1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

RAVENSTHORPE

WESTERN AUSTRALIA

SHEET SI/51-5 INTERNATIONAL INDEX

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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COMPILED BY R. THOM, S. L. LIPPLE AND C. C. SANDERS

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Explanatory Notes on the Ravensthorpe Geological Sheet

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INTRODUCTION

The Ravensthorpe 1:250 000 Sheet area, SI/51-5 of the International Series, is bounded by latitudes 33°00′S and 34°00′S and longitudes 120°00′E and 121°30′E. Four-fifths of the Sheet area lies within the Phillips River Goldfield, the remaining strip on the eastern side being within the Dundas Goldfield.

The northern one-third of the Ravensthorpe Sheet area is undeveloped, but easy access is made by numerous cut lines and tracks that are suitable for four-wheel drive and other sturdy vehicles. Agricultural development now extends over the southern two-thirds of the Sheet area. Access to the area is by Highway 1, which crosses the Ravensthorpe Sheet from east to west, and within the agricultural belt there are abundant graded roads.

Ravensthorpe (population 130) is the largest town within the Sheet area. Formerly the centre of the State's most productive copper-mining area, Ravensthorpe has declined since the closure of the copper mines in 1971, and now, together with Munglinup (population 46), is a centre serving the surrounding agricultural area. Hopetoun (population 70) was formerly a small-vessel port for the shipment of copper ore, but now has become a tourist centre.

The geological field work commenced in April, 1971 and was completed in November, 1971. The petrological work was done by J. D. Lewis and Dr. W. G. Libby.

PHYSIOGRAPHY

Most of the Sheet area falls within the Swanland Physiographic Division of Jutson (1950). The area is characterized by incised drainage, in particular the rivers Phillips, Steere, Jerdacuttup, Oldfield, Young and Lort, which flow southwards to the Southern Ocean (Fig. 1). A small area to the north containing salt lakes and ill-defined drainage is part of Jutson's Salinaland. Between these provinces is a major drainage divide.

Precambrian granitic rocks with a cover of sandplain or gravel plain form the undulating topography of the northern portion of the Sheet area. Where the major drainage dissects the land to the south, low hills and well-defined river channels are more common. Heights above sea level decrease southwards and eastwards, giving a general fall to the southeast (Fig. 1).

Rocks of the Archaean layered succession form the northwest-trending hills of the Ravensthorpe Range, which rise to about 400 m above sea level. These slope

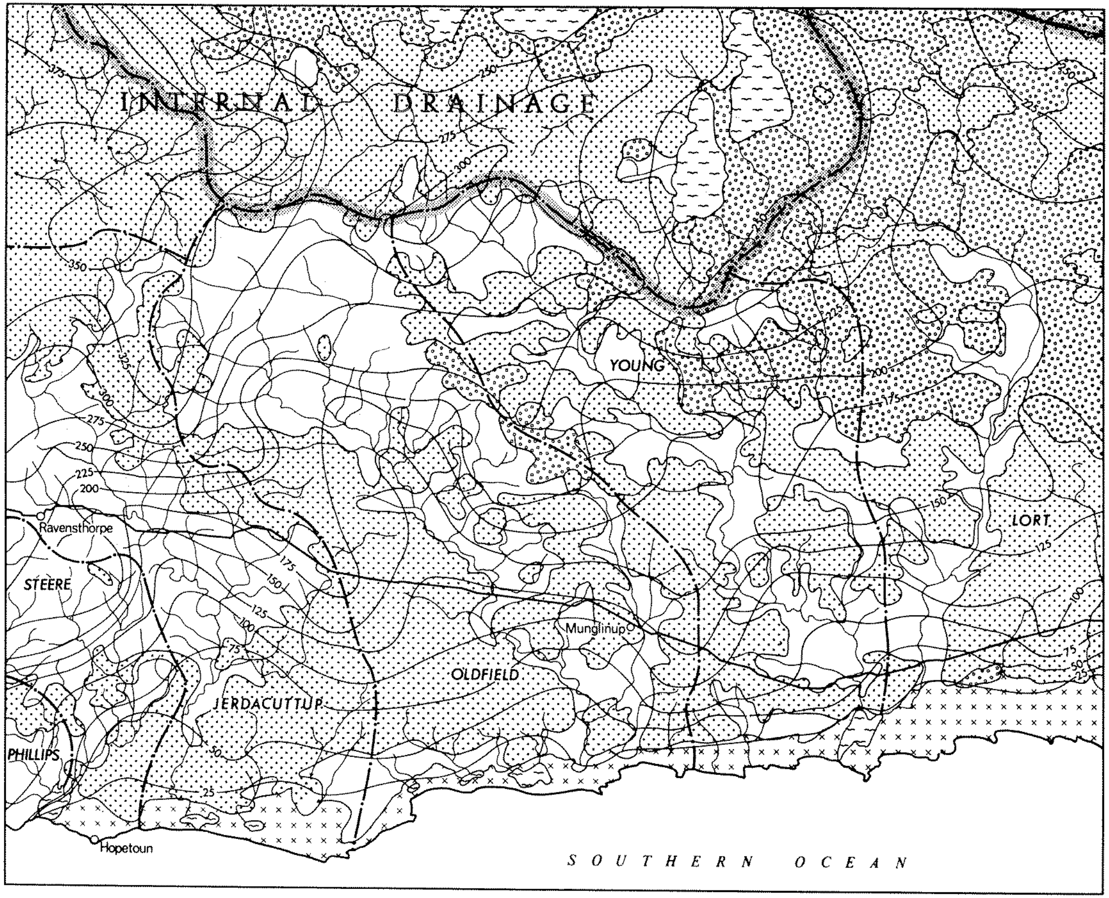


FIGURE 1

PHYSIOGRAPHIC FEATURES

RAVENSTHORPE SHEET SI 51-5

SCALE

10 0 10 20 30
KILOMETRES

REFERENCE

- Sandplain (units Czs, Czc, Czg, Czl)
- Mainly calcareous loam or eolian sand (units Qqs, Qps)
- Mainly colluvium, minor alluvium, and outcrop (units Qpv, Qrt, Qrg; some P and A rock units)
- Coastal plain (units Qrc, Qrf, Qpl)
- Salt lakes, inlets and marginal lake deposits (units Qra, Qrm, Qrp, Qpk)
- Watercourse
- —200— Topographic contours in metres
- Major divide
- Secondary watershed
- Highway

13737

southwards into gravel plain. In the southwestern corner of the Sheet area Proterozoic sedimentary rocks form the Barren Ranges, with East Mount Barren on the coast reaching 300 m above sea level.

Scarps occasionally form significant topographic features within the Sheet area. The Proterozoic sedimentary rocks of the Mount Barren Beds are bounded to the north by a prominent escarpment 5 to 30 m high. Escarpments and low, flat-topped hills are a common feature of the Plantagenet Group, which crops out in the southern part of the Sheet area. These are the remnants of a sedimentary cover deposited during an Eocene marine transgression. A low scarp west of the Lort River is interpreted as the result of a recent earthquake.

Prominent sand dunes and dunes of Coastal Limestone (Qpl) border much of the coast. The scalloped coastline has numerous rocky headlands separating asymmetrical bays, indicating a prevailing current from the west. At East Mount Barren a wave-cut bench, about 80 m above present sea level, is thought to result from a Pleistocene marine transgression (Sofoulis, 1958c; Clarke and Phillips, 1953). The bench shows erosional features such as stranded stacks attributed to sea action.

CLIMATE

Winter rainfall is about 225 mm in the north and 500 mm on the coast. Summer rainfall (mainly from thunderstorms) varies between 125 mm in the north to 175 mm in the south. The rainfall is unreliable and the area is subject to drought.

Temperatures are generally less extreme near the coast than in inland regions. The average January maximum on the coast is about 30°C gradually increasing northwards, and the average July minimum is 18°C, gradually decreasing inland.

VEGETATION

Much of the area is covered by scrubland heath and woodlands of small eucalypts; in general large trees are rare. *Banksia,* 'Christmas Tree' (*Nuytsia floribunda*), *Hakea,* and *Acacia* are fairly common. More detailed information is given by Sofoulis (1958c). Beard (1969, 1972) has produced maps and notes on the vegetation of the adjacent Lake Johnston and Newdegate 1:250 000 Sheets, and much of this information is relevant to the Ravensthorpe Sheet area.

Of particular interest is the '*Eucalyptus preissiana-Dryandra quercifolia* association' or 'Barren thicket' (Beard, 1972) which is confined to soils associated with the Proterozoic Mount Barren Beds. Its presence in areas of no outcrop suggests that the Mount Barren Beds lie beneath the soil cover. Beard suggested a close correlation between floral types and lithological units of the Mount Barren Beds on the Newdegate Sheet.

PREVIOUS INVESTIGATIONS

The most comprehensive work so far is the Phillips River Goldfield Bulletin (Sofoulis, 1958c). Although this encompasses most of the Ravensthorpe 1:250 000 Sheet, the investigations were largely in the area of known economic importance around Ravensthorpe.

One of the earliest descriptions of the area was given by J. S. Roe in 1852, in a report on an expedition southeastward of Perth in 1848-49. Other early investigators include Blatchford (1900), Woodward (1902), and Montgomery (1903). Although concerned largely with the economic aspects of the Ravensthorpe district, there was even then speculation on the relative ages of the layered successions in the area and a tentative correlation was made between the Barren Range and the Ravensthorpe Range. Later workers including McMath (1954) and Sofoulis (1958c) recognized the difference in age and the unconformable relationship.

Accounts of copper and gold mining operations are numerous, and include Low (1963), Sofoulis (1954a, c, 1958b, c) and Noldart (1955, 1958). In addition, there are abundant reports on such mineral occurrences as vermiculite (Johnson and Gleeson, 1951b; MacLeod, 1964), graphite (Sofoulis and Connolly, 1957), magnesite (Johnson and Gleeson, 1951a), spodumene (Ellis 1939; Grubb, 1963) and manganese (Gray and Gleeson, 1951; Townley, 1953). Some chemical analyses are reported in Joplin (1963). The eastern part of the Sheet was the subject of a hydrological report (Morgan, 1969). The geology of the same area was briefly discussed by Sanders (1968). An aeromagnetic survey conducted by the Bureau of Mineral Resources over part of the area around Ravensthorpe is reported by Wells (1962). Some other investigations are noted in the selected bibliography.

REGIONAL SETTING OF THE PRECAMBRIAN ROCKS

The Ravensthorpe Sheet straddles the boundary between the Yilgarn Block and the Albany Fraser Province (Daniels and Horwitz, 1969).

The Yilgarn Block is a stable nucleus of gneiss and granite that enclose elongate greenstone belts. These greenstone belts, which trend north-northwest, consist of alternating mafic and acid-clastic associations which comprise the Archaean layered succession. The succession is strongly deformed by major folds with north-northwest axes. A protracted period of granitic magmatism has been defined, but most of the gneiss and granitic rocks were emplaced in the period 2700 to 2550 m.y. ago (Arriens, 1971), and are younger than the layered succession.

The Albany-Fraser Province consists of a belt of granitic and metamorphic rocks of Proterozoic age, together with slightly metamorphosed sedimentary sequences also of Proterozoic age. The belt consists mainly of gneiss and migmatite, having a northeasterly trend which characterizes the Proterozoic rocks of this region. Age determinations within the belt include the Albany granite at 1100 $\pm$ 50 m.y. (Turek and Stephenson, 1966), Fraser Range pegmatites at 1280 and 1330 $\pm$ 15 m.y. Compston and Arriens, 1968), and granulite from the Fraser Range at 1328 $\pm$ 12 m.y. (Arriens and Lambert, 1969). The Stirling Range shale gave a metamorphic age of 1150 $\pm$ 40 m.y. (Turek and Stephenson, 1966).

YILGARN BLOCK

LITHOLOGIES OF THE ARCHAEAN LAYERED SUCCESSION

The succession at Ravensthorpe consists of mafic and ultramafic rock alternating with sedimentary rock and minor felsic volcanics. Sofoulis (1958c) and Woodall

(1953, 1955) describe what may be a similar succession on the Newdegate 1:250 000 Sheet. The minimum age of the succession at Ravensthorpe is established at about 2900 m.y. (Richards and others, 1966; Jeffery, 1956).

Mafic volcanics

The lowermost mafic volcanic unit crops out mainly north of Ravensthorpe, along the foot of the Ravensthorpe Range near Desmond, and around the mines at Kundip. The unit includes basalt lava, tuff and agglomerate with associated minor outcrops of felsic volcanics. Northwest of Ravensthorpe is agglomerate consisting of felsic or mafic fragments in a mafic matrix. This mafic association, which is estimated at upwards of 2200 m thick, is intruded and rafted by a quartz-diorite pluton which metamorphosed some of the rock to amphibolite facies. Sofoulis (1958c) describes garnetiferous basaltic rock west of the Ravensthorpe Range, and comments that shear zones are often garnetiferous. Metamorphism varies from upper greenschist facies to almandine amphibolite facies. Primary structures and textures are commonly preserved in the greenschist facies rocks.

Higher in the succession is another basalt unit that varies between 1600 m and 3000 m thick. Pillowed, variolitic and amygdaloidal lava is well exposed along the Jerdacuttup River and Bandalup Creek. Variolitic lava occurs throughout the sequence. Mafic intrusions are associated with the lavas. This mafic volcanic association is metamorphosed to upper greenschist or amphibolite facies. Pillow lava along the Jerdacuttup River shows excellent preservation of primary structures and textures but is recrystallized to acicular hornblende, plagioclase, biotite, quartz, calcite, chlorite and iron oxide. North of the Ravensthorpe-Esperance Road (Highway 1) basalt is progressively more metamorphosed towards the granite, and near the contact has reached amphibolite facies.

Minor basalt and felsic pyroclastic rocks occur within the uppermost sequence of sedimentary rocks east of the Jerdacuttup River.

Magnesium-rich basalt is not prominent in the Archaean succession at Ravensthorpe. Table 1 shows that 13 samples contained between 2.1 and 7.6 percent MgO, with an average of 4.61 percent. Hallberg (1972) gives an average MgO content of 6.7 percent for 123 tholeiitic basalt samples from the Kalgoorlie-Norseman area. One sample of a fine-grained chlorite-tremolite rock from near an ultramafic intrusion exposed along Bandalup Creek contains 14.3 percent MgO.

Felsic volcanics

Felsic volcanics in the succession are of limited lateral extent and thickness. They are encountered in and around the mines at Ravensthorpe, Desmond and Kundip, and also at Bandalup and Maydon Farm.

In a porphyritic dacite, southeast of the magnesite quarry at Bandalup, weak metamorphism is indicated by the presence of abundant muscovite with preferred orientation. Metamorphosed quartz-feldspar porphyry occurs east of Bandalup Hill and is apparently a continuation of the porphyritic dacite.

Porphyritic dacite and felsic tuff occur at Kundip. West of the Harbour View mine felsic tuff and coarse agglomerate trend southeast, which is slightly divergent from

TABLE 1. MAGNESIA CONTENTS OF RAVENSTHORPE BASALTS

G.S.W.A. No.	*1971 Field Notebook No.*	*South Latitude*	*East Longitude*	*MgO %*
28370	1481	33°41′26″	120°17′28″	5.34
28392	1305	33°35′29″	120°09′48″	4.41
28401	1882B	33°38′00″	120°18′43″	2.56
28402	1244	33°36′46″	120°11′46″	5.65
29569	1902C	33°37′37″	120°19′08″	5.81
29579	1524	33°42′08″	120°22′16″	3.96
29580	1883	33°38′11″	120°18′42″	7.59
29582	1561	33°36′42″	120°18′37″	6.57
29584	1505	33°37′10″	120°18′06″	14.3
29586	1369	33°35′28″	120°10′37″	5.83
29589	1387	33°35′50″	120°11′56″	2.08
29590	1370	33°35′36″	120°10′11″	2.78
29591	1878	33°36′28″	120°18′35″	2.08
29599	1460	33°38′53″	120°13′52″	5.15

the main succession. The agglomerate consists entirely of volcanic fragments in a fine-grained tuffaceous matrix. Several varieties of subrounded fragments are present, with trachytic, amygdaloidal, and aphanitic textures. Some fragments are of a microcrystalline quartz-feldspar-chlorite rock, with chlorite pseudomorphs of phenocrysts. Rare fragments carry plagioclase laths. The matrix is a felsic tuff of similar appearance to many of the fragments. The rounding of the fragments and the outcrop pattern suggest emplacement of the agglomerate in a vent.

A small lens of felsic agglomerate and tuff occurs within the uppermost sedimentary sequence south of Maydon Farm. The agglomerate is unusual because of its high content of well developed chloritoid porphyroblasts.

Ultramafic rocks

Serpentinized peridotite is well exposed on the eastern slopes of the Ravensthorpe Range. East of Desmond peridotite occurs in conformable bodies about 1600 m thick. The rocks exhibit well preserved spinifex, skeletal, dendritic and porphyritic textures. Abundant spinifex-textured zones, and at least one example of fine-grained amygdaloidal serpentinite, are found 4.5 km east of Desmond. These features suggest rapid chilling. The nature of the contact with overlying pillowed basalt is obscured by shearing. Contact metamorphism and rafting of large xenoliths is observed at the contact with the underlying sedimentary rocks. The amygdaloidal serpentinite may have been an extrusion.

Thin layers of coarsely dendritic-textured chlorite-tremolite rock occur within the major areas of serpentinite, thus outlining many sills or flows of peridotite. The peridotites are completely serpentinized. Original olivine grains are pseudomorphed by serpentine minerals, and pyroxene has altered to tremolite-actinolite. In shear zones there may be alteration to talc, chlorite and amphibole schists. North of the Esperance Highway the discordant, intrusive relationship between peridotite and sedimentary rock is well illustrated. Primary textures of the peridotite in this area are poorly preserved, and massive or schistose serpentinite occurs with talc, chlorite and amphibole schist. Ultramafic schist concealed by Cainozoic and

Quaternary units is indicated in the northern Bandalup Creek area by percussion drilling and the presence of a large aeromagnetic anomaly. Thick laterite that caps Bandalup Hill also conceals serpentinite.

Small, poorly exposed xenoliths of ultramafic rock occur within granitic rocks to the northeast of the main layered succession. It is not certain whether all of these derive from the layered succession at Ravensthorpe.

Sedimentary rocks

The lowermost sedimentary sequence is exposed along the Ravensthorpe Range. It consists of weakly metamorphosed shale, siltstone, sandstone, polymictic conglomerate, chert and banded iron formation. About 300 m of bedded pyritic quartzite, cropping out 3.6 km southeast of Desmond, appears to form the base of the sequence and unconformably overlies basalt and dacite lavas. The quartzite is overlain by a 300 m-thick sequence of laminated graphitic and manganiferous, tuffaceous shales, together with chert and banded iron formation. Graded bedding in the shale is well exposed in an adit at Mount Chester. This sequence is succeeded by alternating sandstone and polymictic conglomerate. Conglomerate may be more extensive than represented on the map, probably extending along strike for several hundred metres before merging into finer grained sediments. The conglomerate contains well rounded cobbles of banded chert, banded iron formation, quartz, and kaolinized quartz-free or quartz-poor cobbles which may be weathered mafic material. The cobbles range in size up to 40 cm x 15 cm x 15 cm. The sandstone horizons consist of quartz grains in a kaolin matrix which is similar to the groundmass of the conglomerate. The conglomerate thus grades into sandstone by the disappearance of cobbles. Above the lowermost conglomerate is several metres of dark carbonaceous shale which has lateral extent of many hundred metres, succeeded by at least six alternations of conglomerate and sandstone with a total thickness of about 100 m. One analysis of a shale sample from lat. 33°38′36″S, long. 120°11′20″E, indicated a carbon content of 0.32 percent and 45 ppm manganese, 20 ppm copper and 2 ppm zinc. The sandstone exhibits graded bedding and well developed crossbedding. Scour channels about 15 cm deep and 40 cm across are infilled with coarser material which exhibits graded bedding. All these features indicate a facing to the northeast. Above the conglomerate and sandstone is several metres of well bedded tuff or tuffaceous shale which exhibits possible slump structures. This unit is overlain by banded chert, followed by 750 m of interbedded chert, siltstone and shale with minor quartzite. The upper portion is intruded, rafted and locally metamorphosed by ultramafic rock.

In the above section beds dip steeply northeast, although to the north of Mount Desmond there is some overturning. The shale, siltstone and chert exhibit small-scale folding and faulting. The beds are of consistent lithology along strike. Sofoulis (1958c) describes garnet and andalusite-bearing schists in this sequence, but metamorphic effects are generally weak. Near Mount McMahon carbonaceous shale exhibits porphyroblastic graphite, and some shale and siltstone beds contain porphyroblastic andalusite. Adjacent to ultramafic intrusions banded iron formation contains grunerite.

Sedimentary rocks of the same sequence crop out north of the Ravensthorpe-Esperance road, and are generally coarser grained, consisting of quartzite, arkose and metamorphosed banded iron formation. A small lens of conglomerate contains abundant well-rounded vein-quartz cobbles. The rocks are schistose and have a pronounced quartz lineation in the dip direction. The dip is consistently at moderate angles to the south.

Exposed along Bandalup Creek is 700 m of polymictic conglomerate and sandstone overlying massive and pillowed basalt. This conglomerate has clasts ranging in size from pebbles up to boulders 60 cm across, and some stretching is apparent. Clasts include well rounded vein quartz, basalt, coarse-grained altered albite-chlorite-hornblende-quartz diorite, metamorphosed banded iron formation and quartzite. One clast of well bedded pyritic quartzite exhibits crossbedding. Metamorphism of this fragment is indicated by the presence of 10 percent grunerite. The conglomerate matrix is amphibolitic and metamorphism has largely obliterated the distinction in thin section between matrix and smaller pebbles. The sandstone interbedded with the conglomerate is a well bedded medium-grained metamorphosed arkose, containing quartz, plagioclase, hornblende, biotite, chlorite, and magnetite with accessory zircon and allanite. The sandstone has graded bedding and possible cross-bedding. Sandstone in the central portion of the unit is intruded by a gabbro sill about 100 m thick. Above the sill sandstone grades upwards into metamorphosed conglomerate with deformed clasts of quartzite and other sediments (including rare possible dolomitic fragments) and minor granitic clasts. Lithologies are consistent along strike.

The basal contact with pillowed basalt is probably an unconformity because there is some discordance in strike of the sediments and lavas. Basal conglomerate contains abundant basalt clasts. Well bedded and cross-bedded quartzite clasts may have been derived from the quartzite and conglomerate to the north. Quartz-diorite boulders are abundant in the lower portion of the unit (Ac) but rare near the top. These are of a similar composition and appearance to the quartz diorite that occurs south of Ravensthorpe, and northeast of Muckinwobert Rock. The absence of this conglomeratic unit on the southwestern limb of the syncline may indicate a lensoid distribution in a nearshore environment.

In the core of the syncline (i.e. just southeast of Maydon Farm) is a sequence of steeply-dipping, tightly-folded siltstone, and carbonaceous and tuffaceous shale which is the uppermost unit of the layered succession. Graded bedding occurs in a thin horizon of tuffaceous shale on the northern limb. Small porphyroblasts of graphite in carbonaceous shale, and andalusite in shale indicate a weak metamorphism.

A small outcrop of folded, metamorphosed fine-grained arkose occurs north of the Munglinup River. It consists of quartz, plagioclase and microcline with accessory muscovite, biotite, rounded zircon and secondary epidote and sphene.

Granitic Rocks

Six groups of Archaean granitic rocks are distinguished on the basis of texture, petrography, and sequence of intrusion. Some of the granitic rocks which exhibit similar textures may represent different plutons, but these are considered to have been emplaced contemporaneously.

Quartz diorite (Agt)

A quartz diorite pluton intrudes the western margin of the Archaean layered succession. It is well exposed in an aggregate quarry along the Hopetoun road, about 6 km southeast of Ravensthorpe. Previous descriptions have been given by Woodward (1909) and Sofoulis (1958c). Simpson and Glauert (1909) describe the quartz diorite and list two chemical analyses. A recent analysis of a sample (28385) from beside the Hopetoun road 2 km north of Kundip is presented in Table 2A. The quartz diorite contains abundant mafic xenoliths stoped from the adjacent basalt.

Older biotite adamellite (Age)

Along Moolyall Creek masses of biotite-rich, fine, even-grained adamellite have been distinguished as Age. This is intruded by adamellite (Agd) which locally forms a migmatic fabric along the margins and contains numerous xenoliths of Age. The older adamellite (Age) is well foliated, and contains untwinned myrmekitic, sodic plagioclase and rare grains of twinned oligoclase. Microcline is usually homogeneous with only a few larger perthitic crystals. The rock contains accessory apatite and zircon, and secondary chlorite and muscovite. Small euhedral garnet was observed in the outcrop.

Poorly exposed fine-grained well foliated adamellite (Age) occurs more extensively in the northwestern portion of the Sheet. It contains microcline, perthite, quartz, oligoclase, and minor biotite altering to chlorite. There is accessory magnetite, zircon and apatite, and secondary muscovite and calcite. Plagioclase shows alteration to sericite. Some outcrops contain more microcline than usual and have the composition of granite. The rock contains biotite schlieren and is intruded by several generations of pegmatite veins.

Younger adamellite (Agb)

North and northeast of the Archaean succession is a large pluton of medium to coarse-grained, weakly porphyritic biotite adamellite (Agb). This rock contains twinned oligoclase and untwinned, more sodic plagioclase. The content of plagioclase generally exceeds that of microcline. The rock contains accessory apatite, zircon, magnetite and rare hornblende, with secondary chlorite, muscovite and some epidote. About 14.5 km east-northeast of Coujinup Hill the adamellite contains accessory sphene, hornblende, allanite and fluorite. Much of the rock has suffered post-crystallization stress which has resulted in strained extinction and recrystallization of quartz. Associated with the adamellite are quartz and pegmatite veins, and microgranite dykes. The pluton is well exposed along the Moolyall and Coujinup Creeks and along the upper reaches of the Oldfield River. Farther north and northeast the pluton is obscured by Quaternary units. The rock is well foliated with planar alignment of feldspar laths and biotite flakes and quartz aggregates. The regional foliation pattern suggests that the granite consists of composite cells bordered by migmatite and xenolith-rich zones. The adamellite contains abundant xenoliths of biotite-rich, fine, even-grained adamellite (Age).

The younger adamellite (Agb) intrudes the Archaean succession and contains xenoliths of mafic and ultramafic rocks, many of which now occur well away from the contact of the main succession. Parallel to the contact is a shear zone where the rock is very strongly sheared, and the rock type is denoted Agb^1. Pronounced lineations along foliation planes plunge south or southeast. The foliation and lineation are thought to be due to upward diapiric, post-consolidation movement of the pluton, possibly from a southeast direction. The foliation becomes weak to the north. It penetrates both Age and Agb^1, and, particularly near the margins of the Archaean layered succession, the adamellite is garnetiferous.

Younger granodiorite (Agd)

Several small stock-like bodies of fine to medium-grained poorly foliated biotite granodiorite (Agd) intrude the adamellite pluton (Agb) in the area north from Boyup Creek. Both rock types are intruded by coarse pegmatite dykes.

Porphyritic adamellite (Agl)

Coarse porphyritic adamellite intrudes the adamellite pluton (Agb) in the area northeast of Coujinup Hill. A small intrusion of porphyritic adamellite south of the main body is thought to be related to the latter, and in fact may be continuous.

The southern portion is a well foliated, poorly porphyritic adamellite containing large xenoliths of fine to medium-grained granitic rock. It is intruded by pegmatite containing much accessory magnetite. In the north a similar foliated porphyritic biotite adamellite (Agb) consists of abundant large phenocrysts of microcline and anhedral perthite set in a matrix of oligoclase, quartz, biotite, sphene and apatite with accessory zircon and magnetite. The proportions of microcline and oligoclase are variable, and quartz is locally abundant. Biotite has partly altered to chlorite and large flakes of secondary muscovite occur in oligoclase. Some sericitized oligoclase is rimmed by unaltered sodic plagioclase. Apatite is common. The small zircon crystals exhibit zoning. The rock is intruded by pegmatite and quartz veins. It is generally poorly-jointed and contains rare biotite schlieren. The proportion of phenocrysts varies from a minor proportion to almost half of the rock. The size of the phenocrysts is also variable.

Porphyritic biotite adamellite (Agl) crops out in the northeastern part of the Sheet. It is the same batholith as that shown as Agl on the Lake Johnston 1:250 000 Sheet (Gower and Bunting, 1972). Pink microcline phenocrysts are common and vary in size up to 8 cm long, and, together with biotite flakes, form well developed foliation in the rock. The pluton contains abundant large xenoliths of biotite-rich, fine to medium-grained metamorphosed adamellite with a foliation parallel to that of the host rock. Both rock types are intruded by coarse pegmatite veins.

Porphyritic biotite adamellite also occurs along the upper part of the Young River. The rock is medium to coarse grained and well foliated. The content of plagioclase (oligoclase) is slightly in excess of that of microcline. The plagioclase is strongly saussuritized, and secondary muscovite is present. Microcline phenocrysts vary in size and abundance. Biotite schlieren and xenoliths of both amphibolite and fine to medium-grained biotite-rich granodiorite are present and in places form a migmatitic fabric. Evidence of small-scale faulting is common. Aplite dykes and pegmatite veins are common.

The porphyritic biotite adamellite appears to be a variation of weakly porphyritic medium to coarse-grained biotite adamellite (Agb) that outcrops to the north and east. This is also well foliated, and contains abundant fine, even-grained biotite-rich, granodiorite xenoliths. To the north amphibolite xenoliths are also abundant. The weakly porphyritic variety is also intruded by pegmatite and aplite veins.

Archaean migmatite (Agm)

Archaean migmatite (Agm) occurs along the northern portion of the Sheet where the outcrop is generally poor. Northeast of Lake Mends is an excellent exposure of folded, stromatic migmatite. Granular amphibolite bands are interlayered with medium to coarse-grained granitic bands. Individual bands vary from centimetres to several metres in thickness. The amphibolite bands are laminated, with alternating feldspar-rich and feldspar-poor zones. Typically the amphibolite consists of about 45 percent plagioclase, 15 percent hornblende and 40 percent clinopyroxene. The rock has been metamorphosed to amphibolite facies. In the feldspar-rich zones the clinopyroxene is partly porphyroblastic.

The migmatite grades into medium to coarse-grained adamellitic rock which is possibly a weakly porphyritic phase of Agl occurring to the east. The rock is well foliated and contains abundant mafic schlieren.

A well-exposed migmatite zone between fine-grained biotite-hornblende-quartz diorite (Age) and medium to coarse-grained adamellite (Agb) occurs northeast of Munkinwobert Rock. The latter intrudes the former. The quartz diorite contains about 30 percent mafic minerals, mostly a red brown biotite, with a lesser amount of hornblende. The remainder of the rock is largely oligoclase and about 5 percent quartz. There is accessory sphene, microcline, apatite, magnetite and zircon. The migmatite has a well developed stromatic and schlieren fabric. Some amphibolite xenoliths are present.

A similar migmatite zone 16 km to the south contains abundant schlieren and xenoliths of amphibolite and some poorly-exposed ultramafic xenoliths possibly derived from the Archaean layered succession. This migmatite may represent a downturn zone between convection cells in the adamellite (Agb).

Migmatite in the northeastern portion of the Sheet consists of well-foliated, medium to coarse-grained, weakly porphyritic biotite adamellite with biotite-rich, fine-grained granodioritic xenoliths and schlieren. This adamellite generally has a nebulitic fabric. Coarse pegmatite intrudes both rock types. Some outcrops are strongly banded by biotite schlieren which may be contorted. Occasional large feldspar phenocrysts suggest that the intrusive phase is a variety of the porphyritic adamellite that occurs to the west. The migmatite merges with homophanous biotite adamellite (Agb). North-northeast trending foliations are pronounced, and the rocks exhibit a porphyroblastic biotite speckling.

STRUCTURE

Regional structure

Gower and Bunting (1972) have outlined three structural zones in the adjoining Lake Johnston 1:250 000 Sheet to the north: a western zone of predominantly

migmatitic rocks, a central zone characterized by plutons of granitic rocks intruded into the Archaean layered succession, with some migmatitic rocks, and an eastern zone consisting almost entirely of porphyritic granite and adamellite.
The possible extension of these zones into the Ravensthorpe Sheet is difficult to determine, primarily because of the lack of aeromagnetic data. The evidence for the presence of these zones is considered below.

The western zone of the Lake Johnston Sheet, although consisting mainly of migmatite, contains areas of granitic rock (Fig. 2). On the Ravensthorpe Sheet, the equivalent zone is mainly granitic rock with smaller areas of migmatite. Outcrop is poor near the common boundary of the sheets, but a transition northwards from granite to migmatite is likely.

Where *the central zone* would be expected there are scattered outcrops of migmatite and several granite types, which does not conflict with the idea of central zone.

The eastern zone of the Lake Johnston Sheet is almost entirely porphyritic granitic rock, and this corresponds with the zone of porphyritic adamellite in the northeastern corner of the Ravensthorpe Sheet. There is also some migmatite in this zone on the Ravensthorpe Sheet.

Structure of the Archaean layered succession

The principal structure of the Archaean succession (Fig. 2) is a south-plunging syncline. A quartz-diorite pluton separates this fold belt from a folded succession of similar lithology on the Newdegate Sheet to the west.

The structure is based on facing evidence (mainly from pillow lavas) and regional distribution of lithologies. The syncline trace is marked by a line of symmetry. The beds on the northeastern limb dip at about 40° to the southwest and are upward facing. The beds on the western limb dip steeply west and are downward facing. The syncline is thus overturned to the northwest away from the quartz diorite pluton. Sedimentary rock exposed in the Ravensthorpe Range exhibits well-developed, small-scale chevron folding. The northeastern limb of the syncline has been extensively intruded by granite which has removed part of the succession. Extensive Quaternary sandplain near Boyup Brook coinciding with a low aeromagnetic anomaly (Wells, 1962) is thought to overlie granitic rock intruded into the succession.

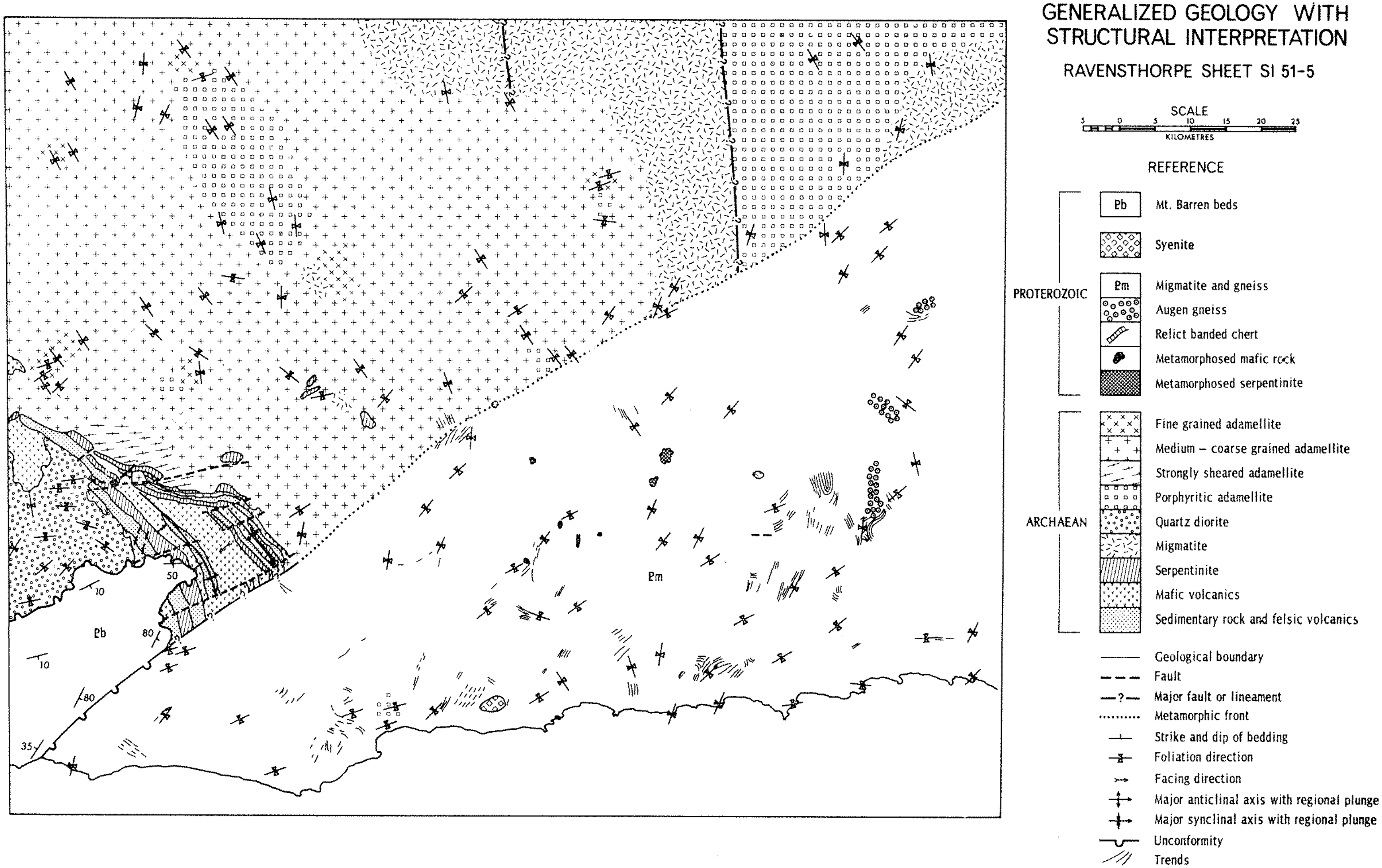
The structure is complicated by numerous faults. Most trend in a northeasterly or north-northeasterly direction with the northwest block displaced northeast. Many of these faults penetrate the adjacent granitic rocks and offset some of the post-metamorphic mafic dykes that intrude the granitic rocks. A large, partly concealed, east-trending fault extends from Cordingup Gap and is marked by shearing, quartz breccias and displacement of the strata. Matching of lithologies and aeromagnetic patterns indicate a north-block-east displacement of 1.6 km. Several subsidiary faults trend northeast.

Prior to faulting, the northern margin of the layered succession and the adjacent granitic rock were metamorphosed and strongly sheared. Quartz lineations on

FIGURE 2

GENERALIZED GEOLOGY WITH STRUCTURAL INTERPRETATION

RAVENSTHORPE SHEET SI 51-5



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bedding and foliation planes suggest a relative upward movement of granitic rock from the southeast.

East of the Jerdacuttup River the Archaean succession is covered by extensive Cainozoic laterite and sandplain. Continuation of the Archaean succession to the south, beneath Proterozoic sedimentary rocks, is suggested by the extension of prominent aeromagnetic anomalies. However, the aeromagnetic flight lines do not extend south of latitude 33°43′S, making interpretation of concealed rocks difficult. Bouguer anomalies (Australia Bureau Mineral Resources, 1964) suggest that the layered succession continues about 13 km southeast of the surface outcrop. The gravity data also suggest that the Archaean layered succession does not swing southwestwards as proposed by Sofoulis (1958c).

MAFIC DYKES

The Archaean granitic rocks are extensively intruded by several sets of mafic dykes. Some undoubtedly belong to the Widgiemooltha Dyke Suite. Recognition of this suite was rendered difficult by the lack of aeromagnetic data for most of the Sheet, and only one dyke, cropping out in 12 km west of Robert Swamp, was considered to belong to this suite. The dyke is an unmetamorphosed gabbro, about 80 m wide. It contains fresh pyroxene and has a layered fabric parallel to the dyke margins. For the area around Ravensthorpe the available aeromagnetic data has several east-northeast-trending magnetic anomalies which suggest the presence of other dykes of this suite.

The quartz diorite south of Ravensthorpe contains dolerite and gabbro dykes, trending mainly northwest with a lesser number east-northeast. It also contains a swarm of acid porphyry dykes, all of which trend about northwest; these occur towards the western boundary of the Sheet, i.e. near the middle of the pluton. Abundant dolerite dykes in sheared biotite adamellite (Agb^1) northeast of Ravensthorpe are clearly post-shearing intrusions.

Approaching the boundary of the Albany-Fraser Province, mafic dykes exhibit increasing grades of metamorphism. Northeast of Lake Mends Archaean migmatite (Agm) is intruded by unmetamorphosed, quartz dolerite dykes, containing about 40 percent primary clinopyroxene.

ALBANY-FRASER PROVINCE

PETROLOGY AND LITHOLOGY

Migmatite and gneiss

A zone of Proterozoic migmatite and high-grade metamorphic gneiss occurs in the southeastern half of the Sheet area. These include a range of homophanous to well banded stromatic migmatite, and are all grouped under the heading of migmatite. Even those more correctly termed gneiss fall within a regional migmatite zone, and either show migmatite features or grade into such rocks. The classification used here is based on the degree of preservation of the palaeosome. The symbol Pmm includes stromatic (layered), banded and raft-structured migmatite (Mehnert, 1971), all of which possess a well-defined palaeosome. Where the palaeosome forms schlieren, or is wispy, nebulous, or indistinguishable, the symbol Pmm is used.

Mappable bodies of mafic material within migmatite are designated Pma and are thought to represent the original mafic country rock in its least-changed state. Pmp denotes ophthalmitic migmatites (Mehnert, 1971), or augen gneiss. 'This rock type consists of augen or porphyroblasts of microcline in a matrix of microcline, plagioclase, quartz and biotite, with rare garnet and accessory zircon. The large microcline crystals are anhedral and may be porphyroblasts. The rock appears to be metamorphic, but it is not clear whether the metamorphic recrystallization accompanied intrusion or was a separate thermal event' (W. Libby, pers. comm.). The symbol Pm represents unassigned migmatite.

The migmatites are mostly of oligoclase adamellite to granodiorite. Samples collected along the Lort River indicate a general northward increase in metamorphic grade. South of the Ravensthorpe-Esperance Road, from the Oldfield River to the eastern margin of the Sheet, the migmatites commonly contain garnet. Migmatites, cropping out on the coastal headlands of the eastern half of the Sheet, contain abundant garnet and orthopyroxene. Metamorphosed dykes contain abundant garnet and orthopyroxene, indicating an upper almandine amphibolite and granulite facies.

The migmatite (Pmn) at Oldfield River, from which Richards and others (1966) obtained an age of about 2900 m.y. from lead, uranium and thorium isotope studies on zircons, is a well foliated nebulitic to stromatic, medium-grained hornblende-biotite-adamellite. Oligoclase is in excess of microcline. The rock contains apatite and accessory zircon, sphene and magnetite. Secondary minerals include muscovite, calcite and epidote. Microcline is poorly twinned, and has been partially replaced by myrmekitic plagioclase. The dark green hornblende is probably of metamorphic origin, and is usually surrounded and partially replaced by olive green biotite. The texture of the rock is allotriomorphic granular, and the rock has been stressed and partly recrystallized. Euhedral biotite, quartz and plagioclase are absent. Plagioclase is unzoned. The grade of metamorphism is probably upper amphibolite facies. The rock contains abundant mafic schlieren and elongate rounded xenoliths of quartz diorite granofels and amphibolite, and is intruded by pegmatite and quartz veins.

Two varieties of zircon can be seen in thin section. One variety is euhedral, clear and unzoned, and apparently of igneous origin. Grains of the other variety lack clarity due to surface relief, inclusions and fractures. Their general form is one of rounded corners and edges, but in detail these are made up of a series of steps which parallel the crystal faces. Zircon grains are mostly of the latter variety. Richards and others (1966) considered the zircons in the migmatite to have passed through a detrital stage, but samples examined in the present study indicate the zircons are of primary igneous origin within the migmatite. The data of Richards and others (1966) may indicate an Archaean origin for the migmatite, and the age of 2800-2900 m.y. probably represents the age of igneous crystallization.

Mafic dykes

Mafic dykes, now amphibolite, are also recognizable in the migmatite-gneiss zone of the Albany-Fraser Province in the southeastern half of the Sheet area. Some are folded or boudinaged, but others are virtually undeformed. Cross-cutting relationships of dykes indicate more than one age of intrusion. It is possible that some of these dykes and the gneissic host rocks are the metamorphosed equivalents of the mafic dykes in Archaean granitic host rocks in the Yilgarn Block.

A quartz gabbro dyke intruding migmatite in the extreme northeastern corner of the Sheet (lat. 33°02′S, long. 121°25′E) has been statically metamorphosed to amphibolite facies. The gabbro contains about 50 percent bluish-green hornblende of metamorphic origin. Plagioclase has partly altered to zoisite-clinozoisite, biotite, and minor hornblende. Rare euhedral feldspar shapes and minor granophyre texture suggest that metamorphism had little effect on the fabric. The composition of the intermediate plagioclase which is in equilibrium with zoisite-clinozoisite suggests temperatures compatible with almandine-amphibolite facies metamorphism.

A gabbro dyke in migmatite near the highway crossing of the Oldfield River has been metamorphosed to granulite facies. It contains an assemblage of brown hornblende, clinopyroxene, labradorite, quartz, bronzite, and garnet. The presence of hornblende with a fresher appearance than pyroxene infers upper almandine-amphibolite facies metamorphism. Gabbro dykes occurring about 10 km west-northwest of Munglinup have also been metamorphosed to at least almandine-amphibolite facies, and contain andesine, green hornblende, diopside, hypersthene, garnet, magnetite, minor quartz, and secondary biotite.

Remnants of metasedimentary and meta-igneous rock

At Munglinup the occurrence of jaspilite (banded chert) was noted by Sofoulis (1958c), and the graphite deposit at the same locality was tentatively attributed to breakdown of the CO_3 radical of a dolomite. All rock types in that immediate area were regarded by Sofoulis as metasedimentary, perhaps representing the metamorphosd equivalent of an Archaean succession.

A pale green amphibolite schist crops out 20 km north-northeast of Munglinup townsite. It is a small remnant within the migmatite-gneiss zone. The rock consists of about two-thirds anthophyllite, one-third tremolite-actinolite, and is thought to be a metaperidotite (W. Libby, pers. comm.).

About 20 km farther east, beside the Young River, is a group of mafic and ultramafic rocks. These are the host rocks of a vermiculite deposit (Johnson and Gleeson, 1951b). They include actinolite-spinel, and actinolite-anthophyllite-hornblende rocks after ultramafic rock, and plagioclase-hornblende rocks derived from metamorphism of north-northwest-trending basic dykes (MacLeod, 1964). On the western edge of this outcrop is metamorphosed sedimentary quartzite with a northerly trend. Three kilometres to the south is another poorly exposed serpentinite.

The possible regional significance of these rock types is discussed in a later section.

Syenite

Two syenitic bodies occur within the granitic and gneissic rocks of the Albany-Fraser Province. A small pluton of coarse-grained porphyritic syenite crops out at Lake Shaster. The rock has a weak foliation, formed by planar alignment of phenocrysts, groundmass feldspar, biotite and hornblende. It consists of numerous phenocrysts of microcline up to 3 cm in a groundmass of microcline, oligoclase, biotite, green hornblende, minor apatite, and accessory sphene, zircon and magnetite. Quartz only occurs in myrmekitic patches.

A foliated quartz syenite crops out about 6 km west-southwest of Shamba Kappa homestead. It contains quartz, microcline, calcic oligoclase, myrmekite, hornblende, minor pyroxene, sphene and apatite, with accessory biotite, opaque iron oxide, zircon and epidote. The rock is similar to the quartz syenite at Peak Charles in the Lake Johnston Sheet (Gower and Bunting, 1972).

Mount Barren Beds

Proterozoic sedimentary rocks of the Mount Barren Beds (otherwise known as the Barren Series, Mount Barren Series, Mount Barren-Stirling Range Series, Stirling-Barren Series) crop out in the southwestern corner of the Sheet area. They consist generally of an unmetamorphosed sequence of interbedded quartzite, phyllite, dolomite and conglomerate. They unconformably overlie the Archaean succession and the granitic rocks of the southern part of the Yilgarn Block.

The quartzite is variable in composition from orthoquartzite to more schistose and pelitic types containing, in places, about 50 percent andalusite. The quartzite is generally well bedded, with bedding units of about 1 m in thickness. Sedimentary structures such as cross-bedding and ripple marks are common. Quartzite forms the scarp on the northern boundary of the Mount Barren Beds and the prominent peaks of the Barren Ranges. Generally the beds dip gently south, but become steeper near the boundary of the migmatite-gneiss belt. Here the metamorphism is more pronounced and at East Mount Barren the quartzite contains kyanite and staurolite.

Intraformational conglomerate containing clasts of quartzite has been observed to the north, where the pebbles are undeformed. Near East Mount Barren stretched-pebble conglomerate is interbedded with quartzite, and indicates the attitude of the beds which is otherwise obscured by pronounced cleavage and transposed bedding.

Phyllite and schist of the Mount Barren Beds are commonly chevron-folded, a feature tentatively ascribed to mild thrusting (Sofoulis, 1958c). In places they appear to be graphitic and manganiferous. At East Mount Barren the phyllite has been metamorphosed to a kyanite-staurolite-garnet schist.

Dolomite crops out only to the north, which suggests that it occurs towards the base of the succession. In places the dolomite contains stromatolites. Although it has been observed interbedded with quartzite and conglomerate, it generally appears to be lensoid in character. A chemical analysis of the dolomite is reported by Simpson (1948).

Basal conglomerate, containing clasts of banded iron formation, crops out at several points along the base of the scarp. About 3 km west of Kundip, this conglomerate can be observed resting unconformably on Archaean quartz diorite.

The southernmost schistose rocks in this area were previously correlated with schistose Archaean sediments in the Ravensthorpe Range, whereas the quartzite of the Mount Barren Beds was regarded as Proterozoic. Chevron-folded phyllite has been observed interbedded with quartzite in the Phillips River just north of Culham Inlet and it is considered that all sedimentary rocks to the southwest of Kundip are of Proterozoic age.

The present authors found no mafic dykes intruding the Mount Barren Beds of the Ravensthorpe Sheet, although they have been reported by Clarke and others (1954). The Mount Barren Beds are regionally continuous with the sedimentary rocks of the Stirling Range. Turek and Stephenson (1966) report a metamorphic age for shale from the Stirling Range of 1150 $\pm$ 40 m.y., and a minimum age of deposition of 1340 m.y.

NATURE OF THE ALBANY FRASER PROVINCE

Fold structures

The structure of the inhomogenous, polygenetic migmatite-gneiss belt is not well understood. Figure 2 shows trends of migmatite and gneiss taken from air-photographs. The variation in direction of these trend lines suggests large sweeping folds, and some individual fold closures up to 3 km across are observed on air-photographs. The overall strike is about northeast, which is the typical trend for the Albany Fraser Province in this area, and the dip is vertical to steeply southeast.

Structural zones

There is some evidence that the previously described structural zones of the Yilgarn Block continue southwards into the Albany Fraser Province.

Although the western zone is not readily distinguishable within the migmatite-gneiss zone, the granodiorite migmatites and gneisses with deformed mafic dykes may be equivalent to the granitic rocks with mafic dykes of the Yilgarn Block.

Towards the middle of the Proterozoic migmatite zone (i.e. where a continuation of the central structural zone might be expected), there occur the following features:

(i) a northerly-trending banded chert and other metasediments at Munglinup,
(ii) a small outcrop of anthophyllite-tremolite schist, thought to be a metamorphosed peridotite,
(iii) arkose,
(iv) metamorphosed mafic and ultramafic bodies with a metamorphosed mafic dyke suite at Young River,
(v) metamorphosed sedimentary quartzite with a northerly trend, at Young River,
(vi) a serpentinite body near Clare Downs, and
(vii) an abundance of mafic material in migmatite near Clare Downs, Munglinup and generally throughout this area.

These are considered to be remnants of an Archaean layered succession. An alternative explanation is that these represent ultramafic and mafic rocks of Proterozoic age.

A distinctive augen gneiss or ophthalmitic migmatite crops out parallel to the Lort River (which has exposed much of the outcrop), and this is believed to be the metamorphosed equivalent of the eastern zone of porphyritic granitic rocks.

The juxtaposition of the augen-gneiss zone to the metasedimentary/meta-igneous-remnant zone suggests that the latter is to be equated with the Bremer Range succession in the Lake Johnston Sheet rather than the Ravensthorpe Range succession; the parallelism of the other lithologies supports this idea.

The occurrence of quartz syenite near Shamba Kappa homestead of a type similar to the Peak Charles syenite suggests that syenite tends to occur near the eastern boundary of the central structural zone, which in turn suggests that there may have been a pre-migmatite boundary between the syenite-porphyritic-granite association and the mafic-ultramafic-sedimentary-rock association. A syenite at Lake Shaster suggests a similar relationship with regard to the western boundary of the central structural zone, though this boundary has not been detected either.

A subdivision of migmatites on the basis of original composition of palaeosome might clarify the nature and distribution of the country rocks before migmatisation.

Nature of the front

This is not a well exposed feature on the Ravensthorpe Sheet, and no aeromagnetic maps are available yet to help establish its position.

Several lines of evidence suggest that the boundary from East Mount Barren to Jerdacuttup, a distance of about 45 km, is a fault. Firstly the change from recognisable metamorphosed sedimentary rocks to migmatite is abrupt. The migmatite here is lithologically unlike the Mount Barren Beds which contain abundant quartzite beds. Secondly deformation in the Mount Barren Beds near the boundary is intense, and diminishes away from the boundary. Thirdly the outcrop of typically Archaean rocks of the Yilgarn Block suddenly stops at this line, suggesting truncation. However, gravity isograds show a 'high' over both the layered succession and its possible extension southeastwards across this line. This suggests that the layered succession either continues underneath the migmatite zone or is disrupted to form a migmatite, rich in mafic and ultramafic palaeosome. Fourthly southeast-trending drainages are diverted southwest at this line (Fig. 1).

Farther northeast the line between Archaean granitic rocks and Proterozoic nebulitic migmatites is difficult to determine. This boundary on the Norseman 1:250 000 Sheet (Doepel, 1970) which is thought to be part of the same major feature that stretches from East Mount Barren to northeast of Zanthus, is used as a guide in placing the boundary in the poorly exposed northeastern portion of the Ravensthorpe Sheet. That the assignation of Proterozoic or Archaean ages in this transition zone is arbitrary is acknowledged by a query before the symbol on the map face. Some control is afforded by contrasts in structural trends. For example, Proterozoic rocks of the Albany Fraser Province trend northeast, and the Archaean rocks of the Yilgarn Block trend northwest.

Chemical analyses of 30 granitic rocks from the granodiorite adamellite areas of the Yilgarn Block, and the granitic phases of the migmatite-gneiss complex of the Albany Fraser Province are tabulated in Tables 2A and 2B. The aim was to determine whether there is any significant variation in geochemistry between the two units. Variation diagrams (including CaO-K_2O-Na_2O, CaO-FeO (total) + MgO-K_2O + Na_2O, Ab-An-Or, CaO-K_2O-Na_2O, MgO/Li, K_2O/Rb and Th/U) have been constructed. With the possible exception of one (K_2O/Rb) all indices failed to detect any significant variations. The mean K_2O/Rb value for the migmatite-gneiss complex (252) is significantly higher (using a two-tail t test) than the granodiorite/adamellites value (158). However, the overall geochemical similarity suggests that much of the Albany Fraser Province represents Archaean granitic material that was reworked during the period of Proterozoic metamorphism.

In the area centred on lat. 33°32′S, long. 120°40′E, medium to coarse-grained adamellite (Agb) with a pronounced northwest-trending photo-lineament appears to be intruded by granitic rock (?Pm). The latter has a pronounced arcuate photo-lineament pattern which trends in a northeast direction. A small stock-like mass (?Ag) with a smooth, non-directional photopattern and of large continuous outcrop may be a later granitic rock intruded along part of the boundary between the previous two rock types. This area warrants ground investigation.

A medium to coarse-grained adamellite near the southern part of the Jerdacuttup River contains abundant fine-grained biotite-rich granodiorite xenoliths. Many of the xenoliths have a granoblastic texture and it is not clear whether they were originally granodioritic or metamorphosed arkose from the Archaean layered succession. Similarly broad bands of granular amphibolite may represent mafic rock derived from the layered succession. Xenoliths and schlieren may be in sufficient abundance to constitute a migmatitic fabric. The adamellite, which is porphyritic in places, is intruded by coarse pegmatite. Gabbro dykes intruding the adamellite have had low-grade metamorphism. Metamorphism increases sharply towards the coast. Apart from metamorphism there appears to be a close resemblance with the Archaean adamellite (Agb) north of Ravensthorpe.

In summary the Archaean-Proterozoic boundary appears to be simply a metamorphic front separating rocks of common origin but now of different metamorphic grade and fabric. Some of the homophanous granitic rocks may represent remobilized portions of the migmatite.

MINERAL DEPOSITS

INTRODUCTION

Mineral production from the Ravensthorpe Sheet area has been principally from copper mining, which has produced 50 percent of the State's total copper production. Gold and silver were produced as by-products of copper mining. Quarrying of magnesite has produced two-thirds of the State's production of about 30 000 t.

TABLE 2A. CHEMICAL COMPOSITION OF ARCHAEAN GRANITIC ROCKS

MAP SYMBOL	Agb	Agb	Agb	Agb	Agl	Agb	Agb	Agl	Agt	Age
SAMPLE No.	28301	28313	288315	28323	28324	28329	28331	28334	28385	29512
NAME	Biotite grano-diorite	Biotite adamel-lite	Biotite adamel-lite	Porph. bi.adamel-lite	Biotite adamel-lite	Altered grano-diorite	bi.-hbl. adamellite	Biotite adamellite	hbl.-bi.-quartz diorite	Adamellite
LONGITUDE E	120°25′38″	120°24′48″	120°26′06″	120°15′36″	120°20′54″	120°15′32″	120°15′10″	120°27′20″	120°10′42″	121°11′20″
LATITUDE S	33°26′50″	33°20′58″	33°15′42″	33°27′08″	33°19′05″	33°27′05″	33°22′35″	33°19′40″	33°40′23″	33°02′33″
MAJOR OXIDE %										
SiO_2	70.6	72.5	74.5	73.9	68.3	74.4	65.4	74.2	70.0	70.0
Al_2O_3	15.7	14.3	14.1	13.9	14.7	13.5	14.9	15.6	15.2	15.2
Fe_2O_3	1.0	1.0	0.7	0.7	1.6	0.8	2.4	0.7	1.2	1.2
FeO (C)	1.35	0.69	0.58	0.38	2.31	0.76	3.08	0.38	2.30	1.79
MgO	0.7	0.1	0.1	0.4	1.0	0.2	1.5	0.2	1.4	0.7
CaO	2.39	1.07	0.83	0.12	1.70	0.97	2.52	1.20	3.15	1.66
Na_2O (C)	4.74	4.91	3.95	3.44	3.83	3.53	3.43	3.36	4.10	4.29
K_2O	1.1	5.0	5.1	5.0	4.7	4.5	3.9	4.1	1.2	3.3
H_2O^+(C)	0.66	0.64	0.40	0.79	1.08	0.40	0.86	0.57	1.14	0.54
H_2O^-(C)	0.10	0.09	0.10	0.12	0 06	0.05	0.08	0.15	0.09	0.09
CO_2(C)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO_2	0.24	0.19	0.15	0.09	0.73	0.20	0.99	0.08	0.37	0.39
P_2O_5	0.09	0.04	0.01	0.01	0.26	0.05	0.39	0.02	0.10	0.14
MnO	0.05	0.04	0.03	0.02	0.07	0.03	0.08	0.02	0.06	0.06
TOTAL	98.72	100.57	100.55	98.87	100.34	99.39	99.53	100.58	100.31	99.36
TRACE ELEMENTS (ppm)										
Ba	250	1170	850	960	1370	790	1530	780	380	1030
Li(C)	20	15	25	15	15	20	45	15	10	25
Rb	60	360	360	265	350	360	285	200	120	265
Sr	400	160	110	160	200	110	220	190	130	330
Th(C)	5	20	5	5	50	90	30	100	10	25
U(C)	2	2	2	2	2	2	2	7	2	2
Zr	170	190	130	80	530	170	740	110	210	270
C.I.P.W. NORMS			*							
Q	32.30	23.00	29.97	33.93	22.80	34.20	22.99	36.14	31.76	27.41
C	2.58	0.00	0.60	2.63	0.84	1.18	1.39	3.50	1.67	1.89
Or	6.50	29.55	30.14	29.55	27.78	26.59	23.05	24.23	7.09	19.50
Ab	40.10	41.54	33.42	29.11	32.41	29.87	29.02	28.43	34.69	36.30
An	11.27	2.22	4.05	0.53	6.74	4.49	9.95	5.82	14.97	7.32
Di	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hy	3.09	0.00	0.54	1.00	4.34	0.96	5.92	0.52	6.22	3.51
Mt	1.45	1.45	1.01	1.01	2.32	1.16	3.48	1.01	1.74	1.74
Hm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Il	0.46	0.36	0.28	0.17	1.39	0.38	1.88	0.15	0.70	0.74
Ap	0.21	0.09	0.02	0.02	0.62	0.12	0.92	0.05	0.24	0.33

MAP SYMBOL	Agl	Agb	Agb	Agl	Agm	Agb	Agl	Abg	Agb	Agl
SAMPLE No.	29513	29575	29585	29594	28383	29524	29526	29578	29581	29596
NAME	Biotite adamellite	Biotite adamellite	Gneissic hornblende adamellite	Biotite adamellite	hbl.-bi. tonalite	porp. bi. grano-diorite	Porphyritic granite	Gneissic biotite granodiorite xenolith	Leuco.-bi. granodiorite	Gneissic porphyritic biotite granodiorite
LONGITUDE E	121°11′20″	120°15′53″	120°10′40″	121°10′35″	120°30′09″	120°39′39″	120°47′01″	120°51′53″	120°49′36″	121°16′11″
LATITUDE S	33°02′33″	33°26′42″	33°32′47″	33°02′43″	33°28′37″	33°27′16″	33°24′04″	33°25′01″	33°25′54″	33°11′23″
MAJOR OXIDE %										
SiO_2	73.5	72.7	73.1	75.9	58.8	68.2	75.1	74.1	76.9	72.8
Al_2O_3	14.6	14.4	13.5	14.8	17.6	1.58	13.2	14.8	14.2	15.7
Fe_2O_3	0.6	0.8	1.1	0.9	4.1	1.8	0.6	1.0	0.5	0.7
FeO (C)	0.84	0.83	0.45	0.84	3.95	2.43	0.65	0.92	0.23	1.17
MgO	0.3	0.5	0.2	0.5	2.7	1.0	0.0	0.5	0.1	0.2
CaO	1.11	1.45	0.67	1.05	6.19	2.99	0.31	2.34	0.70	2.04
Na_2O (C)	3.84	4.17	3.41	3.68	4.72	4.26	2.36	4.97	5.47	4.46
K_2O	4.6	3.4	5.0	4.0	0.9	2.3	7.3	1.4	1.4	2.9
H_2O^+(C)	0.49	0.42	0.39	0.68	0.80	0.66	0.30	0.56	0.57	0.33
H_2O^-(C)	0.08	0.11	0.12	0.09	0.05	0.08	0.09	0.10	0.09	0.10
CO_2(C)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO_2	0.17	0.19	0.16	0.20	0.83	0.52	0.13	0.68	0.05	0.21
P_2O_5	0.08	0.07	0.10	0.15	0.19	0.21	0.02	0.09	0.00	0.06
MnO	0.03	0.04	0.04	0.02	0.13	0.08	0.02	0.04	0.01	0.03
TOTAL	100.24	99.08	98.24	102.81	100.96	100.33	100.08	101.00	100.22	100.70
TRACE ELEMENTS (ppm)										
Ba	1130	770	410	1040	410	650	2170	420	470	990
Li(C)	10	15	15	10	15	50	15	40	20	15
Rb	270	215	660	225	40	170	320	110	80	125
Sr	220	170	80	210	520	350	200	250	170	310
Th(C)	60	10	35	25	15	10	25	65	40	5
U(C)	2	2	4	2	2	3	2	2	3	2
Zr	150	180	160	160	180	240	40	150	70	140
C.I.P.W. NORMS										
Q	30.59	31.49	32.68	36.38	11.05	26.28	32.59	34.04	38.08	30.68
C	1.48	1.39	1.50	2.87	0.00	1.37	0.90	1.07	2.41	1.66
Or	27.18	20.09	29.55	23.64	5.32	13.59	43.14	8.27	8.27	17.14
Ab	32.49	35.28	28.85	31.14	39.94	36.04	19.97	42.05	46.28	37.74
An	4.98	6.74	2.67	4.23	24.18	13.46	1.41	11.02	3.47	9.73
Di	0.00	0.00	0.00	0.00	4.26	0.00	0.00	0.00	0.00	0.00
Hy	1.57	1.87	0.50	1.75	7.41	4.76	0.52	1.89	0.25	1.78
Mt	0.87	1.16	1.12	1.30	5.94	2.61	0.87	1.45	0.63	1.01
Hm	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.07	0.00
Il	0.32	0.36	0.30	0.38	1.58	0.99	0.25	0.34	0.09	0.40
Ap	0.19	0.17	0.24	0.36	0.45	0.50	0.05	0.21	0.00	0.14

*Wol—0.72.
(C)—Analysis by chemical methods.
All other analyses by XRF techniques.
Analyses by the Mineral Division, W.A. Govt. Chem. Labs.

TABLE 2B. CHEMICAL COMPOSITION OF MOBILE BELT GRANITIC ROCKS

SAMPLE No.	28335	28337	28338	28381	29525	29576	29593	28403	28404	28405		
NAME	Biotite granite	Biotite grano-diorite	Biotite granite	Porphyritic bi.granite	Porphyritic biotite granite	Porphyro-blastic bi. adamellite	Bi grano-diorite gneiss (pal-aeosome)	Biot. augen granite gneiss	Biotite adamellite gneiss	Biotite tonalite gneiss	Mean Mobile Belt	Mean Archaean
LATITUDE S	33°44′16″	33°47′40″	33°44′44″	33°51′29″	33°25′44″	33°49′42″	33°12′10″	33°12′10″	33°22′06″	33°21′56″		
LONGITUDE E	120°51′24″	120°59′24″	120°47′40″	120°34′20″	120°48′52″	121°27′36″	121°17′48″	120°56′28″	120°59′46″	120°59′40″		
MAJOR OXIDES %												
SiO_2	69.3	74.8	69.7	68.4	72.7	75.6	70.6	70.0	71.0	73.2	71.53	71.75
Al_2O_3	15.0	14.5	13.9	16.7	14.8	13.2	16.1	16.0	15.8	15.5	15.55	14.78
Fe_2O_3	0.8	0.3	1.0	1.0	0.8	0.6	0.8	0.8	0.8	0.7	0.76	1.17
FeO (C)	1.54	0.32	0.76	1.16	1.17	0.52	1.40	1.63	1.43	0.78	1.07	1.29
MgO	1.4	0.1	0.2	0.9	0.5	0.1	0.8	0.6	0.4	0.5	0.55	0.62
CaO	0.66	1.56	1.04	2.26	1.27	1.12	2.66	1.92	1.60	2.05	1.61	1.72
Na_2O	4.00	3.91	4.00	3.98	4.11	2.90	4.67	3.94	4.35	4.46	4.03	4.04
K_2O	4.6	3.8	4.3	4.5	3.0	5.1	2.1	4.0	4.7	2.5	3.86	3.55
H_2O^+(C)	0.51	0.30	0.40	0.45	0.68	0.12	0.21	0.31	0.28	0.42	0.37	0.61
H_2O^-(C)	0.08	0.09	0.07	0.05	0.07	0.03	0.05	0.01	0.03	0.09	0.06	0.09
CO_2(C)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO_2	0.46	0.06	0.23	0.55	0.26	0.14	0.27	0.29	0.37	0.19	0.28	0.30
P_2O_5	0.18	0.04	0.08	0.20	0.09	0.03	0.11	0.14	0.12	0.08	0.11	0.10
MnO	0.03	0.02	0.01	0.03	0.03	0.01	0.03	0.05	0.03	0.02	0.03	0.05
TOTAL	98.56	99.80	95.96	100.18	99.48	99.47	99.80	99.69	100.91	100.49	99.81	100.07
TRACE ELEMENTS (ppm)												
Ba	1580	1710	1020	1760	840	1500	1400	1570	1860	1150	1439	879
Li(C)	10	10	25	20	30	20	25	10	35	45	23	21
Rb	195	110	225	205	110	130	140	160	240	95	161	243
Sr	180	460	240	390	240	260	570	370	440	470	362	250
Th(C)	5	5	60	25	5	10	15	5	10	25	15.0–16.5	30.5–31.5
U(C)	2	2	10	2	2	3	4	2	2	2	2.5–3.1	1.1–2.5
Zr	300	90	200	340	160	60	140	150	210	150	180	204
C.I.P.W. NORMS												
Q	24.77	34.01	27.58	22.20	33.59	36.64	28.13	26.27	23.38	32.52		
C	2.67	1.21	0.97	1.65	2.70	0.94	1.57	2.03	0.94	1.92		
Or	27.18	22.46	25.41	26.59	17.73	30.14	12.41	23.64	27.78	14.77		
Ab	33.84	33.08	33.84	33.67	34.77	24.54	39.51	33.34	36.80	37.74		
An	2.10	7.48	4.64	9.91	5.71	5.36	12.48	8.61	7.15	9.65		
Di	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Hy	4.95	0.53	0.71	2.69	2.36	0.50	3.51	3.44	2.41	1.82		
Mt	1.16	0.43	1.45	1.45	1.16	0.87	1.16	1.16	1.16	1.01		
Il	0.87	0.11	0.44	1.04	0.49	0.27	0.51	0.55	0.70	0.36		
Ap	0.43	0.09	0.19	0.47	0.21	0.07	0.26	0.33	0.28	0.19		

(C)—Analysis by chemical methods.
All other analyses by XRF techniques.
Analyses by the Mineral Division, W.A. Govt. Chem. Labs.

Minor amounts of graphite, vermiculite, scheelite, manganese and jarosite have been produced. Spodumene was quarried from a complex pegmatite 2 km north-west of Ravensthorpe.

Mineralization is mainly confined to the Archaean volcanic and sedimentary rocks near Ravensthorpe. Exploration for nickel mineralization is in progress.

Copper, Gold, and Silver

Copper, gold, and silver constitute almost the entire metallic mineral production of the Ravensthorpe Sheet area, and production figures for the main mining centres are given in Tables 3 and 4. Some cupreous ore has been mined for use in fertilizer manufacture. The mines were described by Ellis and Lord (1965), Low (1963) and Sofoulis (1958b, c). Greatest copper production was between 1958-1971 when Ravensthorpe Copper Mines N.L. produced about 30 percent of the State's total production from the Elverdton mine.

The lodes occur within 1 to 2 km of the periphery of the quartz diorite pluton that intrudes the Archaean layered succession. The mineralization is mostly confined to felsic and basaltic lavas, and pyroclastic rocks near the contact with the pluton.

The major deposits are situated at Kundip, Desmond and Ravensthorpe. Principal mineral associations are quartz-gold, and quartz-gold-chalcopyrite with minor pyrite and pyrrhotite. The quartz-gold association occurs mainly in the oxidized zone which extends to between 6 and 65 m below the surface. Gold decreases with depth, particularly in the mines of the Kundip area, suggesting secondary enrichment in the oxidized zone. Some silver occurs with the ore, particularly in the Mosaic mine, east of Kundip. This mine is within the ultramafic rocks and recorded production is 54 928.8 g. Minor galena and cobalt occur in some ore shoots, including those of the Elverdton mine.

Sofoulis (1958c) regards the mineralization to be genetically related to the quartz diorite and to be localized in suitable structures in the adjacent volcanic rocks. The ore shoots occur in a series of parallel and *en echelon* shear zones which extend up to 200 m in length and 30 m in width. They are intruded by, or are adjacent to, quartz diorite, and dip steeply away from the pluton margins. Ore shoots are about 65 m in length and 2 m wide. Most mining did not extend below a vertical depth of 165 m because the grade of copper and gold decreased with depth. Recent mining was based mainly on the development of the Elverdton mine at Desmond, but this mine closed in 1971. The deposits probably do not extend below 500 m because the diorite pluton contact dips locally eastward beneath the volcanic and sedimentary succession.

Cobalt

Cobalt is present in the copper mines west of Ravensthorpe and the Elverdton mine, but no production has been recorded. Cobalt contents of up to 0.2 percent in manganese deposits at Mount Chester are mentioned by Sofoulis (1958c).

TABLE 3. PRODUCTION OF GOLD AND SILVER PRIOR TO DECEMBER 31st, 1971, FROM THE RAVENSTHORPE 1:250 000 SHEET

Area	*Ore (tonnes)*	*Gold (kg)*	*Alluvial (kg)*	*Dollied and specimen (kg)*	*Total (kg)*	*Silver (kg)*
Ravensthorpe	32 511.1	910.459	5.100	4.649	920.208	141.262
Desmond	90.4	794.103	—	0.044	794.147	2 297.591
Kundip	93 600.0	1 977.035	6.331	19.570	2 002.936	126.989
Other	27.4	132.365*	5.122	0.454	137.942	16.032
Ravensthorpe 1:250 000 Sheet	126 228.9	3 813.962	16.553	24.717	3 855.233	2 581.874
State	1 681 168.4	2 059 185.487	10 450.032	9 900.441	2 079 535.963	308 787.472
Ravensthorpe Copper Mines NL	—	671.324	—	—	671.324	2 081.647

* mainly from treatment of an uneven quantity of tailings.

TABLE 4. PRODUCTION OF COPPER ORE AND CUPREOUS ORE PRIOR TO DECEMBER 31st, 1971, FROM THE RAVENSTHORPE 1:250 000 SHEET

COPPER ORE			
Area	*Ore (Tonnes)*	*Copper Content (Tonnes)*	*Value $A*
Ravensthorpe	42 522.4	3 416.15	462 326
Desmond	95 121.9	14 901.13	6 994 064
Kundip	7 447.2 (incomplete)	946.68	145 323
Other	1 664.2	130.70	19 690
Ravensthorpe 1:250 000 Sheet	146 755.7	19 394.66	7 621 403
State Total	312 348*	39 115.93	10 528 236
Ravensthorpe Copper Mines NL	52 004†	12 140.94	6 848 741
* ore and concentrates † concentrates			
CUPREOUS ORE (used in fertilizer)			
Ravensthorpe	506.4	64.31	41 271
Desmond	398.9	62.70	33 815
Kundip	—	—	—
Other	379.3	30.62	16 405
Ravensthorpe 1:250 000 Sheet	1 284.6	161.63	91 491

TUNGSTEN AND MOLYBDENUM

Minor scheelite occurs 16 km southwest of Kundip at Dallison's Reward mine, G.M.L. 115. Extraction of a trial parcel of 1.1 t scheelite containing 66 percent WO_3, concentrated from gold ore derived from quartz veins in granite, is recorded by Simpson (1952) v. 3, p. 534. Traces of molybdenite are reported by Simpson and Gibson (1907 from quartz in granitic rocks north of Bedford Harbour.

IRON

Prospecting for iron was carried out in the Ravensthorpe Ranges, especially at Mount McMahon, where minor quantities occur as supergene enrichments of ferruginous chert and banded iron-formation. Twelve small deposits containing 50 million t of hematite and goethite averaging less than 40% iron were indicated to a depth of 25 m. Little ore occurs below 25 m. Some ferruginous material was quarried south of Cordingup Gap for use as flux in the copper smelter earlier in the century. None of these occurrences are of sufficient grade or quantity for development as iron ore deposits.

MAGNESITE

Extensive deposits of high-purity magnesite occur near Bandalup Creek south of the Esperance Highway. These deposits have produced 19 972 t of magnesite valued at $260 000. Quarrying ceased in 1968. Estimated reserves of 5.5 million t of high purity magnesite were reported in 1971.

The magnesite has replaced poorly lithified green Tertiary sands of the Plantagenet Group. At this locality these sands are well rounded quartz veins with a nontronite clay matrix. Various stages of replacement of the sands are present, the final stage being magnesite with a concretionary structure. The magnesite occurs at several levels separated by layers of unreplaced sands. This is thought to result from a fluctuating water table.

The sands unconformably overlie deeply weathered Archaean quartz-mica schist, metamorphosed sandstone and volcanic rocks. Quartz veins 5 to 15 cm thick are preserved in the weathered profile below the undulating unconformity which is denoted by a partially ferruginized eluvial soil with coarse angular quartz fragments. Although the weathered rock is partially replaced by magnesite, the foliation of the schist is preserved. South of the quarry magnesite overlies Archaean quartzite, basalt and dacite lavas.

The deposit has a basinal structure and may have developed in a barred basin environment during the time of the deposition of Plantagenet Group rocks which crop out to the south and southeast. The sand in the basin has been considerably reworked as shown by the degree of rounding, reworking probably being both marine and subaerial. Magnesium-rich solutions permeated the sands and replaced quartz by magnesite. The magnesium-rich fluids were probably originally derived from weathering of ultramafic and mafic rocks in the area.

Small magnesite deposits are present elsewhere in the Ravensthorpe Ranges, mainly overlying ultramafic rocks. Previous reports have been made by Johnson and Gleeson (1951a), and Ellis (1941).

Kyanite

Minor kyanite occurs in impure quartzite and other alumina-rich sedimentary rocks at East Mount Barren. A larger occurrence of kyanite in bands up to 5 cm wide is present in similar metamorphosed sedimentary rocks at West Beach, 8 km west of East Mount Barren, and just west of the Ravensthorpe Sheet. These have been described by Ellis (1951). Although the kyanite meets specifications for refractory use (containing 55 percent alumina, 5 percent ferric oxide, 34 percent silica, 3 percent ferrous oxide and 1 percent titanium oxide) the reserves are insufficient for development. No production has been recorded. Both deposits occur within the Fitzgerald River National Park.

Graphite

Most of the State's small production of 222 t came from graphite mines 6.4 km north of Munglinup. These were worked intermittently to produce 138 t of ore containing 19 percent graphite valued at $2714. The deposits have been described by Blatchford (1917, 1918), Ellis (1944b, c) and Sofoulis and Connolly (1957). The graphite is present as seams in a contorted and metamorphosed carbonaceous shale within a metamorphosed sequence of jaspilite and clastic sedimentary rock, which Sofoulis and Connolly (1957) correlate with the Archaean succession at Ravensthorpe. Ellis (1944b) estimated minimum reserves to a depth of 35 m of 27 500 t containing 22 percent carbon.

A small prospect near the Young River 21 km northeast of Munglinup in graphitic schist interbedded with biotite and hornblende gneiss is described by Ellis (1944c). Excavations reveal one band of graphitic schist at least 3 m wide with high-grade flake graphite similar to that at the Munglinup deposit. No reserves were reported.

Jarosite

A small quantity of jarosite, comprising the State's total production of 9.7 t, was produced from Cordingup Creek in 1947. This was used as a source of potash for fertilizer. A brief description is given by Simpson (1921).

Limestone

Several quarries in coastal limestone near Hopetoun have produced aggregate for road building. During the operation of the copper smelter at Cordingup, limestone was used as a flux.

Manganese

Small supergene-enriched manganese deposits in the Ravensthorpe Ranges are described by Gray and Gleeson (1951), de la Hunty (1963, 1965), Townley (1953) and Sofoulis and Noldart (1958). An adit at Mount Chester into manganiferous tuffaceous shale yielded small amounts of ore, containing 36 percent manganese and traces of cobalt. The ore was used in superphosphate manufacture in about 1950. The adit extends 135 m into the shale, 30 m below the surface, and intersects two manganese-enriched bands, 3 m and 1 m thick, in a zone of manganiferous shale 6.5 m wide. The enrichment zone has a surface strike-length of about 200 m and extends below a depth of 30 m. Although greatest enrichment is near the surface, the zone extends below the adit. De la Hunty (1963) estimated reserves of 24 500 t of material containing 30 to 40 percent manganese.

A superficial deposit of manganiferous boulders 3.6 km northeast of Kundip (Gray and Gleeson, 1951a) contains 49 percent manganese. A similar deposit 2.4 km east-southeast of Desmond consists of manganiferous boulders amongst laterite over ferruginized quartzite and schist. It contains about 30 percent manganese. Reserves of these deposits are insignificant.

SPONGOLITE

Spongolite is an Eocene sedimentary rock of the Plantagenet Group consisting of abundant siliceous sponge spicules. It forms an attractive building stone of low density and moderate strength, and is easily quarried by sawing into blocks. Spongolite has been used in construction of buildings at Ravensthorpe, Hopetoun and elsewhere in the State.

About 2994 t of the State's total production of 3675 t came from a quarry 22 km southeast of Ravensthorpe. This is located 4 km west of the Ravensthorpe Sheet. Spongolite occurs extensively over the southern portion of the Ravensthorpe Sheet, and should a demand arise, adequate supplies could be found. Spongolite may also have uses as low density aggregate in concrete.

Tests by the Government Chemical Laborities on spongolite, reported in the West Australian Department of Mines Annual Reports for 1948, p. 53 and 1950, p. 114 indicate that spongolite may be suitable for high temperature insulating bricks and abrasive material. Ground calcined material has good clarifying properties, comparing favourably with those of imported high-grade diatomite.

AGGREGATE

Crushed dolerite and granodiorite have been used for road surfacing, railway and bridge embankments, and concrete. The main quarry is 6.4 km southeast from Ravensthorpe. Undetermined quantities of gravel, sand, limestone, clay and earth fill have been used for road foundations and surfacing in the populated areas. Large reserves of Proterozoic quartzite in the Mount Barren Ranges may have aggregate potential. However, much of this rock is within the Fitzgerald River National Park.

VERMICULITE

A vermiculite deposit is located near the Young River 23 km northeast from Munglinup. Descriptions have been given by Ellis (1941, 1944d, 1945), Johnson and Gleeson (1951b), Grubb (1963a) and MacLeod (1964). Ultramafic and sedimentary rocks have been metamorphosed and subsequently intruded by muscovite-bearing granite. Accompanying potassium metasomatism of actinolite formed vermiculite along shear zones. Shearing occurred before, during and after vermiculite formation. Johnson and Gleeson (1951b) state that vermiculite was not formed by either alteration of micas or weathering.

Prior to 1953, the deposit yielded 1720 t valued at $22 000, which constitutes most of the State's total production. MacLeod (1964) noted that the vermiculite is in thick, impersistent seams, and reserves could be large. Abundant lower grade vermiculite in dumps near the old workings could be beneficiated.

Kaolin

Kaolin is present over deeply weathered granitic rocks throughout the Sheet. However, it is not known whether there are any economic deposits. One deposit noted near Culham Inlet was estimated to extend over approximately 100 ha to a depth of about 6 m.

Pegmatite Minerals

A large tabular-shaped pegmatite intrudes metamorphosed volcanic rocks 2 km northwest of Ravensthorpe. The pegmatite exhibits zonal variation of its complex mineralogy. The minerals present include spodumene, microlite, lepidolite, quartz, 'curly albite' (formerly thought to be cleavelandite), perthite, orthoclase, microcline, muscovite, pink and green elbaite, schorl, dravite, amblygonite, montebrasite, beryl, manganocolumbite, cassiterite and columbite.

Descriptions of the pegmatite have been made by Ellis (1944a), Sofoulis (1954b, 1958c), Grubb (1963a, 1964) and Ross (1964). Sofoulis (1958c) relates the pegmatite to the nearby granite.

Intermittent quarrying has yielded 108.3 t of spodumene containing about 6670 kg of lithium oxide, indicating an ore grade of about 7 percent Li_2O. This is the State's total production, valued at $3627. Lepidolite and tourmaline have not been utilized. Feldspar has potential for ceramic use. Except for the remoteness of the quarry, feldspar and quartz might have use in decorative crushed aggregates. Prior to 1958, minor amounts of tantalite and columbite were produced, together with 7 kg of bismuth ore. A total of 1.1 t of tantalite containing 716 kg of $TaNbO_5$ were produced, valued at $8084. There has been no recorded production of any mineral from the pegmatite since 1964.

Heavy Minerals

Concentrations of ilmenite, leucoxene, rutile, zircon and monzonite occur at Bedford Harbour, Margaret Cove, Oldfield River Inlet, Stokes Inlet and Barker Inlet. Hornblende, tourmaline, staurolite, garnet, spinel, magnetite, and hypersthene are also present. The proportion of heavy minerals in the sands varies between 1 and 30 percent, with a general average of 2 to 3 percent. Although some of the deposits contain economic grades, their development will be hindered by (a) low titanium content (J. L. Baxter, 1971), (b) the irregular shape of the deposits and (c) the lithified nature of some of the host calcareous sandstones. Reserves of the deposits are unknown.

Nickel

The Archaean ultramafic rocks east of Ravensthorpe have been prospected for nickel since 1965. Twelve intersections of nickel sulphide mineralization, reported by Pickands Mather International in 1971, at a prospect along Boyup Creek ranged from 0.2 percent nickel over a true width of 1.5 m, to 2.3 percent nickel over a true width of 3.6 m. Diamond drilling has indicated nickel-bearing sulphides at two other prospects.

Two deposits of nickeliferous laterite at Bandalup Hill, and along Bandalup Creek north of the Esperance Highway have been investigated. The laterite deposits have formed *in situ* by the weathering of ultramafic rocks. The depth of weathering ranges from 12 m to 35 m. The upper 6 m is non-nickeliferous laterite. Below this, ferruginous ochre averaging about 1.2 percent nickel merges into weathered serpentinite at a depth of 35 m. Reserves are about 22 million t.

Minor deposits of nickeliferous laterite overlying ultramafic rock occur along the Young River.

CAINOZOIC GEOLOGY

GENERAL

Field mapping of Cainozoic units was based on lithology and morphological expression. Although many symbols have been retained for the same Quaternary units as on previous maps of other 1:250 000 sheets, no significance is implied here by the middle letter of a 'Q' unit symbol. Instead the stratigraphy of Cainozoic units is expressed diagramatically in Figure 3.

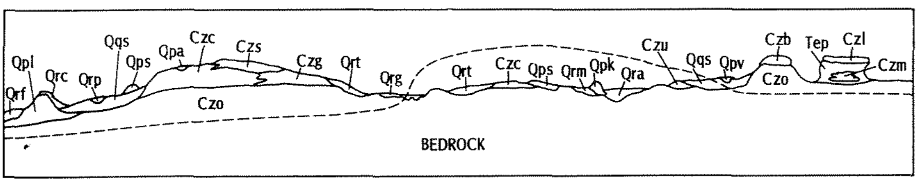

FIGURE 3

CAINOZOIC ROCK UNIT RELATIONSHIPS

RAVENSTHORPE SHEET SI 51-5

(cainozoic symbols as in map reference)

13739

CZ UNITS

'Sandplain' is extensive on the Ravensthorpe Sheet, and is divided into three units. Gravel plain (Czg) consists dominantly of unconsolidated limonite gravel and forms the lowest layer of the sandplain unit. Above this is sand (Czs), often with an undulating surface, and Czc, mainly loam or clay with varying proportions of gravel and sand. Czc grades into Czs and Czg. Czg grades into Czl.

At Bandalup Creek, Tertiary sands, probably Plantagenet Group, have been replaced by laterally-secreted magnesite (Czm) from adjacent mafic and ultramafic rocks. Chalcedonic silica (Czj) occurs as a weathering product over ultramafic rocks. Czo denotes deep-weathered, kaolinized rock, particularly granitic rock. Above the deep-weathered profile is a silcrete (Czb) consisting of angular quartz grains in a siliceous matrix. The term Czl includes limonite deposits and laterite that occur over both granitic and mafic rocks. Czb always overlies granitic rock.

The symbol Czu includes sedimentary rocks of Cainozoic age. At least some of these underlie the Plantagenet Group, and therefore are Eocene in age. Others are certainly younger.

Q Units

In the Salinaland division of the Sheet area are salt lakes containing clay and silt (Qra), usually with marginal gypsiferous sand and clay deposits (Qrm). The unit Qrm also occurs in the upper reaches of the rivers where continuous flow of water is rare, and the alluvium is saline. The halophytic (salt bush) flora on Qrm distinguish it from Qra, which is devoid of vegetation. Gypsiferous eolian deposits adjacent to salt lakes are symbolized Qpk.

Swamps and clay pans of fresh to brackish water are distinguished as Qrp. They are particularly abundant in the southern half of the Ravensthorpe Sheet. This distribution approximately coincides with the Pallinup Siltstone of the Plantagenet Group. With reference to the Werillup Formation of the Plantagenet Group, Smith (Clarke and Phillips, 1953) considers that the swamps which are frequent on the plain near the Stirling Range have possibly been formed by solution of calcareous beds. Although no Werillup Formation outcrop was recognized on the Ravensthorpe Sheet, the formation of some of the swamps may have been due to this process.

Incipient drainage and intermittent drainage in the northern areas have reworked sandplain and other extensive Cainozoic deposits to form colluvium and minor alluvium (Qrt), whereas to the south mature drainage gives rise to alluvium (Qpv). The sandplain to the northwest is characterized by sheet flooding and ill-defined, broad drainage (Qpa). Deeply-eroded surfaces with rock-fragment float, minor outcrop, or thin colluvium over outcrop are distinguished as Qrg.

Dune-bedded, shelly sandstone and grit (Qpl), assigned to the 'Coastal Limestone' of Pleistocene to Recent age, is commonly overlain by dune sand (Qrc) and forms prominent hills parallel to the coast. Beach sand is denoted Qrf.

The clayey to sandy deposit containing sheet and nodular kankar, Qqs is mainly restricted to the northeast of the Sheet area. Often associated with Qqs, and commonly adjacent to salt lakes, is eolian sand (Qps) in sheets and dunes.

Plantagenet Group

Sediments belonging to the Pallinup Siltstone of the Plantagenet Group (Cockbain, 1968a) crop out in the southern one-third of the Sheet area. Light-coloured siltstone and spongolite (a siltstone containing abundant sponge spicules) form characteristic flat-topped hills, the remnant of a more extensive sedimentary cover deposited on an uneven surface in Late Eocene times. The sediments are not folded, and faulting is rare. The Pallinup Siltstone has been observed resting unconformably on Precambrian granitic rocks and the Mount Barren Beds. Frequently beds of the Pallinup Siltstone are richly fossiliferous, and macrofossils include bivalves (e.g. *Cardium, Pecten*), gastropods (*Turritella*), echinoids, bryozoans and sponges. A few foraminifers of the families *Miliolidae, Rotaliidae* and *Bolivinidae* are present. No beds belonging to the Werillup Formation were recognized within the Sheet area.

LORT RIVER FAULT

A curvilinear feature, 40 km long, is clearly discernible on air-photos of the north-eastern part of the Ravensthorpe Sheet. It resembles the traces of the faults at Meckering and Calingiri (Gordon, 1972). The feature is a rounded scarp developed on unconsolidated Cainozoic sand. It is usually about 2 m high, and consistently steps down to the west. The scarp is interpreted as a recent fault, the result of an earthquake perhaps of comparable magnitude to the Meckering earthquake. The earthquake has neither been recorded seismically, nor is it known to any of the local inhabitants. The state of preservation of the scarp in the unconsolidated sand indicates it is of the order of a hundred years old. The scarp cuts across drainages and in places has formed sag ponds by damming of the creeks. The earthquake fault lies outside the South West Seismic Zone defined by Doyle (1971).

WATER SUPPLIES

Three main hydrological terrains are recognized on the Ravensthorpe Sheet. These areas are Salinaland, with internal drainage into salt lakes, Swanland, drainage by major rivers, and a coastal plain. The water supplies of the Sheet area are discussed within each of these divisions.

Salinaland has a rainfall which is generally less than 400 m per year (Fig. 4). There are no developed groundwater supplies except for three abandoned soaks—Peter Soak, Northover Soak, and Welcome Soak—on the old track from Ravensthorpe to Norseman. These soaks contain limited supplies of potable water that accumulated at the base of low sand ridges. It is anticipated that saline water underlies the fresh. Morgan (1969) has classified much of this area into two groundwater provinces—Inland Sand Plain and Hypersaline Province. Both these zones yield brackish to saline groundwater, the difference being that the hypersaline area essentially covers the salt lake depressions.

Much of the Swanland division is known by agricultural authorities as 'Esperance Sand Plain'. The land surface is dissected by the river systems giving topography ranging from undulating hills to occasional rugged terrain. The rivers assume youthful characteristics in their lower reaches where they cut Eocene rocks. Steep-sided, gorge-like valleys 30 to 45 m deep and flanked by breakaways 3 to 10 m high are common, especially on the Oldfield River. Groundwater occurs mostly in the Eocene rocks.

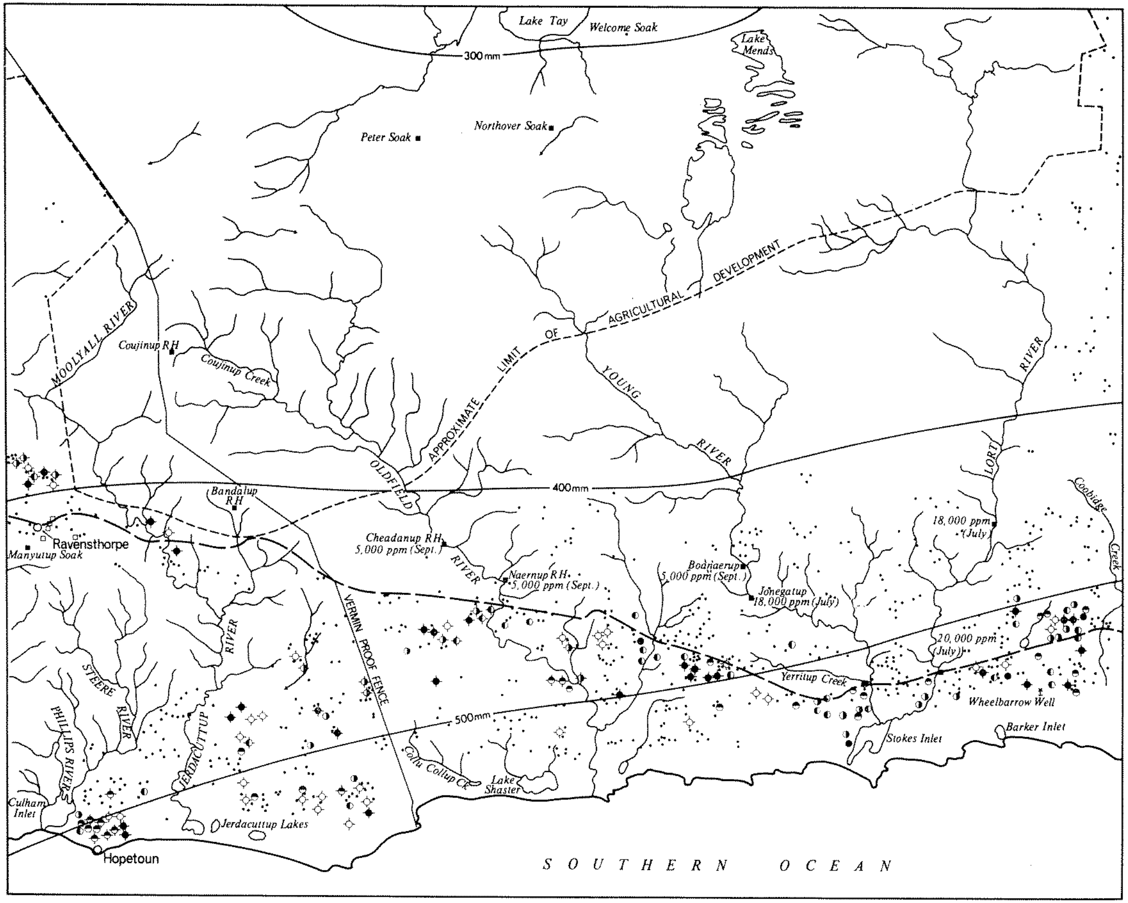

FIGURE 4

WATER SUPPLIES

RAVENSTHORPE SHEET SI 51-5

SCALE

10 0 10 20 30
KILOMETRES

REFERENCE

Highway	— —
Townsite	○
Rainfall in millimetres per year	— 400 mm —
Creek, river	
Claypan, swamp	
Well	
Soak, pool	▪
Rockhole	▪RH
Reservoir	▫
Earth tank or dam	·
Salinity of bores in parts per million total dissolved solids	
0 – 100	
1,000 – 2,500	
2,500 – 10,000	
> 10,000	●
Abandoned bore	

13740

Sanders (1968, p. 20) outlined the hydrogeology of the division and advised that stock-quality groundwater should be found south of the Esperance-Ravensthorpe Road where the Eocene sediments were thickest. Rainwater runoff from the migmatite areas is saline, with salinities often in excess of 18 000 parts per million total dissolved solids (ppm TDS). The rivers when in flow are usually quite salty, although after flash floods, water of a brackish quality (5000 ppm) may occur. At such times the rivers rise and fall rapidly and this water may be trapped in semi-permanent rock pools along the water-courses. Some pools are occasionally pumped for stock supplies by farmers.

The best quality groundwater is usually found close to the coast where rainfall is high. The rainfall declines from about 500 mm per annum near the coast to 400 mm near the northern limit of the Swanland division.

Drilling for groundwater was undertaken in early 1970 following a drought in the southwest of Western Australia, which severely affected farm water supplies. Most farms in the southern part of the Ravensthorpe Sheet had, until early 1970, relied mainly on runoff into surface storage facilities. However the drought relief programme confirmed the Eocene sediments as aquifers, but the permeability was variable. Many test bores yielded less than 5 m^3 of water per day, which was regarded as the minimum bore yield. These bores were usually abandoned, as were bores which contained groundwater of a salinity greater than 10 000 ppm TDS. The results are reported by Lord (1971).

The best supplies of groundwater of fair stock quality occur in the southeastern part of the Sheet, but everywhere the fresher water rests on a regionally saline groundwater body. Bores constructed in the Eocene siltstone usually silt up after a few years of operation, and require periodic cleansing. The towns of Munglingup and Coomalbidgup rely on rain-tank supplies for domestic water.

The rocks of the Archaean succession around Ravensthorpe invariably yield saline water. Plentiful supplies of salt water are obtainable from various mines in the district.

Ravensthorpe draws its water from four dams: No. 1 dam has a capacity of 40 x 10^3 m^3; No. 2 dam 20 x 10^3 m^3; No. 3 dam (constructed in 1969) 102 x 10^3 m^3; and No. 4 dam 59 x 10^3 m^3. The No. 2 dam is usually known as the Cordingup Dam and its water is brackish and is used only for industrial purposes.

A coastal plain with vegetated sand dunes and long limestone ridges is a potential source of potable groundwater. Rainfall ranges from 500 to over 600 mm per annum. The dunes act as excellent recharge points by directing rainwater runoff to the interdunal flats where the water percolates into the underlying sand and limestone. Such a groundwater source has been tapped at Hopetoun for domestic and stock use. One bore yields 218 m^3 per day of 900 ppm TDS groundwater and is used for an emergency supply. Hopetoun at present relies on raintank supplies for drinking water.

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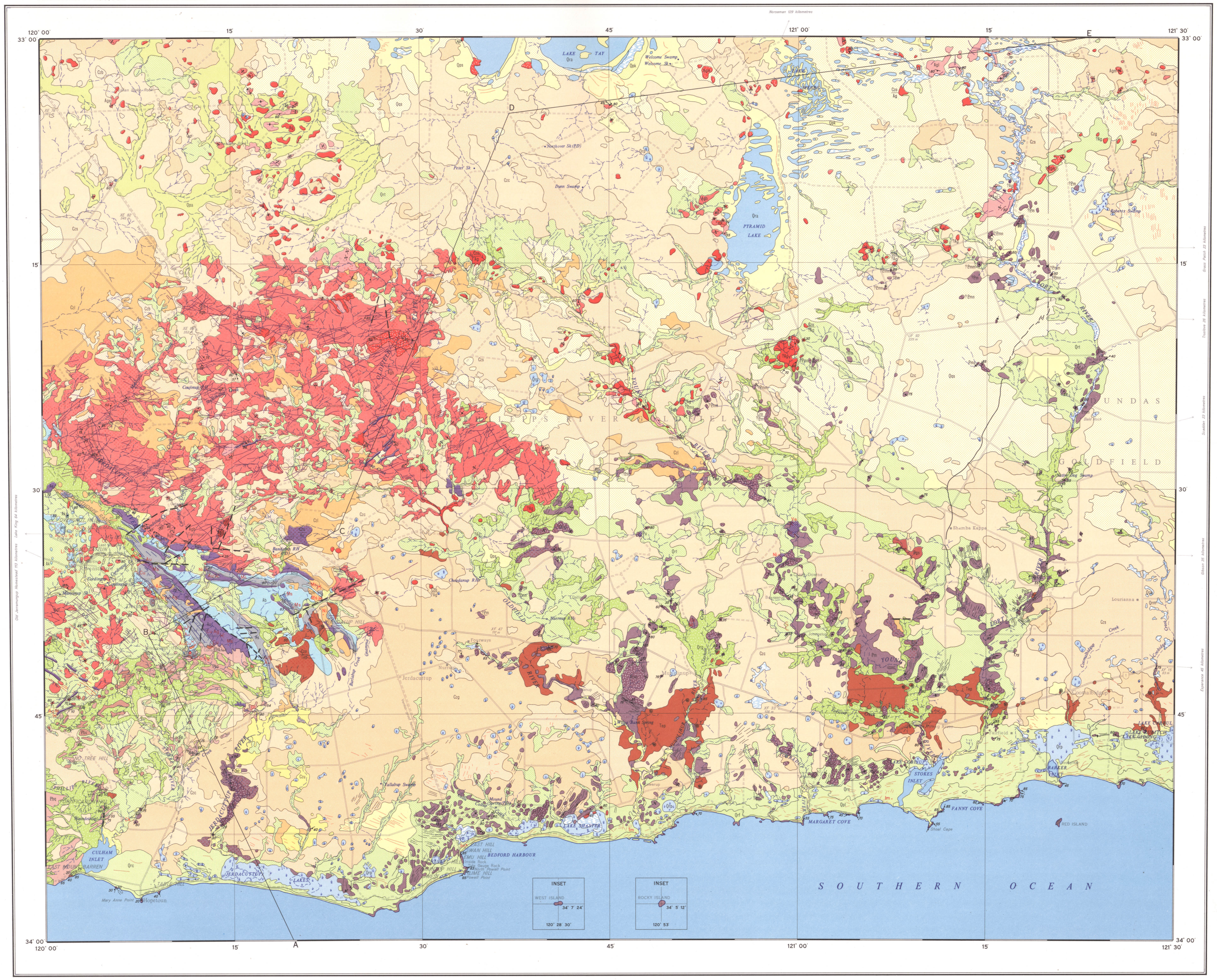
RAVENSTHORPE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



SYMBOLS

- Geological boundary
  - Accurate
  - Approximate
- Fault
- Top of unit
  - Graded bedding
  - Pillow structures
- Bedding
  - Measured (50)
  - Vertical
- Cleavage
  - Measured (50)
  - Vertical
- Foliation (undifferentiated)
  - Measured (50)
  - Vertical
  - Dip undetermined
- Lineation with plunge (30)
- Folds
  - Plunge of minor syncline (30)
  - Plunge of minor anticline (30)
  - Plunge of dragfold (30)
- Air photo lineament
- Sample locality, age determination

- Goldfield boundary
- Highway with national route marker
- Formed road
- Track
- Railway 3′ 6″ abandoned
- Telegraph line
- Townsite, gazetted — Kundip
- Homestead — Fourways
- Locality — Cowerup
- Landing ground
- Bench mark, height accurate — XE 82, 345 m
- Low scarp, breakaway
- Recent fault scarp
- Dune, lunette, sandridge
- Rivers and intermittent watercourses
- Rockhole — RH
- Soak — Sk
- Dam — D
- Position doubtful — (PD)

- Battery (abandoned)
- Mine (abandoned)
- Quarry or open cut (abandoned)
- Prospect
- Mineral occurrence
  - Cobalt — Co
  - Copper — Cu
  - Gold — Au
  - Graphite — Gt
  - Ilmenite — Im
  - Kaolin — Ck
  - Lithium — Li
  - Magnesite — Ms
  - Nickel — Ni
  - Scheelite — W
  - Silver — Ag
  - Vermiculite — Ve

REFERENCE

CAINOZOIC — QUATERNARY

Qra Lacustrine deposit—clay, silt and sand; saline and gypsiferous
Qrm Lacustrine and fluvial deposit—silt, sand and gravel; saline; gypsiferous where adjacent to Qra
Qrp Alluvium—clay and silty clay in claypans and swamps; non-saline to brackish
Qrt Colluvium and minor alluvium derived from units Czs, Czc, Czg, Qqs
Qrg Colluvium of deeply eroded surfaces; contains rock fragments and minor outcrops
Qrc Coastal dune sand forming long parallel dunes on coastal plains; overlies Qpl
Qrf Beach sand

Qpa Alluvium—silt, sand and gravel deposit, sheetwash from units Czs, Czc, Czg
Qpv Alluvium of mature drainage
Qps Eolian deposit—sand in sheets and dunes
Qpk Eolian deposit—gypsum and clay in sheets and dunes
Qpl Calcareous shelly sandstone and grit, forms consolidated coastal dunes and foreshore reefs

Qqs Clay, silt and sand, calcareous; contains nodular and sheet kankar

Czs Sandplain—mostly sand, undulating surface
Czc Sandplain—mostly loam or clay, with some ironstone pebbles and limonite nodules
Czg Gravel plain—mostly unconsolidated limonitic gravel, in part sand or loam matrix
Czl Limonite deposit—cemented ironstone gravel and laterite
Czb Silcrete—subvitreous siliceous rock with angular quartz grains
Czo Deep-weathered rock, kaolinized, in part ferruginized and silicified
Czu Sandstone and conglomerate cemented with hematite and limonite; quartzite; in part underlies Tep
Czm Magnesite with associated Czs

TERTIARY — Plantagenet Group

Tep **PALLINUP SILTSTONE:** yellow to grey siltstone, silty sandstone and spongolite; with fossils

PROTEROZOIC

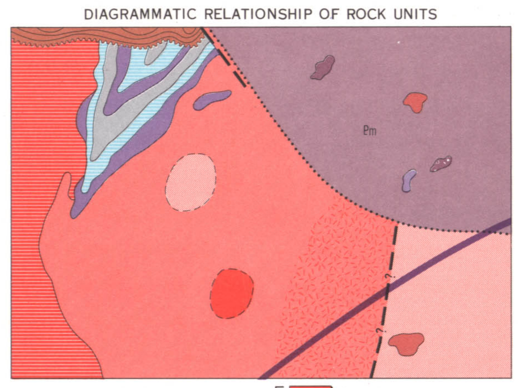
Pbu **MOUNT BARREN BEDS:** sedimentary rocks, unassigned
Pbp Phyllite, schist, minor sandstone and quartzite
Pbq Massive quartzite
Pbd Dolomite, with stromatolites
Pbc Conglomerate, includes basal conglomerate (polymict), and intraformational conglomerate (oligomict)
Pgs Syenite
Dykes—d: dolerite and gabbro; a: aplite; q: quartz
Pd **Widgiemooltha Dyke Suite**
Pu Metamorphosed ultramafic rocks
Pmm Migmatite with layered structure
Pmn Migmatite with nebulitic and schlieren structure, includes banded and highly metamorphosed sediments
Pmp Augen gneiss or metamorphosed granitic rock with megacrysts
Pma Mafic or amphibolitic migmatite
Pm Migmatite, unassigned
?Pm Transitional migmatite of uncertain age

ARCHAEAN

?Ag Transitional granitic rocks of uncertain age
Ag Granitic rock unassigned
Agl Adamellite, porphyritic
Agd Granite/adamellite, younger, fine-grained unit, intrudes Agb
Agb / Agb′ Granite/adamellite, medium to coarse-grained, Agb′ sheared variety
Age Granite/adamellite, older, fine-grained unit intruded by Agb
Agt Quartz diorite, with related lithium-bearing pegmatite indicated (p)
Agm Migmatite, mainly with banded and schlieren structures
Ab Fine-grained mafic rock, pillowed and variolitic in part, includes plagioclase+hornblende±diopside, and tremolite+chlorite+clinozoisite assemblages
Ak Basic agglomerate
Au Serpentinite, after intrusive and minor ~~ex~~trusive peridotite
Ae Ultramafic rock, altered to schistose talc+carbonate+tremolite+chlorite rock
As Sandstone, quartzite, phyllite, chert
Ac Conglomerate
Aj Banded iron and banded chert formations
Al Felsic extrusives, mainly dacite
Ama Amphibolite, includes hornblende+plagioclase±epidote±zoisite±garnet±quartz±calcite±diopside assemblages

Regional metamorphism not uniform, attains almandine-amphibolite facies

DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



- —?— Possible fault
- Unconformity
- Possible metamorphic front

PROTEROZOIC
- **MOUNT BARREN BEDS**
- **Widgiemooltha Dyke Suite**
- Syenite
- Pm Migmatite
- Metamorphosed serpentinite
- Metamorphosed sediment
- Metamorphosed mafic rock

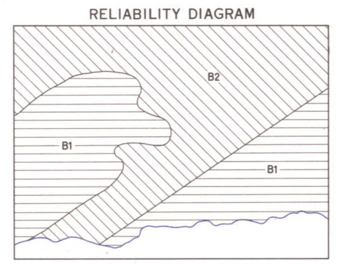
ARCHAEAN
- Quartz diorite
- Porphyritic granite
- Fine-grained granite
- Medium to coarse-grained granite
- Migmatite
- Sedimentary rock
- Mafic rock
- Serpentinite

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

Published by Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, Canberra, A.C.T.

Copies of this map may be obtained from the Geological Survey of Western Australia, in Perth; or the Bureau of Mineral Resources, Geology and Geophysics in Canberra, A.C.T.

RELIABILITY DIAGRAM



B1 Numerous traverses with air photo interpretation
B2 Air photo interpretation with a few traverses

HON. D.G. MAY, M.L.A.
MINISTER FOR MINES
J. H. LORD, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1 : 250,000

5 0 5 10 15 20 25 30 Kilometres

5 0 5 10 15 Miles

TRANSVERSE MERCATOR PROJECTION
ZONE 2 AUSTRALIA SERIES

Geology by R. Thom, S. L. Lipple 1971
Printed by: Mercury—Walch Pty Ltd., Hobart, Australia

INDEX TO ADJOINING SHEETS

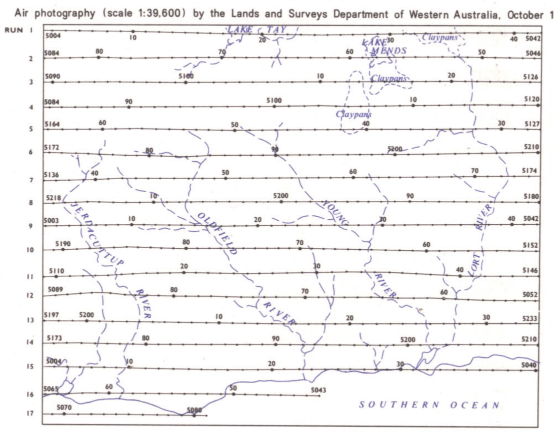
HYDEN SI 50 - 4	LAKE JOHNSTON SI 51 - 1	NORSEMAN SI 51 - 2
NEWDEGATE SI 50 - 8	RAVENSTHORPE SI 51 - 5	ESPERANCE SI 51 - 6
BREMER BAY SI 50 - 12	SOUTHERN	MONDRAIN IS OCEAN

DECLINATION DIAGRAM

The lines indicate magnetic declination, 1970.
+ 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 negligible

FLIGHT DIAGRAM

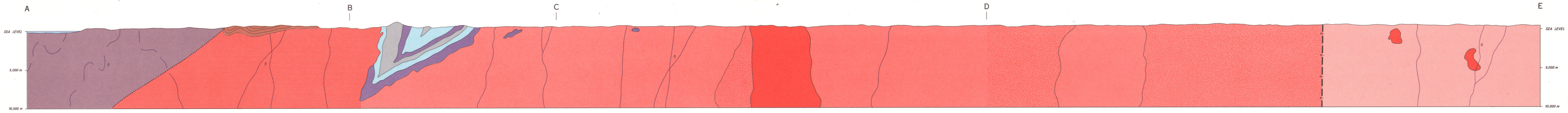
Air photography (scale 1:39,600) by the Lands and Surveys Department of Western Australia, October 1968



DIAGRAMMATIC SECTION

NATURAL SCALE
Topography exaggerated

SECTION A - B - C - D - E



Note: see Rock Relationship Diagram reference for explanation of units

RAVENSTHORPE
SHEET SI 51-5

FIRST EDITION 1974