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SOUTHERN CROSS

WESTERN AUSTRALIA

SHEET SH50-16 INTERNATIONAL INDEX

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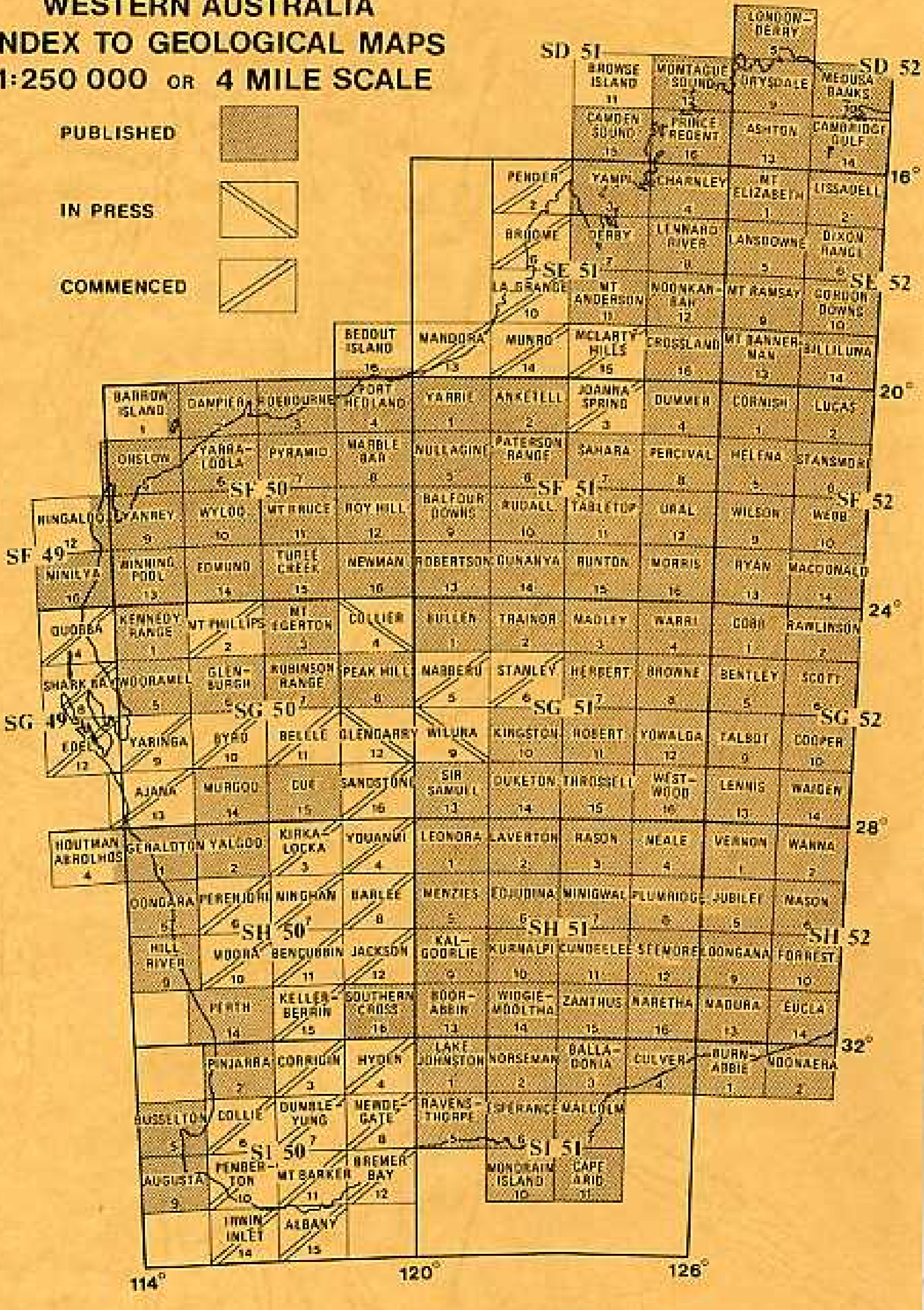

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1:250 000 GEOLOGICAL SERIES—EXLANATORY NOTES

SOUTHERN CROSS

WESTERN AUSTRALIA

SHEET SH50-16 INTERNATIONAL INDEX

COMPILED BY R. D. GEE

PERTH, WESTERN AUSTRALIA 1982

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Explanatory Notes on the Southern Cross Geological Sheet

Compiled by R. D. Gee

INTRODUCTION

The SOUTHERN CROSS* sheet, bounded by latitudes 31° and 32° south, and longitudes 118°31′ and 120° east, lies in the Yilgarn District just inside the eastern edge of the wheat belt. It is crossed by the Great Eastern Highway, the standard gauge Perth to Kalgoorlie railway, and the Eastern Goldfield water supply pipeline, all of which are connected to the town of Southern Cross (population 880 in 1976). The western part of the sheet is under cultivation for crops and is serviced by many sealed and graded roads. The eastern part is mostly uncleared vacant crown land, which has been used for mining and timber gathering. This eastern part supports heath on sand plains, woodlands in valleys, and halophytes around salt lakes.

Gold is reported to have been discovered by prospectors Toomey and Riseley at the Yilgarn Hills in 1888, but the first claim in the area was pegged that year by Hugh Fraser, at what has become known as the Frasers Mine. This initial discovery was quickly followed by many others along the length of the greenstone belt, and the Yilgarn Goldfield was proclaimed in the same year.

Rich gold discoveries at Coolgardie in 1892 and Kalgoorlie the following year largely emptied Southern Cross of its mining fraternity, and, following the construction of the railway from Perth to the Eastern Goldfields, the town became a relatively small gold centre.

The total gold production of the whole sheet is 47 331 kg, most of which was achieved before 1910 (compared with 1.186 million kg from the Golden Mile and Kalgoorlie). Agriculture displaced gold mining as the major industry in the early 1910s, and, although there have been several revivals in gold mining, this predominantly agricultural role persists to the present. There is a Government battery at Marvel Loch, and the present small gold production is by individuals and syndicates.

HISTORY OF GEOLOGICAL INVESTIGATIONS

The first regional geological studies of the Yilgarn Goldfield were the bulletins of Woodward (1912), Saint-Smith and Farquharson (1913), and Blatchford (1915). Further surveys approximately 25 years later resulted in the bulletins of Ellis (1939), Matheson and Hobson (1940), Hobson and Matheson (1940) and Matheson (1947). These bulletins remain valuable sources of detail on the gold mines, most of which are now inaccessible, and they also provide extensive bibliographies of previous work in the area.

The word *Yilgarn*, which derives from this area, is a well-known name in Western Australian geology. It was first applied, in a geological sense to the metasedimentary rocks in the Southern Cross greenstone belt, which were called the "Yilgarn Series" by Clarke (1923). He considered them to be the oldest rocks in the Precambrian Shield, older than the so-called "Kalgoorlie Series", which was predominantly igneous. Following the survey of Ellis (1939), who recognized that the metasediments, which he termed the "Whitestone Series", were younger than the igneous "Greenstone Series", the term "Yilgarn-Kalgoorlie Series (or System)"

* Sheet names are printed in full capitals to avoid confusion with identical locality names.

became fashionable as the stratigraphic term for all the Archaean layered sequence in the Yilgarn and Eastern Goldfields. With the realization that Archaean stratigraphy is complex, and requires far more detailed mapping, this stratigraphic term is now obsolete, although it still does appear in some contemporary geological literature.

The term *Yilgarn* was also borrowed by Andrews (1938) who used the name Yilgarnia for the oldest structural unit of the Australian continent, a term adopted by David (1950). With the more precise definition of the area of Archaean rocks, this region variously became known as the Yilgarn Nucleus, Shield, Craton, and at present, Block.

SOUTHERN CROSS lies in the central part of the Yilgarn Block, and is entirely underlain by Archaean granitoid and greenstone. Its geological interest lies in a comparison of the greenstones with those in the Eastern Goldfields.

Since the geological surveys of the late 1930s, SOUTHERN CROSS has received surprisingly little attention. Miles (1946) based some of his classic paper on metamorphosed banded iron-formations on the jaspilites of the area. Wilson (1953) described some metamorphic rocks from Nevoria. The regional structure and mineralization of the Marvel Loch-Bullfinch area was reviewed by Clappison and Zani (1953) and by Williamson and Barr (1965). Some reports which deal with specific gold occurrences are included in the selected references. Intense but unsuccessful exploration was undertaken in the late 1960s and early 1970s for nickel and base metals, and some of these data are on open file in the Geological Survey. Hallberg (1976) included the Southern Cross area in his petrochemical study of part of the Yilgarn Block, and presented chemical analyses of various amphibolities. An aeromagnetic survey has been carried out by the Bureau of Mineral Resources.

PHYSIOGRAPHY AND CAINOZOIC GEOLOGY

SOUTHERN CROSS lies in the vast area of internal saline drainages on the great plain which is the easterly continuation of the Darling Plateau (Fig.1). The altitude above sea level ranges from 410 m in the west to 455 m in the east, and the hills and "mountains" are the result of dissection of an old erosional surface. This was a gently undulating lateritic duricrust surface completely covering the area, but about half has been removed by Quaternary erosion. The remnants of this blanket are expressed as gently rolling sandplain, small plateaux of laterite above breakaways, and gently inclined laterite slopes passing down into the valleys.

The broad valleys lie about 80 m below the level of the interfluves, and usually lack clearly defined watercourses. Alluvium and colluvium of sand and clay-loam occur in the upper reaches, but the main drainages are marked by strings of clay pans and salt lakes, surrounded by alluvial flats of saline and gypsiferous clays. These valleys drain into a major westerly flowing salt-lake system that incorporates Lakes Seabrook, Deborah and Campion, north of the sheet boundary. Only after extremely heavy rain is there any surface flow in these drainages, but the groundwater underflow must be substantial. In the upper reaches of the tributaries, the groundwater tends to be fresh, but it rapidly becomes highly saline and unusable downstream.

Between the valley floors and the elevated plains are gently inclined areas of currently active sheetwash erosion; it is in these areas that much of the laterite is stripped off and rock exposures are found. In granite country, bold monoliths or flat pavements occur. In greenstone country, elongate subdued hills and occasional rugged strike ridges are formed.

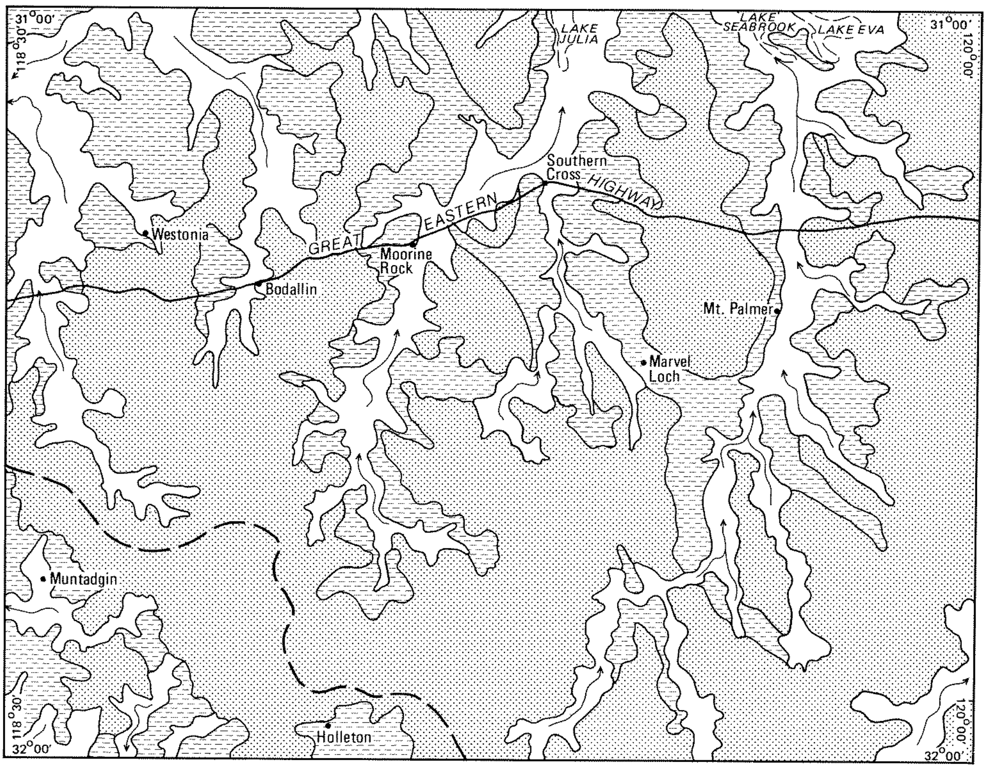

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FIGURE 1

PHYSIOGRAPHY AND DRAINAGE

SOUTHERN CROSS SH 50-16

0 10 20 30 km

REFERENCE

- Remnant of once-continuous blanket of laterite and sandplain developed on old peneplain
- Areas of colluvium and sheetwash where laterite mostly removed, by erosion, exposing scattered bedrock
- Drainage areas — alluvium and saline mud
- Watercourse
- Main water divide

The tertiary units (*Tl* and *Ts*) on the geological map are remnants of the blanket of lateritic duricrust. Included in the laterite unit (*Tl*) are silcrete, indurated cellular limonite and aluminous material, and friable pisolitic gravel. This unit is transitional upward into the sandplain unit (*Ts*), which may contain scattered pisoliths; it is the top part of the duricrust profile and probably represents deeply leached fossil soils (Carroll, 1939). Most of this unit has been stripped off, and the remaining deposits are confined to the higher hills on the interfluves.

Laterite is not strictly confined to the interfluves, but extends down into the valley floors, apparently passing under the valley deposits. This feature is most evident in the easternmost drainage (Fig. 1). It therefore appears that the current drainage follows the ancestral drainage patterns, which are thought to have formed in a pluvial climate in the Mesozoic and which are preserved by the formation in the Early Tertiary of the blanket of lateritic duricrust (van de Graaf and others, 1977).

The Quaternary units are the products of erosion of the lateritic duricrust and underlying rocks. Descriptions of these units are given in the reference of the map.

ARCHAEAN GREENSTONES

EXPLANATION OF TERMINOLOGY

In the greenstone belts of the Eastern Goldfields, the original nature of the rocks is usually recognizable, and it has been the practice on those geological sheets to use igneous and sedimentary nomenclature commonly with the prefix *meta*. In the western part of the Yilgarn Block, the rocks are highly metamorphosed and deformed, and an entirely metamorphic rock terminology is used. SOUTHERN CROSS lies between these two metamorphic environments; all the rocks have medium-grade metamorphic assemblages and metamorphic fabrics, but the original nature of the rocks can be reasonably established or inferred. Metamorphic rock terminology is therefore used, but the units are grouped in the reference in such a way to indicate rock types of pre-metamorphic affinity.

The main classes are ultramafic amphibolite (*Au*), amphibolite of mafic composition (*Aa*), pelitic, psammitic, and calcareous metasediments (*Al*), and metamorphosed iron-formation (*Ai*). Where possible, further subdivision is made on criteria that assist in identifying the original rock. Rock types commonly encountered in the greenstones of the Eastern Goldfields, such as peridotite, pyroxenite, komatiitic basalt, tholeiitic basalt, gabbro, felsic volcanics, pelitic sediments, and banded iron-formation are all represented on SOUTHERN CROSS, and can be identified from the reference of the geological map.

There are, however, some different rock types apparently not encountered on the Eastern Goldfields, such as the fine-grained mafic and ultramafic para-amphibolites (*Aap*), which are related to jaspilite, and possibly have a chemogenic component; and the calc-silicate metasediments that may perhaps have been dolomite.

ULTRAMAFIC AMPHIBOLITES

Peridotite (*Aup*), similar in appearance to the lenses of the Norseman-Wiluna Belt, occurs only in the extreme northern part of the Southern Cross greenstone belt, between Corinthian and Bullfinch. These rocks are serpentinized, but granular textures of palimpsest primary olivine are recognized. Talc-carbonate schist, which occurs on the margins of the peridotite, is included in this unit. Exposure is inadequate to determine whether the peridotite is volcanic or intrusive.

Metamorphosed Pyroxenite (*Aux*) occurs throughout the Southern Cross greenstone belt, and seems to have been emplaced largely to the exclusion of peridotite. It occurs as coarse-grained, tabular, sill-like bodies, from a few metres to hundreds of metres thickness. They generally lack compositional banding or any evidence of differentiation, are weakly foliated, and consist of interwoven coarse-bladed metamorphic tremolite. Accessory minerals include spinel, magnetite and sphene. Commonly, tremolite encloses remnants of primary salitic clinopyroxene, and appears to have pseudomorphed large prismatic clinopyroxene crystals up to 10 mm long.

Coarse-grained chlorite-tremolite (anthophyllite-olivine) rock (*Aur*) includes a variety of coarse-grained ultramafic amphibolites that may represent metamorphosed and recrystalized peridotite, komatiitic basalt, or even sediments. Most common are those found 5 km east of Nevoria; they are dark-green rocks consisting of coarse tremolite growing in rosettes or with random orientation in a groundmass of chlorite and talc, which usually preserves a metamorphic foliation. These rocks are interlayered with the finer grained ultramafic amphibolites (*Aub*), which are metavolcanics.

In the Marvel Loch area, the coarse ultramafic amphibolite contains metamorphic olivine. In hand specimen, these rocks are recognized by a brownish blotchy appearance. Fresh olivine occurs as remnants in larger, equant, porphyroblastic masses (up to 5 mm in diameter) now mostly composed of antigorite serpentine. The olivine porphyroblasts seem to have grown in a mass of chlorite, tremolite, talc and carbonate. Idioblastic bladed tremolite up to 10 mm long, representing a second metamorphic event has grown across the serpentinized olivine, and much of the first-generation tremolite is also serpentinized.

Excellent samples of metamorphic olivine have been seen in drillcore (Minops D.H.SX—4) from near Bells Find, where bladed idioblastic olivine up to 20 mm long has grown in a random network so as to enclose triangular-shaped areas of talc and tremolite. The olivine, although now extensively retrogressed to antigorite serpentine, had clean sharp boundaries against talc, indicating a talc-olivine paragenesis which is a useful indicator of metamorphic conditions (*see* sect. on metamorphism).

Included in this unit is tremolite-anthophyllite schist, which is recognized in the field by its green-grey colour, and lustrous felted masses of pale acicular amphibole embedded in a normal green tremolite groundmass. Anthophyllite usually occurs as long, idioblastic needles over tremolite, but is also finely intermeshed with tremolite. It may range in abundance from a few needles to a dominant component, even to the exclusion of tremolite. Minor amounts of talc and chlorite occur in the amphibole mesh, but olivine has not been observed in anthophyllite-bearing rocks. Anthophyllite was probably formed by a dehydration reaction from talc, and it coexists with tremolite.

It is likely that these coarse-grained ultramafic amphibolites represent rocks of differing origins such as coarsely recrystallized chlorite-tremolite rocks (*Aub*), and more magnesian rocks such as peridotite. Ellis (1939) records anthophyllite rocks with 47-57 per cent SiO_2, 26-33 per cent MgO, 4-7 per cent total FeO, and very little Al_2O_3, CaO and alkalies.

Fine-grained chlorite-tremolite rocks (*Aub*) are the most abundant type of amphibolite, and together with the fine-grained mafic amphibolite (*Aab*), form a thick pile of metamorphosed mafic-ultramafic volcanics. The chlorite-tremolite rocks are considered to be komatiitic basalts, and deformed pillows are recognizable at a number of localities, for example at 31°24'S, 119°18'30"E. Chemical analyses present by Hallberg (1976) support the idea that they are basaltic komatiite.

The chlorite-tremolite rocks are massive or foliated, dark green, commonly with a pencil lineation. They have a mullion-like outcrop, which may either be due to two foliations, or to the weathering expression of deformed pillows. Small amounts of quartz and plagioclase may be present, but the dominant components are chlorite and tremolite. Two generations of tremolite are usually recognized, the earliest of which forms a fine-grained lepidoblastic interlobate groundmass that defines a metamorphic foliation. Thin trails of quartz and plagioclase augen lie in this foliation. The foliation is generally crenulated into a new cleavage, and the second-generation tremolite is longer, more idioblastic and post-dates the second foliation.

MAFIC AMPHIBOLITES

Fine-grained mafic amphibolite (*Aab*) contains plagioclase, actinolite, hornblende, and subordinate quartz, and is probably mostly derived from tholeiitic basalt. It is distinguished in the field from the ultramafic metavolcanics (*Aub*) by its hard, brittle nature, more vitreous lustre, paler green colour, and platy or blocky outcrop pattern. The chlorite-tremolite amphibolite produces a brown, cavernous, clay soil, which supports gimlet gum; whereas these amphibolites produce a pale-grey soil containing calcareous nodules and support salt-bush vegetation.

In areas of good exposure, pillows can be identified. The best examples are at South Mount Rankin, at points 7 km east-northeast of Holleton, 2 km southeast of Banker Mine, 2 km north-northwest of Harris Find, and at several localities along the salt lake near Mount Palmer. In the open cut of Mount Palmer, strongly lineated and mullioned granoblastic amphibolite is deformed pillow lava. The interpillow material is now expressed as spindles of biotite-chlorite schist several centimetres thick and several metres long. Most of the mafic amphibolite is therefore considered to be metabasalt flows, but some could be metamorphosed dolerite sills.

Chemically (Hallberg 1976), and petrographically, these amphibolites are tholeiitic. The amphibole is variously coloured pale green, olive green, or greenish brown and is optically identified as hornblende. It occurs in prisms, which vary from idioblastic to xenoblastic and poikilitic, and forms a granoblastic mosaic with plagioclase. The plagioclase occurs as clean, fresh and generally untwinned grains. The few occurrences of twinning indicate andesine composition. Subordinate constituents include quartz, epidote in large subidioblastic crystals, red biotite in idioblastic flakes, sphene, and opaques. Biotite is common, and appears to be derived by diffusion from interpillow material in which it is abundant. Carbonate is not common, and is not part of the main metamorphic assemblage; where present, it replaces epidote. Some zones of alteration do occur, for example at the Frances Firness mine where amphibolite is veined with calcite and prehnite, and plagioclase is saussuritized.

Medium-grained hornblende-plagioclase amphibolite (*Aab*) has a distinctive black-and-white spotted appearance due to aggregates of amphibole (up to 5 mm across), which pseudomorph stubby crystals of former pyroxene, in a groundmass of recrystallized plagioclase. Compositional layering is evident at the scale of several centimetres, and this is probably relic igneous layering. This amphibolite occurs in sill-like tabular bodies, and is considered to be metamorphosed gabbro.

Texturally these rocks vary from blastophitic, where some original texture survives, to totally metamorphic. In some specimens, the original calcic plagioclase is still preserved. A good example of a blastophitic meta-gabbro sill is the body that extends for about 25 km within the western edge of the greenstone belt from Hopes Hill to Bullfinch. A good example of a banded, foliated, and lineated granoblastic amphibolite is a large raft, about 35 km long, in granitoid west of Skeleton Rock.

Granoblastic amphibolite of high metamorphic grade (*Aah*) is characterized by medium-grained, completely recrystallized polygonal granoblastic textures, and by the presence of either clinopyroxene or orthopyroxene, or both. This unit occurs in mafic rafts within granitoid, and in the more highly metamorphosed parts of the greenstones. Such rocks occur mainly in the central and southern part of the sheet.

At a locality 4.5 km east-northeast of Skeleton Rock, idioblastic garnet (up to 5 mm in diameter), poikiloblastic clinopyroxene (5 mm) and minor orthopyroxene occur in a polygonal mosaic with twinned plagioclase (An 50-70), green-brown hornblende, and subordinate quartz and opaques. This is a granulite-facies rock of mafic composition, and is a small segment of the metagabbro raft (*Aad*).

At a locality 10 km east of Molthomy Rock, amphibolite contains dark-brown hornblende, plagioclase (An 30-70), quartz, large poikiloblastic clinopyroxene (?augite), hornblende, and small amounts of orthopyroxene. These are also gabbroic rocks metamorphosed to granulite facies. However, more felsic varieties consisting of equal amounts of quartz, andesine and hornblende, occur at this locality. An unusual gneiss associated with these granulites contains about equal amounts of quartz, hornblende and epidote, the latter in coarse xenoblastic crystals. Plagioclase is absent, and may have been altered to epidote, but epidote also appears to pseudomorph euhedral pyroxene.

Also included in this unit are unusual ultramafic and mafic rocks near Heaney Find, which are rich in diopside and which contain uvarovite (chrome-calcium garnet) and relics of orthopyroxene. Coarse, fractured diopside crystals up to 15 mm long, with granulated margins, occur in folded and boudinaged veins in a medium-grained amphibolite of probable metabasalt origin. The diopside veins probably formed during an early metamorphic or metasomatic event. The diopside-talc-uvarovite rock contains 60 per cent diopside in fine-grained talc after orthopyroxene, together with idiomorphic sphene, uvarovite and chromite. The origin of this rock is problematical.

Mafic and ultramafic para-amphibolites (*Aap*) are the most unusual rock types on SOUTHERN CROSS. They outcrop poorly and produce a cavernous red-brown clay soil, and are therefore difficult to distinguish from the metamorphosed komatiitic basalts (*Aab*). Their unusual features are only revealed in old mine workings in the Southern Cross greenstone belt, and their true distribution may be more extensive than shown on the map.

They are characterized by a fine, planar, compositional lamination, which is evident on a scale from a fraction of a millimetre up to a centimetre. The lamination pre-dates the metamorphic fabric, and where it is isoclinally folded, there is an axial-plane foliation. It is considered to be a primary sedimentary lamination. When fresh, they are hard, dark-green fissile amphibolites, usually with a bronze tinge. The rocks are delicately colour banded by laminae of actinolitic hornblende (dark green), diopside (light green), quartz and feldspar (pale cream), and biotite (bronze).

The best examples occur in Frasers opencut where they vary from ultramafic to felsic. One specimen consists of elongate, platy olivine crystals, less than 1 mm wide and up to 8 mm long, aligned and entrained into continuous olivine-rich laminae, which alternate with laminae of tremolite and spongy equant olivine.

Most para-amphibolite in Frasers opencut is fine-grained phyllite containing mostly actinolite and up to 20 per cent each of biotite, plagioclase and quartz, plus minor quantities of opaques, microcline and muscovite. Individual laminae consist of: actinolite and poikiloblastic actinolite with quartz inclusions; quartz in a microcrystalline mosaic resembling chert; quartz-feldspar mosaic; red biotite; and trails of magnetite, which are now included in amphibole. Lamination is also the result of variation of grain size, particularly in the quartz mosaic, and some laminae are only the width of a single grain. Amphibole and biotite are usually aligned in the lamination, but elsewhere may be preferentially aligned at an acute angle to the lamination. Despite deformation and metamorphism, the lamination is delicately preserved even on a microscopic scale.

Various types of para-amphibolite occur in the spoil heaps of old gold mines in the belt between White Horseshoe and Dulcie on the Western side of the Parker Dome. This belt also contains a jaspilite bed. These amphibolites are more coarsely recrystallized, but actinolite and actinolite-plagioclase laminae as thin as 1 mm are seen. Some amphibolite in the Dulcie area contains laminae rich in diopside.

The most significant types in the Dulcie area are those immediately adjacent to the jaspilite, and which are themselves iron-silicate rocks. In addition to actinolite, plagioclase and quartz, up to 30 per cent biotite and 10 per cent calcite are present, potash feldspar occurs in the felsic mosaic, and up to 5 per cent magnetite occurs in trails now poikilitically included in biotite and amphibole.

These para-amphibilites appear to have been fine-grained sedimentary rocks consisting of laminae of iron-magnesium silicate minerals and laminae and pods of microcrystalline chert with feldspar and carbonate. No evidence of clastic or pyroclastic texture is present, but they appear to grade across strike into jaspilite. A chemogenic component can therefore be inferred. These amphibolites do not resemble the para-amphibolite in the Sir Samuel area (Bunting and Williams, 1976) which are associated with arenacious clastics; neither do they resemble mafic and ultramafic fragmental rocks of presumed tuffaceous origin (Hallberg, 1976).

JASPILITE

Jaspilite (*Ai*) occurs as continuous ridges over distances of 30 km throughout the Southern Cross greenstone belt. It occurs within metamorphosed basalt units, and in the para-amphibolite unit. Jaspilite occurs in thin beds, from one to 30 m in outcrop width and finely banded in colours of cream, brown and black. On the surface they consist of chalcedony and martite, with a distinct granular texture resembling quartzite.

The subsurface nature of jaspilite has long been of interest, and Ellis (1939) noted "... only one specimen . . . from the unoxidized zone . . . consisted of . . . bands of quartz . . . alternating with augite . . . with occasional trains of magnetite". Miles (1946) examined further samples from mine workings and drill cores in the Marvel Loch and Mount Palmer areas, recording the abundance of metamorphic grunerite, and noting that magnetite was not the dominant iron mineral. He also recorded the presence of metamorphic olivine, hornblende, garnet and hedenbergite-diopside.

The present investigation seems to confirm that most of the jaspilites are not simply metamorphosed chert-magnetite rocks, that the content of magnetite is no more than 5 per cent, and that even iron-silicate minerals are not unusually abundant.

In the decline working at Dulcie mine, the jaspilite, which can be followed for 25 km as a more-or-less continuous single bed within the para-amphibolite, is itself a finely laminated para-amphibolite containing green-brown hornblende, biotite, epidote, plagioclase, calcite, and sphene. It is devoid of iron oxides. These same rocks, with only a small amount of iron oxides are found below surface level in a number of old workings in the jaspilite.

Mine spoil indicates that the jaspilite which passes through the Nevoria mine includes several varieties. The most iron-rich phase is a grunerite-hornblende rock, which is laminated on a scale of 0.1 to 2 mm. It also contains layers (up to 10 mm thick) of coarse porphyroblastic diopside and garnet. Magnetite occurs in trails of small idiomorphic grains, and amounts to only about 5 per cent of the rock. Other types here include finely laminated hornblende-biotite-plagioclase rocks, with or without calcite, quartz, clinopyroxene and alkali feldspar.

The closest approach to a "normal" Archaean banded iron-formation occurs in the Mount Palmer-Yellowdine area. Fresh surface samples contain predominantly quartz (60%), magnetite (20%) and grunerite (20%). Compositional layering occurs on a scale of 0.5 to 3 mm, and is due to alternations of polygonal-textured quartz and laminae of grunerite. Both types of laminae contain micro-laminae, defined by trails of magnetite in the grunerite, and grain size variations within the quartz mosaic. One sample from 200 m east of the Mount Palmer open cut contains discontinuous laminae of heavily altered orthopyroxene (?orthoferrosilite).

BIOTITE GNEISS

The biotite gneiss (*Anb*) is a strongly lineated gneiss of composition intermediate between felsic and mafic. It is interlayered in the greenstone sequence between Marvel Loch and Frances Firness and in the more highly metamorphosed greenstone remnants at Westonia, Colossus (near Bodallin) and Feldsted Find.

Lineation is primarily due to alignment of spindles of biotite, hornblende and quartzose-feldspathic material. When viewed down the lineation, equant, ovoid, microboudinaged or contorted ribbons are discernible, these being the cross sections of the quartzose-feldspathic spindles sheathed in biotite and actinolite. This is interpreted as a fragmental texture. Lath-shaped mosaics of untwinned plagioclase within the quartzose-feldspathic spindles resemble phenocrysts. Accessory minerals include calcite, epidote and sericite.

Similar gneiss occurs in a band between Hill End and Edna May at Westonia, although the granoblastic textures are coarser and more perfectly polygonal. The fragmental texture has disappeared but the spindles of biotite and hornblende are still conspicuous. These rocks contain a little diopside and metamorphic orthoclase. In an appendix to Matheson (1947, p. 223), Miles called this the "Edna May gneiss" describing it as a "hornblende-biotite-diopside-plagioclase granulite gneiss". It is the host of the main gold mineralization at Westonia.

Excellent exposures of felsic biotite gneiss occur in the railway cutting 6 km west of Bodallin. They are of medium to fine-grained lineated granofels having a compositional banding with spacing of up to one metre. These rocks lack fragmental texture but consist of biotite, hornblende, quartz, plagioclase, microcline and diopside, and are grouped in this unit.

A most significant exposure of this gneiss occurs 6 km at 320° from Bodallin. Sharply defined angular fragments, up to 50 mm across and strongly elongate down the lineation, are composed of quartz-plagioclase mosaic within which palimpsest plagioclase phenocrysts up to 4 mm in diameter are recognized. This rock is completely recrystallized to a granoblastic fabric, and contains garnet. This outcrop is considered to be metamorphosed felsic volcanic agglomerate, and it is likely that much of the biotite gneiss is of that origin.

PELITIC METASEDIMENTARY ROCKS

The pelitic metasedimentary rocks (*Alp*) correspond broadly to the "Whitestone Series" of Ellis (1939), and include a variety of aluminous and ferruginous metasediments. They outcrop poorly on low rounded hills and are invariably deeply weathered, so that, in most cases, their constituent minerals (garnet, sillimanite, andalusite and muscovite) can only be recognized by textures and weathering products. Certain layers are of massive iron sulphide and produce conspicuous gossans, for example at Mount Caudan.

Despite the high grade of metamorphism, many of these rocks lack schistosity, but compositional and grain-size layering on a scale of 0.1 mm to 1 m is common. In many places this layering is disturbed only by boudinage and dislocation on shears at a low angle to the layering. Isoclinal and chevron folds may have an axial-plane foliation.

This layering, therefore, resembles bedding, an inference supported by the identification of graded and cross bedding in the area around Moonagidding Rock and at a point 3.5 km south-southeast of Greenmount. Further indication of original sedimentary texture is provided by reports of conglomerate (Ellis, 1939, p. 71; Blatchford, 1915, p. 44). The only conglomerate noted in this survey occurs at 4.7 km at 350° from Moonagidding Rock. Here, rounded and deformed quartzite boulders up to 0.1 m diameter occur in a pelite.

The most common mineral assemblage in the pelites in the Marvel Loch-Mount Caudan area is quartz-graphite-plagioclase (oligoclase)-muscovite-andalusite-almandine. Almandine occurs in idioblasts up to 5 mm in diameter overprinting the layering and the schistosity. Subidioblastic andalusite, usually crowded with graphitic inclusions in chiastolitic structure, occurs abundantly. Sillimanite, instead of andalusite, occurs 4 km west of Cheritons. Graphite is a significant component, commonly forming laminae up to 2 mm thick, and imparting to the rock a lustrous grey phyllitic appearance.

Iron-rich pelites occur in the Hopes Hill area, and near the rifle butts 5 km west of Southern Cross. These rocks are steel grey in colour, and consist of biotite, almandine, and cordierite, together with quartz and plagioclase. Fine banding in these rocks is due to alternating laminae of quartz-plagioclase mosaic, trails of andalusite, entrainment of biotite, and trails of graphite. Cordierite occurs as large shapeless poikiloblasts. Staurolite has been recorded in these rocks by Ellis (1939) and from drill core by exploration geologists.

A bed of Fe-Mg-Al rich pelite was encountered at Hopes Hill in the pelitic sedimentary (*Alp*) unit. It contains predominantly cordierite and anthophyllite, plus lesser garnet, oligoclase, quartz and biotite.

A more highly metamorphosed iron-aluminium-rich pelite occurs in the western part of the Westonia Belt. It is a bluish-grey granoblastic rock with large, poikiloblastic pink almandine up to 5 mm in diameter, aligned clumps of fibrolitic sillimanite, and large, interlocked cordierite. Cordierite-almandine-sillimanite-quartz is an equilibrium assemblage, and can be used as a precise determinant of metamorphic pressure and temperature conditions (see section on metamorphism).

The pelitic sediments contain stratiform layers of massive pyrrhotite, the most notable being that passing through Mount Caudan and Great Victoria mine. Drilling in 1907 intersected over 30 m of massive pyrrhotite, a 1.5 m band of magnetite, and a 10 m band of iron carbonate. This horizon has been the object of repeated but unsuccessful exploration for gold and base metals.

Calc-silicate rock (*Alc*) occurs within the pelite at Harris Find and Edwards Find, and is probably more extensive than shown on the geological map. On the surface it is a pale-green and grey laminated sediment, resembling the pelites, but lacking their kaolinitic and micaceous nature and iron staining.

Fresh rock is obtained from the two gold mines mentioned above. It is characterized by the abundance of large poikiloblastic diopside, in a fine-grained mosaic of actinolite, plagioclase, quartz, biotite, epidote, microcline, carbonate and sphene. These rocks were siliceous dolomite or dolomitic marl. Simpson (1951, vol. 2, p. 151) gives a chemical analysis of this rock from Edwards Find.

PSAMMITIC METASEDIMENTARY ROCKS

A belt of psammitic schist (*Alm*) between the sheared western edge of the Ghooli Dome, and the metavolcanics of the greenstone belt is unlike any other rock type in the greenstone belt in that it contains abundant coarse muscovite, and seems to represent an arenaceous sedimentary sequence. The micaceous rocks are usually strongly schistose and isoclinally folded, but compositional layering oblique to the earliest foliation is probably remnant bedding. At Derwent Jack, the schist contains feldspar, and because of intense shearing, the contact between the metasediments and schistose granitoid is difficult to locate precisely. Away from the contact, the rocks are sericitic slate or phyllite.

What appears to be one single bed of orthoquartzite lies between the muscovite schist and the metavolcanics. The quartzite has a lepidoblastic fabric, is slightly micaceous, strongly lineated and exhibits a flaggy parting which is mostly planar but in places is curved. This could be deformed vestiges of cross bedding. This quartzite "bed" can be seen at Corinthia, Hopes Hill and at a point 3 km east-southeast of Marvel Loch. Matheson (1947, p. 46) interpreted these rocks as "... partially granitized rocks and bleached jaspilite ...", but they are now regarded as a metamorphosed arenaceous sedimentary sequence.

METAMORPHISM

The significant metamorphic assemblages in different rock suites are described below.

In mafic rocks, the universal occurrence of coloured hornblende and andesine-labradorite plagioclase indicates widespread amphibolite facies. Diopside, as an early metamorphic phase predating the syntectonic development of the plagioclase-hornblende fabrics indicates that the first record of metamorphism was amphibolite facies. Hypersthene in some outlying greenstone remnants indicates true granulite facies.

In ultramafic rocks, the paragenesis of olivine-tremolite-talc indicates temperatures in the range of 500-650°C, and the presence of anthophyllite, although not seen with olivine, could suggest temperatures in excess of 650°C.

In pelites, andalusite is abundant and sillimanite less common. The common paragenesis of almandine-biotite-cordierite with andalusite (or sillimanite) indicates amphibolite facies of a low to moderate pressure series. The most significant co-existing assemblage is quartz-sillimanite-almandine-cordierite, which places the metamorphism at Westonia firmly in the granulite facies. More specifically the distribution coefficients of Fe^{2+} and Mg^{2+} in co-existing garnet and cordierite establish a temperature of 760°C and a pressure of 470 MPa which corresponds to a depth of 17 km.

Regional metamorphism in the Southern Cross greenstone belt is amphibolite facies, but some zones, particularly those on the edges of the belt, indicate amphibolite-to-granulite transition. The outlying remnants of greenstone in the central and western part of the sheet are of granulite facies. Although this is above the beginning of "minimum melting" for pelites, there is no evidence of anatexis or migmatization.

Evidence of polymetamorphism is provided by the ultramafic rocks which presumably recrystallized and retrogressed easily. The earliest metamorphism was synchronous with the main deformation, and the second metamorphism post-dates all deformation. However, the main deformation was apparently not penetrative on a regional scale, and many areas, although folded, have escaped penetrative strain and fabric development. Detailed mapping would be necessary to chart the zones of dynamic and static deformation, but it is apparent that the margins of the Southern Cross greenstone belt are the regional zones, and the felsic volcanics are the local zones, of dynamic metamorphism.

STRATIGRAPHIC SEQUENCE IN THE GREENSTONE

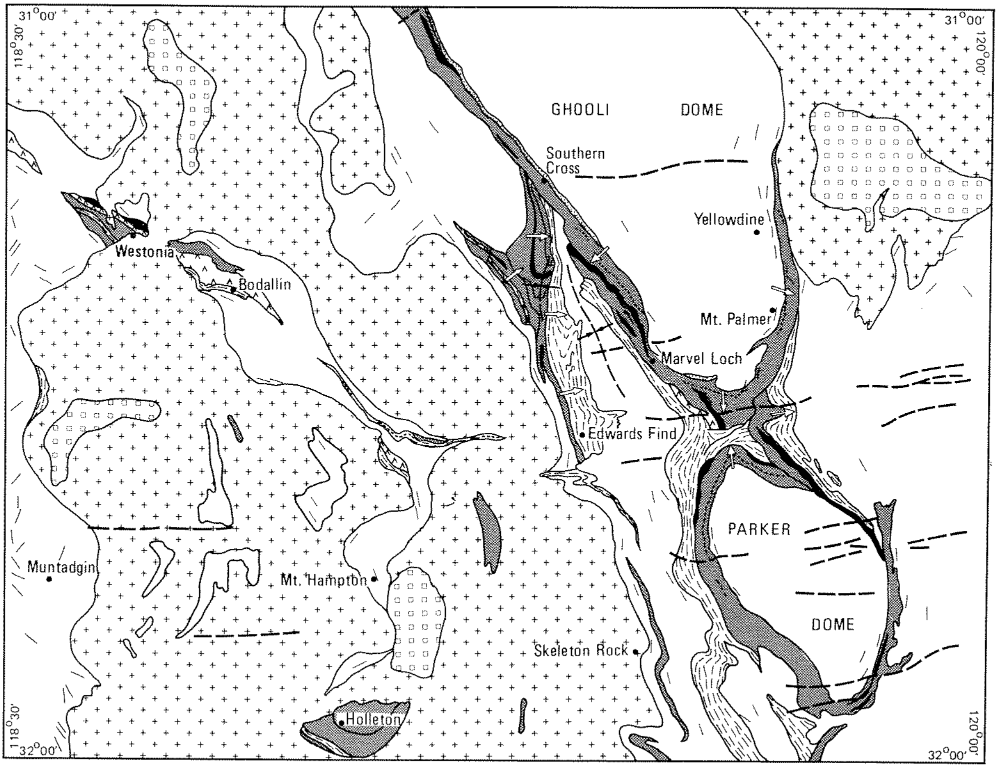
A broad lithological layering, which may have some stratigraphic significance, is evident from the distribution of rock types concentrically around the two granitoid domes (Fig. 2). At the lowermost stratigraphic level is a thin interval of quartz-muscovite schist and quartzite, which occurs in sheared contact with the gneissic granitoid on the western side of the Ghooli Dome. This is overlain, in a structural sense, by a layer of mafic and ultramafic volcanics and related rocks which is 3-5 km thick. At the highest structural levels is the unit of pelitic metasediments, which is also 3-5 km thick.

Ellis (1939) recognized the two major associations, and considered that the mafic unit which he called the "Greenstone Series" was conformably overlain by the pelitic unit which he called the "Whitestone Series". Three lines of evidence from this present survey suggest that the structural layering has stratigraphic significance, corroborating Ellis' stratigraphy.

All sedimentary facings and dips of primary layering are directed away from the dome, and show reversals where major synforms are recognized.

The regionally consistent separation into the two major units over the whole area establishes major sequences of discrete lithogenetic significance. Although the possibility of isoclinal folding and transposition within the major units cannot be ruled out, this does not happen on a regional scale. The thicknesses quoted here are therefore structural rather than stratigraphic thicknesses.

The jaspilites, which have long been used as marker horizons, occur at generally the one structural level within the major unit of mafic-ultramafic volcanics.



GSWA 17947

FIGURE 2

BEDROCK GEOLOGY

SOUTHERN CROSS SH 50 - 16

0 10 20 30
km

REFERENCE

ARCHAEAN

- Porphyritic adamellite — Post-tectonic granitoid
- Adamellite — Post-tectonic granitoid
- Gneiss showing observed trends — Syn-tectonic granitoid
- Pelitic metasediments
- Metamorphosed felsic volcanics
- Mafic-ultramafic metavolcanics
- Jaspilite
- Ultramafic intrusives
- Psammitic metasediments

- Proterozoic dolerite dyke
- Regional facing
- Synform

STRUCTURE OF THE GREENSTONES

The Southern Cross greenstone belt extends the full north-south extent of the sheet, and continues for considerable distances into the adjacent sheets. The most conspicuous features within the belt are the ovoid granitoid domes whose shapes are revealed by geological and aeromagnetic data. The southern dome, called the Parker Dome, is entirely enclosed by greenstone. Part of what is probably another dome occurs to the southwest of the Parker Dome and appears to extend on to HYDEN.

The northern dome is called the Ghooli Dome; it is not completely encircled by greenstones, and the granitoid in the northeast segment is in contact with the voluminous granitoids that lie outside the greenstone belt. Nevertheless, the ovoid character is also revealed aeromagnetically. This difference in expression of the two larger domes is probably a function of tectonic level; the Ghooli Dome has probably risen higher.

Within the domes, the granitoid has a gneissic foliation which is oriented such that dips are radially outward and become steeper toward the margin. In the marginal zone of the granitoid, a lineation expressed by rodded aggregates of biotite, quartz, and feldspar, becomes the stronger fabric. The lineation also plunges radially outward. These features are seen better in the Ghooli Dome which is better exposed than the Parker Dome.

In the greenstone adjacent to the Ghooli Dome, the rocks are strongly foliated and lineated congruently with the fabric in the gneissic granitoid. Stretching and mineral-grain lineation (such as elongate pillows at Mount Palmer, and lineation on the jaspilite and quartzite) all plunge steeply down the dip of the foliation. This indicates an upward movement of the dome, and vertical stretching and lateral flattening of the surrounding greenstone.

Microscopic isoclinal folds in the greenstones occur at this low structural (and stratigraphic) level, and fold axes also plunge steeply, but are not as uniformly directed as the lineation, and are not always parallel to the lineation. These folds, which are best seen within the single formations of jaspilite and quartzite, are truly isoclinal, and do not disturb the overall strike of the formation. These formations can be followed continuously for several tens of kilometres, and are probably continuous over much greater strike lengths.

A characteristic feature of the mesoscopic folds and lineations within the carapace of the dome is their variable but generally steep plunge. At any one locality reversals of plunge are common, a feature which repeatedly led earlier workers to postulate cross folding, and as most previous detailed investigations were centred about gold mines, this further led to the concept of localization of gold mineralization by cross-folding. Variability of plunge is now considered to be a universal feature of the greenstones, and not just restricted to zones of mineralization. Furthermore, the variability of plunge is now recognized as a scatter of reclined fold axes (i.e. each fold has its axis oriented down the dip of the axial plane) about a mean vertical orientation, and does not represent plunge reversals which would produce domes, basins and saddles on sub-horizontal axes. This generalization may meet with an exception at Frasers mine, where mine plans seem to indicate repetition of sequence by shallow-plunging fold axes. Neither does it deny the existence of a major interdomal saddle in the Marvel Loch area.

The foliation and lineation referred to above are the earliest fabrics recognized and are generally parallel to the primary layering. At higher structural (and ?stratigraphic) levels, the rocks, although dipping steeply and thoroughly metamorphosed, are usually without a tectonite fabric. Regionally, the greenstones appear to be structurally simple.

There is evidence for superimposed fabrics in the synclinal saddle between the Ghooli and Parker Domes. Here, intersecting cleavages produce pencil lineation in the mafic schist. The first foliation is the syn-metamorphic tectonite fabric, the second foliation is a spaced strain-slip or crenulation cleavage which is axial planar to chevron-style folds in jaspilite, amphibolite, and pelitic schist. This late deformation is best seen south and east of Nevoria.

The bedrock reconstruction in the synclinal saddle zone (Fig. 2) is tenuous, but is based upon available data, including exploration company data. The stratigraphically low mafic rocks closely follow the margins of the domes; however, the mafic layer on the northeast edge of the Parker Dome swings to the north where it participates in a second-generation crumple fold near Harris Find. In this case it would structurally overlie pelitic metasediments in the middle of the saddle, and also it would overlie the sequence wrapping around the Ghooli Dome.

As well as requiring repeated non-cylindroidal folding, a number of structural dislocations must occur at both high and low angles to primary layering. These structures could be considered as tectonic slides that formed in the early doming stage and themselves became folded as deformation continued.

The interdomal saddle is aligned with a regional, west-southwest-trending zone of chevron folding which extends across the southwest corner of the sheet. In the Edwards Find area, it is expressed by chevron folds of the large rafts of greenstone within the syntectonic granitoid. Deformation is not evident in the large mass of post-tectonic granitoid, but reappears in the belt of gneissic granitoid on the western margin in the Muntadgin area. Here, the gneissic foliation is abundantly chevron folded with west-southwest-trending axial planes spaced about 0.5 m apart. These folds are disrupted by the intrusion of post-tectonic granitoids, a process which contributes to the formation of agmatite.

Dislocation structures occur in the greenstones that extend from Southern Cross to Edwards Find. These rocks occur on the western limb of a synform that extends south from Southern Cross. There is no geological information on the nature of the rocks in the centre of the synform, but aeromagnetic patterns suggest a discordant granitoid. This structure is not a simple synform, as the western limb appears to terminate against the more continuous eastern limb. A major strike-fault is therefore inferred.

Within the western limb, the boundary between the mafic and pelitic unit is in places concordant, and in other places discordant, and another strike fault is postulated here.

What appears to be part of another granitoid dome west of Southern Cross is outlined by the seemingly arcuate ridge of greenstone between Blackbournes and Mount Rankin. However, the disposition of the primary lithological layering, and the facing evidence, indicates a splayed or dilated greenstone sequence rather than a domal fold. Both the Mount Rankin and the Blackbournes sides of the structure are thought to be east facing and both sides join together as a concordant sequence. The line of junction could also be a strike fault.

The style of deformation in the greenstone belt west of the domes seems to be progressive disharmonic folding which generated faults along which there was strike-slip or oblique-slip movement.

Knowledge of the structural history of the outlying greenstone remnants is fragmentary. Part of a regional fold is recognized at Holleton. The Westonia and

Bodallin rocks variously display the same tectonite and nontectonite fabrics as those further east, including steep stretching lineation, and congruency of fabric with the gneiss.

GRANITOIDS

CLASSIFICATION OF GRANITOIDS

Granitoids are not classified according to modal criteria, but are arranged in the reference in a sequence from heterogeneous granitoids with strong fabrics to homogeneous allotriomorphic granitoids. Field criteria indicate that this is a general sequence from the oldest to the youngest age of emplacement. There are transitional types, for example the foliated granitoid (*Agg*) displays a diffuse planar fabric at the granular scale and granoblastic textures that have recrystallized to the extent that they border on an allotriomorphic texture; and agmatite (*Am*) which is a mechanical mixture of both types of granitoid.

Rocks older than the foliated granitoid (*Agg*) have a gneissic fabric and are given the symbol *An*. They are classified as syntectonic granitoids. Those younger granitoids with allotriomorphic textures are classified as post-tectonic granitoids (*Ag*). Syntectonic granitoids have tectonite fabrics (including foliation and lineation that are congruent or synchronous with that in the greenstones) and occur in elongate zones peripheral to, and enclosing, greenstones. This group may include pretectonic granitoids. Post-tectonic granitoids discordantly intrude the older granitoids and greenstones, and display no regional spatial relationship to the greenstone. Syntectonic granitoids include tonalite, granodiorite, adamellite and granite, whereas the bulk of the post-tectonic granitoids are adamellite.

Subdivisions within these two main types are made on textural, or in one special case (the monzonitic rocks) on modal criteria.

SYNTECTONIC GRANITOIDS

Banded quartz-feldspar-biotite gneiss (*Anl*) is exposed in the far southeast corner of the sheet, east of the Parker Dome, at Split Rock west of the Parker Dome, and in the railway cuttings near the northern boundary of the sheet inside the Ghooli Dome. They are characterized by compositionally banded and complexly flow-folded gneiss with varying proportions of less foliated leucocratic neosome, and in this respect are related to the layered migmatite in LAKE JOHNSTON (Gower and Bunting, 1976).

Phases in the banded gneiss range from fine-grained, biotite-rich, lepidoblastic tonalite, granodiorite, or adamellite with subordinate garnet to coarse-grained granoblastic adamellite with sparse biotite. Pods of granoblastic amphibolite occur. Banding is on a scale of 0.01 to 0.2 m, is folded in abundant detached isoclines, and is disrupted by boudinage. The tectonic foliation, which is defined by alignment of sub-idioblastic biotite is parallel to the axial planes of these folds.

The leucosome is equigranular and granoblastic (i.e. metamorphic textured), and contains wispy biotite schlieren; it may partly participate in the folding, or be completely discordant and later than the folding. It does however have the same foliation as the banded gneiss.

The metamorphic fabric is the same style as that in the other syntectonic granitoids, therefore the folded banding is the oldest structure recognized in any of the granitoids. The gneiss is probably entirely orthogneiss.

Gneissic granitoid (*Ang*) appears to make up the bulk of the Ghooli and Parker Domes, and also occurs abundantly on the western margin of the sheet, south of the Great Eastern Highway where it is discordantly intruded by the post-tectonic granitoids.

These rocks have a conspicuous gneissic fabric expressed by quartzose-feldspathic lenticles, shreds, and trails of biotite, and augen of potash feldspar. Biotite, consisting of a multitude of small idioblastic hexagonal plates which may have a preferred or random orientation, commonly occurs in flat spindles up to 10 mm long. Biotite plates also occur in trails that form discrete laminae a few millimetres apart. These rocks are therefore characterized by a metamorphic differentiation on a granular scale, rather than the mesoscopic compositional banding of the banded gneiss.

This foliation is the counterpart of the axial-planar foliation in the folded, banded gneiss, and, itself, is generally planar. However, in the western areas, it is affected by the post-tectonic granitoid, and the foliation is commonly deformed into chevron folds with wavelengths up to 5 m, and axial planes oriented east-northeast. Magnetite is common, and isolated grains of garnet occur in the western areas.

Foliated granoblastic granitoid (*Agg*) occurs in the central eastern part of the sheet, where it is transitional from the gneissic granitoid, and in a broad zone along the entire western side of the Southern Cross greenstone belt. It also occurs as large enclaves within the post-tectonic granitoid in the central part of the sheet.

Being a transitional rock type, its fabric varies from inequigranular gneissic to equant and granoblastic, and apart from porphyroclasts of potash feldspar and granulated remnants of zoned plagioclase, its fabric is metamorphic. Biotite occurs in isolated small idioblastic plates which have a preferred orientation, or an entrainment, which defines a statistical rather than a discrete metamorphic foliation. There is therefore little evidence of metamorphic differentiation.

As the fabric becomes more equant and granoblastic, possibly as the result of static annealing recrystallization, the foliation becomes more diffuse, and the rock merges into the biotite adamellite (*Agb*). This feature is seen in the central eastern region, and is accompanied by the appearance of many tabular bodies of pegmatite. Conversely, clear examples of discordant intrusion by other units of the post-tectonic suite can be seen in the western area. The nature of the boundary between the belt along the western flank of the Southern Cross greenstone belt and the voluminous mass of post-tectonic-granitoid in the central part of the sheet is uncertain, but is also probably discordant and intrusive.

Extensive areas of agmatite (*Am*) (a type of migmatite containing angular blocks of palaeosome encircled by neosome) occur in the central-northern region of the sheet, and in the region flanking the western gneiss. The palaeosome consists of blocks of syntectonic granitoid (mainly *Agn* and *Agg*) varying in size from 0.1 m to several metres. The neosome consists of allotriomorphic post-tectonic types. Excellent examples of this agmatite can be seen at Sandford Rocks, 9 km northeast of Westonia, and at Muntadgin Rock, 3 km northeast of Muntadgin.

Fragmentation has taken place by invasion of magma along axial surfaces of the chevron folds, and most of the block boundaries are sharp, although there are some areas in the western gneiss region where diffuse neosomes appear in the axial planes.

If the post-tectonic granitoids are derived anatectically from the syntectonic granitoids, then the zone of first melting was at a lower crustal level than is now revealed.

POST-TECTONIC GRANITOIDS

Biotite adamellite (*Agb*) is medium-grained, even-grained, allotriomorphic adamellite occurring mainly in the eastern region of the sheet, north of the area of foliated granitoid (*Agg*). It contains up to 10 per cent biotite in small randomly oriented idioblastic books (rather than plates). In better exposures, a diffuse layering is recognized by slight variations in grain size, and faint vestiges of a foliation on a granular scale may be seen. Sheets of pegmatite are common.

Leucocratic adamellite (*Ago*), together with the porphyritic adamellite (*Agl*) forms the bulk of the post-tectonic adamellite in the central part of the sheet. It is so termed because of its variable texture, which may be fine, medium or coarse-grained allotriomorphic, hypidiomorphic, seriate, and porphyritic. Biotite occurs in discrete, unbent, idiomorphic books, generally singly, or in coarsely crystalline schlieren. Variability occurs by diffuse gradation within the one outcrop.

At Dulyalbin Rock, a planar orientation of potash-feldspar megacrysts defines a primary magmatic foliation.

Porphyritic adamellite (*Agl*) is medium to coarse grained with closely packed tabular euhedral megacrysts of potash feldspar about 20 mm long. Large books (5 mm) of unbent idiomorphic biotite occur. Commonly, the megacrysts have a planar alignment, a feature interpreted as alignment by flowage of the magma. Porphyritic adamellite can usually be mapped as discrete bodies of the order of 100 km^2 in area (e.g. Caroling Rocks), with clear evidence of intrusion into the other type of adamellite.

Quartz monzonite and similar rocks (*Agz*) are uncommon; they form small isolated occurrences of uncertain relationship with the other post-tectonic granitoids. Four kilometres southeast of Moorine Rock township is a green and pink granitoid containing andesine, microcline, coarse epidote, about 10 per cent quartz and chloritized biotite.

Five kilometres southwest of Warrachuppin is a coarse-grained pink and green granitoid containing altered plagioclase with prehnite, abundant epidote (pistacite), hornblende (possibly after pyroxene and itself altering to arfvedsonite), and about 15 per cent quartz, which is graphically intergrown with feldspar.

SIGNIFICANCE OF SYNTECTONIC AND POST-TECTONIC GRANITOIDS

The syntectonic granitoids are at least as old as the tectono-thermal event in the greenstones. It is also established that the heterogeneity of the banded gneiss (*Anl*) is due to an early period of migmatization that predates the main tectono-thermal event. There is no evidence of magmatic intrusion of the foliated granitoids into greenstone; rather they are structurally (and broadly stratigraphically) conformable, although along the contact zone there is evidence of high strain.

These granitoids are termed "syntectonic" because they received their fabric during the main tectono-thermal event. However, as they represent deformed and metamorphosed rocks, many of which appear to have been originally magmatic, they could also be considered as pre-tectonic granitoids. Their non-magmatic domal behaviour during the main tectono-thermal event, if interpreted as a diapiric emplacement, indicates that the pre-tectonic granitoids were basement to the greenstones.

SOUTHERN CROSS provides no firm contribution to the question of pre-greenstone sialic basement in the Archaean, except to note that the arguments that have been applied elsewhere (Hickman 1975, Archibald and Bettenay 1977, Gee 1979) apply equally well here.

It can at least be concluded that the pre-tectonic granitoids did not originate by melting of the greenstones and that the geological data on SOUTHERN CROSS are consistent with the postulate of a pre-greenstone basement. Attention is drawn to the stratigraphically lowermost psammitic schist which probably had arkosic components. Unfortunately, its relationships are obscured by a combination of poor outcrop and high strain on the dome margin.

The post-tectonic intrusive granitoids must represent a thermal event later than, and unrelated to, the tectono-thermal event. On available information they could either be derived anatectically from the gneisses, or directly from depth; perhaps the more uniform adamellite composition suggests the former. It is difficult to envisage these vast bodies persisting in depth, and they are probably best considered as thin flat sheets capping the older gneiss.

MINERAL DEPOSITS

GOLD

Gold is by far the most important mineral; 46 696 kg were produced at an overall grade of 10.9 g/t (Table 1). All of this has come from depths of less than 100 m, and the field displays the features of supergene enrichment so characteristic of the Western Australian goldfields. All the gold was free milling, but fine-grained gold in association with sulphides (mainly pyrite) occurs below the level of oxidation.

It is beyond the scope of this regional survey to specifically examine the gold occurrences, but certain comments can be made. Gold occurs in quartz reefs and veins that were emplaced into the greenstone after deformation and regional metamorphism. These quartz bodies may take the form of discrete reefs, either parallel, or oblique to the foliation, of saddle reefs, of veins in fractured jaspilite, or of irregular stringers at contacts between contrasting rock types. Although some mineralization has been called lode, no true lode material—in the sense commonly used in this State of gold-sulphide impregnations in shear zones—seems to exist. Some previous writers have emphasized wall-rock alteration, particularly "granitization" of greenstones and biotitization (e.g. Miles 1942); however, it is likely that much of this allegedly altered rock was originally sedimentary material.

It has long been recognized that most of the gold in this part of the Yilgarn Goldfield, like that in Archaean greenstones generally (Woodall 1975), occurs in the major mafic volcanic piles. Only 12 per cent of the production for the whole sheet has come from the major pelitic metasedimentary unit, from centres such as Edwards Find, Jacoletti, Burbidge and Greenmount. Despite this regional relationship, there is no clear relationship with metabasalts (either tholeiitic or komatiitic). Production directly from metavolcanics (from Mount Palmer, Blackbournes, Holleton and Mount Rankin) amounts to only 14 per cent of the total.

Production from biotite gneiss (metamorphosed felsic volcanics) includes the bulk of the Westonia production, and together with some minor production in the Marvel Lock townsite area, amounts to 24 per cent of the total.

TABLE 1 Summary of gold and silver production to 1978

Mining Centre	Locality	Alluvial (kg)	Dollied & specimens (kg)	Ore treated (t)	Gold therefrom (kg)	Total gold recovered (kg)	Silver recovered (kg)
			YILGARN GOLDFIELD				
Blackbournes				1 701.88	13.142	13.142	
Corinthia							
	Babylonia		0.730	633.51	15.305	16.035	
	Corinthian		0.083	289 278.07	1 827.444	1 827.527	128.699
Edwards Find				77 240.52	919.284		
Greenmount		1.445	0.805	133 046.77	1 018.097	1 020.347	33.685
Holleton							
	Felsted Find			81.28	0.196	0.196	
	Holleton	0.959	0.407	51 867.07	496.011	497.377	1.147
Hopes Hill							
	Pilot			165 075.11	734.526	734.526	135.717
	Other	0.657	5.353	159 610.35	1 272.204	1 278.214	0.114
Kennyville							
	Glendower			240.80	4.668	4.668	
	Other		0.833	71 799.74	779.920	780.753	0.101
Marvel Loch							
	Banker			1 971.13	57.536	57.536	
	Burbidge			188 297.62	472.674	472.674	0.003
	Donovan			4 312.15	98.688	98.688	
	Grand National			2 929.26	15.472	15.472	
	Great Victoria			224 346.47	1 124.770	1 124.770	7.842
	Lennebergs			346.47	1.008	1.008	
	Other	0.353	93.453	1 000 766.81	9 222.710	9 316.516	627.731
Mount Palmer		51.181	0.618	313 134.48	4 949.018	5 000.817	0.078
Mount Rankin							
	Bells Find			4 225.85	130.576	130.576	
	Other	0.119	16.031	1 140.82	207.859	224.009	1.041
Parkers Range							
	Centenary			1 697.81	13.686	13.686	
	White Horseshoe			8 201.38	175.616	175.616	0.806
	Other	0.218	18.857	82 424.22	1 217.677	1 236.752	2.951
Southern Cross							
	Fraser		195.950	679 040.01	6 449.857	6 645.807	619.290
	Other	3.135	28.023	248 126.10	3 576.932	3 608.090	11.895
Westonia							
	Edna May			564 138.67	11 044.910	11 044.910	158.505
	Hill End			225.56	4.763	4.763	
	Other	0.297	2.147	48 896.17	950.883	953.327	0.327
Bullfinch							
	Derwent Jack			59.54	1.191	1.191	
Mount Hampton							
	Symes Find			2 757.39	83.268	83.268	
			SOUTH WEST MINERAL FIELD				
Bennett & Burgess			0.030	1 184.81	30.417	30.447	
TOTAL		58.364	363.320	4 335 841.43	46 779.932	47 331.992	1 729.932

The remaining 50 per cent of production has come mostly from metasedimentary material within the mafic volcanic pile, from such rocks as mafic/ultramafic para-amphibolite, jaspilite, and Fe-rich pelitic sediments, or from contact zones between these rocks and mafic/ultramafic igneous rocks.

A number of significant lines of gold workings can be identified. Gold occurs over a distance of 20 km from Centenary to Dulcie, in a bed of para-amphibolite and jaspilite between metabasalt. On the Lenneburg-Glendower-Kennyville line, mineralization occurs in similar rocks interbedded with basalt. The Nevoria—Golden Cube line probably lies on this same jaspilite group.The lithological control of the Donovan—Marvel Loch line is uncertain, but appears to lie along the contact zone between ultramafic para-amphibolite and biotite gneiss. The Hopes Hill—Corinthian line extends for 10 km along the contact between psammitic metasediments and metabasalt.

Comment has previously been made on the supposed link between gold and cross folding (see Sect. Structure), and a regional structural control is now considered to be unsubstantiated. The more important regional controls are lithological (in particular mafic/ultramafic volcanogenic sediments), and hence there is a stratigraphic control. However, localization of gold-sulphide quartz reefs in structural situations, such as fold cores, cross fractures of fold hinges, axial-plane foliations etc., is well documented; and seems to be one of the last steps in the formation of gold deposits.

The broad association with mafic ultramafic volcanics suggests that they are the ultimate source rock, and the specific association with the interflow sediments indicates they are an intermediate host for the gold. The association of gold with Archaean volcanogenic sediments is well known (Ridler, 1972, 1973; Fripp, 1976; Annhaeusser, 1976); and an exhalative origin, involving syngenetic precipitation from hot waters in sulphide chemogenic sediments on the sea floor during periods of volcanic quiescence has become popular. However, sulphide-rich sediments interbanded with volcanics are not known within the mafic volcanic pile, and this exhalative origin may not apply, although it may be applicable to the thick unit of pelitic metasediments.

Gold is known to occur in association with massive sulphide beds in the meta-pelites of Burbidge and Greenmount. These beds could be termed sulphide-facies banded iron-formation, and the possibility exists for exploring for bulk low-grade gold deposits. Some recent exploration has been directed to this, and has revealed values of 1-2 g/t of possible open-cut material.

Perhaps more relevant to the situation on SOUTHERN CROSS are the findings of Keays and Scott (1976) who found significantly lower gold values in the altered interiors of basalt pillows, relative to the pillow skins. They suggested that a certain proportion of gold ("extractable gold") was leached by hot seawater after the initial cracking of pillows, leaving "locked-up" gold in the rims, and further postulated that the leached gold was precipitated and loosely bound in interpillow and interflow material.

The para-amphibolites are probably derived by total disintegration of ultramafic lavas, the products of which would be susceptible to immediate deuteric alteration and to penetrative leaching of contained gold. Relocation and precipitation of gold could constitute a first stage in concentration to an ore body. A second stage could be the release of gold during metamorphism of these sediments, whereby submicroscopic particles of gold bound to complex anions are transported in fluids generated by dehydration reactions, and pressure solution. The third stage would be the deposition with quartz in zones of pressure release at the conclusion of deformation and metamorphism. The final stage in the production of an economic deposit is supergene enrichment by vadose water.

OTHER MINERALS

Silver is the only metal produced as a by-product of gold mining in the area. Molybdenite, scheelite, wolframite, galena, bismutite and chalcopyrite are reported to occur in the gold-quartz reefs, but there is no evidence of any production. There is a record of production of 12 tonnes of scheelite from a prospect at Hopes Hill.

The massive pyrrhotite at Mount Caudan has, in the past, been seen as a source of sulphur and its gossanous cap has been investigated as a source of ferro-manganese (MacLeod 1975). There has been no production.

Assays of up to 18 per cent arsenic have been obtained from the Jupiter mine (Greenmount), where massive arsenopyrite occurs in pelitic metasediments. There was, in fact, 3 600 tonnes of arsenic concentrate produced in the period 1915-1924. These sulphide layers (beds?) in the pelites could be prospective for base metals, although to date they have not been very encouraging. The best values recorded in a drilling programme at Jupiter Mine disclosed 500 ppm Cu, 400 ppm Pb and 30 ppm Zn.

From a small pit on the shore of the salt lake 2 km south of Heaney Find, 2 395 tonnes of "vermiculite" have been extracted. This is a bronze-coloured, poorly expanding form of hydrobiotite. Adjacent but unrelated to the "vermiculite", is a coarse pegmatite intruding ultramafic rocks, from which some mica has been quarried.

Because of the prevailing westerly winds, the eastern margins of salt lakes usually have deposits of granular and crystalline gypsum and impure gypsiferous sands (kopi). Some deposits have been exploited for plaster manufacture (de la Hunty and Low, 1957; Low, 1975) and two deposits (Lake Seabrook and Mount Palmer) rank as important resources, which have produced on demand over the last 20 years. The Lake Seabrook deposit (which occurs partly on JACKSON) contains in excess of 1 Mt averaging at least 95 per cent gypsum. The distribution of these gypsiferous dunes is shown on the geological map as the Quaternary unit *Qd*.

Alunite (hydrous sulphate of potassium and aluminium) occurs as a powdery veneer on some of the salt lakes in SOUTHERN CROSS, and more importantly those in the Lakes Seabrook-Deborah-Campion chain in JACKSON. Alunite constitutes a sizeable resource of potash, and unsuccessful attempts have been made to economically produce agricultural potash.

APPENDIX: Localities mentioned in text

	Lat.	Long.
Banker	31°32′	119°37′
Bells Find	31°22′	119°18′
Blackbournes	31°18′	119°18′
Bodallin	31°22′	118°51′
Caroling Rocks	31°17′	119°48′
Cheritons	31°50′	119°39′
Corinthia	31°07′	119°09′
Derwent Jack	31°02′	119°09′
Donovan	31°29′	119°31′
Dulcie	31°46′	119°36′
Dulyalbin Rock	31°35′	118°59′
Edwards Find	31°34′	119°23′
Felsted Find	31°36′	119°05′
Frances Firness	31°30′	119°31′
Frasers mine	31°14′	119°20′
Glendower	31°21′	119°25′
Glenelg Hills	31°56′	118°47′
Great Victoria	31°32′	119°34′
Greenmount	31°18′	119°19′
Harris Find	31°33′	119°41′
Heaney Find	31°21′	119°41′
Holleton	31°57′	119°01′
Hopes Hill	31°11′	119°17′
Kennyville	31°17′	119°23′
Lake Seabrook	31°00′	119°38′
Lennebergs	31°23′	119°27′
Marvel Loch	31°28′	119°30′
Molthomy Rock	31°44′	119°08′
Moonargidding Rock	31°28′	119°22′
Mount Caudan	31°37′	119°33′
Mount Cramphorne	31°50′	118°43′
Mount Palmer	31°24′	119°40′
Mount Rankin	31°19′	119°15′
Muntadgin	31°46′	118°33′
Nevoria	31°30′	119°35′
Skeleton Rock	31°51′	119°28′
Split Rock	31°56′	119°39′
Westonia	31°18′	118°42′
Yellowdine	31°18′	119°39′

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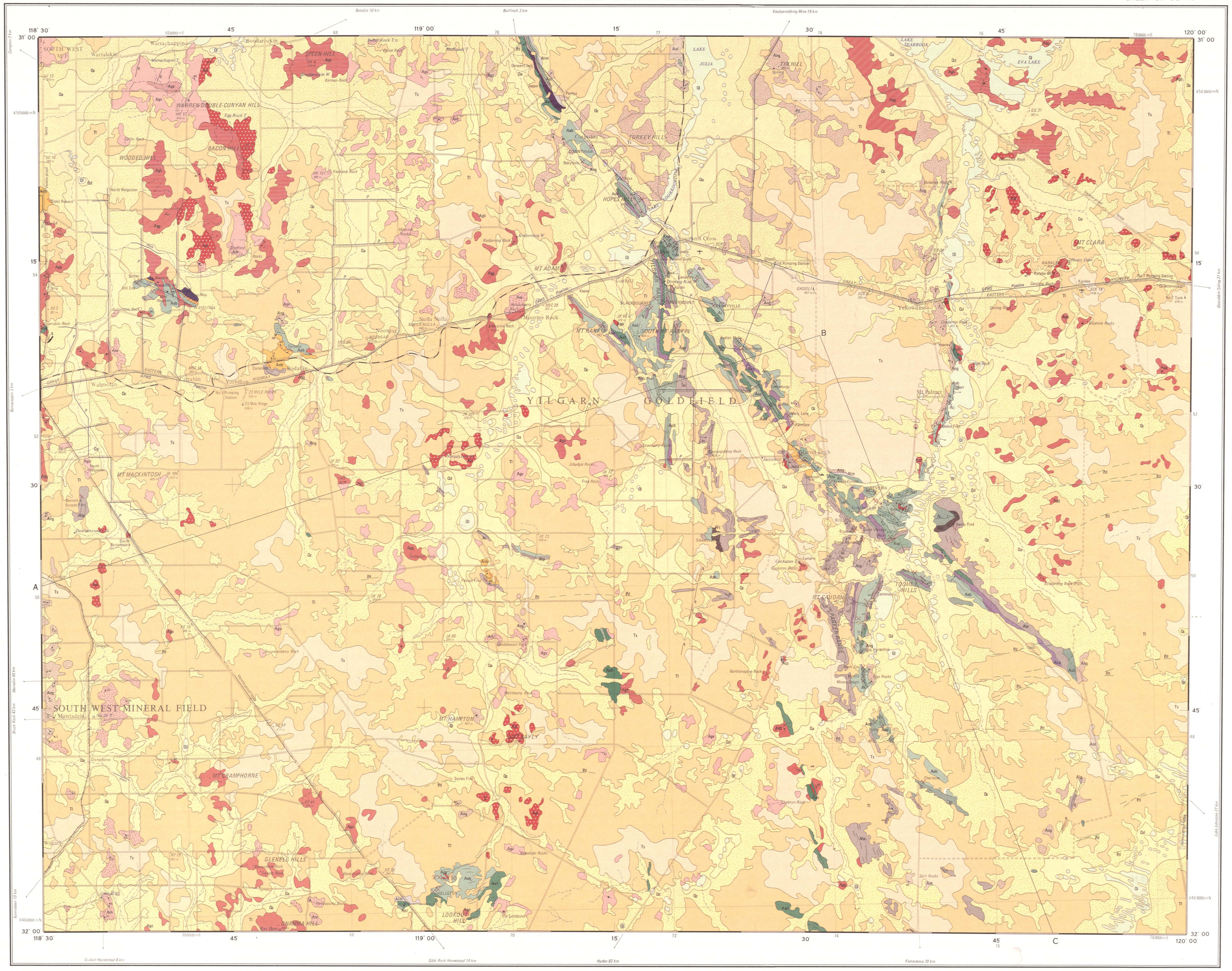
SOUTHERN CROSS

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



SYMBOLS

- Geological boundary
- Strike and dip of strata (facing not inferred)
- Facing
  - Indicated by graded bedding
  - Indicated by cross bedding
  - Indicated by pillow lava
- Metamorphic foliation
  - Inclined
  - Vertical
- Lineation or minor fold
- Primary alignment of phenocrysts in porphyritic granitoid
- Lithological trend visible on air photographs
- Gossanous cap

- Goldfield boundary
- Highway with route marker
- Formed road
- Track
- Railway, 4'8"
  - 3'6"
  - Station or siding — Tandagin
- Bridge
- Power line
- Townsite, gazetted; less than 1000 — Walgoolan
- Locality — South Walgoolan
- Homestead — Mt Lookout
- Building
- Landing ground
- Horizontal control; major, minor
- Benchmark, height accurate — XE 3 340 m
- Microwave tower

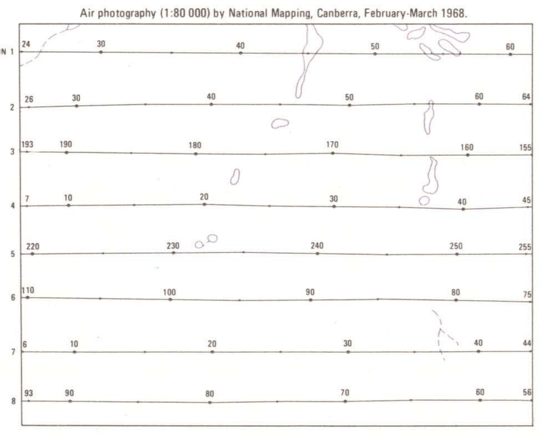
- Watercourse, intermittent
- Pipeline — P
- Well — W
- Soak — Sk
- Tank — T

- Mining centre — KENNYVILLE
- Gold mine (may or may not be working) — Jasper King
- Gold prospect, minor shaft
- Battery
- Mineral occurrence
  - Corundum — Cn
  - Vermiculite mica — M

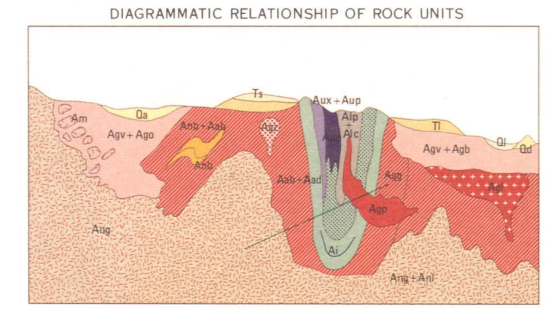
REFERENCE

QUATERNARY		Ql	Saline and gypsiferous clay and silt in playa lake deposits
QUATERNARY		Qd	Gypsiferous sand and silt in dunes, adjacent to playa lakes
QUATERNARY		Qa	Sandy loam; alluvial wash
QUATERNARY		Qc	Clay, silt, sand; buff or red, with quartz fragments and calcareous nodules; mainly colluvial deposits
TERTIARY		Ts	Clean sand, yellow to white, containing scattered limonite nodules; remnants of extensive Tertiary sandplain
TERTIARY		Tl	Laterite; limonite nodules in cemented matrix; grades upward into Ts and downward into weathered bedrock
PROTEROZOIC		Pd	Dolerite and gabbro in dykes; broken line indicates dyke inferred from air photo lineament or from aeromagnetics
ARCHAEAN		q	Quartz dyke
ARCHAEAN	Post-tectonic granitoids	Agp	Pegmatite
ARCHAEAN	Post-tectonic granitoids	Agz	Quartz monzonite and related quartz deficient granitoids
ARCHAEAN	Post-tectonic granitoids	Agf	Medium to coarse-grained porphyritic adamellite
ARCHAEAN	Post-tectonic granitoids	Agv	Variable textured, medium to coarse-grained adamellite; commonly seriate due to continuous variation in grain size
ARCHAEAN	Post-tectonic granitoids	Agb	Biotite adamellite; even grained, allotriomorphic, with biotite in books
ARCHAEAN	Post-tectonic granitoids	Ago	Leucocratic adamellite; allotriomorphic or hypidiomorphic with sparse biotite
ARCHAEAN	Pre- and syn-tectonic granitoids	Am	Agmatite; granoblastic or gneissic palaeosome of Ang or Agg or Anl, enclosed by allotriomorphic leucosome of Agv or Ago
ARCHAEAN	Pre- and syn-tectonic granitoids	Agg	Foliated adamellite granodiorite or tonalite, with granoblastic textures and sparse garnet; foliation defined by entrainment and alignment of grains; biotite in small discrete flakes
ARCHAEAN	Pre- and syn-tectonic granitoids	Ang	Adamellite granodiorite or tonalite gneiss, commonly strongly lineated; biotite in clusters of small plates; includes augen gneiss
ARCHAEAN	Pre- and syn-tectonic granitoids	Anl	Quartz-feldspar-biotite-(garnet) gneiss, compositionally banded with abundant flow folds, and amphibolitic bands
ARCHAEAN		Ai	Iron-formation; laminated Fe-amphibole rock with magnetite, and/or quartz, pyroxene, garnet, biotite, potash feldspar
ARCHAEAN		Alm	Quartz-muscovite-feldspar schist and quartzite
ARCHAEAN		Alp	Pelitic metasediments containing quartz, biotite, muscovite, graphite, andalusite (or sillimanite), feldspar, garnet, cordierite, amphibole
ARCHAEAN		Alc	Calc-silicate rock containing diopside, actinolite, carbonate, epidote, plagioclase, microcline, biotite, quartz
ARCHAEAN		Anb	Biotite gneiss; grey coloured, strongly lineated; containing also microcline, sodic plagioclase; with fragmental structure, probably derived from felsic volcanics
ARCHAEAN		Aap	Para-amphibolite from mafic and ultramafic sedimentary material; generally finely laminated
ARCHAEAN		Aah	Amphibolite; medium-grained, granoblastic textured; contains hornblende, clinopyroxene and calcic plagioclase
ARCHAEAN		Aad	Amphibolite; medium-grained, with remnant igneous textures; contains actinolite and/or hornblende, and calcic plagioclase
ARCHAEAN		Aab	Amphibolite; fine-grained; contains actinolite and/or hornblende, and calcic plagioclase; deformed pillows common; derived from mafic volcanics
ARCHAEAN		Aub	Chlorite-tremolite rock; with fine-grained acicular texture; lacks plagioclase; derived from komatiitic basalt
ARCHAEAN		Aur	Chlorite-tremolite rock; with coarse acicular or porphyroblastic texture; contains metamorphic olivine and anthophyllite
ARCHAEAN		Aux	Meta-pyroxenite; large actinolite (or hornblende) pseudomorphs after primary clinopyroxene; contains remnant igneous texture and mineralogy
ARCHAEAN		Aus	Serpentinite; with palimpsest olivine textures recognisable; includes talc carbonate schist

FLIGHT DIAGRAM



DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



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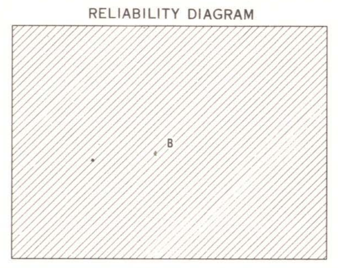

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MINISTER FOR MINES
A.F. TRENDALL, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1 : 250 000

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TRANSVERSE MERCATOR PROJECTION

ZONE 50 AUSTRALIAN MAP GRID

INDEX TO ADJOINING SHEETS

BENCUBBIN SH 50-11	JACKSON SH 50-12	KALGOORLIE SH 51-9
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CORRIGIN SI 50-3	HYDEN SI 50-4	LAKE JOHNSTON SI 51-1

Geology by R.D. Gee, 1973–76
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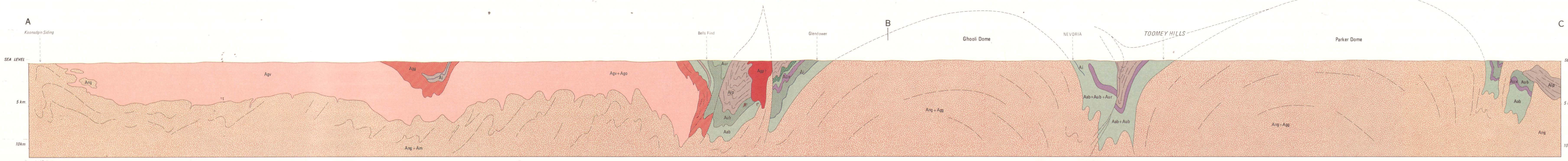
DECLINATION DIAGRAM

DIAGRAMMATIC SECTION

NATURAL SCALE

SECTION A - B - C



SOUTHERN CROSS
SHEET SH 50-16

FIRST EDITION, 1981