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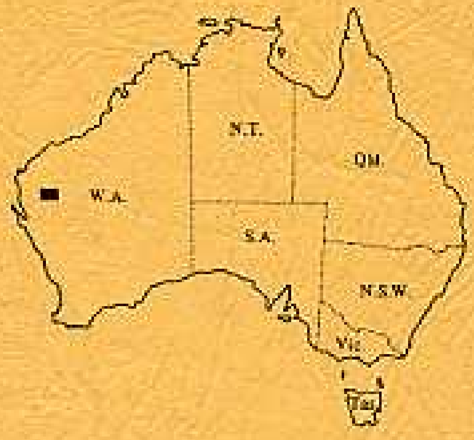
MOUNT PHILLIPS

WESTERN AUSTRALIA



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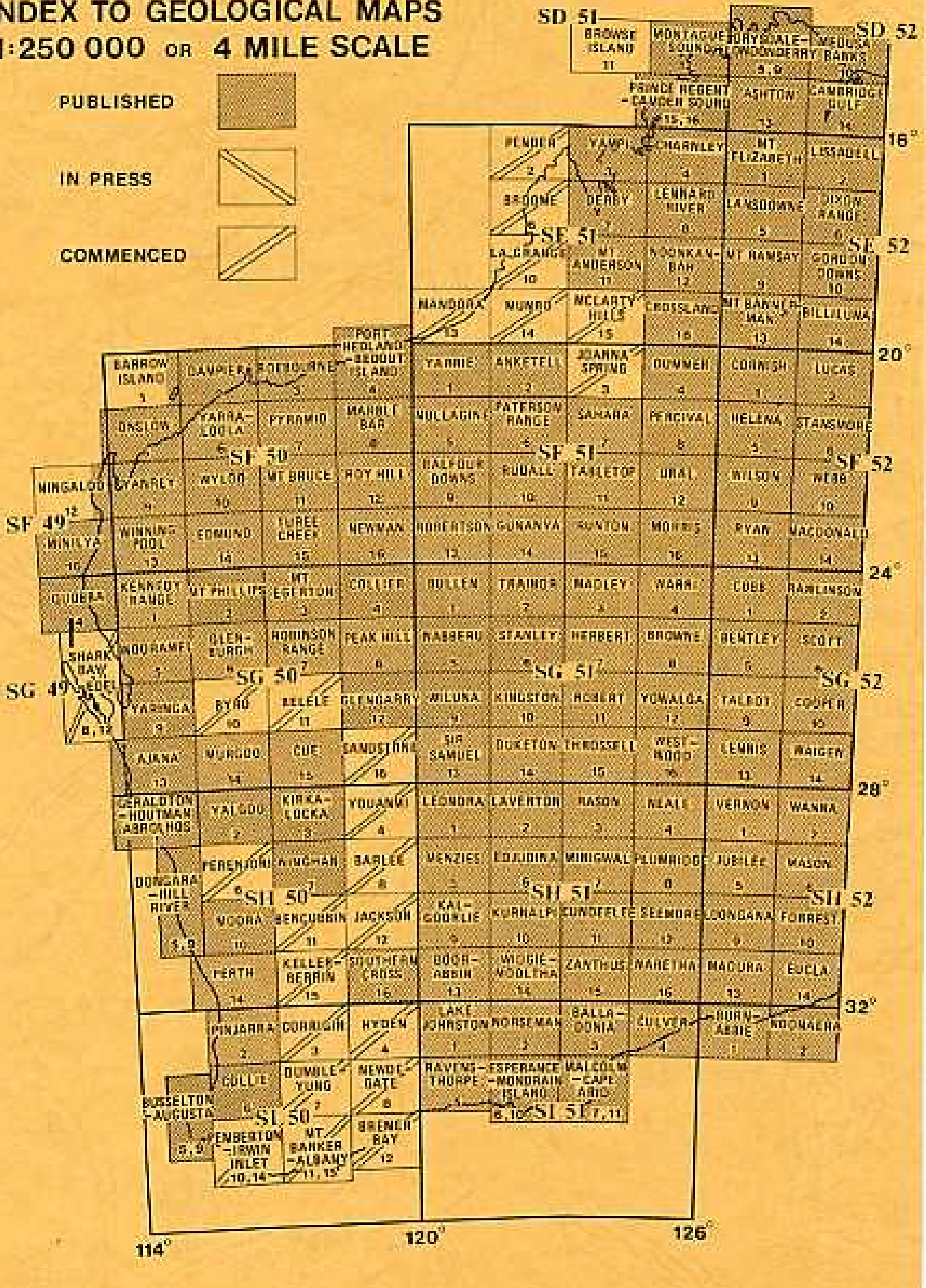

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

MOUNT PHILLIPS

WESTERN AUSTRALIA

SHEET SG50-2 INTERNATIONAL INDEX

COMPILED BY S. J. WILLIAMS, I. R. WILLIAMS, R. J. CHIN, P. C. MUHLING, AND R. M. HOCKING.

PERTH, WESTERN AUSTRALIA 1983

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Explanatory Notes on the Mount Phillips Geological Sheet

Compiled by S. J. Williams, I. R. Williams, R. J. Chin, P. C. Muhling, and R. M. Hocking

INTRODUCTION

The MOUNT PHILLIPS* 1:25 000 sheet, SG 50-2 of the International Series, is bounded by latitudes 24°S and 25°S and longitudes 115°30E and 117°E. The small resident population is mainly engaged in the pastoral (cattle and sheep) industry. Graded roads connect the pastoral properties with: Gascoyne Junction, 110 km to the southwest; Canarvon, 250 km to the west; Meekatharra, 330 km to the southeast; and Mullewa, 450 km to the south. The region is well serviced by station tracks, althouh in the hilly, rocky terrain, off-track traversing is difficult even for four-wheel-drive vehicles; the Lockier Range and Clever Mary Hills are largely inaccessible to vehicles.

The climate is semi-arid: summers are hot and winters mild. Annual rainfall, the bulk of which comes from summer thunderstorms and tropical cyclones, is generally less than 250 mm.

PREVIOUS INVESTIGATIONS

The prominent topographic features were named by the explorer F. T. Gregory in 1858, when he traversed down the Gascoyne River to its mouth and returned via the Lyons River to Mount Augustus before turning south to the Murchison River. Maitland (1909) described a muscovite occurrence near the Lockier Range and the gold deposits at Bangemall. Talbot (1926) also visited Bangemall and described the geology between Mount James homestead and Mount Augustus. Mineral shortages during World War II resulted in investigations for muscovite, beryl, and bismuth in the Yinnetharra district (Ellis, 1940, 1941b; Matheson, 1944).

Johnson (1950) carried out reconnaissance mapping in the Eudamullah and the Mount Gascoyne—Mount James districts. The Permian sedimentary rocks were investigated between 1953 and 1955 by the Bureau of Mineral Resources (BMR) (Condon, 1967) WAPET (West Australian Petroleum Pty Ltd). A preliminary total-magnetic-intensity map of the western half of the sheet was produced by the BMR in 1963. Compston and Arriens (1968) sampled granitoid rocks from the Minnie Creek homestead area for geochronology. A Bouguer anomaly map of the area was published by the Bureau in 1973.

The first overall account of the geology—based on airphoto interpretation—the results of which were incorporated in Daniels (1975), was undertaken by Daniels in 1969. Geochronology results stemming from this programme were published by de Laeter (1976). The present survey was commenced in 1973 by P C. Muhling and A. T. Brakel on the Bangemall Basin rocks. This was followed in 1976 by systematic regional mapping of the Phanerozoic rocks (R. M. Hocking and W. J. E. van de

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*Sheet names are printed in full capitals to avoid possible confusion with place names

Graaff) and of the metamorphic and igneous rocks of the Gascoyne Province (S. J. Williams, I. R. Williams and R. J. Chin). These results were published in Williams and others (1978). The present text is a revised version following detailed, reassessment of the Gascoyne Province by S. J. Williams in 1980.

PHYSIOGRAPHY

The region is best described as a well-dissected plateau with relicts of a Tertiary duricrust on the drainage divides. Prominent topographic highs, such as Mount Augustus (1 106 m), Mount Gascoyne (789 m), Mount Phillips (780 m), and Mount James (602 m), are erosional relicts, which are at a higher elevation than the general level of the old duricrusted surface. Away from the flood plains and sheet-wash areas adjacent to major rivers and creeks, the topography is hilly and rugged.

The topography reflects the weathering characteristics of the underlying rocks. Proterozoic sedimentary rocks (Bangemall and Mount James Groups) form the larger hills, such as Mount Augustus and Mount Gascoyne, and the prominent strike ridges of the Cobra homestead region. Granitoid rocks generally weather to a gently rolling surface, but there are scattered inselbergs. Metamorphic rocks weather to low hills, and produce strongly dissected country.

The Carnarvon Basin section has a subdued topography. Low, rolling plains and widely spaced drainages characterize the Permian Lyons Formation. Strike ridges and mesas are formed by the Callytharra Formation, the Moogooloo Sandstone, and the Lyons Formation.

MOUNT PHILLIPS is entirely drained by the Gascoyne River system, which includes the Lyons River; both of these are mature braided streams; but some of their smaller tributaries are actively eroding headward. The Thomas River is unusual in that the part upstream of Pink Hills is sluggish and mature, but the lower section, before it joins the Gascoyne River, has become rejuvenated. Dissected calcrete occurs along the Gascoyne, whereas both trunk valley and dissected calcretes (Butt and others, 1977) occur along the Lyons River and its tributaries.

An unusual feature of both the Gascoyne and Lyons Rivers is the change—at the 116°E longitude—of directon from northwest to south. This elbow shape is possibly due to epeirogenic movement of the margin of the Precambrian shield.

TECTONIC SETTING

GASCOYNE PROVINCE

The Gascoyne Province is that part of an early Proterozoic orogenic belt not covered by major sedimentary basins and which is largely exposed on MOUNT PHILLIPS. It appears to have evolved over the interval 2.0 to 1.6 b.y. Part of the Gascoyne Province consists of well-banded biotite gneiss, which is considered to be Archaean. This gneiss is best exposed on GLENBURGH to the south of MOUNT PHILLIPS. It formed a basement to Proterozoic shelf and trough sediments. Orogenic activity deformed and metamorphosed these sediments, which now form the Morrissey Metamorphic Suite. The Archaean basement was also reworked. Granitoids related to this orogenic event were emplaced at various intervals in the Morrissey Metamorphic Suite.

Late-tectonic ?fluvial sediments of the Mount James Formation were deposited—in localized grabens—unconformably overlying Proterozoic granitoid, Morrissey Metamorphic Suite, and older gneissic terrain. The sediments were deformed and weakly metamorphosed in localized zones.

BANGEMALL BASIN

Part of the Bangemall Basin, a folded sequence of marine and continental sediments (ca. 1.1 b.y. old), occupies the northeast corner of MOUNT PHILLIPS where it unconformably overlies rocks of the Gascoyne Province. This sequence is strongly folded, but virtually unmetamorphosed. Faults delineate the present southern margin of the Bangemall Basin. Outliers of the Bangemall Group also occur in the central and southeastern parts of MOUNT PHILLIPS.

CARNARVON BASIN

Part of the Bidgemia Sub-basin of the Phanerozoic Carnarvon Basin occupies the southwestern corner of MOUNT PHILLIPS. The dominant rocks are lithified Early Permian glacigene sediments, which unconformably overlie Gascoyne Province rocks.

GASCOYNE PROVINCE

REWORKED ARCHAEAN GNEISS

Proterozoic reworking of Archaean gneiss includes recrystallization, partial melting, shearing, folding, and development of foliation. The symbol *Æ* is used to denote rocks resulting from these processes.

Banded medium-grained quartz-feldspar-biotite gneiss (*Ænb*) is mainly of granite or adamellite composition and contains the accessory minerals: muscovite, sphene, opaques, zircon, apatite, and garnet. Banding is defined by continuous, pink quartzo-feldspathic bands about a centimetre thick separated by: (a) finer grained bands containing biotite, or (b) biotite films, or (c) quartz-rich bands. In the area 4 km southwest of Paddy Well, this unit contains porphyroblastic augen of microcline. In other areas, this unit also consists of metre-wide zones of grey, fine-grained, biotite-rich tonalite gneiss or granodiorite gneiss, within a sea of pink granite gneiss. Associated with the banded gneiss and included in the *Ænb* unit are migmatite phases, which contain foliated medium- to coarse-grained biotite granite or adamellite and pegmatoid. These are considered to be a Proterzoic anatectic product. The banded gneiss grades into *Ᵽgbp* as the granitoid component becomes dominant.

MORRISSEY METAMORPHIC SUITE

Definition

The Morrissey Metamorphic Suite is composed of prograde and retrograde pelitic schists, phyllite, quartzite, micaceous quartzite, and thick sequences of fine-grained, quartzo-feldspathic paragneiss. It is a metamorphosed sequence of shale, siltstone, sandstone, greywacke, arkose, and conglomerate; migmatite is extensively developed; and small bodies of amphibolite and calc-silicate gneiss, and marble are derived from basalt and carbonate sediments.

Typical phyllite and prograde pelitic schist occur between Nardoo Well and 3 km south of Ti Tree Well. South of Nardoo Well the schist passes transitionally into anatectic migmatite. Typical quartzite and pelitic schist occur in the area south of Ring Well. A typical area for paragneiss is around Middle Spring, and, between Middle Spring and Midway Outcamp, paragneiss grades into anatectic migmatite. A type area for meta-arkose is between Lucky Bore and Daly Well; calc-silicate gneiss is also common in this area.

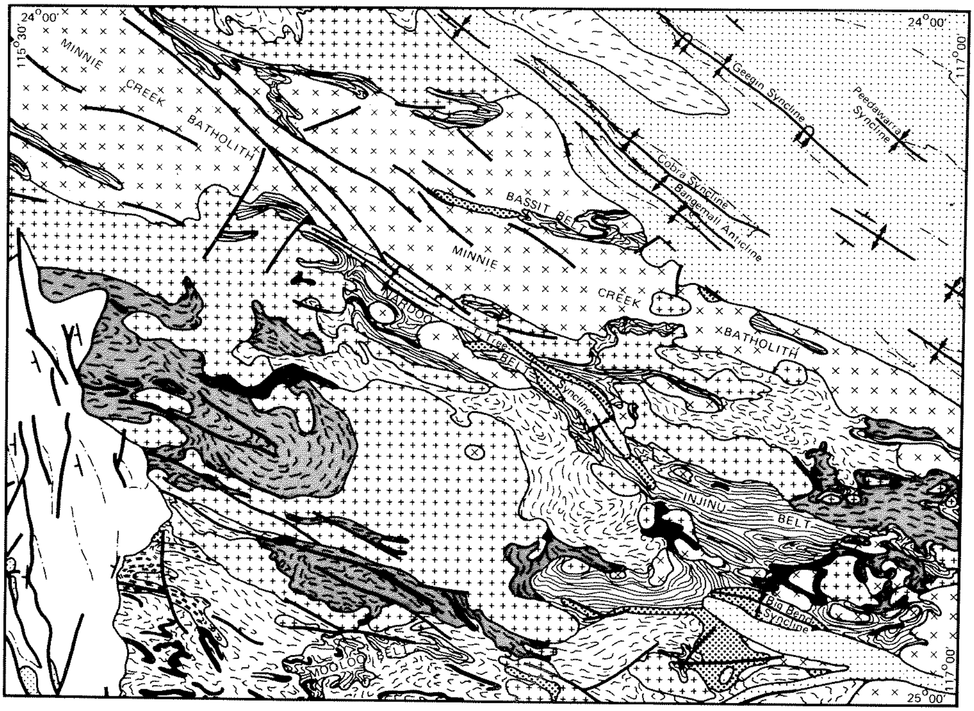

FIGURE 1

STRUCTURAL INTERPRETATION

MOUNT PHILLIPS SHEET SG 50–2

0 10 20 30 km

REFERENCE

PERMIAN / LATE CARBONIFEROUS
- Wooramel Group
- Lyons and Callytharra Formations

PROTEROZOIC
- Bangemall Group
- Mount James Formation
- Late-stage granitoid
- Early-stage gneissic granitoid
- Schist and phyllite (Morrissey Metamorphic Suite)
- Quartzite (Morrissey Metamorphic Suite)
- Paragneiss (Morrissey Metamorphic Suite)
- Migmatite (Morrissey Metamorphic Suite)
- Reworked Archaean banded gneiss

- Geological boundary
- Fault or shear zone
- Anticline axial trace
- Syncline axial trace
- Overturned syncline
- Bedding with dip direction
- Lithological trend line

Rock types

Schist and quartzite: Crenulated dark-green phyllite (*Ᵽlp*), which weathers to purplish brown, is the main rock type in the northern part of the Nardoo Belt (Fig. 1), where it is interlayered with sericite schist. The phyllite consists of sericite, fine chlorite, quartz, scattered coarser chlorite (possibly after biotite), and magnetite octahedra. Tourmaline is common, and increases in abundance toward the tourmaline-bearing granitoids.

Fine-grained, finely banded, iron-stained, sugary-textured quartzite with a streaky lineation (*Ᵽiq*) is interlayered with phyllite 2.5 km northwest of Moran Well. The quartzite is probably recrystallized chert.

Fuzzy, ill-defined textures, suggesting retrograde metamorphism, are a feature of some varieties of green or brown quartz-mica schist (*Ᵽlm*). The schist is generally pelitic and of medium grain size, but there are fine- and coarse-grained varieties. The quartz fabric is granoblastic either as a mosaic, or within lozenges and ribbons which, together with aligned mica, define the schistosity. Sericite and muscovite are the dominant micas with lesser amounts of chlorite (often after biotite). Schist, in the belt 7 km northwest of Bustler Well, contains clots of sericite and quartz after poikiloblastic ?cordierite. This schist (*Ᵽlm*) also occurs in shear zones within paragneiss (*Ᵽnp*), in which case quartzo-feldspathic bands and veins have altered to sericite.

Medium- to coarse-grained, quartz-muscovite-biotite-chlorite schist (*Ᵽlm*) with dominantly prograde mineral assemblages is a part of the western Nardoo Belt. Quartz forms a sugary granoblastic mosaic, and the clean, well-crystallized mica contrasts with the sericitic assemblages in retrograde schists. The prograde schist has well-aligned micas and sharp differentiation into quartz- and mica-rich zones. Tourmaline is a common minor component, and garnet and andalusite occur in some areas.

A more iron-rich variation of this pelitic schist (*Ᵽlg*) contains, along with well-crystallized quartz, muscovite, biotite, and chlorite, very coarse-grained, euhedral porphyroblasts of deep-red garnet and dark-brown staurolite. Andalusite also occurs at a locality northwest of Nardoo Well where porphyroblasts (including chiastolite) are up to 60 mm long. Sillimanite-bearing schist (*Ᵽlg*) has only been recorded in two areas. One is 5.5 km west-southwest of Mullet Well, where a raft of coarse granofels within Proterozoic granite contains garnet (up to 20 mm across), biotite, chlorite, sillimanite, and staurolite, all set in poikiloblastic cordierite. The other locality is 9 km southwest of Spring Camp outcamp, where layers of sillimanite needles occur.

Retrograde, coarse-grained, blue-grey granofels and semi-schist (*Ᵽlo*) occur in zones of low-grade alteration, such as the Pink Hills. This rock contains large masses of sericite intergrown with coarse quartz, muscovite, biotite, andalusite, and magnetite. Andalusite and muscovite have been partially sericitized, and biotite has been chloritized. Sericite with fine chlorite masses may be after cordierite. Similar rock, 2 km south-southeast of Number 2 Well, has chloritoid-quartz-chlorite masses, possibly after staurolite, and quartz-muscovite knots, probably after andalusite, together with small amounts of garnet.

Thin, isolated zones of schistose or lepidoblastic chlorite-carbonate-amphibole-quartz rock (*Ᵽlc*) are intercalated with schist in the Mooloo Belt. The rock has low-grade, retrogressive assemblages. The outcrops are characteristically stained with manganese oxides.

Two main varieties of quartzite (*Ꝑqm*) occur. One type, in which the fabric varies from a weak mortar texture to a nearly completely recrystallized mosaic, is foliated and coarse grained. Minor sericite and/or coarse muscovite may be present. The quartzite tends to be massive, and thick sequences of coarse quartzite characterize the Lockier Range, the Injinu Hills, and the Clever Mary Hills.

The other variety of quartzite is white, fine- to medium-grained, flaggy, and laminated. It is foliated and lineated, and has annealed quartz ribbons and films of aligned sericite. Cross-lamination is preserved in some localities. In migmatite terrains, the quartzite may be interfoliated with granitoids. There are numerous ridge-forming quartzite units in the Mooloo Belt; and its migmatized equivalents make a distinct zone within the Morrissey Metamorphic Suite.

Paragneiss: A thick unit of medium to coarse-grained paragneiss (*Ꝑnb*), of mainly adamellite or granite composition, forms a conspicuous, arcuate belt around the augen gneiss body (*Ꝑgla*) centred on Yinnetharra. The paragneiss consists of quartz, microcline, oligoclase, muscovite, and biotite; and is distinguished from reworked Archaean gneiss by the ubiquitous presence of muscovite and by its obvious metasedimentary character. There are compositional variations from layer to layer, and coarse-grained pelitic schist horizons are commonly intercalated. Small units of calc-silicate gneiss and marble are also present in places. The paragneiss (*Ꝑnb*) probably represents metamorphosed arkose or feldspathic arenite. This unit may have been derived from the older augen gneiss body centred on Yinnetharra.

A different symbol (*Ꝑnl*) is used wherever the pelitic schist component becomes abundant. This unit consists of heterogeneously banded paragneiss and schists, and includes: fine- and medium-grained, grey, biotite-muscovite-quartz schist; coarse-grained grey, muscovite-quartz schist; pink or grey, quartz-biotite-muscovite-feldspar paragneiss; and thin layers of micaceous quartzite. Accessory minerals in these assemblages are garnet, tourmaline, zircon, and opaques. The high content of biotite, muscovite, and quartz, and the low content of feldspar (particularly the lack of plagioclase) distinguishes *Ꝑnl* from *Ꝑnb*.

Another type of paragneiss (*Ꝑnp*) forms a thick sequence in the Middle Springs area. This is a dark-grey microgneiss of dominately grandiorite composition. It consists of quartz, plagioclase, microcline, biotite, muscovite and small amounts of tourmaline and garnet. In places, cross-lamination is preserved, for example 2 km south of Shot In Well. The gneissic banding is bedding that has been enhanced by metamorphism, and is defined by thin, regularly spaced trains of well-crystallized mica. The original rock was probably greywacke. The paragneiss may show retrogressive alteration which involves: sericitization, saussuritization or albitization of plagioclase; chloritization of biotite, and partial sericitization of coarse muscovite; and mosaic recrystallization of quartz.

Meta-conglomerate (*Ꝑnr*) lenses occur within paragneiss in the area southeast of Middle Spring. Deformed granule- to boulder-sized angular to rounded clasts in open framework are set in a quartz-feldspar-muscovite-biotite matrix. The clasts include a variety of gneissic granitoids, notably augen gneissic granitoid (*Ꝑgla*), banded biotite adamellite gneiss, (*Ænb*), biotite tonalite gneiss (which also forms part of *Ænb*) and quartzite. This older suite of Archaean and Early Proterozoic rocks is, thus, part of the source for the conglomerate.

Black and dark-green, fine-grained, schistose or granofelsic amphibolite (*Ꝑna*) contains hornblende (green or brown), calcic plagioclase, quartz, and minor epidote, opaques and sphene. Some varieties contain light-brown garnet and/or clinopyroxene. Actinolite is present in zones of retrograde metamorphism, such as the Mooloo Belt. Amphibolite generally occurs as thin bodies parallel to compositional layering in the metasediments, but large bodies occur in the northwestern part of the Injinu Belt around Murrumburra Pool. The amphibolite is probably metamorphosed basalt or dolerite, but some actinolite-rich and quartz-rich varieties in the Nardoo Belt may be para-amphibolite.

Thin bodies of calc-silicate gneiss and granofels (*Pnc*) occur throughout the Morrissey Metamorphic Suite; they are particularly abundant in migmatized paragneiss east of Lucky Bore, and between Nardoo Well and Robinson Bore. The calc-silicate rocks consist of layered assemblages of actinolite, tremolite, quartz, plagioclase (mainly bytownite), microcline, clinopyroxene, epidote, and sphene. Carbonate and garnet occur in some types. Calc-silicate rocks are interlayered with schist, quartzite, marble, and paragneiss. Strongly deformed and statically recrystallized calc-silicate granofels and calc-silicate quartzite occur 3 km west of Mount James. This unusual quartzite contains 60 per cent quartz, plus actinolite, microcline, and clinopyroxene. Talc schist is associated with calc-silicate gneiss at a locality 2 km northeast of Mick Well.

Calc-silicate gneiss is considered to be derived from sedimentary rocks such as siliceous dolomite, or marl. The compositional layering is probably bedding enhanced by metamorphic differentiation.

Marble (*Pnm*) is associated with calc-silicate gneiss in localities such as Paddy Well and 1.5 km north of Mick Well. The marble is layered, coarsely crystalline, and contains grains of dolomite and/or calcite, chlorite, humite, and tremolite.

Migmatite (*Pm*): The Proterozoic migmatites (*Pmb, Pmm*) possess a dark phase of paragneiss or schist and a light granitoid-pegmatoid phase. The latter phase makes up between 15 and 80 per cent of the migmatite.

Migmatite is developed at least locally in all rock types of the Morrissey Metamorphic Suite. There is no preferential development near the major granitoid bodies, and in fact, migmatite is poorly developed adjacent to the Minnie Creek Batholith. The emplacement of this batholith and other smaller plutons post-dates the formation of migmatite and is responsible for deformation in adjacent migmatite terrains.

Migmatite varies in style from simple, leucosome-veined paragneiss or schist to nebulous, light and dark banded, schlieren-structured, anatectic granitoid, in which palaeosome and neosome are no longer recognizable. Distinct plutons of the latter advanced migmatite occur in the Midway outcamp area.

Three main components are generally recognizable in less advanced migmatites. The first component is the palaeosome. In *Pmb* migmatites, this paragneiss of either metagreywacke (*Pnp*) or meta-arkose (*Pnb*) style and in *Pmm* migmatites the palaeosome is mainly pelitic or semi-pelitic schist (*Plm, Plg*). The palaeosome has narrow veins or pods of leucocratic granitoid parallel to the gneissic layering or schistosity, and this leucosome constitutes the second component of the migmatite. This leucosome commonly has biotite selvages, or in some cases scattered clots of biotite. There are some injection features, but, generally, the leucosome appears to be generated *in situ*.

The leucosome-veined palaeosome passes gradationally over several centimetres of nebulous material into grey, medium- to coarse-grained granitoid which is the third and main neosome component of the migmatite. Zones of veined palaeosome and neosome alternate irregularly over widths of a few centimetres or even metres. The neosome contains biotite and muscovite and may be either granodiorite, adamellite, or granite, depending on the composition of the palaeosome. In pelitic schist migmatite (*Pmm*), the neosome is generally more muscovite- and potash-rich than in paragneiss migmatite (*Pmb*). An igneous texture is preserved in some areas, particularly in the northern part of MOUNT PHILLIPS, but elsewhere the neosome is commonly recrystallized to a metamorphic granular-textured rock. Biotite and muscovite are either disseminated, arranged in distinct layers, aggregated in clots (with leucocratic haloes), or in schlieren. Rafts and xenoliths of paragneiss, schist, amphibolite, and calc-silicate gneiss occur within the neosome and may be rotated, stretched, boudinaged, or pulled apart. These structures, along with convolute, swirly, flow-folds, are well-developed in the Midway Outcamp and Injinu Spring areas.

Tourmaline occurs throughout the neosome phase (especially in pelitic schist migmatite) as disseminated crystals; as clusters which may have a felsic halo; as individual crystals up to several centimetres long, or in fine-grained veins.

Metamorphism

M_1 metamorphism: Throughout the Morrissey Metamorphic Suite, there is evidence of polyphase metamorphism. The first regional metamorphism (M_1) accompanied the main Proterozoic deformation and was higher grade than the later (M_2) metamorphism. In pelitic rocks, the mineral assemblage is muscovite, biotite, garnet, andalusite, and staurolite, which indicate medium-pressure regional metamorphism in the lower amphibolite or upper greenschist facies. The widespread amphibolites contain hornblende and calcic plagioclase (An_{20} to An_{90}), which indicate amphibolite-facies conditions. A similar grade is inferred for the actinolite-clinopyroxene-plagioclase assemblage of calc-silicate gneiss. Brown hornblende in some amphibolites, and sillimanite in some pelitic schists, indicate upper amphibolite facies (Miyashiro, 1973, p. 254) for some areas.

Overall, a medium-pressure facies series is inferred for M_1 with a temperature range of 380 to 700°C and a load pressure range of 350 to 700 MPa (3.5 to 7 kilobar) (Miyashiro, 1973, p. 72).

The formation of Proterozoic migmatites took place during M_1 regional metamorphism. According to Wyllie (1977, Fig. 15), the maximum temperature at which water-undersaturated granite liquid would start to form from a wide variety of rock compositions (including greywacke and shale) with 2 per cent water is about 620°C at 700 MPa (7 kilobar) pressure. At 350 MPa (3.5 kilobar) the required temperature is about 650°C. Anatexis therefore is possible and likely in the areas of higher grade. Local metamorphic gradients exist in the western Nardoo Belt, where low-grade phyllite grades southward over a distance of 5 km into coarse-grained schist, and into migmatite a further 4 km south.

Some of the early-stage gneissic granitoids (*Pgla* and *Pgbs*) intruded the Morrissey Metamorphic Suite prior to the peak M_1 metamorphic period. These gneissic granitoids subsequently underwent partial melting at the same time as the metasediments. The neosome phase in these partially melted granitoids is lighter in colour, poorer in biotite, and more microcline rich than the parent granitoid. This suggests that decomposition of biotite into microcline has occurred in the formation of the neosome. The reaction by which biotite breaks down into microcline during anatexis is discussed by Olsen (1977).

M_2 metamorphism: Early dynamic metamorphism was followed by the static metamorphism which resulted in coarse crystallization of quartz, muscovite, biotite, garnet, staurolite, and andalusite. Coarse micas formed at this time are mimetic on earlier foliations, but may grow across it at high angles. The effects of M_2 are widespread throughout the Morrissey Metamorphic Suite, but are best seen in the western Nardoo Belt where the obscuring effects of later deformation are absent.

The M_2 recrystallization may be related to the emplacement of late-stage Proterozoic granitoids; however, it is not simply a contact effect as there is no well-defined aureole around any of the Proterozoic granitoid plutons.

M_3 and M_4 metamorphism: The next Proterozoic metamorphic event (M_3) was dynamic, of low grade, and involved widespread retrogression. In pelitic schists, this retrogression includes formation of chlorite from biotite and garnet; growth of sericite after andalusite, muscovite, and feldspar; alteration of staurolite to chlorite, quartz, and chloritoid; and the granulation of quartz. The M_3 metamorphism also affected large areas of paragneiss and migmatite particularly in the Mooloo Belt. In some amphibolites, hornblende is partially retrogressed to actinolite, and in calc-silicates clinopyroxene is altered to actinolite. The M_3 retrograde metamorphism took place under lower greenschist facies conditions within the chlorite zone.

Granular recrystallization of quartz occurred during or after the M_3 dynamic metamorphism, and in the Mooloo Belt static growth of chlorite and muscovite prophyroblasts occurred. In the Injinu Belt, there was static growth of euhedral garnet prophyroblasts in pelitic schists. These events taken together constitute a late period of Proterozoic metamorphism (M_4).

Many of the early-stage granitoids have post recrystallization strain effects, such as strained quartz; and greenschist-facies retrograde metamorphic effects, such as saussuritization of plagioclase. In *Ɇgbb*, 2 km southeast of Saucepan Bore, the anatectic neosome phase, which is inferred to be contemporaneous with Proterozoic M_1, contains secondary epidote and prehnite. These low-grade alterations may be related to Proterozoic M_3 retrograde metamorphism.

Metasomatism

Boron and sodium metasomatism occurred—at about the time of the M_2 regional metamorphism—in a zone from Morrissey Hill, through the northern side of the Mortimer Hills down to Minneritchie Well. The alterations are: biotite to muscovite or phlogopite; calcic plagioclase and potash feldspar to albite; and formation of tourmaline.

The strongest effects are in the dravite prospects south of Morrissey Hill, where 6 m wide zones—of sugary-textured rock composed of quartz, albite (An_9), phlogopite, hydrophlogopite, and very coarse dravite crystals—occur in augen adamellite (*Ɇgla*). In the altered zone, albite replaces microcline augen. The occurrence of magnesium-rich mica (phlogopite) and magnesium tourmaline (dravite) indicate magnesium has been introduced.

Throughout the belt of metasomatism, there is pegmatite which contains coarse books of muscovite, tourmaline and beryl, and rare bismutite, euxenite, and pitchblende. Other minor components include fluorite, garnet, lepidolite, and green tourmaline.

Early-stage gneissic granitoids

Early-stage, gneissic granitoids intruded the Morrissey Suite prior to, during, or just after the peak of the M_1 metamorphic episode. A metamorphic, elongate-granoblastic fabric is developed throughout these granitoids and this is considered to be due to crystal-plastic deformation which occurred during the main Proterozoic orogenic phase.

Augen gneiss (*Ɇgla*) is the most abundant granitoid in this suite, and it occurs in a series of coalesced plutons centred on Yinnetharra and Eudamullah. The augen gneiss is surrounded by arkosic paragneiss. This arkose may have been initially derived from the augen gneiss—which implies that the augen gneiss was initially emplaced prior to the formation of the Morrissey Metamorphic Suite—however, the gneiss has subsequently intruded its mantle of Proterozoic metasediments. One sample of augen gneiss from a pluton north of Ring Well fits on an isochron with an apparent age of 1 672 ± 18 m.y. (de Laeter, 1976). This is probably a Proterozoic metamorphic age. A high initial $^{87}Sr/^{86}Sr$ (0.7131 ± 0.0002) suggests that the augen gneiss is derived by anatexis, or by remobilization of older sialic material.

The gneiss is coarse- to medium-grained and contains microcline augen. It varies from granite to granodiorite, and contains up to 20 per cent biotite. Rounded microcline augen (average length 15 mm) constitute 5 to 30 per cent of the rock. In some varieties, the microcline forms euhedral or subhedral laths. Minor minerals include muscovite, sphene, apatite, sericite, epidote, zircon, fluorite, metamict allanite, and opaques. Rafts and xenoliths of dark microgneiss, banded gneiss, leucocratic gneiss, and biotite schlieren are common.

The gneissic texture is expressed by a granoblastic quartz-feldspar mosaic and spaced discontinuous films of biotite. Some clusters of randomly arranged biotite and coarse subhedral feldspar and quartz may be remnant igneous texture. The augen may originally have been phenocrysts.

TABLE 1 SELECTED CHEMICAL ANALYSES

	Alkaline anorthositic gneiss			Calc-silicate gneiss		Meta-dolomite
	44724	44726	44829	44731A	44738B	44830
Barium, Ba	140	20	220	450	90	20
Cerium, Ce	200	240	120	60	100	10
Fluorine, F	770	570	570	700	600	260
Lanthanium, La	110	140	60	30	40	<10
Niobium, Nb	35	35	25	15	25	<5
Scandium, Sc	20	10	15	20	25	15
Strontium, Sr	480	140	320	250	410	40
Tantalum, Ta	<5	<5	<5	<5	<5	<5
Thorium, Th	50	60	90	20	30	10
Uranium, U	1	2	<1	1	<1	<1
Yttrium, Y	95	75	65	25	45	<5
Phosphorous Pentoxide, P_2O_5	0.31%	0.27%	0.15%	0.32%	0.26%	0.29%
LOCALITY	2 km NW Peak Bore	4.5 km NW New Well	12 km SW Daly Bore	3.5 km SW Stiles Bore (Eud. Stn)	5 km NW Stiles Bore (Eud. Stn)	1.5 km SSE Nine Mile Bore

Alkaline anorthositic gneiss (*Ꞓgk*) occurs in the Peak Bore, New Well, Pyramid Hill, Yinnetharra, and Wabli Creek areas. It always occurs in narrow bodies which are closely associated with the augen gneiss (*Ꞓgla*). The anorthositic gneiss is leucocratic, and has a coarse granoblastic texture. It consists up to 90 per cent of plagioclase (An_{10}-An_{30}), together with green clinopyroxene (10 per cent), and quartz (0-10 per cent). Feldspars show a distinctive blue schiller in hand specimen. The rocks contain abundant sphene and yellow-brown allanite, together with green amphibole, epidote, apatite, microcline, zircon, xenotime, and magnetite. Mineral assemblages in the anorthositic gneiss resemble those in the calc-silicate gneiss; however, in the latter, the feldspar is very calcic (bytownite-anorthite), and mafic minerals are more abundant than feldspar.

Analyses of three anorthositic gneisses, two calc-silicate gneisses, and one metadolomite are given in Table 1.

Tentative conclusions are that the rocks are not part of a carbonatite suite because: Nb/Ta is too low; Th/U, Th, and Y are too high; and there is only minor carbonate. They resemble alkaline (syenitic) rocks of the type described by Herz (1969) because of their analogous feldspar composition and Y/Th ratio, but they are too low in Ba and too high in Sc, Sr/Ba, rare earths and Th. Their Ba, Sr/Ba, Sc, and feldspar content is similar to that of anorthositic rocks. The rocks are enriched in rare earths and thorium compared with normal anorthosites.

Even-grained, pink, gneissic granite-to-adamellite containing traces of biotite and muscovite (*Ꞓgbp*) is another type of early-stage Proterozoic granitoid. It forms discrete plutons in the Ring Well and Eudamullah areas.

Partial melting of both the augen gneiss and the even-grained gneiss occurred during the peak (M_1) metamorphic episode. This produced a migmatite (*Ꞓgbn*) which contains a palaesome of biotite adamellite gneiss or granodiorite gneiss, and a neosome of coarse-grained, light-coloured granitoid containing coarse biotite and garnet (locally muscovite, magnetite and hornblende as well). The neosome occurs in veins parallel to the gneissosity; in diffuse clots, particularly in boudin necks; and in cores of folds.

Fine- to coarse-grained, Biotite-rich gneissic granodiorite (*Ꞓgbs*) has minor and accessory epidote, muscovite, hornblende, opaques, zircon, and sphene. Some remnants of orginal igneous texture are preserved, but in other types, recrystallization is much stronger and gives the rock a sugary appearance. Schistose varieties of this unit occur in the Toohey Well area. The gneissic granodiorite contains diffuse xenoliths of biotite-rich microgneiss and amphibolite.

Mixed granitoid (*Ꞓgbb*), consisting of dark biotite-rich granodiorite (*Ꞓgbs*), and light-coloured, coarse-grained pegmatitic biotite-muscovite adamellite is common in the Megan Bore area. The adamellite phase cleanly intrudes the granodiorite phase in some areas. In other areas, the granitoid mixture is an agmatite and contains small and large angular blocks of granodiorite in the later adamellite. In some places, the granitoid mixture is nebulitic, and individual phases are difficult to separate.

Gneissic, biotite-muscovite adamellite and granite (*Ꞓgmb*) is a more homogeneous equivalent of migmatite neosomes in the Morrissey Metamorphic Suite. This granitoid is considered to have been generated from the anatexis of metasediment and then to have been emplaced as discrete plutons (or sheets) at higher crustal levels.

A more heterogenous granitoid apparently derived from the anatexis of metasediment occurs between Six Mile Well and Stone Tank Well on the north of MOUNT PHILLIPS. This is weakly foliated, biotite-muscovite(-garnet) tonalite-to-adamellite (*Pgmt*) which contains abundant metasedimentary xenoliths, some augen gneiss xenoliths, mafic schlieren, and nebulous light and dark phases. This heterogeneous granitoid grades northwards into migmatite and southwards into more homogeneous granitoid and is probably a transitional phase in the development of meta-sedimentary granitoids.

Late-stage granitoids

Late-stage granitoids are concentrated in the northern and southeastern parts of MOUNT PHILLIPS. Emplacement of these granitoids caused widespread secondary deformation in the Morrissey Metamorphic Suite. The largest body of late-stage granitoid is the Minnie Creek Batholith. This batholith has a broad selvage of foliated granitoid which is intruded by a dominant central phase of coarse-grained, mostly unfoliated granodiorite. Emplacement of the voluminous central granodiorite probably caused deformation of the surrounding granitoids.

The main type of granitoid in the foliated selvage is coarse-grained biotite(muscovite) granodiorite and adamellite (*Pglb*). It is mostly porphyritic with laths of microcline, but there are seriate and even-grained varieties. A discrete pluton of foliated, medium-grained, biotite grandiorite (*Pgbt*) occurs in the White Well area. This pluton has a marginal phase of foliated, even-grained, biotite-muscovite adamellite and granite (*Pgve*). A larger body of *Pgve* containing tourmaline intrudes the southern margin of the Bassit Belt.

The dominant phase of the Minnie Creek Batholith is medium- and coarse-grained biotite granodiorite and adamellite (*Pgbr*). Seriate phases have laths of microcline. Leucocratic potash-rich varieties occur south of Mortimer Bore. A related type is medium- to coarse-grained biotite-muscovite adamellite and granite (*Pgbm*), which forms discrete plutons and dykes around the margins of the Minnie Creek Batholith. Large plutons of *Pgbm* also occur in the Coondoondoo Hills and Injinu Hills area.

Several discrete plutons of late-stage granitoid intrude the Morrissey Metamorphic Suite in the Nardoo Belt. The plutons consist of both coarse- and fine-grained, biotite-tourmaline-muscovite granite and adamellite (*Pgvl*). Some phases are porphyritic and seriate, and a leucocratic type occurs 3 km south of Smith Well. Associated pegamitite usually contains tourmaline.

Late-stage muscovite-tourmaline granite with abundant pegmatite phases (*Pgmv*) intrudes paragneiss, schist and quartzite in the Coondoondoo Hills area. This potash-rich ?high-level granite forms some discrete, large bodies, but mostly intrudes as a network of dykes and sheets.

Rb/Sr isotopic ages: Compston and Arriens (1968) quote an age of 1 690 m.y. for a granitoid (*Pgbr* type) collected from near Minnie Creek homestead. In the same publication, a slightly older, but poorer quality, isochron of 1 730 ± 240 m.y. was quoted for "gneiss" collected about 60 km northwest of Yinnetharra homestead. These samples were apparently collected from gneissic granitoid (*Pglb*) in the Christmas Well-Gifford Creek woolshed area.

A more precise age of 1 672 ± 18 m.y. was found by de Laeter (1976) for *Pglb* from the Gifford Creek woolshed area, and for *Pgvl* from the Nardoo Well area.

Structural sequence in the Morrissey Metamorphic Suite

The Morrissey Metamorphic Suite has a series of tight, steeply inclined folds with northwest-trending axial surfaces and generally steep southeasterly plunges. These folds have an earlier schistosity or gneissosity (a bedding foliation) as a form-surface, and have an axial-surface crenulation cleavage (or in some cases a more penetrative secondary foliation). There is an associated crumple, or mineral elongation lineation subparallel to fold hinges. Major folds of this style determine the regional orientation of compositional layering and early schistosity in the Morrissey Metamorphic Suite. Refolded folds are outlined on the regional scale by quartzites in the Mooloo Belt and in migmatite to the west.

Shear zones, characterized by mylonite textures of finer grain size than the surrounding rock, are well developed in early- and late-stage Proterozoic granitoids, but not so well developed in the Morrissey Metamorphic Suite.

Relationship between deformation metamorphism and granitoid emplacement.

The steeply inclined folds, foliations and cleavages in the Morrissey Metamorphic Suite suggests vertical tectonic movements. These are considered to have been related to the rising up through the crust of a hot metamorphic tumour, less dense than its cooler overburden, and thus affecting both Archaean basement and Proterozoic supracrustals.

The early-stage gneissic granitoids were generated at lower crustal levels during M_1 metamorphism and were emplaced at higher crustal levels in a high-strain environment. Some of the schistosity and gneissosity development in the Morrisey Metamorphic Suite is attributable to the emplacement of the early-stage granitoids.

The late stage granitoids were emplaced at crustal levels much higher than their zone of generation. Their diapiric emplacement post-dates the M_1 and ?M_2 metamorphic effects and is possibly responsible for M_3 and M_4 metamorphism. Some of the folds, crenulation cleavage and discrete shear zones in the Morrissey Metamorphic Suite are related to the intrusion of late-stage granitoids.

Deformation has continued after the emplacement of late-stage granitoids and the strain is expressed in granitoids as discrete northwest-trending shear zones, and as north-northeast-trending fracture systems.

MOUNT JAMES FORMATION

Definition and distribution

The Mount James Formation consists of deformed and metamorphosed sedimentary rocks in disconnected belts and isolated exposures throughout central and southeastern MOUNT PHILLIPS. It unconformably overlies the Morrissey Metamorphic Suite and the Proterozoic granitoid, and is, in turn, overlain unconformably by the Bangemall Group. On the basis of lithological and structural similarities, the formation is correlated with parts of the Padbury Group (Barnett, 1975) which has an age 1 600 to 1 700 m.y. (Elias and Williams, 1977).

The Mount James Formation is defined in the type area between Mount Gascoyne (lat. 24°57′25″S, long. 116°38′15″E) and Spring Camp outcamp (lat. 24°54′50″S, long. 116°34′50″E). The thickness preserved exceeds 2 000 m. The basal unconformity is exposed near Spring Camp outcamp, where the sequence from the base upwards is: polymictic boulder conglomerate, well-bedded metasandstone and meta-arkose, and massive quartz metasandstone. Three kilometres northwest of Mount Gascoyne the latter is overlain by interbedded metasiltstone and metasandstone.

Rock Types

The basal conglomerate (*ⱣJr*) is characterized by well-rounded clasts, up to 1 m in length, of vein-quartz, quartzite, granitoid, and migmatite. The matrix is a poorly sorted meta-arkose, or quartz-feldspar-mica schist; 5 kilometres east-southeast of Reid Well, the conglomerate has a phyllitic matrix.

An interbedded quartzose, arkosic, and conglomeratic metasandstone unit (*ⱣJa*) overlies the basal unit and onlaps basement in some areas. Clasts in the conglomerate are up to 0.2 m long and consist of well-rounded quartzite and vein-quartz. Pebbly, poorly-sorted, quartz metasandstone containing feldspar and mica, dominates the upper part of this unit. Beds are up to 3 m thick. Trough-like cross-beds, outlined by concentrations of heavy minerals, exist at all levels.

The interbedded pelites are phyllite and fine-grained sericite schist (*ⱣJp*), which contain euhedral magnetite crystals up to 5 mm long. Three kilometres south of Murrumburra Pool phyllite contains garnet; and andalusite is recorded from phyllite 9 km northwest of Spring Camp outcamp.

The association of metasediments which forms the Big Bend Syncline (Fig. 1) is included in the Mount James Formation, but its stratigraphic position is not firmly known. The lowest unit consists of faintly banded, ferruginous metachert and graphitic shale (*ⱣJc*). The metachert has hornfelsic texture and contains porphyroblastic grunerite and garnet. The unit (*ⱣJc*) is overlain by green, micaceous metasiltstone interbedded with quartz metasandstone (*ⱣJi*). The grain size of the metasandstone varies from fine to very coarse, and scours in the sandstone contain pebble conglomerate.

Metamorphism

Sericite and fine muscovite are the main metamorphic minerals, and, overall, the metamorphic grade is low. An early low-grade dynamothermal metamorphism was followed in some cases by static, moderate-grade metamorphism, which produced prophyroblasts of biotite, garnet, andalusite, and grunerite.

The metamorphism of the Mount James Formation post-dates all significant metamorphism (M_1, M_2, M_3) in the Morrissey Metamorphic Suite. However, the static metamorphism in the Mount James Formation in the Big Bend Syncline may be equivalent to the static M_4 event in the nearby Injinu Belt.

Structure and sedimentation

The present distribution of the Mount James Formation in linear zones along regional shear zones, suggests that these structures controlled initial sedimentation. The conglomerate and sandstone are fluvial sediments that may have accumulated in restricted downfaulted areas, many of which appear to have been half-grabens. Continued activity on these zones of dislocation deformed and metamorphosed the sediments.

Deformation produced upright, east-southeast-trending folds with plunges up to 45°. Parallel to the axial planes of these folds is a penetrative cleavage which has flattened quartz grains and clasts. Subsequent deformation produced a crenulation or spaced cleavage at a low angle to the earlier foliation.

Folding and cleavage development in the Mount James Formation post-dates the main deformation episode in the Morrissey Metaphoric Suite.

BANGEMALL BASIN

STRATIGRAPHY

The stratigraphy is similar to that described on adjacent sheets (Daniels, 1969; Muhling and others, 1976).

The Mount Augustus Sandstone (*ЕMa*) is a discontinuous continental unit on the basal unconformity. It comprises coarse-grained quartz arenite with scattered larger clasts and local lenses of conglomerate. The upper contact is not exposed, but it is probably conformably overlain by the Irregully Formation, which is the basal unit of a continuous marine sequence. The three marine formations overlying the Mount Augustus Sandstone form a sequence marked by vertical and lateral changes in lithofacies.

The Irregully Formation (*ЕMi*) is laminated dolomite, which is laterally discontinuous; it is overlain by black shale, which crops out as a prominent cream-coloured siliceous shale having a streaky texture superficially similar to volcanic texture. The dolomite (*ЕM(d)*) in the northeast of MOUNT PHILLIPS is regarded as a separate unit from the Irregully Formation because it appears to overlie the Kiangi Creek Formation. It contains the stromatolite *Baicalia capricornia* (K. Grey, GSWA, pers. comm.).

The Kiangi Creek Formation (*Еmk*) is a white, siliceous, well-sorted, medium-grained quartz arenite which crops out along continuous ridges (for example Cobra Syncline). It is thin compared with the thickness developed on adjacent sheets and may be missing from parts of the northeast limb of the Geegin Syncline. The Jillawarra Formation (*ЕMj*) is a brown-, white-, and grey-weathering, black, pyritic and siliceous shale, which contains minor chert. The unit thins from about 310 m in the southeast to about 130 m in the northwest.

The Discovery Chert (*ЕMd*) is a prominent marker in the Peedawarra Syncline. It is a black and grey, bedded, laminated, pyritic chert, rich in carbonaceous detritus, and contains some algal remnants. Molds after gypsum crystals are locally common and acritarchs have been reported (Marshall, 1968). In the Ti Tree Syncline the unit is 50 m thick; this is significantly less than elsewhere. Overlying the chert is the Devil Creek Formation (*ЕMv*), comprising laminated dolomite and occasional siltstone and fine-grained sandstone. Scour structures are present in the good exposure south and east from Cobra homestead. The Ullawarra Formation (*Еml*) overlies and also passes laterally into the Devil Creek Formation. It consists of thin bands of siltstone, fine-grained sandstone, chert, and fine-grained dolomitic sandstone, all interlayered with thick dolerite sills (*b*). Overlying the Ullawarra Formation are three laterally extensive formations, the lowest of which is the Curran Formation (*ЕMu*), a black shale and siltstone which weathers to a pale, cream-coloured siliceous rock. This is transitional into the overlying Coodardoo Formation (*ЕMc*), a medium-grained, moderately to poorly sorted, poorly bedded quartz sandstone, with minor micaceous mudstone and shale. These rocks vary from grey to purple. The youngest unit, the Fords Creek Shale (*ЕMs*), is a thick, green micaceous shale and silty mudstone with lesser amounts of arenite, and chert.

Fault-bounded outliers of Bangemall Group rocks in the southeast of MOUNT PHILLIPS consist of sandstone, conglomerate, siltstone, shale, slate, and phyllite. The rocks have similarities with the Tringadee Formation on MOUNT EGERTON (Muhling and others, 1976). The unconformable basal contact can be seen only at Mount Gascoyne where flat-lying sandstone overlies the steeply dipping Mount James Formation. The mapped units include: a medium-grained, well-sorted quartz sandstone; minor fine-grained sandstone (*ƐM(a)*); a sequence of shale, siltstone, sandstone, and conglomerate (*ƐM(r)*); and interbedded shale and siltstone with minor sandy layers (*ƐM(s)*).

STRUCTURE

Part of the Edmund Fold Belt, an elongate, curved area characterized by zones of open and tight folds (P. C. Muhling and A. T. Brakel, pers. comm.), extends into MOUNT PHILLIPS. Long zones of doubly plunging folds are parallel to major structures in the basement. The structural pattern on MOUNT PHILLIPS is the westerly continuation of that on MOUNT EGERTON, where there are two major structural axes (Muhling and others, 1976). One axis trends northwesterly and extends into the northeastern part of MOUNT PHILLIPS.

The other structural axis which trends southwest on MOUNT EGERTON continues on to the southeastern part of MOUNT PHILLIPS to form a series of folds controlled and bounded by faults.

Fold styles consist of a series of tight synclines (such as the Geegin and Cobra Synclines) with intervening broad anticlines of gently folded rocks such as at Mount Augustus. The tight synclines are characterized by tight minor folds and slaty cleavage, indicating they are zones of high strain. In these zones, shale has been altered to slate (for example, Ti Tree Syncline), chert to siliceous slate, and the edges of dolerite sills to chlorite schist.

CARNARVON BASIN

STRATIGRAPHY

Late Carboniferous—Early Permian

The Lyons Formation (*CPl*) is a glacigene sequence which rests unconformably on Precambrian rocks. It is expressed mostly as boulder fields of weathered-out glacial erratics and scattered low ridges of poorly-sorted feldspathic sandstone and siltstone. The erratics include numerous Precambrian rocks. Cobbles of stromatolitic chert and dolomite and of banded iron-formation from near Democks Well indicate the source area of some of the erratics lies 100 km to the northwest (Grey and others, 1977.) Condon (1967) gave the thickness of the Lyons Formation west of Arthur River outcamp as 1 830 to 2 200 m, but he did not recognize the extensive faulting in the area that reduces the apparent thickness considerably. A Sakmarian age has previously been assigned to the unit (Dickins, 1956, 1957, 1963; Dickins and Thomas, 1959), but correlation with other equivalent units in Western Australia (Kemp and others, 1977) suggests that a large part of the unit is of Late Carboniferous age.

A basal ?fluviolacustrine, quartzo-feldspathic sandstone, the Austin Member of the Lyons Formation (*Cla*), is locally developed in the Cream Creek area and north of Onslow Creek.

TABLE 2 LATE CARBONIFEROUS-PERMIAN STRATIGRAPHY

Age	Symbol and rock unit			Maximum thickness (m)	Lithology	Stratigraphic Relationships	Remarks
ARTKINSKIAN	*Pb*	Billidee Formation	Wooramel Group	60	Quartz sandstone and siltstone with calcareous cement. Herringbone cross-lamination, Pyritic in subsurface; gypsiferous in outcrop	Conformably overlies Moogooloo Sandstone Conformably overlain by Coyrie Formation (Kennedy Range Sheet area)	Cool to cold ?intertidal to subtidal environment. Burrows and trails locally common, some driftwood
ARTKINSKIAN	*Pm*	Moogooloo Sandstone	Wooramel Group	20	Quartz sandstone, siltstone, minor conglomerate, and pebbly sandstone in transgressive sequence. Some herringbone cross-bedding	Disconformably overlies Callytharra Formation. Conformably overlain by Billidee Formation	Cool to cold, deltaic to subtidal environment. Burrows and trails locally abundant; minor driftwood. Infills karst on Callytharra Formation south of Tallangatta outcamp
SAKMARIAN	*Pc*	Callytharra Formation		64	Friable calcisiltite and siltstone (lower part); hard, cross-bedded calcarenite (upper part). Very fossiliferous	Conformably overlies Lyons Formation. Disconformably overlain by Moogooloo Sandstone	Shallow-water deposition in relatively cold climate. Fauna includes brachiopods, bryozoans, crinoids, bivalves, corals, gastropods, nautiloids, blastoids, ammonoids; full faunal list see Condon (1967). Thickness near Tallangatta outcamp by Condon (1967)
LATE CARBONIFEROUS-SAKMARIAN	*CPl*	Lyons Formation		1 800	Immature sandstone siltstone, shale and tillite. Contains numerous glacial erratics, minor fossiliferous. Calcareous beds.	Unconformably overlies Precambrian rocks. Conformably overlain by Callytharra Formation	Fluvioglacial, glacio-lacustrine, marine glacial environments. Poor exposure. Northerly provenance
LATE CARBONIFEROUS-SAKMARIAN	*Cla*	Austin Member Lyons Formation		30	Quartzo-feldspathic sandstone, moderately sorted and rounded	Unconformably overlies Precambrian rocks	Basal member Lyons Formation. Local distribution only. ?Fluviolacustrine origin

Permian

The Callytharra Formation (*Pc*) conformably overlies the Lyons Formation. Its lower unit of friable, fossiliferous calcisiltite and siltstone is overlain by an upper unit of hard, fossiliferous, cross-bedded calcarenite. Locally, an overall coarsening-upwards sequence is apparent. The formation is highly fossiliferous; the most abundant forms are brachiopods, bryozoans, and crinoids, and it is of Sakmarian age (Glenister and Furnish, 1961). The lower part of the formation was deposited in quiet water, whereas the upper part formed in a shallower, higher energy environment.

The Wooramel Group, which on MOUNT PHILLIPS consists of the Moogooloo Sandstone and Billidee Formation, is a transgressive, sandy and silty sequence of Artinskian age. The Moogooloo Sandstone (*Pm*) overlies the Callytharra Formation with a regional disconformity, and formed in a high energy, deltaic to subtidal environment. On the east side of the Weedarra Inlier and near Tallangatta Outcamp it is 15 to 20 m thick. The finer grained Billidee Formation (*Pb*) conformably overlies the Moogooloo Sandstone, and commonly has a calcareous cement. It was probably deposited in a quiet ?intertidal to subtidal environment, rather than the hyper-saline lagoonal environment suggested by McGann (1976). McGann based his conclusions on the occurrence of gypsum, which is not primary but a weathering product of pyrite and calcium carbonate.

The Late Carboniferous-Permian stratigraphy of MOUNT PHILLIPS is summarized in Table 2.

STRUCTURE

Palaeozoic sediments in the area lie within the Bidgemia Sub-basin of the Carnarvon Basin, within which sedimentary rocks of the Lyons Formation dip uniformly westward at 15° to 20°. Extensive faulting, which is only locally mappable, complicates the sub-basin. Outcrop patterns and dips indicate that the sub-basin is a half-graben and that the western boundary is a faulted contact with the Weedarra Inlier. The overall structure and the eastward dip of the main bounding fault indicate normal faulting, although slickensides at lat. 24°49′43″S, long. 115°30′00″E indicate some sinistral transcurrent movement. Dextral transcurrent movement was established for some minor intra-basinal faults at lat. 25°32′47″S, long. 115°35′52″E; but for all other fault-plane observations in the Bidgemia and Byro Sub-basins, for which sense of movement could be deduced from slickensides, the faulting was normal.

A zone of synclines and anticlines in the Permian sequence east of the Weedarra Inlier extends from KENNEDY RANGE on to MOUNT PHILLIPS. These folds are clearly associated with the main faults, and are interpreted as drag structures caused by normal movement along an irregular fault plane, in the manner described by Hamblin (1965).

GEOLOGICAL HISTORY

The Late Caboniferous and Early Permian glaciation is the earliest recorded Phanerozoic event on MOUNT PHILLIPS, and associated sediments appear to have been deposited continuously over this part of the Carnarvon Basin. The Sakmarian had a frigid climate, and during much of the Artinskian, the climate was cold. Erosion of the Callytharra Formation, probably in the Late Sakmarian, may reflect isostatic uplift after melting of most of the ice sheet. A widespread transgression followed, during which the Artinskian Wooramel Group was deposited. Normal faulting, probably during the Late Permian to Triassic, shaped the Bidgemia Sub-basin as a structural unit.

CAINOZOIC GEOLOGY

The Cainozoic deposits are divided into alluvial, colluvial, and eolian units of Quaternary age, and older, semi-consolidated colluvium, lacustrine deposits, calcrete, and remnants of the duricrust surface (laterite and silcrete) of probable Tertiary age. The precise ages of these older units are uncertain, and they are collectively referred to as Cainozoic.

The alluvium (*Qa*) is restricted to unconsolidated silt, sand, and gravel along present-day drainage systems. Colluvium (*Qc*) is a mixed, unconsolidated unit adjacent to rock outcrop, which passes downslope into alluvium (*Qa*), or into the mixed colluvial and eolian unit (*Qw*), which occurs on broad flood plains and piedmont plains adjacent to the major drainage lines. This mixed unit (*Qw*) is made up of small clay- and silt-pans, separated by low anastomosing banks of wind-blown sand. Where wind-blown sand forms a continuous blanket over the plains a *Qs* unit is mapped. Low longitudinal dunes occur in this unit.

The Nadarra Formation (*Czn*) is a carbonate-rich (?freshwater) laucustrine deposit, preserved as a distinct valley-fill east of Gubbiddy Well but intensely dissected elsewhere. Because it overlies the laterite duricrust, and pre-dates most of the unconsolidated alluvial and colluvial deposits, its age is believed to be in the range Miocene to Pleistocene.

The consolidated hardpan unit (*Czc*) is an old colluvium-alluvium deposit, which contains silt, sand, and pebbles, and which may exhibit crude bedding. Most outcrops are strongly dissected, and up to 15 m of material may be exposed. The hardpan occurs in broad valleys or adjacent to large erosional monadnocks, for example, Lockier Range. Large areas of hardpan are found along the upper reaches of Little Minnie Creek and between the Injinu Hills and Coondoondoo Hills.

Two types of calcrete (*Czk*) are recognized. Dissected valley calcrete, which is common in the Gascoyne River drainage, and buried trunk-valley calcrete which occurs over Bangemall Rocks at Jamieson Well and along Spring Creek (Butt and others, 1977). Fossil drainage systems, unrelated to present systems, are also reflected by dissected high-level calcretes. The calcrete overlies the hardpan in some areas.

The calcretes are commonly capped by silcrete (*Czb*), which belongs to an old duricrust surface and which may have been quite extensive. Laterite (*Czl*) was also part of this old duricrust surface. However, active erosion associated with the Gascoyne and Lyons Rivers has left only remnants of laterite along the watersheds.

ECONOMIC GEOLOGY

MINERAL DEPOSITS

Gold

The only recorded production is from the Bangemall Mining Centre (discovered in 1896) which lies 1 km southwest of Cobra Station homestead (Maitland, 1909). Total production is 356 t yielding 8 896.6 g of gold for an average grade of 25 g/t. A small amount of gold has also been found at McCarthy's Find, 14 km northwest of the Bangemall mines, in a similar geological setting. The gold is confined to shale near the top of the Jillawarra Formation (Bangemall Group), which, at the Bangemall mines, is abundantly intruded by dolerite sills. Gold and minor sphalerite occur in association with pyrite and carbonate in quartz saddle reefs, axial-plane reefs (dip 75° to 220°), and thin quartz stringers within the shale. Both Bangemall and McCarthy's prospect are situated in the cores of steep, southeasterly plunging anticlines.

Lead

Lead mineralization has been recorded from two localities in the Bangemall Group and from four localities in Proterozoic granitoids, where it is associated with copper sulphides and carbonates. Argentiferous galena and cerussite occupy a siliceous fault zone and small quartz stringers along joint planes in a flat-lying dolomite (probably Irregully Formation) 1 km southwest of Deep Well; this is the Kurabuka deposit (Simpson, 1951; Blockley, 1971). A thin (0.4 m) vein of anglesite cuts shale of the Kiangi Creek Formation, 2 km north of Mount Genoa.

At a prospect 1.5 km east of Tabletop Well, which is northeast of Gifford Creek homestead, a lens of sheared porphyritic granitoid, intruding migmatized paragneiss, carries disseminated galena and copper carbonate. Two fluorite-bearing quartz dykes—carrying disseminated galena, malachite, and chrysocolla—are contained within a porphyritic tourmaline granite 17 km northeast of Yinnetharra homestead (one beside and the other 2km east of the main Yinnetharrra—Mount Phillips road). Other unmineralized quartz-fluorite reefs are known from this general area.

A mylonized granodioritic rock, 2.5 km east of Ti Tree Well, contains traces of galena, chalcopyrite, and molybdenite.

Copper

Copper carbonates and sulphides have been found in siliceous fracture fillings of stromatolitic dolomite of the Irregully Formation 4 km west-southwest of Mount Genoa. Disseminated pyrite, chalcopyrite, and sphalerite have been noted in weathered and bleached black shale in the upper Irregully Formation 4 km west of Dunnice Well.

Thin films of malachite on joints in bleached and weathered shale of the Jillawarra Formation have been found 1 km north of Alston Well on Cobra Station, 9.5 km southeast of Mount Augustus homestead, and 9 km southwest of Mount Genoa. Chrysocolla and malachite occur in joints within the Discovery Chert, at the southern end of the Ti Tree Syncline, 27 km east-northeast of Yinnetharra homestead.

Disseminated pyrite, chalcopyrite, and malachite in a quartz-filled fault zone in foliated porphyritic granodiorite has been prospected 1 km southeast of Dry Corner Bore, Gifford Creek Station.

Shallow pits and costeans 10.5 km southeast of Gubbiddy Well on Eudamullah Station expose a brecciated vuggy quartz-veined quartzite containing malachite, ?azurite, and chrysocolla. The mineralization, in joints and fractures, is traceable over a length of 100 m and is up to 3 m wide. The prospect lies in migmatite of micaceous schist and paragneiss with a tourmaline-rich granitoid and pegmatite neosome.

Malachite has been recorded 9 km northwest of Mount Gascoyne from a quartz-filled shear zone between migmatite and Proterozoic granitoids (Simpson, 1952). Malachite staining in sheared gneissic granodiorite has been found 7.5 km south-southwest of Mount Phillips homestead.

Chrysocolla, malachite, and cuprite have been prospected in a bold-outcropping, vuggy quartz-vein 1 km southeast of Mick Well on Mooloo Downs Station. The mineralized area is slightly radioactive.

Further east (3 km east of Number 1 Well) several shallow shafts and pits expose malachite, chrysocolla, and cuprite at the Kingfisher Mine. From here patchy copper mineralization in a shear zone within kaolinized gneiss and granitoid can be traced east-southeast for over 2 km. The vertically dipping lode has a maximum width of about 1.2 m. Although there is evidence of some development work, no production has been recorded from the mine. Six kilometres east-southeast of the Kingfisher Mine, malachite and anomalous radioactivity occur in a prominent quartz reef within a mylonite zone. The mineralization is similar to the prospect 1 km south of Mick Well.

Barite

Discontinous lenses of low-grade barite carrying copper and lead mineralization have been prospected 3 km southeast of Reid Well (13 km northeast of Yinnetharra homestead). The barite occurs in quartz-biotite-muscovite-feldspar-garnet schist of the Morrissey Metamorphic Suite. Other visible minerals are chalcopyrite, galena, pyrite, malachite, covellite, and chalcocite. A quartz shear trending north-northeast in augen gneiss (*Ꝑgla*), 1.5 km south-southeast of Corktree Bore, has been found to contain barite and fluorite.

Uranium

Exploration since the early 1970's has led to the discovery of at least 45 separate uranium occurrences (Table 3) some of which are described by Butt and others (1977). Despite the many occurrences, no economic deposit has been located.

Secondary, yellow or olive-green carnotite is the main uranium mineral in the calcrete and weathered bedrock occurrences. In all cases, the mineralization is near the surface, and is erratic in distribution and grade; in the calcrete deposits, it is generally related to present or past water tables. The carnotite was precipitated in cavities, as coatings along joints and on quartz grains in calcrete and underlying clays. Caps of opaline silica on uraniferous calcrete may be fluorescent (for example, Yinnetharra area). At Minindie Creek, carnotite is disseminated in the calcrete and underlying clays to a depth of 3.5 m.

Southeast of Injinu Hills, carnotite has been found at shallow depth in joint, exfoliation, and schistosity planes in deeply weathered granitoid and quartz-mica schists. Uranium mineralization has also been found in clays and calcareous soils overlying mottled saprolite.

Zoned pegmatite may also contain primary uranium and rare-earth minerals. Euxenite occurs as pods and discrete blebs. Pitchblende, beta-uranophane, and gummite have also been reported (Table 3). Such occurrences, together with anomalous radioactivity of some gneiss and granitoid (for example, *Ꝑgla, Ꝑnb*) point to the probable source for the uranium in calcrete.

Regionally, the uranium-bearing pegmatite forms two arcuate belts, situated within or near Proterozoic migmatite in the Morrissey Metamorphic Suite. The major belt stretches from the Thirty-one River area, to south of White Well, hence southeasterly to just west of Injinu Hills. The lesser one extends west-northwesterly from the Wabli Creek area to south of Pyramid Hill. Between these two belts, and partly enclosed by them, is the augen gneiss (*Ɇgla*), which has above average background radioactivity. The basement gneisses probably were the source rocks for the Proterozoic clastic rocks which were subsequently metamorphosed and migmatized to form the Morrissey Metamorphic Suite, and it is feasible that uranium could become concentrated during this cycle.

TABLE 3

LOCATION OF URANIUM MINERALIZATION—TYPE OF DEPOSIT

Dissected valley calcrete	Trunk valley calcrete	Older colluvium calcareous soils weathered bedrock	Pegmatite-ferruginous veins
1 km E Victory Bore 3 km NNE Yinnetharra homestead 3 km E Yinnietharra homestead 1 km S Doweranin Bore 1 km W Mutherbukin Pool 2 km N Mutherbukin Pool 2 km SE Mango Bore, Minindi Creek prospect 3 km W Daly Bore 4 km SE Cobra Well 5 km E Police Station woolshed 13.5 km SW Daly Bore 9.5 km SW Daly Bore 11.5 km SW Daly Bore 5 km ENE Mt James 2 km NW Madonga Pool 7.5 km N Mt Steere 3 km E Ted Well 9.5 km NE Mt James 5 km S No. 2 Bore (Mt Phillips Stn) 6.5 km SSE Camel Hill 3 km S Stiles Bore 1 km N Minneritchie W (Alm) 1.3 km ESE Dry Corner Bore 4 km SE Rubberoid Well 3.5 km SW Kendall Well 2.5 km SW Frog Well	Jamieson Well area 13 km NW Jamieson Well (Spring Creek)	2 km NW Mummill Well 3 km NW Mummill Well 10-15 km ESE Injinu Springs (4 prospects) 10 km NE Injinu Springs (2 prospects) 6 km NW Bustler Well 2.5 km NW Kendall Well 6.5 km SW No. 2 Bore (Mt Phillips 37 m (2 prospects)	2.5 km E Mummill Well (beta-uranophane) 2 km W Nardoo Hill Well (euxenite) 13 km SW Daly Bore (euxenite) Wabli Creek 4.5 km E Court Well (gummite-pitchblende) 5 km NE Court Well (gummite-pitchblende) 2.5 km NNE Minneritichie Well (euxenite) Ted Well area (pitchblende-euxenite) 2 km E No. 2 Well (Mooloo Downs) 6 km ENE Tobin Well (euxenite)
Carnotite	Carnotite	Carnotite	Euxenite, pitchblende, gummite beta-uranophane
Secondary mineralization	Secondary mineralization	Secondary mineralization	Primary mineralization

The zoned pegmatite carrying the primary uranium minerals post-dates the migmatization of the metamorphic rocks and seems to be genetically related to the tourmaline granitoid plutons (*Ꝑgve, Ꝑgvl*) of the Nardoo area. It is suggested that the uranium in the pegmatite resulted from scavenging and enrichment by hydrothermal solutions from the Morrissey Metamorphic Suite.

The proximity of the uranium-bearing pegmatite to the calcrete uranium prospects suggests that the pegmatite contributed uranium to the secondary deposits. The Minindi Creek and Wabli Creek occurrences are good examples of this relationship.

Rare earths

Rare earths in euxenite have been recorded from pegmatites 2 km west of Nardoo Hill Well, 13 km southwest of Daly Bore (Wabli pegmatite), 6 km east-northeast of Tobin Well, and 2.5 km north-northeast of Minneritchie Well.

Anomalous rare-earth values have also been obtained from alkaline anorthositic gneiss 2 km northwest of Peak Bore, 3 km southwest of Yinnetharra homestead, and 4.5 km northwest of New Well (*see* partial analysis, Table 1).

Pegmatite minerals

The Yinnetharra district is well known for the production of mica (muscovite), beryl, and bismuth. Muscovite in pegmatite was first recorded by Woodward (1890). However, production occurred only between 1939 and 1944 and in 1949, and resulted in 11.23 t of mica. Maitland (1909), Wilson (1923, 1927), Ellis (1941b), and Matheson (1944, 1945a) have all reported on the deposits.

The muscovite was mined from shallow open cuts in zoned pegmatites, which consist of quartz, albite, microcline, accessory tourmaline and beryl, and patchy magnetite, bismutite, biotite, tantalite-columbite and uranium-rare-earth-bearing minerals.

The bulk of the muscovite production came from pegmatites in the Proterozoic migmatite (*Ꝑmb*) at the Morrissey Hill and the Cairn mining centres. Muscovite has also been prospected 3.5 km north of Daly Bore, 3.5 km west-northwest of New Well, and 7.5 km northeast of Pyramid Hill.

Most muscovite mines have produced some beryl, largely from eluvial deposits surrounding the pegmatite (Owen, 1944; Matheson, 1945b). However, beryl has also been found in pegmatite away from the main muscovite prospects. Pegmatites that contain beryl and small amounts of euxenite, pitchblende, and gummite are common between the Thirty-three River and the western end of Injinu Hills. Beryl has also been recorded from the Wabli Creek area and from a prospect 6 km east-northeast of Tobin Well.

Beryl production has been intermittent. A total of 20.569 t of BeO from 169 t of ore was produced during the periods 1943 to 1944, 1949 to 1954, and 1959 to 1962.

The Yinnetharra district has been the major bismuth producer of Western Australia. Bismutite, was recovered mainly from eluvial deposits adjacent to the muscovite- and beryl-bearing pegmatites of the Cairn mining centre and Morrissey Hill areas (Ellis, 1940, 1941a). A total of 7 311.8 kg of bismuth ore has yielded 4 601.6 kg of bismuth metal.

A rare bismuth mineral, clinobisvanite (monoclinic $BiVO_4$), has been found in pegmatite 6 km north-northeast of Tobin Well. It is associated with beryl, spessartine, and bismutite (Bridge and Pryce, 1974).

Small parcels of tantalite-columbite ore have come from the Cairn mining centre and from 1.5 km east of Nardoo Hill Well (Miles and others, 1945). The material is derived entirely from eluvial deposits adjacent to muscovite- and beryl-bearing pegmatite. Total production amounted to 1.21 t yielding 759.1 kg of $(Ta,Nb)_2O_5$. Renewed operations at the Cairn mining centre in 1979-80 have produced a further 3.007 tonnes of concentrates averaging 19 per cent Ta_2O_5 from eluvial deposits. Tantalite-columbite has also been recorded from pegmatites 6 km north-northeast of Tobin Well.

Scheelite

Scheelite has been identified in skarn-like assemblages associated with the calc-silicate and marble units (*Pnc*, *Pnm*). Scheelite mineralization has been found 3.5 km south-southwest of Frog Well, 1 km northwest of O'Connor Well and just north of Mick Well.

Gemstones

The Yinnetharra district is widely known for specimen-quality minerals and semi-precious gemstones. Dravite crystals (brown magnesium-rich tourmaline) have been obtained from an open cut 9 km north of Yinnetharra homestead. The recorded production is 8 640 kg. The dravite occurs in zones parallel to the schistosity in a phlogopite schist within augen gneiss (*Pgla*). Black dravite in hydrophlogopite schist has been prospected 1.5 km to the north.

Dravite has also been reported from a number of localities in the Proterozoic migmatite between Thirty-one River and Morrissey Creek.

Large crystals of black tourmaline (schorl) are a common accessory in late-stage muscovite-bearing pegmatite emplaced in both Proterozoic and Archaean metamorphic rocks. The recorded production from the Cairn mining area is 827 kg.

Good specimens of garnet, staurolite, and cordierite have been found in quartz-muscovite-biotite schists (*Plg*) between White Well and Morrissey Creek.

A total of 4 163 kg of amethyst has been produced from a small prospect 5 km south of Leake Spring. Poor quality amethyst has been recorded 3.5 km southwest of Gillie Bore, and rose and smoky quartz 5.5 km south-southwest of Gillie Bore. Rose quartz has also been found 8 km southwest of Gillie Bore and at the Cairn mining centre.

The amethyst, rose quartz, and smoky quartz are found in quartz segregations in zoned pegmatite bodies. The amethyst is associated with pegmatite which lies near manganese-stained calc-silicate and marble palaeosomes of the Proterozoic migmatite.

ECONOMIC POTENTIAL OF PALAEOZOIC ROCKS

No significant base-metal mineralization has been recorded within that part of the Carnarvon Basin on MOUNT PHILLIPS. No potential petroleum source or reservoir rocks are likely to be at depth.

The only prospective coal unit is the Billidee Formation, but it is unlikely that significant coal measures are present because of the formation's tidal and subtidal environment.

The paralic Moogooloo Sandstone is prospective for uranium, but the relatively cold climate during the Artinskian (Williams and others, 1980) lessens the chances of economic mineralization.

WATER

Stock and domestic water supplies are drawn from 205 wells and 97 bores. Water quality ranges from 100 mg/L to 15 000 mg/L TDS. However, 82 per cent of the wells and bores contain less than 5 000 mg/L TDS.

Most wells and bores have been sunk in or adjacent to drainage lines in consolidated colluvium and alluvium (*Czc*). Buried trunk valley calcrete, such as at Jamieson Well, yields suitable stock water, but the dissected calcrete along much of the Gascoyne River has limited yields. Average depths of wells is 10 to 20 m but bores extend to 45 m.

Stock and domestic water is obtained from sandstone intervals in the Permian Lyons Formation. The Permian Moogooloo Sandstone provides moderate supplies of potable water at Tallangatha outcamp.

The Gascoyne, Thomas and Lyons Rivers all contain scattered semi-permanent pools. Rock holes are common in the strongly dissected drainages between the Thomas River and Mount James homestead. Twenty-four pools and seven active springs were located during the mapping programme.

APPENDIX

LOCALITIES MENTIONED IN TEXT

PLACE NAME	LATITUDE (S)	LONGITUDE (E)
Alston Well	24°13′15″	116°31′45″
Arthur River outcamp	24°42′30″	115°44′45″
Bangemall mining centre	24°12′15″	116°27′15″
Bassit Bore	24°19′15″	116°27′00″
Bluebush Well	24°09′45″	115°45′15″
Bustler Well	24°47′15″	116°57′30″
Cairn mining centre	24°30′00″	116°04′00″
Camel Hill	24°36′45″	116°22′15″
Clever Mary Hills	24°50′30″	116°46′15″
Cobra homestead	24°12′15″	116°51′30″
Codra Well (4 km SE)	24°46′00″	116°20′30″
Coondoondoo Hills	24°48′15″	116°51′30″
Corktree Bore	24°39′45″	115°42′45″
Court Well (4.5 km E)	24°38′15″	116°22′15″
Daly Bore	24°49′00″	116°22′30″
Deep Well (Yinnetharra Stn)	24°46′45″	116°27′45″
Deep Well (1 km SW) (Mt Augustus Stn)	24°02′30″	116°41′15″
Della Well	24°42′45″	116°09′45″
Democks Well	24°37′30″	115°30′00″
Doweranin Bore (1 km S)	24°41′00″	116°13′45″
Dry Corner Bore	24°05′30″	115°56′30″
Dunnice Well (4 km W)	24°16′30″	116°38′45″

PLACE NAME	LATITUDE (S)	LONGITUDE (E)
Frog Well (2.5 km SW)	24°49′45″	115°56′30″
Gillie Bore (3.5 km SW)	24°41′30″	116°25′30″
Gubbiddy Well	24°54′30″	115°40′30″
Hart Bore	24°01′00″	116°22′00″
Injinu Hills	24°45′15″	116°33′15″
Injinu Springs	24°46′45″	116°31′45″
Jamieson Well area	24°08′15″	116°32′30″
Jamieson Well (13 km NW) (spring Creek)	24°03′00″	116°27′30″
Kendall Well (2.5 km NW)	24°24′45″	116°27′45″
K25 Hill	24°51′00″	116°01′30″
Leake Spring (5 km S)	24°30′15″	116°33′45″
Lockier Range	24°32′45″	115°54′30″
Lockwoods (3.5 km N Daly Bore)	24°47′15″	116°22′00″
Lucky Well	24°44′30″	116°23′45″
Madonga Pool	24°54′15″	116°28′30″
Mango Bore (2 km SE) (Minindi Creek Prospect)	24°49′00″	116°13′45″
McCarthy Fine (14 km NW of Bangemall mining centre)	24°07′15″	116°22′00″
McCarthy Well	24°34′15″	115°46′15″
Megan Bore	24°35′00″	116°39′00″
Mick Well	24°52′45″	116°02′00″
Middle Spring	24°43′00″	116°52′00″
Midway outcamp	24°35′00″	116°39′15″
Minneritchie Well	24°43′45″	116°20′00″
Minniarra Rock Hole	24°41′15″	116°47′00″
Minnie Creek	24°01′45″	115°41′45″
Minnie Creek homestead	24°02′00″	115°41′30″
Moran Well	24°27′30″	116°09′15″
Morrissey Hill	24°32′30″	116°10′30″
Mount Augustus	24°18′30″	116°50′15″
Mount Gascoyne	24°57′30″	116°38′15″
Mount Genoa	24°24′30″	116°59′00″
Mount James	24°52′15″	116°28′00″
Mount James homestead	24°51′30″	116°53′30″
Mount Observation	24°26′00″	116°40′30″
Mount Phillips	24°21′30″	116°30′15″
Mount Phillips homestead	24°24′00″	116°18′30″
Mount Steere (7.5 km N)	24°55′30″	116°21′45″
Mulka Well	24°48′15″	116°02′30″
Mullet Well	24°16′45″	115°53′30″
Mummill Well (2 km NW)	24°33′15″	116°16′00″
Murrumburra Pool	24°38′00″	116°29′45″
Mutherbukin Pool (1 km W)	24°46′15″	116°14′00″
Nardoo Well	24°28′00″	116°06′15″
Nardoo Hill Well (1.5 km E)	24°31′00″	116°06′45″
New Well	24°28′00″	115°58′30″
Nine Mile Bore	24°56′00″	115′59°30″
Number 1 Bore	24°49′30″	116°51′45″
Number 2 Bore (Mt Phillips) (5 km S)	24°36′45″	116°31′15″
Number 1 Well (Kingfisher mine) (3 km E)	24°55′15″	116°10′45″

PLACE NAME	LATITUDE (S)	LONGITUDE (E)
Number 2 Well (Mooloo Doowns) (2 km E)	24°55′45″	116°14′00″
Number 6 Bore	24°31′45″	115°50′45″
O'Connor Well	24°29′15″	116°27′30″
Paddy Well	24°47′15″	115°44′30″
Peak Bore	24°21′30″	115°50′15″
Pink Hills Bore	24°34′28″	116°55′45″
Pink Hills	24°37′15″	116°56′00″
Police Station woolshed	24°43′45″	116°15′00″
Pyramid Hill	24°41′30″	115°51′45″
Reid Well	24°30′45″	116°18′45″
Ring Well	24°54′15″	116°06′15″
Robinson Bore	24°31′30″	115°58′45″
Rubberoid Well (4 km SE)	24°53′00″	116°59′00″
Salt Well	24°38′00″	115°42′45″
Saucepan Bore	24°38′00″	116°35′30″
Shot In Well	24°43′15″	116°58′30″
Spring Camp outcamp	24°54′50″	116°34′50″
Stiles Bore	24°26′00″	115°49′45″
Tabletop Well	24°01′15″	116°17′30″
Tallangatta outcamp	24°59′45″	115°32′15″
Ted Well area	24°50′30″	116°09′30″
Ti Tree Well	24°21′15″	116°03′45″
Tobin Well (6 km NNE)	24°44′15″	115°51′45″
Tommie Well	24°20′15″	115°54′00″
Toohey Well	24′29°00″	116°18′30″
Top Spring	24°43′15″	116°52′00″
Victory Bore (1 km E)	24°36′00″	116°08′30″
Wabli Creek	24°52′30″	116°17′30″
White Bore	24°12′15″	116°21′45″
Yinnetharra homestead	24°39′00″	116°09′45″

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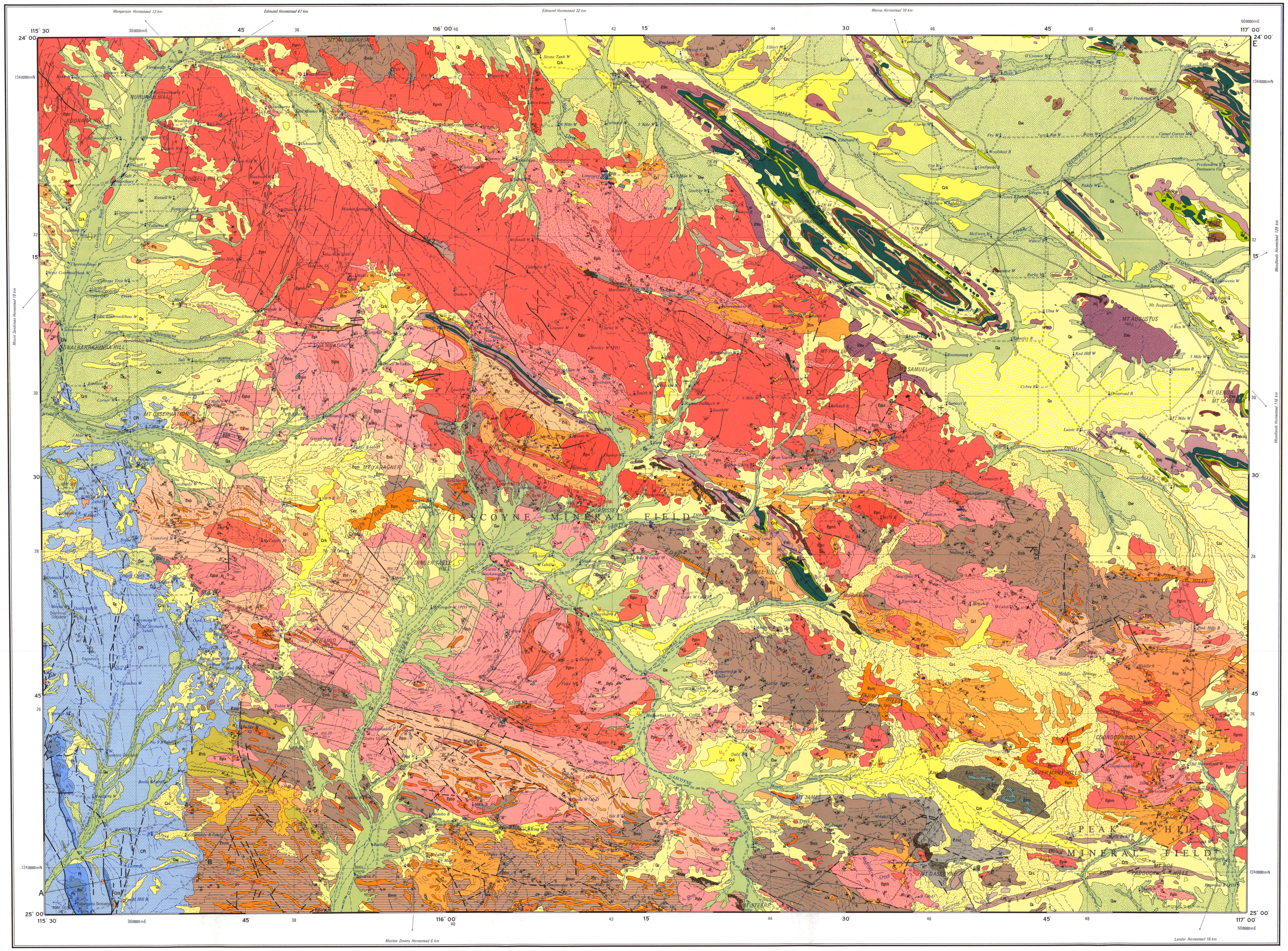
MT PHILLIPS

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

AUSTRALIA 1 : 250 000 GEOLOGICAL SERIES

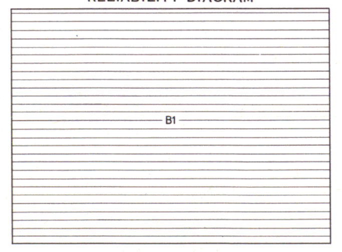
SHEET SG 50 - 2



Compiled and published by the Geological Survey of Western Australia. Cartography by the Geological Mapping Section, Department of Mines. Topographic base from compilations by the Department of Lands and Surveys.

Copies of this map may be obtained from the Geological Survey of Western Australia, 66 Adelaide Tce., Perth.

RELIABILITY DIAGRAM



B1 Numerous traverses with air photo interpretation

HON. P. M'C. DOWDING, M.L.C.
MINISTER FOR MINES
A.F. TRENDALL, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1:250 000

0 5 10 15 20 25 30 Kilometres

TRANSVERSE MERCATOR PROJECTION
ZONE 50 AUSTRALIAN MAP GRID

INDEX TO ADJOINING SHEETS

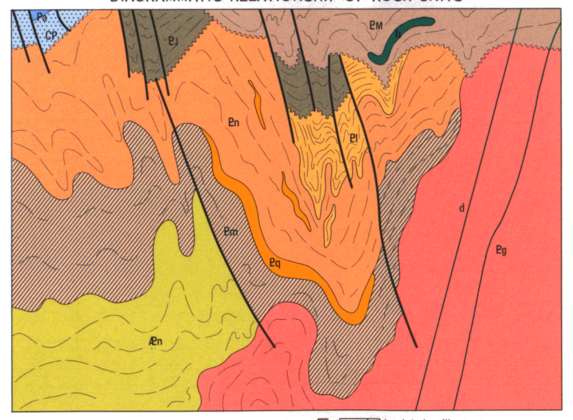
WINNING POOL SF 50 - 13	EDMUND SF 50 - 14	TUREE CREEK SF 50 - 15
KENNEDY RANGE SG 50 - 1	MT PHILLIPS SG 50 - 2	MT EGERTON SG 50 - 3
WOORAMEL SG 50 - 5	GLENBURGH SG 50 - 6	ROBINSON RANGE SG 50 - 7

Geology : Carnarvon Basin — R.M. Hocking, W.J.E. van de Graaff 1976
Bangemall Basin — P.C. Muhling, W.A. Davidson, A.T. Brakel 1973
Gascoyne Province — S.J. Williams 1976-77, 1980, R.J. Chin 1976-77, I.R. Williams 1976

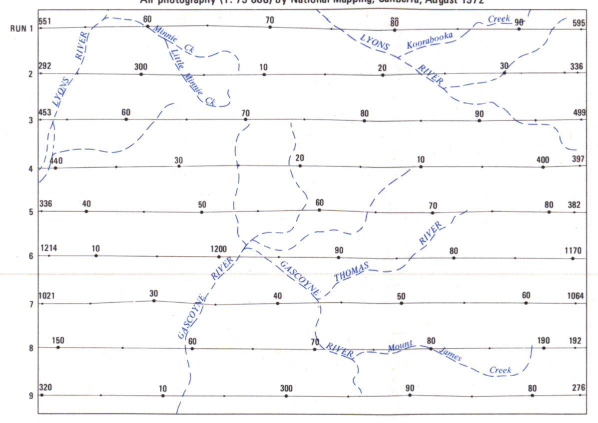
DECLINATION DIAGRAM

The lines indicate magnetic declination, 1980
+ means declination is east and correction must be added to compass bearing to give true bearing
— means declination is west and correction must be subtracted from compass bearing to give true bearing
Annual change is — 2′ westerly

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



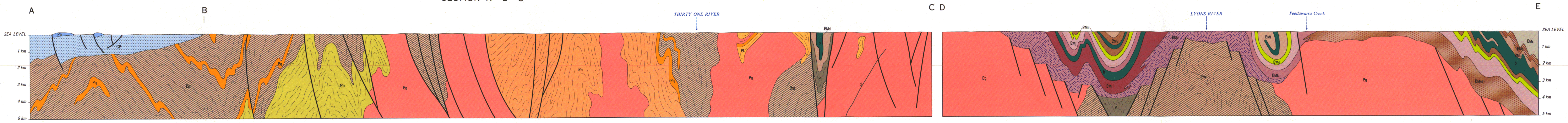
FLIGHT DIAGRAM



DIAGRAMMATIC SECTIONS

SCALE V/H = 2

SECTION A - B - C SECTION D - E



REFERENCE

QUATERNARY

Qa Alluvium—unconsolidated silt, sand and gravel associated with watercourses
Qw Alluvium—unconsolidated silt and sand in sheet-wash and piedmont plains overlying Tertiary hardpan surfaces, often with banks of windblown sand
Qc Colluvium—unconsolidated silt, sand, gravel and rubble forming scree or talus slopes
Qs Eolian and residual sand

Czn **NADARRA FORMATION :** lacustrine limestone, includes minor calcrete

TERTIARY

Czc Hardpan—consolidated and semi-consolidated colluvium and alluvium, silt, sand, gravel and rubble, commonly dissected
Czk Calcrete and kankar, in part replaced by opaline silica
Czl Laterite and ferruginous deposits
Czb Silcrete and intensely silicified sandstone
Czd Chalcedonic capping on dolomite

PERMIAN — ARTINSKIAN — Wooramel Group

Pb **BILLIDEE FORMATION :** quartz sandstone and siltstone commonly with calcareous cement, rare glacial erratics; shallow marine

Pm **MOOGOOLOO SANDSTONE :** quartz sandstone and siltstone minor conglomerate, rare glacial erratics; fluviatile to shallow marine

SAKMARIAN

Pc **CALLYTHARRA FORMATION :** hard and soft fossiliferous calcarenite, calcisiltite and siltstone; shallow marine

LATE CARBONIFEROUS

CPl **LYONS FORMATION :** glacigene sandstone, siltstone and tillite, rare varves; continental to marine

Cla **Austin Member** : quartz sandstone to feldspathic arenite; ? shallow marine basal member of Lyons Formation

b : Dolerite sill; d : dolerite dyke (may be weakly altered) (age variable)
q : Quartz vein; qf : vuggy quartz vein may contain fluorite (age variable)

MIDDLE PROTEROZOIC — Bangemall Group

ᵽMs **FORDS CREEK SHALE :** green to dark grey shale, minor arenite and siltstone

ᵽMc **COODARDOO FORMATION :** moderate to poorly sorted grey arenite, with minor siltstone and shale towards base

ᵽMu **CURRAN FORMATION :** white shale, siliceous in outcrop

ᵽMl **ULLAWARRA FORMATION :** fine-grained, maroon or grey arenite with siltstone shale, minor dolomite

ᵽMv **DEVIL CREEK FORMATION :** dolomite, dolomitic shale

ᵽMd **DISCOVERY CHERT :** bedded, black to cream chert, may be wavy bedded, and laminated

ᵽMj **JILLAWARRA FORMATION :** shale and siltstone with minor chert

ᵽMk **KIANGI CREEK FORMATION :** medium-grained arenite with shale, coarse-grained arenite beds and pebble beds

ᵽMk(d) Dolomite unit

ᵽMi **IRREGULLY FORMATION :** dolomite, with shale and minor arenite, stromatolites present

ᵽMi(s) Shale unit

ᵽMa **MT AUGUSTUS SANDSTONE :** coarse-grained quartz arenite, minor conglomerate

ᵽM(a) Sandstone
ᵽM(s) Shale
ᵽM(r) Conglomerate
ᵽM(d) Dolomite
ᵽM(c) Chert

MOUNT JAMES FORMATION
ᵽJ(a) Metamorphosed, foliated quartz arenite, with thin metaconglomerate lenses in some areas
ᵽJ(r) Metaconglomerate, polymictic
ᵽJ(p) Phyllite
ᵽJ(c) Metamorphosed chert and cherty, graphitic shale commonly ferruginous, contains grunerite and garnet
ᵽJ(i) Interbedded micaceous metasandstone and metasiltstone, commonly garnetiferous

ᵽdm Metadolerite or metagabbro, dyke or sill (age uncertain)
ᵽu Tremolite (- chlorite) rock, ultramafic dyke (age uncertain)
pv Pegmatite dyke with tourmaline and beryl (age uncertain)

ᵽgbr ᵽgbm ᵽgvl ᵽgvm ᵽgve ᵽglb ᵽgbt

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