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COLLIE
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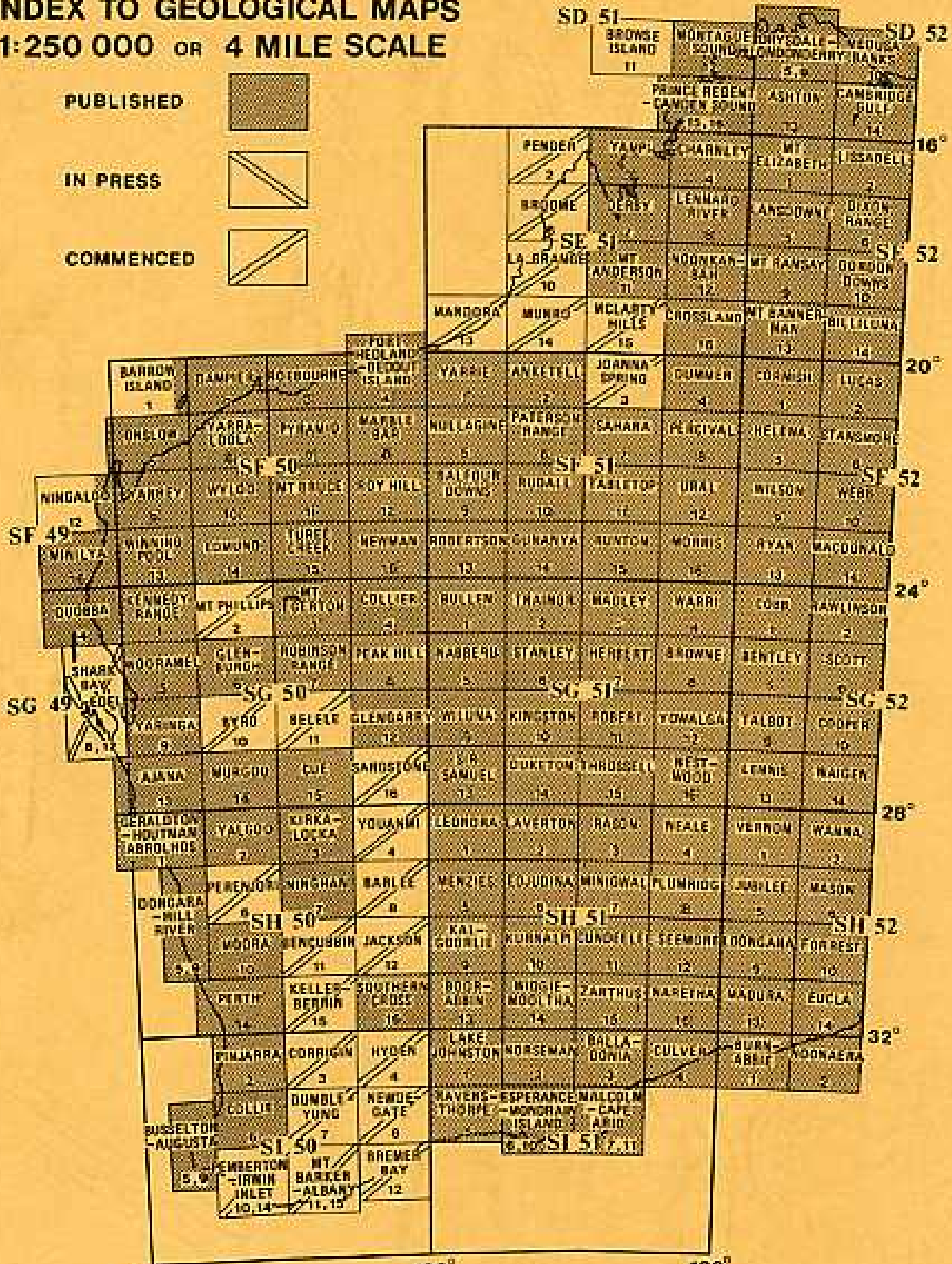

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

COLLIE

WESTERN AUSTRALIA

SHEET SI 50-6 INTERNATIONAL INDEX

COMPILED BY S. A. WILDE AND I. W. WALKER

PERTH, WESTERN AUSTRALIA 1982

20949—1

DEPARTMENT OF MINES, WESTERN AUSTRALIA
Minister: The Hon. P. V. Jones, M.L.A.
Under-Secretary: D. R. Kelly

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Director: A. F. Trendall

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Explanatory Notes on the Collie Geological Sheet

Compiled by S. A. Wilde and I. W. Walker

INTRODUCTION

The COLLIE* 1:250 000 Geological Sheet (SI/50-6 of the International Series) is bounded by latitudes 33°S and 34°S and longitudes 115°30′E and 117°00′E. It is divided into two distinct geological provinces by the north-trending Darling Scarp, the surface expression of the Darling Fault. Phanerozoic sediments of the Perth Basin lie to the west of the Darling Fault, whereas Archaean rocks of the Yilgarn Block (Prider, 1954) constitute the basement east of the fault.

Urban population is concentrated in the city of Bunbury (pop. 20 000, 1978 estimate) and Collie (pop. 6771, 1976). Other important towns are Boyanup, Boyup Brook, Bridgetown, Brunswick Junction, Capel, Donnybrook, Harvey, Nannup and Williams. There is an extensive road and rail network to centres north, south and east of the sheet area.

HISTORY OF INVESTIGATIONS

Most geological investigations on COLLIE have dealt with specific mineral deposits, particularly coal at Collie, tin at Greenbushes and mineral sands at Capel and Yoganup. The more important of these reports are referred to in the section on Economic Geology.

The first specific mapping of the Archaean is that of Chung (1957) at Ferndale. Elsewhere in the Yilgarn Block Finkl (1971) made some reference to the geology of the Balingup-Bridgetown area in a geomorphic study, whilst Taylor (1971) mapped the Kirup Conglomerate. General comments on the whole area were made by Wilson (1958).

Much of the early work on the Perth Basin dealt with the prospects for coal (Woodward, 1917; Blatchford, 1930; Lord and de la Hunty, 1950). Prior to 1935, knowledge of the geology was restricted to the upper few hundred metres and the great thickness of sediments underlying the coastal plain was not appreciated until the gravity investigations of Vening Meinesz (1948). The Commonwealth Bureau of Mineral Resources (BMR) subsequently carried out a regional gravity survey throughout the Perth Basin (Thyer and Everingham, 1956).

In recent years, seismic work carried out by West Australia Petroleum Pty Ltd (Wapet) has further clarified the structure and stratigraphy of the Basin. The surface geology was mapped by Wapet in 1956 (Playford and Willmott, 1958). Fairbridge (1953) discussed aspects of the regional geology. A more recent account is contained in Playford and others (1976).

A Bouguer anomaly map for the sheet has been prepared by the Bureau of Mineral Resources. Total magnetic and radiometric surveys have been carried out but the information is not yet available (March, 1981).

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

For this survey, the Perth Basin was mapped by D. C. Lowry in 1963 (Lowry, 1965) and explanatory notes prepared by Low (1972). S. A. Wilde and I. W. Walker mapped the Yilgarn Block during 1975 and 1976, and also carried out a re-interpretation of the Blackwood Plateau. D. P. Commander and K. J. Hirschberg prepared notes on the groundwater. This report first appeared in expanded form as a Geological Survey Record (Wilde and Walker, 1979).

CLIMATE, SOIL AND VEGETATION

The area has a humid mesothermal climate of the dry-summer subtropical (Mediterranean) type. Rainfall isohyets trend generally north-south and annual precipitation ranges from 554 mm at Williams to more than 1 300 mm east of Harvey (c.f. Fig. 5).

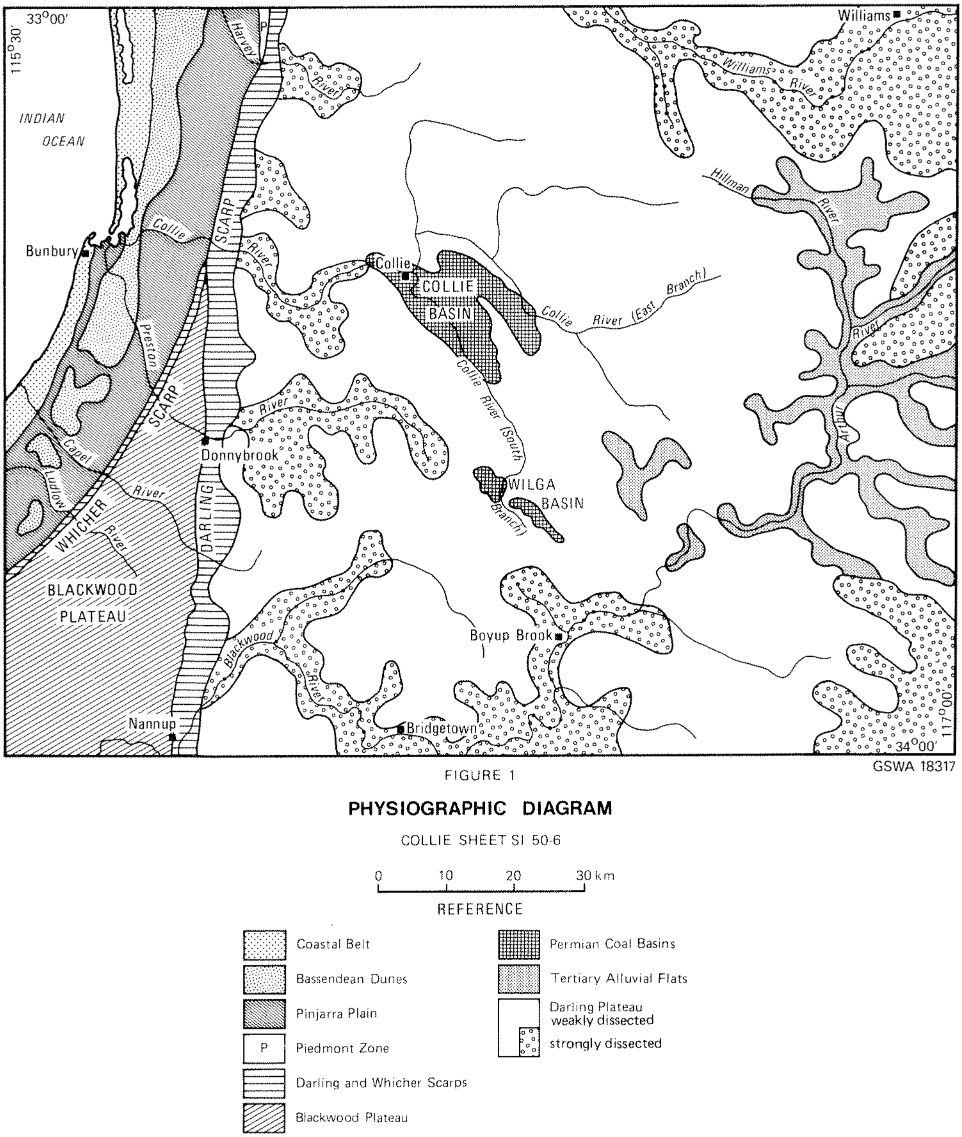


FIGURE 1

PHYSIOGRAPHIC DIAGRAM

COLLIE SHEET SI 50-6

Soil and vegetation types are strongly controlled by geology and are further modified by rainfall distribution. The soils on the Darling Plateau (Fig. 1) also vary with age, position in the landscape, and the degree of dissection by the present drainage (Mulcahy, 1973; Churchward and McArthur, 1980).

There is a progressive westward decrease in maturity of soil profiles on the Swan Coastal Plain, passing into unmodified calcareous sand along the present coast (McArthur and Bettenay, 1960).

In general, the greater the age of the soil, the more leaching has occurred and the more infertile it is, although the natural vegetation is well adapted to soil and moisture conditions.

On the Darling Plateau, extensive natural vegetation is restricted to areas of State Forest, with an open sclerophyllous forest of jarrah (*Eucalyptus marginata*) dominant on the laterite areas. Sandy sites carry mixed jarrah and marri (*E. calophylla*), whereas wandoo (*E. wandoo*) is prominent over dolerite dykes, as well as forming a more open woodland in the drier areas to the east. South of Williams, brown mallet (*E. astringens*) occurs on laterite hills and breakaways, with York gum (*E. loxophleba*) and *Acacia accuminata* on the lower slopes and valleys. The broad alluvial flats of the Arthur and Beaufort Rivers support swamp yate (*E. occidentalis*) and York gum.

The Blackwood Plateau is largely uncleared and is characterized by jarrah and jarrah-marri open forest. The more sandy soils along the Whicher Scarp have shrubby jarrah woodland with mountain marri (*E. haematoxylon*), *Nuytsia floribunda*, and *Banksia* spp. in the understory.

Much of the fluviatile portion of the Swan Coastal Plain has been cleared of natural vegetation. It originally consisted of marri open forest, with flooded gum (*E. rudis*) and wandoo, and jarrah on the higher, gravelly sites. The Bassendean Dunes have a scrubby woodland of jarrah and *Banksia* spp., with *Melaleuca* spp. in the interdunal swamps. The coastal dunes are composed of limestone, overlain locally by sand, and support a high woodland of tuart (*E. gomphocephala*), with jarrah and marri on the more sandy areas. The Quindalup Dunes along the present shoreline support open heath and scrub.

Pine plantations have been developed by the Forests Department on both the Darling Plateau and the Perth Basin, and there are private plantations in the Bridgetown area. Further details on the geological control of vegetation are given by Wilde and Walker (1979). Smith (1974) has prepared a vegetation map at 1:250 000 scale, and more detailed information on the western part of the area is given by Heddle and others (1980).

GEOMORPHOLOGY

The area falls within the South West Physiographic Division (Swanland) of Jutson (1934) and contains three main geomorphic units that are separated from each other by prominent escarpments (Fig. 1). The Darling Plateau occupies more than 80 per cent of the sheet area and is underlain mainly by Precambrian rocks. The Darling Scarp separates this unit from the Blackwood Plateau and the Swan Coastal Plain, both underlain by Phanerozoic sediments of the Perth Basin. The Whicher Scarp separates the Blackwood Plateau from the coastal Plain.

The Darling Plateau is an ancient erosion surface that has an average elevation of 300 m above sea level. It forms part of the Great Plateau of Western Australia which appears to be an exhumed peneplain that was originally formed during the Early Proterozoic (Fairbridge and Finkl, 1978). The old, undulating plateau surface is strongly lateritized and is best preserved in the higher rainfall areas of the west. The Collie and Wilga Basins are depressions within the Archaean bedrock containing Permian sediments that have been extensively reworked and lateritized in the Tertiary. Later dissection of the plateau by present rivers and their precursors has led to a variety of valley forms which are discussed by Finkl (1971), Bettenay and Mulcahy (1972) and Finkl and Churchward (1974). Broad alluvial tracts characterize the Arthur and Beaufort River valleys upstream of their confluences with the Blackwood River (Fig. 1), and represent an early stage in the rejuvenation of the drainage.

The Darling Scarp marks the eroded western edge of the Darling Plateau, and is the surface expression of the Darling Fault, which lies between 1 and 3 km to the west. North of Burekup, the scarp has a relief of about 200 m and rises abruptly from the Swan Coastal Plain. South of Burekup, it marks the eastern edge of the Blackwood Plateau and is more subdued, with a relief of 40 to 100 m.

The Blackwood Plateau (Cope, 1972; Low, 1972) has a gently undulating surface covered by laterite, lateritic gravel, and sand. It ranges from 80 to 180 m above sea level and is mainly developed over the Lower Cretaceous Leederville Formation. Remnants of an early drainage system are locally preserved at an elevation of from 120 to 180 m above sea level. These deposits are cut by the present cycle of erosion which shows at least two stages of development. Along the Whicher Scarp and all major valleys, the original lateritized plateau surface is cut by a distinct bench at 80 to 130 m above sea level. This bench is preserved in the heads of valleys and as spurs, since the later dissection was less extensive. The bench was also lateritized prior to the present dissection and this supports the original view of Prider (1948), who postulated two levels of laterite along the Darling Scarp at Ridge Hill, although he has since refuted this (Prider, 1966). Indeed, the constant 75-80 m altitude of this bench along the Whicher Scarp suggests that it is the southern continuation of the Ridge Hill Shelf, not previously recognized south of Burekup.

The Whicher Scarp is a complex marine erosional feature that marks the western edge of the Blackwood Plateau and probably ranges from Tertiary to Pleistocene in age. Besides the aforementioned bench, there is also a distinct strand-line deposit at 75 to 80 m above sea level, south of Yoganup (the Middle Escarpment Shoreline of Welch, 1964). The lower laterite surface extends down to the coastal plain where another strand-line deposit (the Yoganup Formation) occurs at 50 m above sea level. There was possibly once a continuous cover of Cretaceous rocks extending from the Blackwood to the Dandaragan Plateau, north of Perth (Wilde and Low, 1978b), that was successively removed by Late Tertiary to Quaternary marine erosion.

The Swan Coastal Plain extends west from the Darling and Whicher Scarps to the Indian Ocean (Woolnough, 1920). It ranges up to 60 m above sea level, and several units (closely related to the geology) can be identified (Fig. 1). These lie roughly parallel to the present coastline.

A narrow piedmont zone lies at the foot of the Darling Scarp near Harvey and consists of colluvial fans and the remnants of a strand-line deposit. It has been equated with the Ridge Hill Shelf (McArthur and Bettenay, 1960), but the average height of 45 m above sea level suggests that it is related instead to the Yoganup Shoreline. The zone passes west into a 10 km-wide alluvial tract (the Pinjarra Plain) corresponding to the distribution of the Guildford Formation. It ranges from 10 to

30 m above sea level and is variously dissected by younger streams. Further west, at least three generations of coastal dunes overlie the fluviatile deposts (McArthur and Bettenay, 1960).

ARCHAEAN GEOLOGY

GENERAL

The area east of the Darling Fault forms part of the Yilgarn Block; a stable Archaean craton composed of granite, migmatite and gneiss, and enclosing a number of elongate 'greenstone' belts.

The bulk of the Archaean rocks on COLLIE are granitic and represent the southern continuation of a major plutonic complex (the Darling Range Batholith) that extends from the Swan-Avon River, some 160 km to the north. Metamorphic rocks, consisting of ortho- and paragneiss, metasediments and some mafic and ultramafic intrusions, form a wedge-shaped area bounded on the west by the Darling Fault. This is referred to as the Balingup Metamorphic Belt (Blockley, 1980; Wilde, 1980). The belt widens south from Harvey, reaching a maximum width in the Nannup to Bridgetown area. In the south, it is separated from the granitic terrain by a north-northwest trending zone of migmatite and deformed quartz monzonite. Migmatite forms only a minor constituent of the metamorphic belt, and elsewhere on the sheet it is restricted to the periphery of other metamorphic rocks enclosed by granite.

The Saddleback Group (Wilde, 1976a) extends for a short distance onto COLLIE, where it is terminated by faults along the Williams River. Smaller areas of banded gneiss, enclosed in granite, occur near Boyup Brook, Maltrup, Cargonup and Collie.

There are few age data from COLLIE. The only date from the main gneissic terrain is by Nieuwland (written communication, 1977), giving an age of 2 838 $\pm$ 200 m.y. for paragneiss 5 km southeast of Bridgetown. The date is in accord with other gneissic terrains in the southwestern Yilgarn Block (Arriens, 1971). An age of 2 635 m.y. was obtained by Riley (Wilson and others, 1960) from a porphyritic granite 8 km southwest of Boyup Brook.

Rb-Sr data from the Harvey area suggest an age of around 2 575 m.y. for the porphyritic granite and its marginal deformation zone (Blight and others, 1981). Six samples of granite from the Williams - Arthur River area give a preferred model age of 2 972 $\pm$ 768 m.y. (Arriens, 1971), although the pooled age for 61 samples from the 'wheat belt' gave an isochron of 2 661 $\pm$ 51 m.y. A pegmatite at Queenwood, 8 km east-northeast of Donnybrook, gives an age of 590 m.y., although enclosed biotite yields an age of 475 m.y., (Compston and Martin, unpublished data). Pegmatites from Wellington Dam (Riley, 1961) and near Donnybrook (Compston and Arriens, 1968) give an age of 660 m.y. whereas muscovite from a pegmatite at Mullalyup has an age of 1 073 m.y. (Wilson and others, 1960). There is also a date of 2 650 m.y. for the foliated tin-bearing pegmatite at Greenbushes (de Laeter and Blockley, 1978).

METAMORPHIC TERRAINS

BALINGUP METAMORPHIC BELT

A continuous belt of metamorphic rocks extends from beyond Harvey in the north to Nannup and Bridgetown in the south, a distance of 112 km. It continues south onto PEMBERTON and north for 48 km to Pinjarra (Wilde, 1980). The western limit is the Darling Fault and the zone widens from 5 km near Harvey to about 33 km in the Nannup-Bridgetown area, where the greatest lithological diversity and best exposures occur. The metamorphic belt is characterized by the tectonically controlled emplacement of masses of orthogneiss into an already deformed layered sequence of paragneiss and metasediments. In general terms, there is a southward decrease in the amount of orthogneiss and a corresponding southward increase in the amount of quartzite, schist and ultramafic rock within the paragneiss.

Layered sequence

Gneiss: The most common rock-type in the sequence is a fine- to medium-grained, layered gneiss (*Anb*). It consists of various proportions of quartz, microcline, plagioclase, biotite and, locally, garnet. The most obvious compositional banding is due to variations in the amount of biotite. Included in this group are layered rocks with a mylonitic or blastomylonitic fabric that are particularly abundant along the Darling Scarp between Harvey and Burekup, and north of Nannup. Some layered gneisses probably represent intensely deformed plutonic rocks, for example near Harvey and Mount Lennard, and at Katterup.

In the area south and southeast of Donnybrook, a more leucocratic variety of gneiss (*Anl*) is interbanded with *Anb*. It is medium grained and consists of elongate lenses of quartz interleaved with a granular aggregate of microcline and oligoclase. It is commonly associated with deformed pegmatite.

Hornblende is a minor constituent in certain of the layered gneisses and is the chief mafic mineral in two small areas, one 7 km northeast and the other 13 km south of Brunswick Junction. These hornblende-bearing gneisses (*Anh*) are associated with amphibolite, and the sequence is similar to that near the Canning Dam on PINJARRA (Wilde, 1976b).

A large area of quartz-feldspar-biotite (-hornblende-garnet) granofels (*Anf*) extends from a few kilometres north of Mullalyup south to the Whinston Hills, a distance of 30 km. It has a maximum width of 20 km. There are also smaller areas north and west of Bridgetown and at Gunderup, 15 km north of Nannup. The rock is a bluish, melanocratic, fine- to medium-grained gneiss with a weak foliation, strong lineation and granoblastic texture. It is essentially similar to the granofels occurring in the Chittering Valley, near Perth (Wilde and Low, 1978a). Some compositional variation is evident, and there are interbands of *Anb* near the margins of the main body. Banded iron-formation and quartzite are interdeveloped with the granofels in several localities, and it seems probable that the rock was originally a psammo-pelitic sediment or greywacke.

Distinctive gneisses with calc-silicate affinities (*Anc*) crop out 7 km east of Brunswick Junction and around Mornington Mills. They have medium-grained diopside-epidote-plagioclase-microcline-sphene assemblages, with local garnet, magnetite and quartz. The proportions of microcline and plagioclase vary considerably. Myrmekitic intergrowths are common, and quartz forms rounded inclusions within feldspar. In the southwest of the belt, near Gunderup, finer grained calc-silicate gneisses are associated with schist, quartzite, and granofels. They have diopside-epidote-actinolite-microcline-plagioclase assemblages, with minor sphene and magnetite. Thin bands have a granofelsic texture and consist principally of quartz, microcline, diopside and hornblende.

An irregular zone of poorly exposed granulite-facies gneisses (*Ahm*) extends for 8 km southwest from Mornington Firetower. Felsic varieties consist of quartz-plagioclase-biotite-hypersthene (-microcline) assemblages and predominate over well-banded, basic units that have a plagioclase-hypersthene-clinopyroxene-horblende-garnet paragenesis. The basic varieties, together with nearby dolerites, often have coronas of hornblende around pyroxene, or of garnet around both hornblende and pyroxene (Blight, 1978).

Schist: Numerous lenses of schist extend south from near Brunswick Junction to the Bridgetown area. The most extensive developments are from Donnybrook to Dudinyillup where two parallel belts, up to 3 km wide, sporadically crop out over 42 km. The schists are frequently interbanded with quartzite and there is commonly a gradational relation.

Three types of schist are recognized, although these are not mutally exclusive and may change in composition along strike. Quartz-biotite schist (*Alb*) and quartz-muscovite-chlorite phyllitic schist (*Alm*) are interdeveloped near Donnybrook, and exposures are generally ferruginized. Some *Alm* units are medium- to coarse-grained and consist of large, deformed 'boudins' of muscovite in a somewhat finer grained quartz-muscovite (-chlorite-biotite) matrix.

Quartz-mica-garnet schist (*Alg*) forms two lenses north of Donnybrook and a larger area around the Stewart Firetower. Both biotite and muscovite are generally present, and the texture may be either granoblastic or schistose, with elongate lozenges of quartz and mica.

Other rock units: Thin bands of metasedimentary and meta-igneous rocks occur throughout the belt and form an increasing proportion of the sequence south from Donnybrook to Bridgetown. Together with the schist units, these bands of distinctive lithology enable the general structure of the terrain to be determined; although most bands do not form positive relief features and are not amenable to photo-interpretation.

Quartzite (*Aqo*) is the most abundant and widespread of the metasedimentary units. It occurs as isolated rafts or boudins between Logue Brook Dam and Donnybrook, and as more continuous bands south and east from Donnybrook and in the Hester-Bridgetown district. Discontinuity of exposure in the latter two areas is the result of both boudinaging and superficial cover. The rocks are metamorphosed orthoquartzites with some muscovite or green chrome-muscovite along foliation surfaces. Two distinctive variants are present, notably in the Donnybrook—Wellington Mill—Preston area: a hornblende-bearing variety with scattered clinopyroxene (*Aqh*) and an epidote-bearing quartzite (*Aqe*), both probably representing original calcareous sandstones.

Banded iron-formation (*Ai*) are present from just south of Kirup to near Bridgetown. Most form small rubbly outcrops of no great extent. They are most abundant as lensoid units associated with quartzite east of Bridgetown, although the largest unit, 8 km west of Bridgetown, is exposed sporadically over 10 km. The typical assemblage is quartz-magnetite-grunerite (-garnet), although magnetite may be strongly altered to hematite. Some units, particularly west of Bridgetown, contain hornblende-grunerite layers and are transitional to amphibolites.

An unusual purple to bluish, banded metasediment (*Aln*) occurs 3 km south of Bridgetown. It consists of alternating bands of medium-grained quartz and finer grained bands containing quartz, kyanite, staurolite and muscovite.

Amphibolite (*Aa*) is only a minor constituent of the layered sequence. Two lensoid bodies, up to 200 m wide, occur at Mullalyup and consist of a medium-grained, granoblastic-seriate development of hornblende, labradorite, subordinate sphene and opaques, with a few large poikiloblastic crystals of hornblende. Fine-grained amphibolites are associated with banded iron-formation, 8 km west of Bridgetown. They have a granoblastic texture and consist of strongly aligned prisms of hornblende, with minor plagioclase, quartz and sphene. Some portions are banded, with quartz-plagioclase layers alternating with layers rich in hornblende, clinopyroxene and magnetite. They are transitional to amphibolitic iron-formations. Thin units of fine-grained amphibolite are also present east of Bridgetown.

Ultramafic rocks (*Au*) occur as small lenses within paragneiss south of latitude 33°30′S. They are most abundant in the Bridgetown area, where they are interdeveloped with quartzite and banded iron-formation. Contacts are poorly exposed and, although they are believed to be later intrusives, they have been deformed with the host rocks and now have a subparallel trend. The ultramafic rocks are variously altered to tremolite-chlorite (-talc-magnetite), anthophyllite-talc-chlorite (-tremolite) and serpentine-talc-carbonate assemblages. The texture varies from granoblastic to schistose; tremolite porphyroblasts (after pyroxene) are locally abundant and some large cubes of magnetite occur. Both pyroxenites and peridotites are represented, although actinolite-clinozoisite (-plagioclase-sphene) assemblages from east of Bridgetown indicate a basaltic or doleritic parent for these varieties.

An unusual occurrence is that of three pods of serpentine-talc rock within granite 5 km north of Winnejup Crossing. These are 7 km east of the metamorphic belt and have a general northwesterly alignment, suggesting that they are post-granite intrusives rather than xenolithic remnants.

Orthogneiss

A distinctive feature of the Balingup Metamorphic Belt is the abundance of orthogneiss infolded with the earlier layered sequence. Three textural varieties of orthogneiss are recognized, making up about 30 per cent of the belt. In the north near Harvey, they form a deformed marginal facies to the Logue Brook Granite (Blight and others, 1981). In the south, they occur as elongate bodies, from 5 to 30 km in length, which trend a few degrees east of north.

Porphyritic granite gneiss (*Anp*) and augen gneiss (*Ana*) have developed from porphyritic granite by cataclasis and metamorphic recrystallization. Porphyritic granite gneiss forms zones within less deformed porphyritic granite and more extensive masses between Donnybrook and Wellington Dam, but does not occur south of Donnybrook. The rock is a coarse-grained, quartz-microcline-oligoclase-biotite (-hornblende) gneiss, with tabular microcline megacrysts. It is distinguished from porphyritic granite by the strong biotite foliation and gneissic recrystallization of the feldspathic matrix. Augen gneiss results from an intensification of the gneissic fabric and the modification of microcline megacrysts to augen. It likewise occurs as narrow zones in porphyritic granite (and in *Anp*), as well as forming discrete bodies within the layered sequence.

In the southern part of the metamorphic belt, augen gneiss is interdeveloped with granitic gneiss (*Ang*), and extremely variable unit characterized by its granite composition, coarse grain size, and imperfectly developed gneissic fabric. It commonly has a braided biotite foliation developed around compound felsic areas. However, there are portions that are more leucocratic with a less distinct alignment of felsic minerals, and also zones where some mobilization has occurred resulting in a migmatitic fabric. Much of the granitic gneiss seems to have developed from porphyritic granite, particularly north of Donnybrook. However, the irregular texture and migmatitic development suggests that some non-porphyritic granitoids may also be involved.

OTHER GNEISSIC AREAS.

Gneissic rocks occur in eight small areas outside the Balingup Metamorphic Belt. In addition, the volcanogenic Saddleback Group (Wilde, 1976a &b) just extends onto the northern part of the sheet, northwest of Quindanning.

South of Boyup Brook, three elongate areas of gneiss, up to 7 km long, trend north-northwest within migmatite. The gneisses range from well-banded, quartz-feldspar-biotite types to more streaky and partially mobilized granitic gneiss. A narrow band of quartzite and adjacent ferruginous schist crops out 7 km south of Boyup Brook. The schist is extremely fine grained and composed of quartz, sericite and biotite. A talc-chlorite ultramafic rock is present in migmatite 2 km further south.

South of Maltrup and Kulikup, hornblende-bearing, banded granitic gneisses are exposed discontinuously over 20 km. They are associated with amphibolite and some augen gneiss. No metasedimentary remnants were discovered.

Medium-grained quartz-feldspar and quartz-feldspar-biotite gneisses occur north and northeast of Cargonup, near the eastern margin of the sheet. The rocks are enclosed in granite and appear to be deformed granitoids.

Well-banded, quartz-feldspar-biotite gneiss crops out 10 km northeast of Collie. Its origin is uncertain, although it is not associated with metasediments.

Saddleback Group

Two small, soil-covered areas of Saddleback Group rocks are present 13 km northwest of Quindanning. Fragments of metabasalt (*Aba*) predominate, but there is also some felsic volcanic and metasedimentary material. They have been grouped with the Marradong Formation (Wilde, 1976a) because of the preponderance of basalt and regional extension from PINJARRA (Wilde and Low, 1978b).

MIGMATITE

Original gneissic rocks that are sharply intruded or pervaded by a granitic component are grouped as migmatite. The proportion of gneiss to granite is roughly equal although, east of Bridgetown, the gneissic palaeosome may make up only 30 per cent of individual outcrops. Certain gneissic areas grade into migmatite, especially around Boyup Brook, Kulikup, and east of Nannup. The gneissic foliation becomes increasingly contorted with the development of complex flow folds and the disruption of layering by either intrusive granite or *in situ* generated material. Gneisses containing segregation pegmatites are not classed as migmatite.

Migmatite (*Am*) forms several small areas within the granitic terrain in the eastern part of the sheet. It is also abundant around the Maltrup-Kulikup gneisses, the Saddleback Group, and east of Nannup in the Balingup Metamorphic Belt. However, the chief development is in two *en echelon* linear zones along the eastern margin of the metamorphic belt, in association with Gibralter Quartz Monzonite. Between Karkartherup and Boyup Brook there is a complex interdevelopment of migmatite, tectonized quartz monzonite, and various post-tectonic granites, all with a strong north-northwest alignment.

PLUTONIC ROCKS

MONZONITIC VARIETIES

Quartz-poor igneous rocks, chiefly of quartz monzonite composition, have been grouped into two main types by Walker (1978): the Gibralter Quartz Monzonite (previously called "Gilbralter" in Walker, 1978) and the Darkan Quartz Monzonite. On the map, a textural subdivision into even-grained (*Agze*) and porphyritic (*Agzp*) types has been applied, although the distribution of the two named units is shown in Figure 2. In addition there are three smaller outcrops of dioritic to syenitic rock (*Agd*) unrelated to the above types.

Gibralter Quartz Monzonite

The Gibralter Quartz Monzonite forms two linear belts, only 4 km wide, along the eastern margin of the Balingup Metamorphic Belt between Lyalls Mill and the southern sheet margin. It continues further south to Palgarup on PEMBERTON, a total distance of nearly 100 km.

The quartz monzonite is typically fine to medium grained, although variants with potash feldspar megacrysts occur south of Goonac and east of Bridgetown. The rocks are fairly leucocratic and consist of microcline, plagioclase and hornblende with minor quartz, biotite, sphene, epidote and opaques. Clinopyroxene is locally abundant south of Mumballup. A strong fabric is evident and varies from a lineation to a penetrative foliation. The least deformed rocks have a xenoblastic intergrowth of feldspar and quartz, which forms a groundmass to microcline-perthite megacrysts in the porphyritic varieties. However, most rocks show stronger deformation with sutured grain boundaries, marginal granulation and development of myrmekite in the groundmass.

The Gibralter Quartz Monzonite is fairly uniform in composition, although there is a local range to quartz syenite (Walker, 1978). However, the distribution of hornblende, clinopyroxene and biotite is more variable and may give a banded appearance in outcrop. There are also abundant xenoliths of amphibolite, some of which are partially digested.

Darkan Quartz Monzonite

The main body of Darkan Quartz Monzonite is centred 8 km south of Darkan and occupies an area of about 150 km^2. Six smaller outcrops to the south and southeast occupy a total area of around 100 km^2.

In contrast to the Gibralter Quartz Monzonite, the Darkan Quartz Monzonite is chiefly porphyritic, has a less pronounced fabric, and is more variable in composition. It typically consists of tabular microcline megacrysts set in an allotriomorphic granular groundmass of saussuritized plagioclase, microcline, hornblende and strained quartz. Clinopyroxene locally forms cores to hornblende, and chloritized biotite, sphene and apatite are accessory minerals. There is also a subtle compositional range from quartz monzonite to granodiorite and adamellite (Walker, 1978). More even grained, melanocratic variants near the margins of the bodies are of diorite or quartz diorite composition. Amphibolite xenoliths are common throughout.

Other bodies

Two narrow, dyke-like bodies of quartz diorite to quartz monzodiorite occur about 15 km southwest of Williams. The bodies are 10 km apart and are not exactly on the same strike. However, both trend northeast, and were probably comagmatic intrusions. Contact relations are not clear, but they appear to be interbanded with the granitic rocks. Both bodies are rich in microcline, with hornblende the chief mafic mineral. The small intrusion is 1.5 km long, and the larger 3 km long: both are about 300 m wide.

A small patch of pyroxene-quartz syenite, occurring 8 km east of Burekup, is enclosed by layered gneisses. Its relations are unclear, though it may be the result of local metasomatism and/or mobilization associated with granulite facies conditions (*see*, METAMORPHISM).

Origin

Walker (1978) presented petrographic and chemical evidence showing that the Gibralter Quartz Monzonite is distinct from the Darkan Quartz Monzonite and not merely a more deformed equivalent. He favoured two distinct magma types of quartz monzonite/syenite affinities and suggested that they were emplaced prior to the main period of regional granitoid intrusion.

The Gibralter Quartz Monzonite is related to a linear feature along the eastern edge of the Balingup Metamorphic Belt (the Hester Lineament), and the strong tectonite fabric and association with migmatite imply that this zone was important during its evolution. It appears likely that very deep-level partial-melting of quartzo-feldspathic gneisses and amphibolite from the metamorphic belt, in a high temperature, relatively anhydrous environment, could account for the presence and distribution of the Gibralter Quartz Monzonite (cf. Young, 1978).

The Darkan Quartz Monzonite is intruded by even-grained adamellite. However, interbanding of adamellite and quartz monzonite near Darkan, without obvious intrusive relations, suggests that it may be comagmatic with other granitoids in the area.

GRANITIC VARIETIES

Granitic rocks in the granodiorite-adamellite-granite range occupy approximately half of COLLIE. They constitute part of a huge batholith, known as the Darling Range Batholith to the north (Wilde and Low, 1978b) and informally as the "Wheat Belt Granite" to the east. They have been mapped on a textural basis, and within each group there is some compositional variation. There is no regular pattern to the distribution of the various textural types, and the interdevelopment suggests that they are phases of a single magmatic event that occurred about 2 660 m.y. ago (Arriens, 1971). The granites are post-tectonic, except for the porphyritic bodies in the northwest, which show marginal deformation and infolding with layered gneiss. Leucocratic adamellite (*Agg*) is fine to coarse grained, with marked variations in grain size. An integral component is diffusely developed pegmatite/aplite in veins and segregations. The overall texture is allotriomorphic granular, and the rock contains oligoclase, microcline, quartz, small amounts of biotite, and accessory muscovite, epidote and magnetite. It is best developed in association with migmatite near Dinninup, Quindanning, and northwest of Darkan. Gneissic xenoliths are present and relations are commonly gradational. The leucocratic adamellite also forms large areas south of Capercup, where it is a component of a distinctly banded granite, and near Darkan, where it is interlayered with quartz monzonite.

Even-grained granitic rocks (*Age*) are the most variable in grain size and composition when considered on a regional scale. However, they are typically medium-grained, allotriomorphic granular adamellites consisting of andesine/oligoclase, microcline, quartz and biotite. They are the most abundant granitic type and exposed relations suggest that they are generally the latest phase. However, medium-grained *Age* intrudes fine-grained *Age* near Culbin, suggesting at least minor variations in the time of emplacement. There is a local coarsening of grain size adjacent to banded or porphyritic granites in the Williams to Bocal area. Xenoliths of fine-grained granodiorite and tonalite are also abundant around Williams, whereas diopside-bearing gabbroic xenoliths are abundant near migmatite contacts south of Qualeup.

A fine- to medium-grained adamellite with scattered microcline megacrysts (*Agv*) forms small, irregular areas in the Williams and Narlingup districts, and more extensive areas northwest and southeast of Collie, where it is associated with porphyritic granite. It also forms a narrow, northwest-trending strip between Bridgetown and Boyup Brook, where it is interdeveloped with gneiss, migmatite, Gibralter Quartz Monzonite, and *Age*. The rock is essentially similar to *Age*, except for the development of ragged megacrysts of microcline containing numerous inclusions of plagioclase. The rock grades into porphyritic granite as the size and abundance of megacrysts increases, and into *Age* as these decline. Xenoliths of granodiorite are present near White Horse Hill.

Porphyritic granite (*Agp*) is almost entirely restricted to the western part of the granitic terrain: a small body 4 km east of Bocal is the only exception. The main development is east of Harvey, where the Logue Brook Granite (Blight and others, 1981) occupies an area of 900 km^2 on PINJARRA and COLLIE. It is separated from similar rocks at Mount Lennard by a narrow zone of *Agv*. The rock contains tabular megacrysts of microcline in an allotriomorphic granular matrix of microcline, oligoclase, quartz and biotite. Megacrysts typically constitute 60 to 70 per cent of the rock and are strongly aligned. The granite is progressively deformed westward into porphyritic and augen gneiss, and eventually into layered gneiss and mylonite. The first stage of deformation is a recrystallization of the matrix with a few local zones of blastomylonite. The frequency of the mylonite zones increases westward, accompanied by more pronounced recrystallization. Similar features are evident at Mount Lennard and Wellington Dam. Around Stirling Dam and Mount Lennard, the porphyritic granite has been strongly metamorphosed (*see*, METAMORPHISM).

Two varieties of mixed granitic rocks have been distinguished. In the Murray River, 28 km west-northwest of Quindanning and near Meridian Hill, 15 km east-southeast of Quindanning, mixed granite (*Agm*) consists of *Age* and *Agp* in sharp contact and in roughly equal proportions.

Scattered throughout the granitic terrain are small areas where two or more varieties of granitoid are interbanded in a regular fashion (*Agmb*). They are best developed south of Moodiarrup where they occupy an area of about 100 km^2. Most areas consist of bands of *Age* and *Agv/Agp* repeated on a centimetre or metre scale. Contacts are generally sharp, although no intrusive relations can be discerned. Discrete bands of *Agv* and *Age* are locally developed in *Agg*. There is also some interbanding of *Agg* and *Agv* with Darkan Quartz Monzonite. South of Williams, much of the banded granite consists of two varieties of *Age*; a fine-grained, mafic granodiorite occurring with a more medium-grained leucocratic adamellite. Xenoliths of amphibolite or granite gneiss may occur, but are generally restricted to only one of the granite types present. In general, the trend of the banding parallels the foliation in the enclosing rocks, whereas the orientation of the banded granite areas is unrelated to this trend. The origin of the banding is uncertain but appears to be the result of magmatic processes.

PRECAMBRIAN UNDETERMINED

MINOR INTRUSIVE ROCKS

GRANITE DYKES AND VEINS

Rare veins and small dykes of fine- to medium-grained adamellite occur in the granitic complex in the eastern part of the sheet area. They commonly contain xenoliths of the host rock, which is usually *Age* or *Agv*. The intrusions have a general easterly or northeasterly trend.

PEGMATITE DYKES AND VEINS

Two distinct groups of pegmatite have been distinguished: a foliated variety that is extensively developed in the gneissic terrain along the Darling Scarp and late-stage intrusives in the post-tectonic granites in the eastern part of the area.

Large, foliated bodies of pegmatite are a characteristic feature of the southern part of the Balingup Metamorphic Belt. Dykes up to 50 m wide are common and can be traced for up to 10 km. They consist of quartz, microcline, albite, and muscovite, with local concentrations of tourmaline, beryl, garnet and other rarer minerals. The tin-bearing pegmatites at Greenbushes are distinctive in containing much more albite than microcline and in being weathered to depths of 30 to 50 m. All these pegmatites are subparallel to the regional foliation and are variously deformed and folded. They are present in both the layered sequence and orthogneiss, and pre-date the latest deformation. There are also smaller bodies of less-deformed pegmatite, not shown on the map, that appear to have been 'sweated out' of their gneissic host. Bodies of this type are abundant in the granofels unit between Balingup and Bridgetown.

A date of 2 650 m.y. was obtained for the Greenbushes pegmatite by de Laeter and Blockley (1978). However, pegmatite ages of 1 073 m.y., 660 m.y. and 590 m.y. (*see*, **ARCHAEAN GEOLOGY** GENERAL) attest to several periods of activity.

Veins and more irregular bodies of pegmatite, with minor aplite, are abundant in the granite terrain, particularly south of Williams. They are not restricted to any particular granite type, although they have not been distinguished in *Agg* since pegmatite is an integral component of the rock type. The veins are generally less than 0.5 m wide and cannot be traced for more than a few metres. They consist almost exclusively of quartz, microcline and albite, and are undeformed. They have a marked easterly trend through the region, in common with similar intrusions on the Perth and Pinjarra Sheets (Wilde and Low, 1975 and 1978b, respectively).

QUARTZ DYKES AND VEINS

Quartz dykes with a general northwesterly trend define a major zone from the Williams River south to Muradup. In the north, they are part of the fault zone that terminates the southern extension of the Saddleback Group. Dykes with a general east-northeasterly trend are prominent south of Williams and in a major zone extending from north of Cargonup across to near Nannup. There are also quartz dykes along the Darling Scarp with a northwesterly or northeasterly trend. In addition, there are numerous veins and segregations of quartz, in both the metamorphic and granitic terrains, that are too small and irregular to show at the map scale.

20949—4

A unique intrusion occurs south of Donnybrook. It is 4 km long and consists of plates of chalcedonic quartz enclosing a high percentage of voids. It is the locus of gold mineralization and has a northwesterly trend, cutting Archaean gneisses and extending up through the overlying Cretaceous Donnybrook Sandstone; the only known intrusion that cuts the Phanerozoic on COLLIE. However, it possibly represents the re-activation of an original Precambrian feature, and has therefore not been separated in the map reference.

DOLERITIC DYKES

Dykes of tholeiitic quartz dolerite intrude all Precambrian rock-types. They have a marked easterly trend, the only exceptions being in the metamorphic terrain along the Darling Scarp, where northwest and northeast trends predominate.

Near Williams, an early set of east-northeast dykes is cut by an east-southeast trending set. The former are characterized by the abundance of quartzo-feldspathic xenoliths, great width (up to 700 m), and the presence of selvedges of remelted granite with pyrometamorphic textures (Wilde and Walker, 1979). The dyke 6 km south of Williams can be traced by sporadic outcrop and aeromagnetic pattern for at least 585 km eastward across the Yilgarn Block to the Widgiemooltha area, where it has been named the Binneringie Dyke (Sofoulis, 1966; McCall and Pears, 1971). Smaller xenolithic dykes with similar textures have been described from near Meckering (Lewis, 1970; Wilde and Low, 1975). The later east-southeast set of dykes extend west to the Darling Fault and can be traced below the extensive laterite cover as photo-lineaments.

The dolerites have a primary mineralogy of plagioclase (andesine-labradorite), augite, hornblende, minor quartz and accessory apatite and sphene. Many are altered, with saussuritization of plagioclase and breakdown of pyroxene to fibrous amphibole, whilst certain dykes near Mornington Mills and the Collie River contain hypersthene and have garnet corona structures (Blight, 1978). In contrast, dykes between Mount Lennard and the Collie River are converted to amphibolite, though chemical analyses indicate that they are compositionally similar to fresher dykes occurring east of Collie (Bettenay and others, 1980). A number of dykes in the southern and eastern parts of the sheet, including the wide, xenolithic dykes near Williams, have a plagioclase-phyric texture.

A number of dykes near Bridgetown have marginal alteration zones of quartz, epidote and clinozoisite, and some appear to be gently folded. A few dykes have centimetre-scale banding, owing to variations in grain size and to zones of augite alteration.

The Widgiemooltha Dyke Suite has been dated at 2 420 $\pm$ 30 m.y. (Turek, 1966), and the east-northeast dykes near Williams are probably of similar age. There are no data pertinent to the other dyke suites, although Giddings (1976) gave radiometric and palaeomagnetic evidence for six periods of intrusion in the Yilgarn Block, ranging from Archaean to Late Proterozoic in age.

STRUCTURE AND METAMORPHISM OF THE YILGARN BLOCK

The Precambrian rocks can be broadly divided into three major tectonic units separated by marked aeromagnetic lineaments (evident on unpublished company data). The Boyup Brook Lineament (Walker, 1978) trends north-northwest for 40 km from Boyup Brook and separates post-tectonic granites from migmatite and Gibralter Quartz Monzonite to the west. A parallel feature 20 km further west, the

Hester Lineament (Blockley, 1980), separates the latter terrain from the Balingup Metamorphic Belt that extends west to the Darling Fault. The Hester Lineament is a 70 km long curvilinear aeromagnetic "low" that continues southeast onto PEMBERTON. Both lineaments appear to be terminated to the north by the intrusion of porphyritic granite. It would appear that the 20 km wide zone between the lineaments was the locus of magmatic activity and deformation.

BALINGUP METAMORPHIC BELT

Two discrete events can be recognized within the metamorphic belt. An early paragneissic sequence, with metasedimentary and metavolcanic horizons, has been deformed and metamorphosed and then invaded by tectonically controlled bodies of orthogneiss. The orthogneiss is related, at least in part, to the Logue Brook Granite.

The earliest structures in the layered sequence are small rootless isoclines and 'eye' folds developed rarely within the main foliation. Distinctive lithological units can be traced over tens of kilometres and repetition of the sequence and accompanying changes in dip allow a number of 'regional', north-northeast trending fold axes to be plotted (Fig. 2), although their time of formation is uncertain. Asymmetric tight to close folds, with a strong axial planar fabric, post-date the rootless isoclines and have undergone a later phase of more open-style refolding. Changes in amount and direction of plunge of minor folds and of the prominent lineation are also evident (Wilde and Walker, 1979).

The major north-northeast anticlines are the locus for similar-trending bodies of orthogneiss. Axes cannot be traced in all such bodies, though their shape, distribution and texture suggest that they were emplaced during tectonism. However, the deformation and folding of later pegmatite instrusions in the orthogneiss indicates further deformation after consolidation. This also appears true for the orthogneiss developed around the Logue Brook Granite and other porphyritic granite masses between Maxicar and Collie. Along the Collie River, dolerite dykes have intruded orthogneiss developed from the granite and have themselves undergone later deformation subparallel to the earlier trend. However, Rb-Sr data from the Logue Brook Granite and its marginal deformation zone (Blight and others, 1981) suggests no great time interval between granite emplacement and the main deformation. There has been a later, open-style folding of augen gneiss at Mornington Mills, although there is no evidence of extensive shearing along contacts between paragneiss and orthogneiss.

GRANITIC TERRAIN

The distribution of the various granitic types has already been discussed. The most notable feature is that the trend of the mineral foliation is independent of lithology (Fig. 2). It shows local variations across the area, although the overall regional trend is northwest to north-northwest. There is a strong correspondence between the foliation and dolerite dyke trends, particularly south of Collie and Darkan. Adjacent to dolerite, the granite commonly has a fracture foliation parallel to the dyke margins.

The Logue Brook Granite and other porphyritic granites west of Collie are variously deformed to porphyritic gneiss, augen gneiss and blastomylonite. These granites appear to truncate the Hester Lineament and therefore post-date tectonism along this feature. Radiometric data suggest an age of around 2 575 m.y. for the Logue Brook Granite and its marginal deformation zone (Blight and others, 1981).

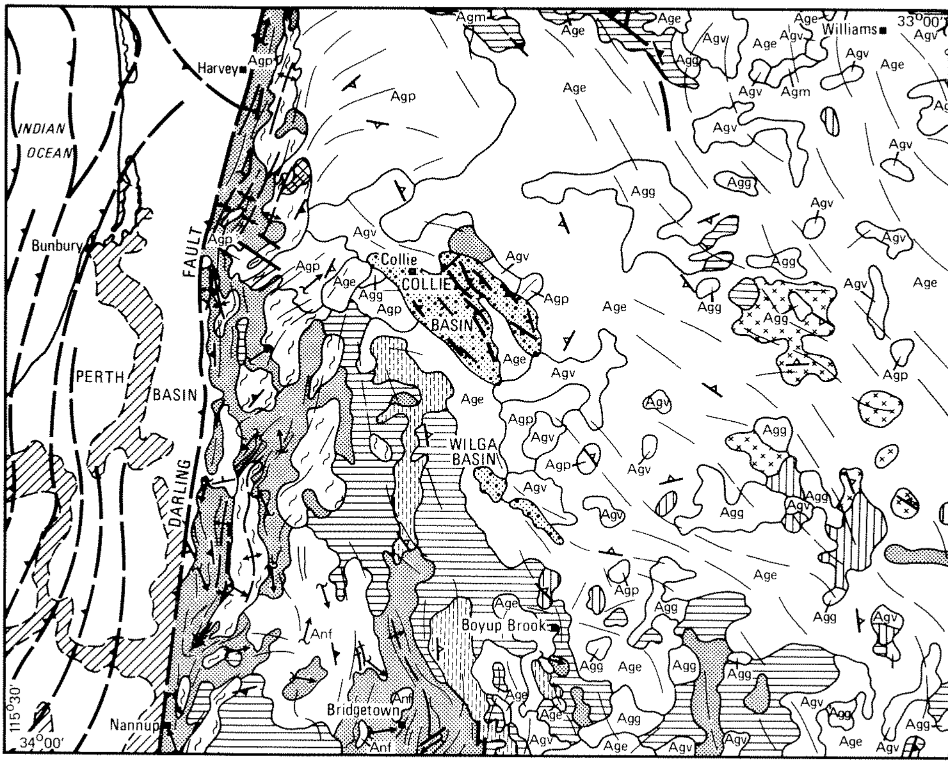


FIGURE 2 GSWA 18318

STRUCTURAL SKETCH MAP

COLLIE SHEET SI 50-6

0 10 20 30 km

REFERENCE

PHANEROZOIC ROCKS
- Bunbury Basalt
- Permian Coal Measures

SADDLEBACK GROUP

GRANITIC ROCKS
- Age — Even-grained adamellite
- Agv — Even-grained adamellite with megacrysts
- Agp — Porphyritic granite
- Agg — Leucocratic adamellite with pegmatite
- Agm — Mixed granitic rocks
- Banded granitic rocks
- Darkan Quartz Monzonite
- Gibralter Quartz Monzonite

MIGMATITE

GNEISSIC ROCKS
- Orthogneiss
- Layered gneiss (amphibolite facies)
- Granulite facies assemblages
- Anf — Granofels
- Stanniferous pegmatite (Greenbushes)

- Fault, with direction of downthrow
- Geological boundary
- Subcrop
- Anticline
- Syncline
- Plunge of minor folds
- Regional foliation in igneous rocks
- Regional foliation in metamorphic rocks
- Dip of bedding
- Trend lines (lithology or foliation)

Faults in Perth Basin from seismic data at top of Sue Coal Measures (Permian)

FAULTING

The most important fault on the sheet is the Darling Fault, which separates Precambrian rocks of the Yilgarn Block from Phanerozoic strata of the Perth Basin. Its position has been determined from gravity data, and there has been up to 9 km of downthrow to the west in pre-Cretaceous times.

There is evidence from areas to the north (Wilde and Low, 1975 and 1978b) that an original Archaean deformation zone at least partially controlled the position of the Phanerozoic Darling Fault. In the present area, blastomylonite is extensively developed along the Darling Scarp, especially between Harvey and Brunswick Junction, and north of Nannup. Near Harvey, the increasing westward deformation of the Logue Brook Granite resulted in zones of blastomylonite. Discrete mylonite bands occur further west in the layered gneisses, and the whole gneissic sequence shows evidence of strong cataclasis. The deformation zone is up to 10 km wide and is of amphibolite facies metamorphic grade. Folding of the contact between layered gneiss and orthogneiss, and of augen within the orthogneiss, supports the Precambrian age of this event.

Few faults cutting Archaean rocks in the Yilgarn Block have been detected. A major fault-zone trends southeast along the Williams River and marks the southern limit of the Saddleback Group. A number of minor faults truncate units in the metamorphic terrain, whilst two northwest-trending faults cut porphyritic granite and its gneissic deformation zone near Burekup.

METAMORPHISM

The gneissic terrains, Saddleback Group, migmatite, Gibralter Quartz Monzonite, and western part of the Logue Brook Granite all show evidence of metamorphism; the post-tectonic granitic rocks and most of the intrusive dolerite dykes appear to be unmetamorphosed.

The Saddleback Group crops out only as fragmentary rubble. Metabasalt with an actinolite-albite-epidote assemblage indicates greenschist facies conditions. This is consistent with the main belt to the north, although here there is an extension into the lower amphibolite facies (Wilde, 1976a).

The palaeosome of the migmatites consists of pre-existing gneissic rock, and garnet has developed locally in the granitic leucosome.

The Gibralter Quartz Monzonite has a metamorphic fabric and appears to have undergone deformation at elevated temperatures and pressures. The presence of hornblende and clinopyroxene with microcline is compatible with amphibolite-facies conditions.

Diagnostic mineral assemblages are generally absent from the small gneissic areas enclosed by granite. However, the occasional presence of amphibolite bands with a hornblende-andesine (-clinopyroxene-quartz-epidote) paragenesis indicates amphibolite-facies conditions.

Critical assemblages are largely absent from the Balingup Metamorphic Belt between Harvey, Nannup and Bridgetown. Alumino-silicates are absent from the schist units and many iron-formations are deeply weathered. However, the quartz-grunerite-magnetite(-garnet) assemblage of fresher iron-formations, the diopside-epidote-plagioclase-microcline-sphene assemblage of the calc-silicate gneisses and the hornblende-clinopyroxene-labradorite-magnetite assemblage of fine-grained amphibolites, are indicative of the amphibolite facies. Furthermore, the kyanite-staurolite assemblage of *Aln* at Bridgetown implies moderate to high pressure conditions. All ultramafic rocks have greenschist-facies assemblages.

Around Mornington Mills and Mount Lennard, granulite-facies assemblages have been identified in felsic and mafic gneisses and in the later intrusive dolerites in a north-northeast trending zone measuring 30 km by 5 km. There is also metamorphism of porphyritic granite within this zone, including breakdown of feldspar and the development of biotite clots around orthopyroxene. Blight (1978) has attributed this local development of granulite facies to intrusion of dolerites into rocks already at amphibolite facies temperatures. However, there is nothing, apart from metamorphic textures, that distinguishes these dykes from others in the area, whilst corona development and clouding of feldspar indicate subsequent retrograde metamorphism with slow rates of cooling. It seems more likely that the area was subjected to local heating from sources unknown, but probably associated with deformation of the granite and its conversion to orthogneiss.

PHANEROZOIC GEOLOGY

GENERAL

Cainozoic deposits occur throughout the sheet area and effectively cover 70 to 80 per cent of older rock units. They are not always restricted to major tectonic or physiographic provinces and are therefore discussed together in a separate section.

Phanerozoic rocks older than the Cainozoic are present in three separate areas: the Collie, Wilga and Perth Basins. The Collie and Wilga Basins, which contain Permian sedimentary rocks, are restricted depressions within the Precambrian shield. The Perth Basin is more extensive and stretches for almost 1 000 km along the western side of the Australian continent (Playford and others, 1976). Silurian rocks are known from the northern part of the basin, but the oldest formations identified in the present area are of Permian age.

COLLIE AND WILGA BASINS

The Collie Basin extends for 26 km southeast from Allanson, and has an average width of 13 km. It is subdivided by basement highs into three units: the Cardiff, Shotts and Muja Sub-basins (Fig. 3a). Each sub-basin is asymmetric in profile (Fig. 3b), with the deepest portion close to the southwestern margin. The maximum thickness of Permian strata is about 1 300 m in the Cardiff Sub-basin. A smaller basin with a similar northwest-southeast trend occurs east of Wilga, about 36 km south of Collie (Fig. 3a). There appear to be two sub-basins, separated by a basement high, with a combined length of 15 km and average width of 1.5 km. The Wilga Basin contains up to 365 m of Permian strata, which are completely obscured by superficial deposits.

The only working coal mines in Western Australia are located in the Collie Basin. Coal was first discovered in the Collie River, about 6 km west of the Collie townsite, in 1883. Elsewhere, the strata are obscured by later deposits, orginally referred to as the "Lake Beds". The first detailed survey of the coalfield was made by Lord (1952), and this was supplemented by a deep drilling programme instigated by the Geological Survey of Western Australia in 1950 (Low, 1958).

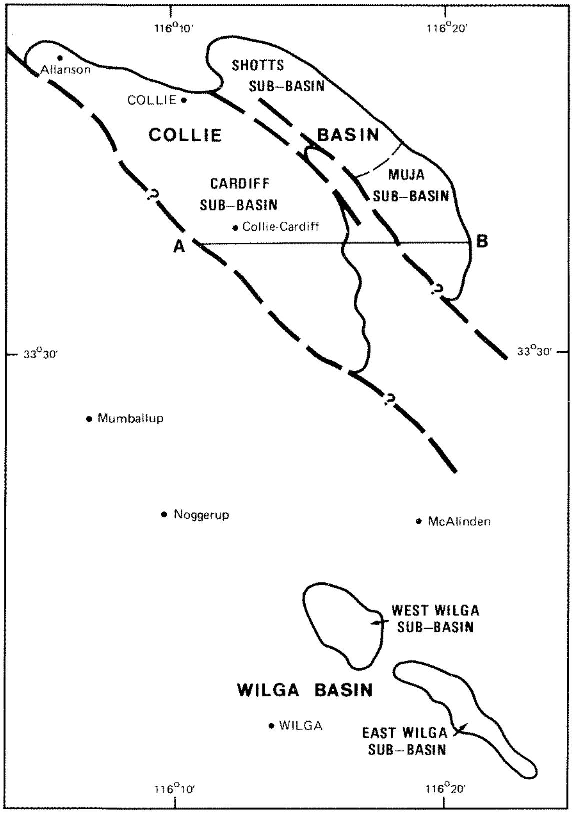


FIGURE 3a

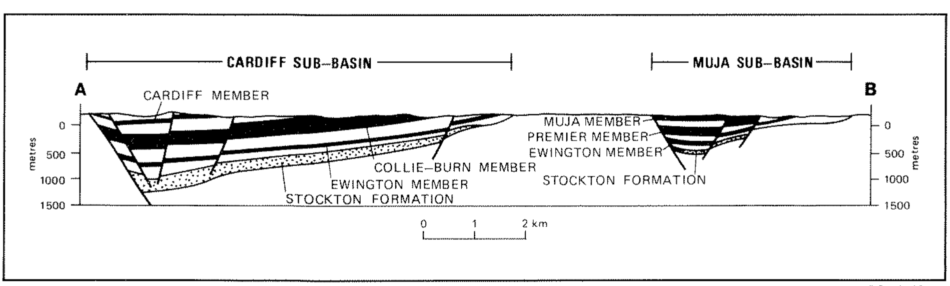


FIGURE 3b

GSWA 18319

STRATIGRAPHY AND SEDIMENTATION

The Permian strata of the Collie and Wilga Basins consist of the Stockton Formation and the Collie Coal Measures. The Stockton Formation is up to 260 m thick and rests on a glacially striated pavement of Archaean rocks. It comprises a basal tillite containing dolerite and granitic fragments, and is overlain by a sequence of pale claystone, siltstone and fine-grained sandstone. It is equated with similar Sakmarian tillites elsewhere in Western Australia. The Collie Coal Measures, which appear to conformably overlie the Stockton Formation, consist of a succession of weakly lithified conglomerate, sandstone, siltstone and claystone, with intercalated seams of sub-bituminous coal. They reach a maximum thickness of 1 050 m. Medium- to coarse-grained sandstones make up the bulk of the sequence, and large-scale cross-bedding is common. Quartz grains are angular to sub-angular and are associated with clay derived from decomposed feldspar. Lowry (1976) suggests that the cross-bedded sandstones were deposited as transverse or longitudinal bars in a fast-flowing braided river system, and that the finer grained sandstones, siltstones, and coal lenses represent flood-plain deposits. However, three main periods of coal formation (mappable as distinct members) occur throughout the Collie Basin and it is possible to correlate major seams within these members in the various sub-basins (Table 1). This indicates the recurrence of widespread swamp conditions throughout the basin. The sediments range from Early to Late Permian in age (Playford and others, 1975), although at Wilga, only the Stockton Formation and Early Permian (Ewington Member) are believed to be present.

TABLE 1. Correlation of Coal-Bearing Members and Coal Seams of the Collie Coal Measures

			CARDIFF SUB-BASIN	SHOTTS SUB-BASIN	MUJA SUB-BASIN
Upper	PERMIAN	Collie Coal Measures	*Cardiff Member* No. 1 Seam No. 2 Seam No. 3 Seam No. 4 Seam Cardiff Seam Neath Seam	Not Present	*Muja Member* Ate Seam Bellona Seam Ceres Seam Diana Seam Eos Seam Flora Seam Galatea Seam Hebe Seam
Upper	PERMIAN	Collie Coal Measures	*Collie Burn Member* No. 1 Seam Wyvern Seam No. 2 Seam Phoenix Seam Griffin Seam	*Premier Member* No. 1 Seam No. 2 Seam No. 3 Seam No. 4 Seam No. 5 Seam No. 6 Seam No. 7 Seam No. 8 Seam	*Premier Member* Apis Seam Uraeus Seam Unicorn Seam Pegasus Seam Hydra Seam Briareus Seam Chiron Seam Centaur Seam
Lower	PERMIAN	Collie Coal Measures	*Ewington Member* No. 1 Seam Moira Seam Stockton Seam Wallsend Seam No. 5 Seam	*Ewington Member* Moira Seam Stockton Seam Wallsend Seam	*Ewington Member* Achilles Seam Ajax Seam Ares Seam

STRUCTURE AND ORIGIN

Two main theories have been advanced for the origin of the Collie Basin: that it was a topographic depression in the Yilgarn Block (Maitland, 1899), or that it resulted from later downfaulting (Jack, 1905). Recently, Lowry (1976) has proposed that an originally extensive sheet of Early Permian deposits was preserved at Collie by the development of an active, localized graben, which controlled sedimentation in the Late Permian.

Lord (1952) favoured the topographic depression hypothesis and this appeared to be supported by the recognition of tillites at the base of the sequence, with the possibility of glacial scouring. Recently, Finkl and Fairbridge (1979) have supported a glacial scour origin for the basin and suggested a gradual filling by swamp deposits followed by development of a through-flowing fluvial basin. The sequence was then compacted and swamp conditions returned. Three main periods of swamp formation correspond to the three members of the Collie Coal Measures.

However, the fluviatile nature of the sandstones (Lowry, 1976), not only between members but between individual coal seams, indicates gradual submergence of the area and not the infilling of a deep basin. Furthermore, Wilde and Walker (1978) found that foreset directions in the sandstones were remarkably consistent and indicated palaeocurrent from the south throughout the Permian. The present Collie Basin was, therefore, not a discrete depositional basin, and the overall southerly dip of the Permian strata and the basement contact must be due to later tilting. Considering this information, it is difficult to explain the present configuration of the basin (Fig. 3b) without postulating a major fault along the southwestern margin. However, the presence of a glacial pavement and basal tillite suggest that some scouring occurred during the Early Permian. Similarly, the general warping of the strata into asymmetrical synclines, with axes close to the southwest margins of the sub-basins, would have been accentuated by differential compaction (Wilde and Walker, 1978). It seems likely that glacial topography controlled the distribution of the Stockton Formation, whereas the present disposition of the Collie Coal Measures is the result of compactional deformation and post-depositional tectonics.

PERTH BASIN

INTRODUCTION

The Perth Basin is a narrow, longitudinal trough almost 1 000 km long. It extends west from the Darling Fault for 80 to 100 km to the edge of the continental shelf. The structure of the basin is controlled by north-trending faults (Fig. 2). The northern part of the basin began as a marginal downwarp in the Ordovician-Silurian and was probably controlled by Precambrian basement structures. In the southern Perth Basin, rifting was initiated in the Late Permian to Early Triassic, and a thick sequence of continental and fluviatile sandstones was deposited. Extensive rifting occurred in the Middle and Late Jurassic and was the precursor to major tectonism and continental break-up in the Early Cretaceous (Neocomian). Break-up probably occurred along a large transform fault situated close to the western margin of the rift, leaving the Perth Basin as a passive, "trailing" margin of Atlantic type. Further details are given by Johnstone and others (1973) and Veevers and Cotterill (1978).

STRATIGRAPHY

Pre-Cretaceous

There are up to 9 km of sediments in the Perth Basin on COLLIE. These are almost totally obscured by Cainozoic deposits, although small areas of Cretaceous rocks are exposed along the Darling Scarp. The lower units are known only from geophysical work, deep water bores, and by extrapolation from oil-well data to the north, south and west of the area (Low, 1972).

The Sue Coal Measures overlie Precambrian Basement and consist of over 2 000 m of continental sandstone and siltstone, with coal seams. They range in age from Sakmarian to Late Permian and are correlated with the Collie Coal Measures. The coal seams act as seismic reflectors and have been used for delineating the position of faults in the basin (Fig. 2). The overlying Triassic rocks are up to 2 500 m thick and consist of the Sabina Sandstone of Scythian age and the Lesueur Sandstone ranging from Early to Late Triassic in age. The Sabina Sandstone is a sequence of continental sandstone with minor interbeds of shale, whilst the overlying Lesueur Sandstone is a thick fluviatile sequence of pale feldspathic sandstone interbedded with conglomerate and siltstone. Major rifting associated with movement of the Darling Fault is believed to have commenced during the Middle Triassic.

The Jurassic is represented by about 4 000 m of continental and fluviatile sediments on COLLIE. The Early Jurassic Cockleshell Gully Formation conformably overlies the Lesueur Sandstone and is a continental sequence of sandstone, siltstone, and claystone, with an upper coal-bearing unit (the Cattamarra Coal Measures). The overlying Yarragadee Formation is conformable and is a thick sequence of poorly sorted sandstone and siltstone with thin bands of conglomerate and clay. It ranges from Middle Jurassic to Early Cretaceous in age, and changes from a continental fluviatile deposit in the Jurassic to a paralic sequence in the Neocomian.

Cretaceous

Major tectonism occurred during the Neocomian, and continental break-up affected the southern Perth Basin about 125 m.y. ago, with the initiation of sea-floor spreading (Veevers and Cotterill, 1978). There was subsidence offshore in the Vlaming Sub-basin, and a major transgression was initiated. The tectonic events were reflected in the eruption of the Bunbury Basalt and the deposition of the Donnybrook Sandstone and Maxicar Beds. An interbedded sequence of sandstone, siltstone, shale and claystone—the Leederville Formation (Cockbain and Playford, 1973)—is also present, but is known only in the subsurface. Post-Neocomian subsidence in the Perth Basin appears to be largely due to compaction of the thick pile of sediments (Johnstone and others, 1973).

Bunbury Basalt: The Bunbury Basalt (McWhae and others, 1958; Burgess, 1978), consisting of at least two lava flows of porphyritic tholeiitic basalt, is locally vesicular and displays columnar jointing. It crops out along the foreshore at Bunbury and is also exposed in a quarry at Gelorup, 8 km south of Bunbury. The basalt is extensive in the subsurface, and its distribution, based on geophysical and bore-hole data, is shown in Figure 2. The maximum known thickness is 85 m (in the Boyanup Bore). The basalt is believed to have filled valleys eroded into the Yarragadee Formation, which it disconformably overlies. A K-Ar date of 85-105 m.y. was obtained by Wellman (McDougall and Wellman, 1976), but this is considered too young. A dolerite that intrudes the Permian Sue Coal Measures in Sue No. 1 Well (west of the sheet area) may be comagmatic with the Bunbury Basalt (Burgess, 1978), and gave a K-Ar age of 136 $\pm$ 3 m.y. (Wilford *in* Williams and Nicholls, 1966). South of the sheet area, Bunbury Basalt extends east of the Darling Fault (Lowry, 1965) and thus post-dates the last major movement along the fault.

Donnybrook Sandstone: The Donnybrook Sandstone (Saint-Smith, 1912), is a thick-bedded, pale-yellow, fine- to medium-grained, feldspathic sandstone. Playford and Willmott (1958) proposed a type section 6 km north of Donnybrook, in a tributary of Joshua Creek. The sandstone is generally well-sorted with sub-angular quartz grains, and has local shale partings, ripple-marked surfaces, and pebble beds. A previously unrecorded coarse-grained sandstone facies occurs 5 km east and northeast of Donnybrook. This appears to link up with the sandstone in the Brookhampton area, formally considered to be an outlier. The sandstone dips westward at 5 to 10 degrees and generally rests upon Precambrian metamorphic rocks. However, it does appear to extend west of the Darling Fault, although the exact position of the fault in this area is not accurately known. The unit is about 200 m thick, although the thickest continuous section is 60 m at Brookhampton (Lowry, 1965). Teichert was quoted by Maitland (1940) as having discovered footprints of a four-footed vertebrate near Brookhampton and he suggested a Triassic age for the sandstone. However, regional correlations suggest that it is probably of Neocomian age (Playford and others, 1976) and equivalent to part of the Leederville Formation. It was probably deposited close to the shoreline.

Maxicar Beds: The Maxicar Beds (Lowry, 1965; Playford and Low, 1972) consist of 9 m of poorly-sorted, ferruginous, feldspathic sandstone at the type locality, 6.5 km east of Dardanup. Some portions are cross-bedded, and poorly preserved moulds of several bivalves have been found. A sequence of white claystone, siltstone, and fine-grained sandstone with carbonaceous layers is exposed in a clay pit 1 km north of the type locality. This section would overlie the sandstones but is considered to be part of the Maxicar Beds: the total thickness is around 60 m. A pit exposure of similar siltstone and fine-grained sandstone, 4 km south of Burekup, is likewise considered part of this formation. J. M. Dickins, quoted in a report by Playford and Willmott (1958), identified *Pterotrigonia* sp. from the type locality and suggested a Jurassic or Cretaceous age for the Maxicar Beds. The deposit is a shallow-marine to paralic sequence and occupies a similar stratigraphic position to the Donnybrook Sandstone, and is also probably of Neocomian age.

STRUCTURE

The Darling Fault marks the eastern limit of the Perth Basin and is the most important fault in the area, having a downthrow to the west of almost 9 km. It is a normal fault and has developed sub-parallel to a Precambrian deformation zone. There are several other normal faults in the basin and most are sub-parallel to the Darling Fault (Fig. 2). Geophysical evidence indicates that a northwest-trending fault near Harvey marks the southern edge of the Harvey Ridge, which may have been a positive feature since the Permian. The area south of the Harvey Ridge forms part of the Bunbury Trough. The main movement on the faults took place between the Middle Triassic and earliest Cretaceous; few faults affect strata above the Neocomian unconformity, although some flexuring may have occurred due to differential compaction. Cope (1972) postulated an east-west axis of uplift (the Jarrahwood Axis) extending across the Perth Basin from about latitude 33°50′S. It continues slightly south of east across the Yilgarn Block to link up with the Manjimup-Lake Muir Hinge Line (Finkl, 1971) on PEMBERTON. The axis was probably initiated in the Middle to Late Tertiary.

CAINOZOIC DEPOSITS

The precise age of the Cainozoic deposits is generally unknown, although a relative chronology can be established. There are differences between the three main physiographic provinces—the Darling Plateau, Blackwood Plateau and Swan Coastal Plain—related to bedrock conditions and geological evolution, although certain units are found in all three environments. A fuller account of the deposits has been given by Wilde and Walker (1979). A schematic view of the relationships of the various Cainozoic units is presented in Figure 4.

DARLING PLATEAU

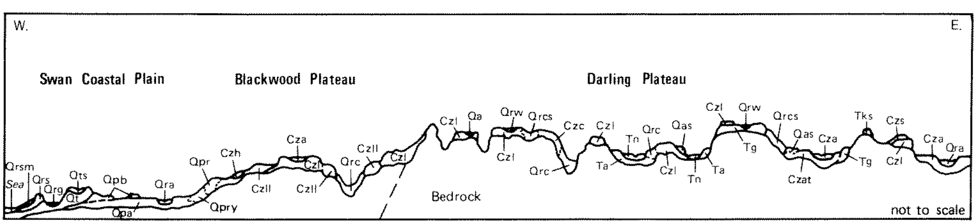
Tertiary and unassigned Cainozoic deposits

The oldest deposits occupy the highest position in the landscape, along watersheds and major interfluves, and there has thus been a major "inversion of relief" since their formation.

The Kojonup Sandstone (*Tks*) was defined in Churchill (*in* McWhae and others, 1958). The type area is east of COLLIE, but a further outcrop was discovered 10 km southwest of Muradup. This consists of silicified sandstone, up to 3 m thick, overlying granitic rocks. The basal coarse-grained sandstone contains well-preserved leaf impressions and other plant material, and a single, non-marine unionid bivalve was obtained (Wilde and Backhouse, 1977). Churchill correlates the Kojonup Sandstone with the Eocene Platagenet Group occurring south and southeast of the sheet area.

Extensive deposits of conglomerate, sand, and clay (*Tg*), of possible alluvial origin, occur along major divides. They are associated with numerous small, rounded swamps and are locally lateritized. The deposits range from 220 to 340 m above sea level and form part of the Darling Plateau surface. Good profiles through the deposits at Greenbushes ("old alluvium" of Hobson and Matheson, 1949) revealed a basal conglomerate overlain by leached white sand with a lateritic "hardcap". Quartzite cobbles predominate, and occur locally at the surface in other areas. Blockley (1980) has proposed the name Greenbushes Formation for the unit at Greenbushes.

When best preserved, the unit gives the appearance of a sheet deposit. Hobson and Matheson (1949) proposed a beach origin for the basal conglomerate at Greenbushes, and it is possible that the unit may be in part marine and associated



Cainozoic Symbols as on Map Reference

FIGURE 4

CAINOZOIC ROCK UNIT RELATIONSHIPS

COLLIE SHEET SI 50–6

with the widespread Eocene transgression. It overlies the Donnybrook Sandstone at Newlands and is considered to be of Eocene age by correlation with the Kojonup Sandstone, which occupies a similar geomorphic position. However, Fairbridge and Finkl (1978) propose an Early Cretaceous age.

In the upper Collie River drainage basin, Tertiary fluviatile sediments are the result of repeated reworking of the underlying Permian Collie Coal Measures. There appears to have been little modification of the sediment and it is difficult to locate the Permian-Tertiary boundary when truncated coal seams are absent. Sediments overlying the coal measures were originally grouped as the "Lake Beds" (Lord, 1952), but were subsequently re-defined as Nakina Formation by Playford and others (1975). However, several distinct units can be recognized and re-definition is again necessary.

Near Muja, cross-bedded sands of fluviatile origin overlie Permian strata. Current directions were from the northeast, although the sediments no longer define a recognizable drainage pattern. They are the oldest Tertiary sediments in the basin and are grouped with *Tg*. An extensive, integrated network of alluvium truncates these deposits and extends as far west as Allanson. The name Nakina Formation (*Tn*) is applied to this unit since it contains the original type section proposed by Playford and others (1975). Locally, an older sandy alluvium (*Ta*) forms terraces to the Nakina Formation and commonly has a strongly developed laterite profile. Extensive reworking of both *Ta* and *Tn* by the present drainage has resulted in colluvial deposits, sometimes directly overlying Collie Coal Measures, as at Ewington.

Broad tracts of sandy alluvium (*Cza*) occupy the Hillman, Arthur and Beaufort River valleys, upstream of major Quaternary rejuvenation of the Blackwood system (Fig. 1). The alluvium ranges from 240 to 280 m above sea level. Close to the Blackwood-Collie drainage divide, a distinct terrace (*Czat*) is commonly preserved and is locally lateritized. There is no difference in height between the Blackwood system alluvium and *Ta* and *Tn* in the Collie system. However, away from the divides there are major differences in appearance, with *Cza* occupying broad, though irregular, valleys and being traversed by low sand dunes.

Remnants of an earlier Tertiary drainage system near Kirup are grouped as *Cza*, although it is not implied that they are necessarily the same age as *Cza* in the Blackwood system.

Conglomeratic deposits (*Czc*) are locally abundant on the Darling Plateau. The clasts are chiefly orthoquartzite and generally larger than those associated with *Tg*, ranging up to boulder size. The age of these deposits is the subject of considerable debate. Churchward and Bettenay (1973) favour a Mesozoic age for conglomeratic deposits preserved along minor interfluves along the Harvey River—the Harvey Beds of Playford and others (1976). However, the eastern outcrops contain relatively few clasts, and they pass imperceptibly into areas of *Tg* at 280 m above sea level. We thus consider them to be of Tertiary age.

A major conglomerate deposit extends in an arcuate band, 2.5 km wide, from near Mayanup 80 km northwest to the Kirup area (Fig. 5). It ranges from 140 to 240 m above sea level and has been called the Kirup Conglomerate (Finkl, 1971; Taylor, 1971; formally defined by Finkl and Fairbridge, 1979). It changes along its length from an orthoconglomerate in the southeast, to a paraconglomerate, with less than 10 per cent orthoquartzite clasts, near Goonac. The matrix is a clayey sand that is poorly sorted along the whole length of the deposit. The orthoconglomerate rests directly on bevelled Precambrian rocks whereas the paraconglomerate occupies a valley up to 30 m deep and has sedimentary structures that indicate transport from the southeast. Finkl and Fairbridge (1979) postulate that the Kirup Conglomerate is a fluvioglacial deposit of Permian age. However, it contains clasts of Cretaceous Donnybrook Sandstone, 1 km south of Mullalyup, and many of the orthoquartzite clasts in this area can be equated with the previously unrecorded coarse-grained facies of the Donnybrook Sandstone. Furthermore, the conglomerate grades laterally into *Tg*, 10 km west of Boyup Brook, at about 230 m above sea level. It is possibly also of Eocene age, and the original orthoconglomerate may have been a beach deposit formed during the Eocene transgression. Later fluvial reworking could account for the paraconglomerate facies occupying valleys.

The most extensive Cainozoic deposit is laterite (*Czl*). It forms an undulating capping over granitic rocks of the Darling Range, although it has largely been stripped from the metamorphic terrain and in the Blackwood drainage basin. The laterite has developed *in situ* by weathering of basement rocks (Sadleir and Gilkes, 1975; Wilde and Low, 1975). It is chiefly massive and cemented, and may be either pisolitic or vesicular. It ranges from 4 to 5 m thick, and upper portions locally consist of loose pisolites. Some laterite in the eastern part of the sheet has developed *in situ* in various eluvial and colluvial deposits.

The age of lateritization is uncertain. It is likely that deep weathering was pronounced in the Early Tertiary, although initial weathering of Archaean bedrock may have occurred much earlier. Induration of the saprolite profiles probably occurred in the Early Oligocene (Schmidt and Embleton, 1976) and this also affected Eocene sediments. However, Pleistocene sediments in the Perth Basin have also been lateritized (ferruginized), and Lowry (1965) reports laterite forming today at the watertable.

Small deposits of sand, locally overlying the laterite (*Czs*), are related to ancient drainage courses. The sands are variously leached and have undergone some eolian modification. They may grade downslope into colluvial sand or sandy alluvium.

Quaternary deposits

The oldest deposits on the Yilgarn Block are ribbons of reworked sand (*Qas*) associated with Tertiary drainage systems. They have a hummocky surface and vary considerably in height, commonly linking-up separate areas of alluvium. Near Treesville, they are equivalent in part to both *Tg* and *Ta*. However, they are considered to be Quaternary on account of the extensive reworking.

Thin ribbons of alluvium with minor colluvium (*Qa*) overlie laterite in the Darling Range (Wilde and Low, 1975 and 1978b), but are restricted to the area of Logue Brook Granite. They occupy the heads of present valleys and pass downstream into colluvium or rock outcrop.

Colluvial deposits (*Qrc*) are extensive on the Darling Plateau at the heads of valleys where streams are actively incising the laterite surface. In the eastern part of the area, particularly in the Blackwood drainage basin, colluvium forms large areas upstream from alluvium or developed between alluvium and rock outcrop. In the Collie drainage basin colluvium has resulted from reworking of Tertiary alluvium.

Colluvial deposits occurring below the laterite east of Nannup are referred to as the "Boronia Swamp Alluvium" by Finkl and Fairbridge (1979), who suggest a Late Cretaceous or Eocene age for the deposits. However, they incise *Tg* and are similar to colluvial deposits elsewhere on the Darling Plateau. They are truncated downstream by prominent knick-points at 280 m above sea level. This attests to the great amount of downcutting along the Darling Scarp by the Blackwood River in the Late Cainozoic, rather than the antiquity of the deposits.

Distinctive areas of sandy colluvium (*Qrcs*) are associated with the Tertiary drainage systems. These valley-fill deposits represent reworking of sandy Tertiary alluvium, although some are derived by slope wash from *Czs*.

Swamp and lacustrine deposits (*Qrw*) occur in rounded clay pans and lakes associated with Cainozoic drainage deposits. Small lakes are particularly abundant in association with *Tg* and *Qas*, whereas a number of larger lakes (Towerrinning Lake and Mamine Swamp) are associated with *Cza*.

Recent alluvium (*Qra*) is present along many of the more youthful drainage lines. It is extensive along the Preston and Williams Rivers and the lower reaches of the Blackwood River. In the upper reaches of the Blackwood River, it forms an entrenched flood plain several metres below the more extensive Tertiary alluvium.

BLACKWOOD PLATEAU

Tertiary and unassigned Cainozoic deposits

A high-level laterite (*Czl*) is equated with that developed on the Darling Plateau (Finkl, 1971), although it is only strictly continuous north of Kelson Firetower. The laterite is generally quartz-rich, reflecting the composition of the bedrock. Near the western margin, it is bounded by distinct breakaways. However, there is less relief in the central and eastern parts of the plateau, and a distinction between high- and low-level laterite cannot be made. Unless there is a distinct breakaway the laterite is classified as *Czl*. Areas of sand overlying laterite (*Czs*) are rare and largely confined to the Whicher Scarp.

Along the present drainage lines, a dissected, lateritized bench is preserved at spurs and in the heads of valleys, particularly in the west-flowing streams. This lower laterite (*Czll*) developed over weathered bedrock and colluvium after the dissection of the earlier high-level laterite. It is generally less indurated, contains more quartz, and has a weaker vesicular texture than *Czl*. It rises gradually upstream from 80 to 130 m above sea level, and is also present over the Cretaceous outliers (Donnybrook Sandstone) east of the Darling Fault.

Broad, sandy alluvial tracts (*Cza*) are preserved at 7 km and 18 km southwest of Cambray. They are truncated by the present drainage and appear to pre-date the formation of *Czll*.

Along the Whicher Scarp, a distinct bench at about 80 m above sea level is equated with the Ridge Hill Shelf. The bench is lateritized, and there is a sporadic development of beach and dune sand (*Czh*), with local concentrations of heavy minerals. The bench was termed the Middle Escarpment Shoreline by Welch (1964) and is here called the Happy Valley Shoreline.

Quaternary deposits

The Blackwood Plateau has a well-developed dendritic drainage system. However, the valleys are filled with colluvium (*Qrc*) and appear to have formed in an earlier pluvial period. North of the Blackwood River watershed (Fig. 5) the valleys are steep-sided and clearly defined. In contrast, the tributaries of the Blackwood River often show a gradation from sandy colluvium (*Qrcs*) into loose lateritic gravel at the headwaters.

The major rivers traversing the plateau—the Preston, Capel and Blackwood—have terraces that grade downstream into the Guildford Formation (*Qpa*) on the Swan Coastal Plain, as well as a lower flood plain of more recent alluvium (*Qra*). In addition, terraces equated with *Cza* occur along the Blackwood River near Nannup.

SWAN COASTAL PLAIN

About 1.5 km of sediment has been deposited over the Perth Basin since continental break-up in the Neocomian. This is thin considering the geological environment and attests to the generally low denudation rate in the source area, the Darling Plateau (about 0.1-0.2 m per million years according to Fairbridge and Finkl, 1978). The bulk of the sediments are fluviatile, although marine incursions are known. The present morphology of the plain, however, is due largely to marine action, resulting in a series of benches along the Darling and Whicher Scarps and at least three periods of dune formation along the present shoreline. All exposed deposits are considered to be Quaternary in age.

Pleistocene deposits

The Yoganup Formation (Low, 1971 and 1972) is a shoreline deposit consisting of a basal conglomerate and foredune, with local concentrations of heavy minerals. The type section at Yoganup was 9 m thick, but has since been destroyed by mining.

The deposit consists principally of a medium- to coarse-grained, rounded and well-sorted quartz sand. It occurs in two geomorphic environments: North of Paradise Creek (a tributary of the Ferguson River), it forms part of a distinct shelf (*Qpr*), whereas south of the creek it occurs at the base of the shelf (*Qpry*). The shelf was equated with the Ridge Hill Shelf by McArthur and Bettenay (1960). However, the Yoganup Formation (in both geomorphic environments) lies between 35 and 90 m above sea level (average 50 m) and appears to be related to the Waroona Shoreline of Baxter (1977). No fossils have been found, but the formation is considered to be of Early Pleistocene age (Playford and others, 1976).

Unconformably overlying the Leederville Formation over most of the coastal plain is the Guildford Formation (*Qpa*) (Baker, 1954; Low, 1971). It consists of alluvial sands and clays, but also includes minor shallow-marine and estuarine lenses. It is approximately 30 m thick and is believed to be of Middle or Late Pleistocene age. The formation extends east of the Darling Fault along the Preston River for a distance of 5 km.

The oldest of the three major dune systems is the Bassendean Sand (*Qpb*) (Playford and Low, 1972), which forms a discontinuous zone of low vegetated hills. The formation consists of a basal beach conglomerate overlain by quartz sand, with local concentrations of heavy minerals. It forms part of the Capel Shoreline (Baxter, 1977) that ranges from 8 to 25 m above sea level. The total thickness of the formation may exceed 46 m (Low, 1972). The dunes may have been modified and leached of original calcium carbonate (Playford and others, 1976). The formation is thought to be Middle to Late Pleistocene in age (Low, 1972).

The Tamala Limestone (*Qt*) (Playford and others, 1976), was previously known as the "Coastal Limestone" (Saint-Smith, 1912), and is equivalent to the Spearwood Dune System of McArthur and Bettenay (1960). It is chiefly a cross-bedded, eolian calcarenite, but it also includes beach deposits and soil horizons with calcified root structures. The formation ranges from 5 m below sea level to 58 m above, and progressively overlies Bunbury Basalt, Leederville Formation, Guildford Formation and Bassendean Sand east from the present shoreline. It consists mainly of round, frosted quartz grains and calcium carbonate sand with sponge spicules, feldspar, and heavy minerals. The calcium carbonate fractions represent comminuted foraminifers and molluscs. Weathering has caused some solution and re-precipitation of lime, resulting in a layer of hard "cap rock" and an overlying leached quartz sand. Areas where this sand is extensive have been shown on the map as *Qts*.

Recent (Holocene) deposits

The youngest dunes fringing the present coastline form the Quindalup Dune System of McArthur and Bettenay (1960). They have been named the Safety Bay Sand (*Qrs*) (Passmore, 1970; Playford and Low, 1972) and consist of unlithified, calcareous sand composed of mollusc and foraminifer fragments. The amount of quartz sand is variable and heavy minerals locally reach economic levels, e.g. Koombana Bay, near Bunbury. As the dunes become vegetated, lithification of the sand is proceeding at the watertable. There are local mobile patches (*Qrsm*) along the coast with dunes rising to 20 m above sea level.

Recent deposits of clay and silt, with lenticular shell beds, (*Qrg*) are present in lagoons and estuaries east of the Safety Bay Sand and Tamala Limestone (e.g. Leschenault Inlet).

Holocene alluvium (*Qra*) is developed along the rivers of the Swan Coastal Plain and inland east of the Darling Fault. There are at least two terrace levels incised into the Guildford Formation by the Preston and Capel Rivers.

Swamp deposits (*Qrw*) occur throughout the coastal plain. The largest is Benger Swamp, which has been drained for agricultural purposes. Small, seasonal swamps are particularly abundant in interdunal swales in the Bassendean Sand.

Weak lateritization (ferruginization) has affected most units on the Swan Coastal Plain (Lowry, 1965), and seems to be occurring now at the water table.

ECONOMIC GEOLOGY

METALLIC MINERALS

GOLD (Au)

Gold was obtained from chalcedonic quartz veins cutting Archaean gneisses and the overlying Donnybrook Sandstone, about 2.5 km south of Donnybrook. The Donnybrook Goldfield was proclaimed in 1899 and cancelled in 1908. A total of 1 681.8 t of ore were treated for 23.863 kg of gold. Forman (1936) concluded that further discoveries of economic gold were unlikely.

Traces of gold in quartz-muscovite schist and associated quartzite, 3.5 km west-southwest of Kirup, were tested by shafts and costeans, although no production was reported. These, and reported occurrences in a quartz vein at Nannup, were investigated by Saint-Smith (1912). Gold was reported from a pyrite-bearing quartz vein 4.8 km east of Brunswick Junction along the Brunswick River (Maitland, 1899) and within the upper reaches of the Ferguson River, about 5 km west of Wellington Mill (Blatchford, 1900). Costeans and shafts were also excavated in a quartz shear zone 10 km west-northwest of Quindanning. Early reports of alluvial gold at Nannup and in the Preston Valley were investigated by Hardman (1884).

TIN (Sn)

The first commercial tin deposits in Western Australia were found at Greenbushes in 1888. Historical and geological details are given by Hobson and Matheson (1949) and Blockley (1980). The host of cassiterite mineralization is a series of northwest-trending pegmatite lenses in granofelsic country rock. The pegmatites are deeply weathered and are locally covered by thick Tertiary deposits. They consist of albite, quartz and tourmaline with a variety of minor and accessory minerals (Pryce and Chester, 1978). Early production was based mainly on alluvial concentrations of cassiterite at the base of the Tertiary sediments (*Tg*), whereas present operations largely involve open-cut mining of the weathered pegmatite. Future operations will involve hard-rock mining of the pegmatite. Total production of tin concentrate (containing about seventy per cent tin) to December 1980 was 20 378 t.

TANTALUM (Ta)

Tantalite and stibiotantalite have been important by-products of tin mining at Greenbushes for many years. However, current high prices have given these minerals equal importance to tin in the mining operations, and they will become the prime minerals in future years. Aggregate production to December 1980 was 1 841.6 t of concentrate (including 23 t of tantalo-columbite). The concentrate contains approximately 42 per cent Ta_2O_5.

MOLYBDENUM (Mo)

Traces of molybdenite occur in a ferruginous quartz shear zone 7.5 km southeast of Williams. A few flakes are also present in banded granites southwest of Williams.

IRON (Fe)

Ferruginous laterite was obtained from quarries 0.5 km northeast of North Greenbushes, and about 7 600 t were extracted to 1904.

Other small deposits scattered across the western part of the sheet area were investigated by Lord and others (1953).

VANADIUM (V)

Vanadium-bearing titaniferous magnetite is present in a narrow gabbroic dolerite dyke 5 km south-southeast of Tallanalla (Baxter, 1978). The known mineralization is not economic.

BAUXITE (Bx)

Bauxitic laterite is extensive over the granitic rocks of the Darling Range, and portions of the Alcoa and Worsley mineral leases extend south onto COLLIE. There are also a number of mineral claims held by Project Mining. The refinery for the proposed operations at Mount Saddleback will be situated near Worsley.

No bauxite has been mined from the sheet area. However, bauxitic laterite over the Logue Brook Granite may be exploited in the future, following the construction of the third Alcoa refinery at Wagerup, just north of the sheet area.

INDUSTRIAL ROCKS AND MINERALS

COAL (C)

Following the discovery of coal in the Collie River in 1883, a coal mining district was gazetted in 1896, and mining commenced in 1898 on completion of the railway. The history and development of the coalfield to 1950 is summarized by Lord (1952), whilst further information from a deep drilling programme instigated by the Geological Survey of Western Australia is contained in Low (1958).

All underground mining at Collie has been by the "bord and pillar" method. At present there is only one operating underground mine (Western Collieries No. 2), and all old workings are flooded and inaccessible. Open-cut mining commenced in 1943 and the bulk of present production is by this method. There are two current operations: Western Collieries No. 5 and Muja Open-Cut (worked by the Griffin Coal Mining Co). Annual production from the coalfield for the year ended 31 December 1980 was 3 151 470 t, whilst total production to that date was 60 997 329 t. Total coal in the ground was estimated as 1 907 Mt by Low (1958), whilst total recoverable coal is now estimated at around 405 Mt.

Coal was discovered 9 km northeast of Wilga by Michael O'Grady in 1918. Several surveys have been undertaken of the Wilga Basin, but the deposits are sub-economic at the present time. Seams of low-grade coal were encountered in shafts sunk for gold at Donnybrook (Saint-Smith, 1912), and several other narrow seams of Jurassic and Cretaceous coal have been intersected in bores west of the Darling Fault (e.g. at Jarrahwood, Saint-Smith, 1912). None of these deposits is economic, either because of quality or depth of burial.

HEAVY MINERAL SANDS (Hm)

Local concentrations of heavy minerals are present along Cainozoic strandlines in the Perth Basin (Baxter, 1977). The principal deposits are in the Yoganup Formation near Yoganup and in the Bassendean Sand near Capel. Holocene deposits in the Safety Bay Sand at Koombana Bay have already been mined out. There is also a potential for heavy minerals in the highest of the strandline deposits, the Happy Valley Shoreline, at about 80 m above sea level.

The principal economic mineral is ilmenite, but leucoxene, rutile, zircon, monazite and xenotime are also recovered. Total production from the sheet area to 31 December 1980 was 10 331 220 t of ilmenite, 159 689 t of leucoxene, 26 751 t of rutile, 865 671 t of zircon, 50 825 t of monazite and 326 t of xenotime.

A prospect for heavy minerals, 9 km east of Kirup, contains cassiterite in addition to ilmenite, rutile and zircon. Concentrations appear to be at the base of Tertiary alluvial deposits (*Tg*), overlying pegmatite. The area was originally considered prospective for kaolin.

CLAY (Ce)

Lenses of clay, suitable for ceramic and brick manufacture, which occur in the Guildford Formation, are being utilized at Waterloo. Material for the Waterloo Brickworks is also obtained from clays in the Maxicar Beds, 1 km north of Maxicar.

Good-quality clays have been produced in small quantities from the Collie Coal Measures, particularly in the vicinity of Shotts (Lord, 1952).

KAOLIN (Ck)

Kaolin was obtained from the pallid zone of the weathering profile over gneissic rocks, 7 km east of Roelands. Kaolin suitable for tile and stoneware was reported in a railway cutting 1.5 km north of Newlands (Woodward, 1917). Kaolinization of the tin-bearing pegmatites at Greenbushes is extensive and preliminary investigations have been made to test the material.

MICA (Mi)

Small amounts of muscovite were mined from pegmatite dykes in the Mullalyup and Kirup districts (Matheson, 1944a). Similar material was tested near Bussell Brook, 19 km southwest of Collie. The mica is generally of good quality, but little would trim to more than washer size. Total recorded production from Mullalyup was 3 683.2 kg prior to 1942.

FELDSPAR (Fs)

Small quantities of microcline suitable for ceramic purposes were obtained from a pegmatite dyke at Ferndale, 6 km southwest of Balingup (Matheson, 1944a; Chung, 1957).

BERYL

Beryl concentrates from the Ferndale pegmatite and nearby dykes were marketed on various occasions up to 1959. Total production was 10.91 t.

TALC (T)

Lenses of soapstone were worked, 8 km north of North Greenbushes. However, the material deteriorated with depth (Matheson, 1944b). Talc is also reported from ultramafic rock, 1 km south of Bridgetown (Simpson, 1952).

ASBESTOS

An ultramafic rock, 9 km south-southeast of Donnybrook, was tested for suitability as a source for asbestos, but quality was poor (Lord, 1951).

GARNET

Large garnets of specimen quality are reputed to have been collected from weathered schists north of Glen Mervyn.

LIMESTONE AND LIMESAND (Ls)

Large quantities of calcium carbonate are available along the coast in the Tamala Limestone and Safety Bay Sand. Some material has been extracted near Bunbury for use in road construction.

A small amount of lime for use as a soil conditioner has been extracted from the Tamala Limestone near Capel.

BUILDING STONE (Bs)

Donnybrook Sandstone, quarried earlier this century for use as a building and facing stone, was employed in a number of Perth buildings. Some stone is still quarried periodically for specific local jobs and renovation work. Substantial deposits remain (Wyatt, 1960), although high extraction costs make further large-scale quarrying unlikely.

Cobbles and boulders from the Kirup Conglomerate have been extracted from a pit 14 km south of Boyup Brook. These have been used as ornamental garden stones in Perth, and there is potential for further exploitation.

A dolerite dyke 6 km west-southwest of Bridgetown is considered prospective as a source for good quality "black granite" facing slabs and gravestones.

AGGREGATE, BALLAST AND ROAD METAL

Abundant supplies of rock suitable for crushed rock aggregate (Rc) are available along the Darling Scarp and at selected localities further east. A quarry at Roelands supplied fill for the development of Bunbury Harbour and is now a source of ballast. Fill material for the major dams was obtained from quarries on site. Bunbury Basalt is obtained from a quarry at Gelorup, 8 km south of Bunbury, and used mainly for road aggregate.

Pisolitic laterite gravel (Gr) is used extensively for road making and many pits are opened up from time to time on the Darling Plateau. Some weathered basement rocks (Rm) are used locally.

SAND

There are abundant supplies of unbonded silica sands (Sd) in the Bassendean Sand. The sands are generally clean, well graded and range from medium to coarse grained. They are suitable for steel and general cast-iron moulding, for bottle and window glass, and for lime-brick manufacture (Low, 1972).

East of the Darling Scarp, small pits for local use have been opened up in sand developed over laterite or associated with drainage systems.

Glass sands (Sg), 4 km east of Donnybrook, form part of a larger deposit that is not of glass specifications (de la Hunty, 1955).

WATER SUPPLIES

SURFACE WATER

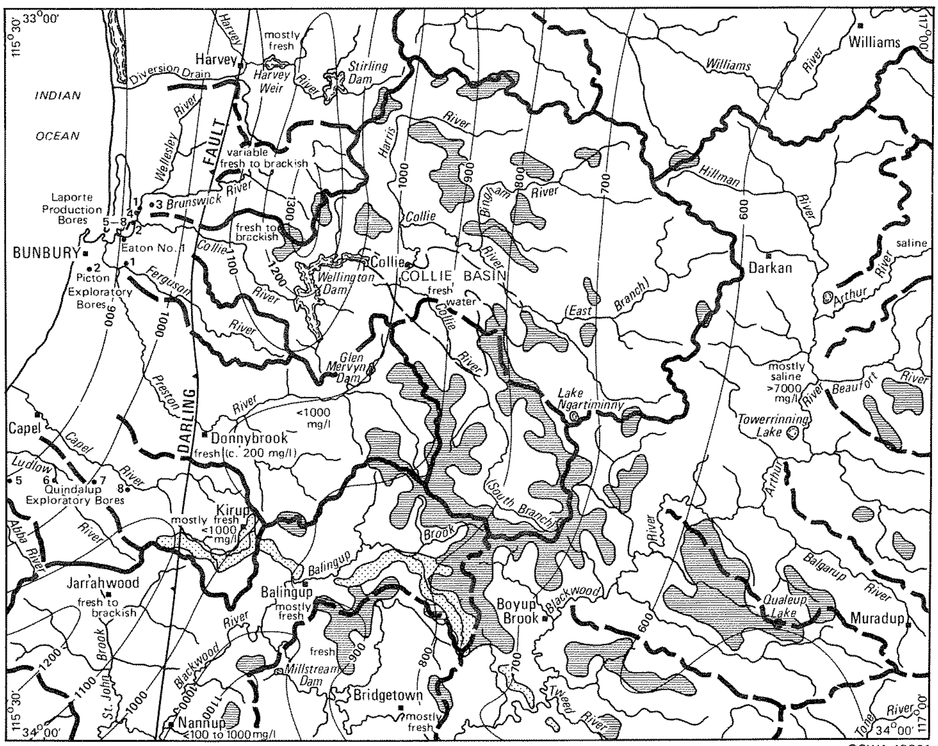
The rivers and streams draining the forested catchments of the Darling Range are fresh and many have been dammed for domestic and agricultural supplies (Fig. 5). Wellington Dam on the Collie River is the major dam in the area, supplying water to Collie and centres further east. The Logue Brook, Harvey, and Stirling Dams, which are part of the Harvey-Waroona irrigation scheme network, support intensive agriculture on the Pinjarra Plain. The small Glen Mervyn Dam, 17 km south of Collie, provides irrigation water to the Preston Valley.

Rivers and streams in the eastern part of the sheet area are generally intermittent and brackish, and therefore, unsuitable for domestic or irrigation use. The Blackwood River is the largest drainage system and has the greatest discharge of all the rivers in the southwest of Western Australia (Bettenay and Mulcahy, 1972). Unfortunately, its headwaters are saline.

GROUNDWATER

Yilgarn Block

Groundwater resources on the Yilgarn Block are small and usually suitable only for household supplies or stock watering. In the high-rainfall areas of the Darling Scarp, shallow wells produce fresh or brackish water from the soil and weathered rock profile. Salinity increases further east in the lower rainfall areas, and location of



GSWA 18321

FIGURE 5

WATER SUPPLIES

COLLIE SHEET SI 50–6

0 10 20 30 km

REFERENCE

- Townsite
- —600— Rainfall isohyets in millimetres per year
- River, creek
- Lake, swamp, dam
- Drainage divide
- Early Tertiary alluvial sands
- Kirup Conglomerate
- <7000 mg/l Salinities of unconfined ground water in milligrams/litre total dissolved solids
- •4 Exploratory bores in Perth Basin

stock water is limited to favourably sited bores drawing water from deeply weathered or fractured bedrock. Fresh water is generally available from the thick Tertiary sands of map unit *Tg*.

Collie Basin

A substantial amount of groundwater is available from through-flow and storage in the Permian sediments of the Collie Basin. Water-table observations indicate a general groundwater flow to the northwest. The salinity is usually less than 500 mg/L T.D.S. (Total Dissolved Solids), though exceptions up to 2 000 mg/L T.D.S. are known. The acidity of the water is high, owing to oxidation of pyrite in the coal seams, and pH values as low as 3.0 have been recorded. The water also has a high iron content and treatment is necessary before use. The main user of groundwater is the Muja Power Station, and demands will increase with the future expansion of generating capacity.

Perth Basin

Unconfined Groundwater: Water of variable quality is present in the Guildford Formation, though it is commonly brackish. Clayey soils in the Harvey and Dardanup irrigation areas are distinctly saline.

North of Australind, the Bassendean Sand contains low salinity water—less than 500 mg/L T.D.S.—and may be saturated over a thickness of 40 m. South of Bunbury, the formation is thinner and the water is often brackish.

The Lake Clifton exploratory bores have tested the Tamala Limestone and Safety Bay Sand aquifer. It has a saturated thickness of 20 to 30 m and a salinity of less than 1 000 mg/L T.D.S., although brackish groundwater occurs near swamps. A salt-water interface exists along the east side of Lake Preston and along the coast, with a thin lens of fresh water above it. The aquifer is used extensively for irrigation.

Confined groundwater: The Jurassic Cockleshell Gully Formation has been encountered in the Picton and Quindalup Line Bores but contains saline water.

The overlying Yarragadee Formation has a maximum known thickness of 720 m in Picton No. 4 bore. The salinity is low—200 to 400 mg/L T.D.S.—and the groundwater flow is northwest from recharge areas on the Blackwood Plateau. The aquifer is used for the Bunbury water supply and for industrial and mining purposes. It is the most important aquifer in the region.

Groundwater from the Leederville Formation is used for town supply and industrial purposes in the Bunbury-Capel area. It has a maximum known thickness of 261 m. The lowest salinities—less than 500 mg/L T.D.S.—are in the south, and there is a general increase northwards.

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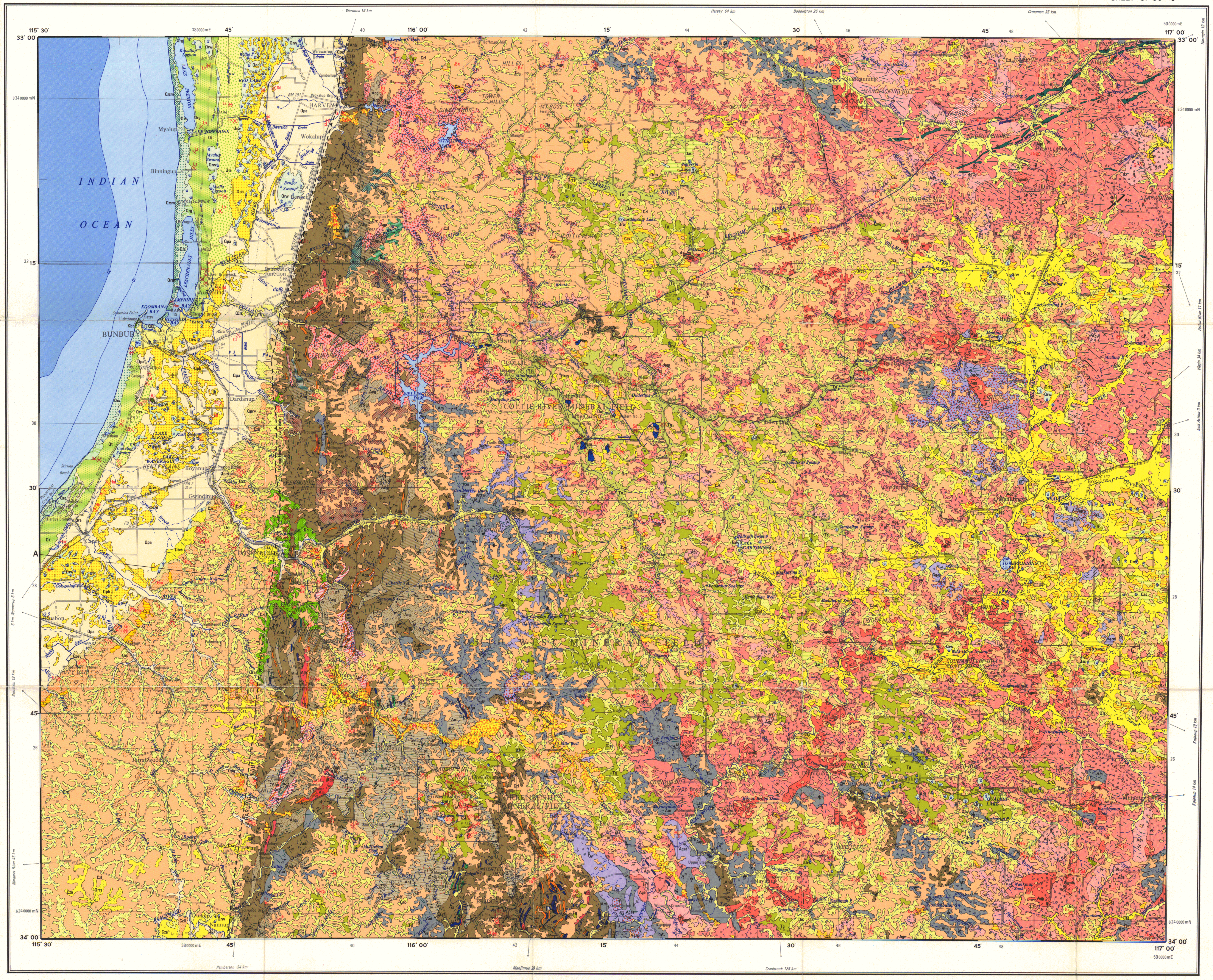
COLLIE

AUSTRALIA 1 : 250 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

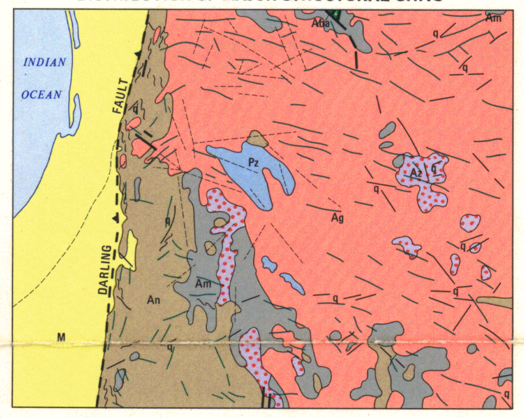
SHEET SI 50 - 6



SYMBOLS

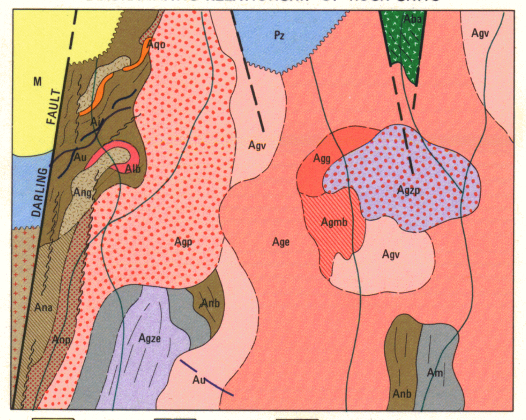
Geological boundary
Fault
Plunge of minor fold
Bedding
Gneissic foliation
Mineral foliation in plutonic rocks
Schistosity
Direction and plunge of lineation
Mylonitized shear zone
Air photo lineament
Type section locality
Fossil leaf locality
Geochronological site
Mineral field boundary
Highway with national route marker
Formed road
Track
Railway
Bridge
Power line
Townsite, gazetted
Locality
Airfield
Landing ground
Horizontal control
Bench mark, height accurate
Transmitting station
Sand dunes
Watercourse
Bore
Pool
Spring
Pipeline
Bathymetric contour line, depth in metres
Permanent water
Mine
Mine, abandoned
Quarry
Quarry, abandoned
Alluvial workings
Alluvial workings, abandoned
Prospect
Mineral occurrence

DISTRIBUTION OF MAJOR STRUCTURAL UNITS



Major Lineaments

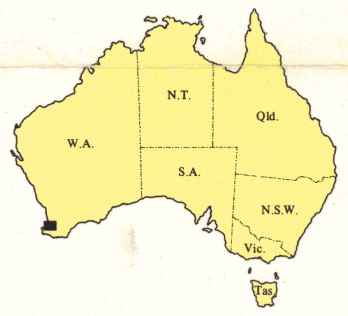
DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



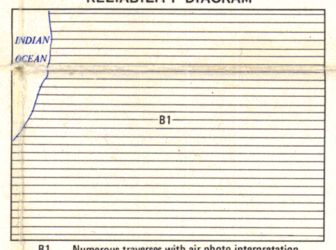
M MESOZOIC	Pz PALAEOZOIC	PRECAMBRIAN undifferentiated
Ag Granite	Am Migmatite	Az Quartz Monzonite
An Gneiss	Unconformity	

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

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



RELIABILITY DIAGRAM



B1 Numerous traverses with air photo interpretation

HON. P.V. JONES, M.L.A.
MINISTER FOR MINES
A.F. TRENDALL, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1 : 250,000

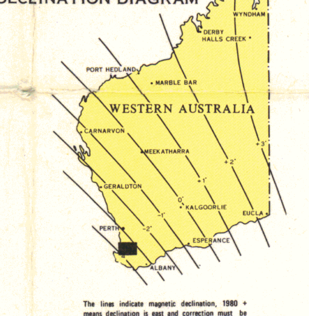
TRANSVERSE MERCATOR PROJECTION
ZONE 1 AUSTRALIA SERIES
Grid represents the 10000 metre superimposed Australian Map Grid

Geology: Perth Basin – D.C. Lowry 1963
Yilgarn Block – S.A. Wilde and I.W. Walker 1975–6

INDEX TO ADJOINING SHEETS

INDIAN OCEAN	PINJARRA SI 50 - 2	CORRIGIN SI 50 - 3
BUSSELTON SI 50 - 5	COLLIE SI 50 - 6	DUMBLEYUNG SI 50 - 7
AUGUSTA SI 50 - 9	PEMBERTON SI 50 - 10	MT. BARKER SI 50 - 11

DECLINATION DIAGRAM



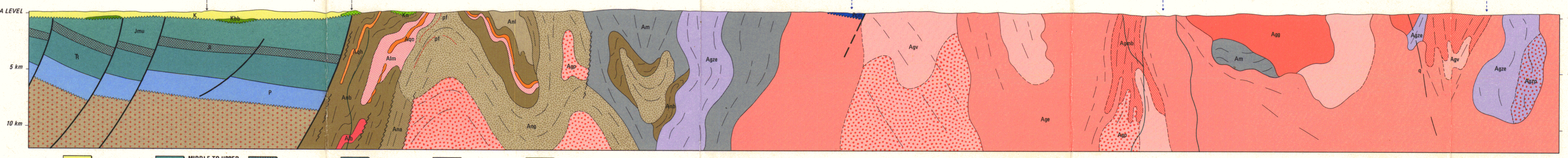
The lines indicate magnetic declination, 1980 + means declination is east and correction must be added to compass bearing to give true bearing – means declination is west and correction must be subtracted from compass bearing to give true bearing.

Annual change is –1′ westerly

DIAGRAMMATIC SECTION

NATURAL SCALE

SECTION A - B - C

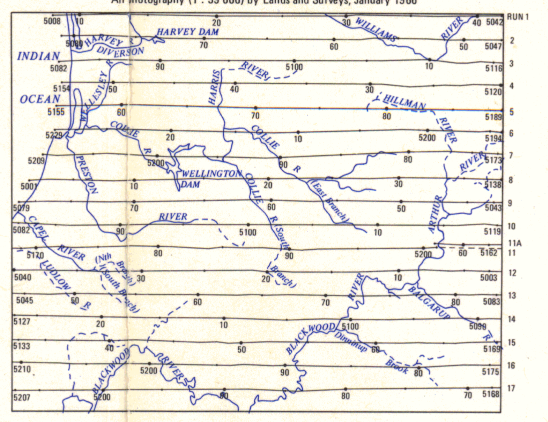


K	CRETACEOUS
Jmu	MIDDLE TO UPPER JURASSIC
Jl	LOWER JURASSIC
T̄R	TRIASSIC
P	PERMIAN
	PRECAMBRIAN

REFERENCE

PHANEROZOIC – CAINOZOIC – QUATERNARY – RECENT; PLEISTOCENE–RECENT; PLEISTOCENE
TAMALA LIMESTONE
BASSENDEAN SAND
GUILDFORD FORMATION
YOGANUP FORMATION
TERTIARY
NAKINA FORMATION
KOJONUP SANDSTONE
MESOZOIC – CRETACEOUS
MAXICAR BEDS
DONNYBROOK SANDSTONE
BUNBURY BASALT
PALAEOZOIC – PERMIAN
COLLIE COAL MEASURES
PRECAMBRIAN UNDETERMINED
ARCHAEAN
WARRADONG FORMATION – Saddleback Group

FLIGHT DIAGRAM



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FIRST EDITION 1983

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