained, highly sheared in places	Quartz, muscovite, sillimanite, plagioclase, microcline; secondary sericite, saussurite	Quartz and feldspathic arenite	Derived from *Nq* and *Nf* by intense deformation in shear zones,within quartzite or along contacts with adjacent gneisses
Clinopyroxene quartzite	*Np*	Grey, green-grey, brown cellular weathered surface, fine to medium grained	Quartz, clinopyroxene, amphibole, plagioclase; secondary amphibole, saussurite; accessory apatite, opaques, sphene	Calcareous arenite	Scattered lenses
Banded calc-silicate gneiss	*Na*	Grey, grey-green, reddish-brown weathered surface, fine to medium grained, banded	Clinopyroxene, tremolite, plagioclase, quartz, microcline; secondary epidote; accessory sphene,	Siliceous dolomite, very calcareous quartz wacke, marl	Occurs in small pods
Oligomict quartz-pebble metaconglomerate	*No*	Blue, blue-grey, white to reddish-blue weathered surface. Clasts 5 mm to 100 mm diameter, subrounded to rounded	Matrix; quartz, sillimanite (fibrolite), muscovite; secondary sericite	Clasts and minor matrix-supported quartz-pebble conglomerate	Quartz pebbles strongly deformed in shear zones; forms scattered lenses
"Faserkiesal" quartzite	*Nr*	Spotted or blotchy grey, brown, reddish-grey, medium grained, with pronounced "faserkiesal" texture	Quartz, fibrolite (sillimanite), muscovite; secondary sericite	Quartz arenite with clay matrix	May occupy keel of a syncline
Andalusite-corundum rock	*Nl*	Mid- to dark-grey, lumpy weathered surface, fine grained, schistose	Andalusite, corundum, chlorite, muscovite; minor quartz	Iron-alumina-rich clay; bauxitic laterite	A possible regolith

TABLE 6. MINDLE METASEDIMENTARY ROCKS

Rock type	*Symbol*	*Description*	*Metamorphic mineral assemblage*	*Sedimentary precursor*	*Remarks*
Clinopyroxene quartzite	*Mp*	Grey-green, green-brown, pitted and cellular weathered surface, fine to medium grained	Quartz (80-95%), clinopyroxene, minor albite-andesine, microcline; accessory sphene, apatite, opaques, pyrite; secondary amphibole, saussurite, epidote, zoisite (thulite)	Calcareous arenite	The quartzite grades to calc-silicate gneiss with increasing clino-pyroxene content, and to iron-formation with increasing magnetite content
Banded calc-silicate gneiss	*Ma*	Dark greenish-grey, red-brown weathered surface, banded; bands tend to be monomineralic	Clinopyroxene (90%), quartz, minor plagioclase; accessory sphene, apatite, opaques; secondary carbonate, amphibole, epidote, and pink zoisite (thulite)	Siliceous iron-magnesium-rich carbonate rocks; marl	Occurs as pods closely associated with *Mp*
Banded and granular iron formation	*Mi*	Well banded or granular, grey-greenish and purplish	Quartz, magnetite, clinopyroxene, orthopyroxene, grunerite; accessory apatite; secondary amphibole	Siliceous iron formation	Closely associated with *Mp*
Feldspathic quartzite	*Mf*	Grey, pale-brown, fine and medium grained	Quartz (70-80%) plagioclase (oligo-clase-andesine), minor microcline; accessory amphibole, biotite sphene; secondary stilpnomelane, epidote, saussurite	Feldspathic arenite	Minor component of Mindle metasedimentary rocks
Biotite gneiss	*Mb*	Dark-grey, medium grained	Quartz (40%) oligoclase (50%) biotite; accessory sphene, zircon; secondary saussurite	Feldspathic wacke or siliceous arkose	Minor component of Mindle metasedimentary rocks

TABLE 7. OTHER METASEDIMENTARY ROCKS IN THE MEEBERRIE AND DUGEL GNEISSES

Rock type	*Symbol*	*Description*	*Metamorphic mineral assemblage*	*Sedimentary precursor*	*Remarks*
Sillimanite-muscovite-garnet quartzite	*Wq*	White, buff, light-brown, fine, medium and coarse grained. Strong flaser fabric, some mortar texture.	Quartz (85-95%) sillimanite, muscovite, garnet; accessory zircon, opaques; secondary muscovite, sericite, clinozoisite. Minor andalusite in some specimens.	Quartz arenite	
Clinopyroxene quartzite	*Wp*	Grey-green, green-brown, pitted and cellular weathered surface, fine to medium grained flaser fabric, some mortar texture.	Quartz (up to 95%) clinopyroxene, cummingtonite, plagioclase; accessory apatite, zircon, sphene, opaques, allanite; secondary amphibole, saussurite	Calcareous arenite	
Banded calc-silicate gneiss	*Wa*	Dark greenish-grey, red-brown weathered surface, banded	Clinopyroxene (up to 80%), quartz, plagioclase; accessory sphene, apatite; secondary amphibole, saussurite, clinozoisite	Siliceous iron-magnesium-rich carbonate rocks; marl	
Banded and granular iron-formation	*Wi*	Well banded or granular, grey-greenish and purplish-brown	Quartz, magnetite, grunerite, cummingtonite, tremolite-actinolite, clinopyroxene, orthopyroxene (eulite, hypersthene), minor feldspar, garnet; accessory apatite; secondary amphibolite, sericite, stilpnomelane	Iron-formation; siliceous iron-formation	Two types of iron-formation are present: a) Quartz, magnetite, grunerite; high iron content. b) Quartz, amphibole, clinopyroxene, orthopyroxene, magnetite; low iron content
Polymict meta-conglomerate	*Wc*	Dark grey, purple-grey to red-maroon, polymict; clasts range from pebble to large cobble size; matrix supported; clasts are quartzite, vein quartz, banded iron-formation and banded chert; clasts are subangular to subrounded	Matrix; quartz (70%), garnet, orthopyroxene (hypersthene), grunerite; accessory magnetite, zircon; secondary amphibole	Polymict conglomerate, matrix supported	Resembles polymict metaconglomerate at Mount Narryer
Orthopyroxene-bearing paragneiss	*Wg*	Grey, dark-grey, blue-grey medium to coarse grained	Garnet, quartz, cordierite, biotite, orthopyroxene, plagioclase, sillimanite, clinopyroxene; accessory opaques, zircon, apatite; secondary muscovite, saussurite	Quartz wacke	
Quartz-biotite-muscovite gneiss and schist	*Wb*	Grey-brown,reddish-brown fine to medium grained	Quartz (50%) biotite, muscovite, plagioclase (oligoclase); secondary chlorite	Silty quartz wacke; quartz wacke	Layers in quartzo-feldspathic gneiss *(Mgn)*
Cordierite-gedrite gneiss	*Wm*	Dark grey, greenish-grey, blue-grey, medium grained, faintly banded	Cordierite, gedrite, quartz, minor biotite; accessory opaques	Shale and siltstone, rich in magnesium, iron and aluminium	Layers in quartzo-feldspathic gneiss *(Mgnm)*

TABLE 8. MOUNT MURCHISON METASEDIMENTARY ROCKS

Rock type	*Symbol*	*Description*	*Metamorphic mineral assemblage*	*Sedimentary precursor*	*Remarks*
Quartzite	*Rq*	White, grey, buff, pale-green, greenish-grey fine, medium and coarse-grained Strongly recrystallized tectonic fabric	Quartz (90-99%) sillimanite (fibrolite), cordierite, minor muscovite (fuchsite), biotite, plagioclase, garnet; accessory zircon, rutile; secondary muscovite	Quartz arenite	Part of main quartzite unit of Mount Murchison includes some small lenses of oligomict quartz-pebble meta-conglomerate (not shown on map)
Clinopyroxene quartzite	*Rp*	Grey-green, medium grained	Quartz (85%), clinopyroxene, hornblende; secondary clinozoisite, amphibole	Calcareous arenite	Part of main quartzite unit of Mount Murchison

TABLE 9. ACID INTRUSIVE ROCKS, MOUNT NARRYER REGION

Rock type	*Symbol*	*Description*	*Remarks*
Biotite monzogranite and syenogranite	*gb*	Medium to coarse grained; even-grained seriate and porphyritic phases; some alteration of biotite to chlorite, oligoclase to sericite; igneous zoning preserved in oligoclase; most quartz is recrystallized; secondary muscovite and epidote; biotite schlieren; few xenoliths.	This unit is the largest and youngest acid intrusion in the Mount Narryer region; restricted to the vicinity of Mount Murchison and equated with the "Archaean Yilgarn cratonic granitoids" to the southeast; *gb* is intruded by a single large dyke of mesocratic biotite monzogranite (*gt*); *gb* intrudes both the Mount Murchison metasedimentary rocks and the Meeberrie gneiss
Foliated biotite monzogranite and syenogranite	*gbf*	Heterogeneously foliated and lineated; medium to coarse grained; seriate phases; texture is unequigranular interlobate; biotite schlieren abundant, some xenoliths; oligoclase altering to sericite, biotite altering to chlorite, quartz recrystallized; secondary muscovite and epidote.	*gbf* is intruded by *gb* but, genetically, is closely related; equated to similar rocks of the "Yilgarn cratonic granitoids;" intrudes both the Mount Murchison metasedimentary rocks and the Meeberrie gneiss
Recrystallized biotite monzogranite	*ge*	Fine to medium grained; even grained, completely recrystallized, cut by narrow shear zones; quartz, microcline, oligoclase, biotite; accessory apatite, zircon, magnetite assemblage; recrystallized under greenschist-facies conditions	Occurs as small plutons and dykes in Meeberrie gneiss west of Mount Narryer and Mount Dugel. A single body also intrudes the Mount Narryer matasedimentary rocks (southern sector). Post-dates regional deformation episodes. Sm-Nd model age 3100 Ma[4], zircon age 2600 Ma[1], Rb-Sr isochron 2600 Ma[4]
Gneissic biotite monzogranite	*gg*	Medium grained; mixed, even grained, seriate and porphyritic phases; gneissic fabric, discrete shear and mylonite zones; some brecciation; quartz, microcline, oligoclase, biotite, accessory zircon, pyrite, apatite assemblage; secondary sericite muscovite, carbonate and epidote; some igneous textures preserved: dynamic upper greenschist-facies metamorphism.	Intrudes Mount Narryer metasedimentary rocks and Meeberrie gneiss (contains large xenoliths of this gneiss); probably emplaced during the waning stages of D_3 deformation episode
Granodiorite and monzogranite gneiss; augen gneiss	*na*	Intensely deformed mylonitic and flaser fabric, medium-grained groundmass; microcline augen; ribbon quartz, microcline, oligoclase, biotite, accessory apatite, magnetite, zircon, allanite assemblage. Secondary sericite, chlorite, minor carbonate. Some partial melting; recrystallization of quartz ribbons in amphibolite facies followed by retrograde metamorphism of low amphibolite to greenschist facies	Intrudes Meeberrie gneiss; probably emplaced during D_2 deformation episode; deformed and retrograded during D_3 deformation episode. Zircon age 3330 Ma[1]

TABLE 10. SEQUENCE OF DEFORMATION AND METAMORPHISM

Igneous age (Ma)	*Rock unit*	*Deformation episode*	*Syntectonic metamorphic facies*
		Deformation	Greenschist
2600[1,4]	Monzogranite (*ge*) intruding Meeberrie gneiss and Mount Narryer metasedimentary rocks		
		D_4 open flexure folds	Amphibolite
		D_3 tight and isoclinal folds with steep north-south axial surfaces. Axial-plane cleavage defined by biotite	Amphibolite
3300[1]	Monzogranite (*na*)	D_2 tight and isoclinal folds with steep east-west axial surfaces. Axial-planar quartzo-feldspathic flaser fabric	Granulite
	Narryer metasedimentary rocks		
		D_1 formation of gneissose banding	
3500 -3400[1,4,5]	Dugel syenogranite (gneiss)		
		Mindle metasedimentary rocks	
		Deformation	
3650[1]	Meeberrie monzogranite (gneiss)		
		Deformation	
3730[1]	Manfred Complex		

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52795/2/87-L/4240 WILLIAM BENBOW, Acting Government Printer, Western Australia


MOUNT MURCHISON
MOUNT DUGEL
MOUNT NARRYER
SYMBOLS
geological boundary mapped
geological boundary inferred
measured dip of bedding in Mount Narryer metasedimentary rocks
vertical bedding in Mount Narryer metasedimentary rocks
overturned bedding
primary way-up indicated by cross-bedding
primary way-up indicated by graded bedding
measured dip of gneissic banding
vertical dip of gneissic banding
measured dip of gneissic foliation and flaser fabric
vertical gneissic foliation
fracture cleavage associated with Elizabeth Springs mylonite zone
mylonite zone
fault exposed, tick indicates downthrow
fault concealed
axial trace of D2 antiform
axial trace of D2 synform
axial trace of D2 synform inferred
axial trace of D3 antiform
axial trace of D3 synform
axial trace of D3 synform inferred
direction and plunge of D2 minor fold
direction and plunge of D3 minor fold
plunge of mineral lineation
locality of superimposed minor folds
Fe hematite
Be beryl
track
fence
well or bore with windmill
creeks (ephemeral)
airstrip
isotopic age sample locality, number indicates reference in footnotes for Tables
AUSTRALIA
Mount Narryer Region
LOCATION MAP
LOCALITY MAP
MOUNT NARRYER FAULT WEST
MOUNT NARRYER FAULT EAST
MURCHISON RIVER
Meeberrie Homestead 52 km
Meeberrie Homestead 80 km
REFERENCE
CAINOZOIC
Q Alluvium, colluvium and eolian deposits
Tl Laterite, ferricrete
Tb Silcrete, silicified colluvium and scree
? 2600 – 1800 Ma
q Quartz veins, various ages
dg Dolerite, quartz gabbro, diorite dykes; very low-grade static metamorphism
a,p,g, Aplite, pegmatite, granite dykes of various ages
do Olivine gabbro, dolerite; low-grade static metamorphism
ARCHAEAN
~2600 Ma
ge Monzogranite and quartz monzonite; medium to fine-grained; recrystallized and locally deformed
gb Monzogranite and syenogranite; medium-grained; seriate and porphyritic; recrystallized
gbf Foliated gb
gt Monzogranite dyke; mesocratic
gg Monzogranite; medium to coarse-grained; porphyritic to seriate; gneissic
dm Amphibolite, fine-grained; in Elizabeth Springs mylonite zone
da Amphibolite; fine to medium-grained; deformed basic dykes
dag Metagabbro sheets with amphibolite margins; deformed
du Serpentine-chlorite-tremolite pods; deformed
~3300 Ma
na Augen gneiss and orthogneiss; strongly deformed granodiorite and monzogranite
MOUNT NARRYER METASEDIMENTARY ROCKS (NORTHERN SECTOR)
Nq Quartzite with sillimanite, muscovite and garnet
Nf Quartzite with sillimanite, muscovite (fuchsite), plagioclase and microcline
Ns Quartz-muscovite-sillimanite-feldspar schist
Np Quartzite with clinopyroxene, amphibole and plagioclase
Na Banded calc-silicate gneiss; with clinopyroxene, amphibole, quartz and plagioclase
No Metaconglomerate; oligomictic with quartz pebbles
Nr Quartzite with fibrolite and muscovite; "faserkiesal" texture
Nl Andalusite-corundum-chlorite-muscovite rock
MOUNT NARRYER METASEDIMENTARY ROCKS (SOUTHERN SECTOR)
Eq Quartzite with sillimanite, garnet and biotite
UNIT E
Dr Gneiss with quartz, sillimanite, biotite, garnet, microcline, muscovite, plagioclase and cordierite; "faserkiesal" texture
UNIT D
UNIT C
Cq Quartzite with garnet, sillimanite, cordierite and biotite
Cc Metaconglomerate; polymictic with clasts of banded ferruginous chert, banded quartz-magnetite-grunerite -orthopyroxene rock, vein quartz, quartzite and garnet-biotite schist
Cb Gneiss with quartz, cordierite, garnet, biotite and sillimanite; and para-amphibolite with grunerite, plagioclase, quartz and biotite
UNIT B
Bq Quartzite with sillimanite and garnet
Bf Quartzite with sillimanite, microcline, plagioclase and muscovite (fuchsite)
Bo Metaconglomerate; oligomictic with quartz pebbles
Br Gneiss with quartz, sillimanite, plagioclase, microcline; "faserkiesal" texture
Bb Gneiss with quartz, cordierite, biotite, microcline, garnet, sillimanite, plagioclase and muscovite
UNIT A
Aq Quartzite with sillimanite, garnet and biotite
Af Quartzite with plagioclase, microcline, biotite and muscovite (fuchsite)
Ap Quartzite with clinopyroxene, amphibole, plagioclase, microcline and biotite
Aa Banded calc-silicate gneiss with clinopyroxene, hornblende, quartz, plagioclase and biotite
Ao Metaconglomerate, oligomictic with quartz pebbles
Ab Gneiss with cordierite, quartz, biotite, garnet, plagioclase, microcline and sillimanite
MOUNT MURCHISON METASEDIMENTARY ROCKS
Rq Quartzite with sillimanite, muscovite (fuchsite), cordierite, biotite and garnet
Rp Quartzite with clinopyroxene and hornblende
uh Banded amphibolite, medium to coarse-grained, strongly deformed dolerite and gabbro
ux Metapyroxenite; two-pyroxene (olivine) granulite
ua Meta-anorthosite
~3400 Ma
DUGEL GNEISS
Dgn Banded gneiss with quartz, plagioclase, microcline, biotite and amphibole; deformed and recrystallized syenogranite and granodiorite
Dgnf Banded leucocratic gneiss with quartz, microcline, plagioclase, biotite, muscovite and garnet
MINDLE METASEDIMENTARY ROCKS
Mp Quartzite with clinopyroxene and plagioclase
Ma Banded calc-silicate gneiss with clinopyroxene, quartz and plagioclase
Mi Banded iron-formation with quartz, magnetite, clinopyroxene, orthopyroxene and grunerite
Mf Quartzite with plagioclase and minor microcline
Mb Gneiss with quartz, plagioclase and biotite
OTHER METASEDIMENTARY ROCKS IN MEEBERRIE GNEISS
Wq Quartzite with sillimanite, muscovite and garnet
Wp Quartzite with clinopyroxene, cummingtonite and plagioclase
Wa Banded calc-silicate gneiss with clinopyroxene, quartz and plagioclase
Wi Banded iron-formation with quartz, magnetite and grunerite; banded iron-formation with quartz, amphibole, clinopyroxene and orthopyroxene; some massive granular iron-formation
Wc Metaconglomerate, polymictic with clasts of quartzite, vein quartz and banded quartz-magnetite-orthopyroxene rock
Wg Gneiss with garnet, quartz, cordierite, biotite, orthopyroxene, plagioclase, sillimanite and clinopyroxene
Wb Paragneiss and schist with quartz, biotite, muscovite and plagioclase
Wm Gneiss with cordierite and gedrite
~3650 Ma
MEEBERRIE GNEISS
Mgn Banded gneiss with quartz, microcline, oligoclase and biotite; deformed and recrystallized monzogranite
Mgnl Banded flaser-gneiss with quartz, microcline, oligoclase and biotite
Mgng Gneiss with quartz, microcline, plagioclase and biotite; folded nebulitic banding, some partial melting
Mgnm Mgng with numerous metasedimentary xenoliths
~3730 Ma
MANFRED COMPLEX
MCg Metagabbro
MCh Amphibolite
MCp Metaperidotite, metapyroxenite
MCax Inclusions of meta-anorthosite, metaleucogabbro in gneiss
MChx Inclusions of amphibolite in gneiss
MCpx Inclusions of metaperidotite in gneiss
SCALE 1 : 25 000
0 1 2 3 KM
TRANSVERSE MERCATOR PROJECTION
Geology by : I.R. Williams 1981–2, J.S. Myers 1983.
Cartography by the Surveys and Mapping Division, Department of Mines, Western Australia.
Published by and available from the Geological Survey Division, Department of Mines, 66 Adelaide Terrace, Perth, Western Australia.
Printed by Mercury Walch, Hobart, Australia.
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