1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

PERTH
WESTERN AUSTRALIA

SHEET SH50-14 INTERNATIONAL INDEX

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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COMPILED BY S. A. WILDE AND G. H. LOW

PERTH, WESTERN AUSTRALIA 1978

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Explanatory Notes on the Perth Geological Sheet

Compiled by S. A. Wilde and G. H. Low

INTRODUCTION

The Perth 1:250 000 sheet (SH/50-14 and part of SH/50-13 of the International Series) is bounded by latitudes 31°S and 32°S and by longitudes 115°15′E and 117°00′E. It is effectively divided into two distinct regions by the north-trending Darling Scarp, a surface reflection of the Darling Fault.

Perth, the capital of Western Australia, lies to the west of the Darling Scarp in the Perth Basin, an area underlain mainly by Phanerozoic rocks. The Perth area, including outlying suburbs, has a population approaching 700 000 (1971). Other towns of importance in the Perth Basin are Midland Junction, Bullsbrook, Gingin, Yanchep, and Lancelin. The sheet area also includes Rottnest Island, which lies 18 km west of the coast, opposite Perth.

The area to the east of the Darling Fault is underlain by Precambrian rocks and forms part of the Yilgarn Block (Prider, 1954). Much of the land has been cleared for agriculture. The main town of Northam is linked by bitumen roads to Perth and the other population centres at York, Toodyay, Bolgart. Calingiri, and Goomalling. These are interconnected by numerous sealed and unsealed roads.

The Perth area has a dry-summer subtropical (Mediterranean) climate with an average annual rainfall of 890 mm. Most of the rain falls during the cooler winter months of May to September. The summer months of December to March are hot and dry, whilst October, November, and April are warm and changeable. East from the Darling Scarp, precipitation decreases markedly and the average annual rainfalls at Northam and Meckering are only 434 mm and 384 mm, respectively.

Rainfall and geology exert a strong control on the vegetation. In the Perth Basin, natural vegetation still covers part of the area north of Perth. Forests and woodlands of *Eucalyptus gomphocephala* predominate on the Coastal Limestone belt, with *E. calophylla* and *E. marginata* scattered throughout. *Banksia grandis* and *Casuarina fraseriana* comprise the under-storey. Tall trees are absent along the coast and the main vegetation is *Acacia* sp. The sandplain flora is characteristically a scrub vegetation dominated by *Banksia* sp., with some *Casuarina fraseriana* and *E. marginata.* In the swampy areas *Melaleuca parviflora* dominates, with a dense ground cover of sedges and rushes. On the clay-loam-laterite soils of the foothills and scarp, the vegetation consists mainly of *Eucalyptus marginata—E. calophylla* forest, with *Banksia grandis* and *Casuarina fraseriana. Banksia attenuata* is common on the sandier soils near the western edge of the foothills whilst *Nuytsia floribunda* grows on the loamy flats.

The vegetation on Rottnest Island belongs to a scrubby coastal complex including *Acacia rostellifera, Acanthocarpus preisii* and various grasses. *Melaleuca pubescens* is found in the vicinity of swamps and lakes. Fossil pollen and megascopic remains in swamp sediments indicate that *Eucalyptus gomphocephala* woodland existed on the island in the past (Storr and others, 1959).

East of the Darling Scarp, a sclerophyllous forest of jarrah (*Eucalyptus marginata*) is characteristically developed on the laterite of the Darling Plateau. Small associated trees and an undergrowth of sclerophyllous shrubs are also present. More sandy areas have prominent marri (*E. calophylla*). On the granitic and clayey soils of the Darling Range, wandoo (*E. wandoo*) occurs, but is subordinate.

East of the 385 mm isohyet it becomes dominant and, with its associates *E. foecunda* var. *loxophleba* and *Acacia acuminata,* forms an open, temperate savannah woodland.

Halophytic forms occur in saline areas in the extreme northeast portion of the sheet area. Species of *Atriplex, Bassia* and *Kochia* are most abundant (Gardner, 1944).

GEOMORPHOLOGY

Most of the Perth sheet area lies within the South West Physiographic Division (Swanland) of Jutson (1950). The Darling Scarp (Saint-Smith, 1912) separates the area into two main physiographic units; the Darling Plateau to the east and the Swan Coastal Plain to the west.

DARLING PLATEAU

The Darling Plateau overlies Archaean granitic rocks and has an average elevation of about 300 m. It represents an ancient erosion surface which has been dissected by streams that vary from youthful to mature. The principal river systems are the Moore and the Swan-Avon-Mortlock. The eastern part of the plateau lies within the "Wheat Belt" natural region of Clarke (1926) and has largely been cleared for agriculture.

The northeast corner of the sheet area forms part of Jutson's Salinaland, with intermittent and internal drainage towards a system of salt lakes.

SWAN COASTAL PLAIN

The Swan Coastal Plain extends west from the Darling Scarp to the Indian Ocean (Woolnough, 1920). It ranges in elevation from 0 to 75 m above sea level and several physiographic subdivisions can be recognized (Fig. 1).

The Darling Scarp is the surface expression of the Darling Fault and forms the eroded western edge of the Darling Plateau. South of Bullsbrook it rises steeply to over 200 m, but further north is only 90 m high. High-level terraces and the freshness of the scarp south of Bullsbrook suggest comparatively recent (probably late Tertiary) movement along the Darling Fault (Jutson, 1950). There is no record of movement in historic times.

The Dandaragan Plateau is a sand and laterite covered plain that overlies flat-lying Cretaceous rocks. It is bounded on the east by the Darling Scarp and on the south-west by a 73 m high erosion scarp (the Gingin Scarp). The plateau rises from 130 m in the south to 230 m above sea level in the north near the Moore River. It is not well dissected and most of the precipitation is absorbed by surface sand.

The Piedmont Zone is a narrow strip of country, 1.5 to 3 km wide, along the foot of the Darling Scarp, that extends southward from about 19 km northwest of Bullsbrook along the western edge of the Dandaragan Plateau. It consists of coalescing alluvial fans deposited by streams losing grade at the bottom of the scarp, and by soil creep down the face of the scarp. Remnants of two strand-line deposits, the Ridge Hill Sandstone and the Yoganup Formation, occur in the mapped area.

The Pinjarra Plain (McArthur and Bettenay, 1960) is an alluvial tract extending west from the Piedmont Zone for 1.5 to 5 km. It extends for a further 16 km westward down the Swan River. The elevation increases northward from 7 to 75 m above sea level. South of Bullsbrook, the plain consists of clays and loams which usually form a fertile soil.

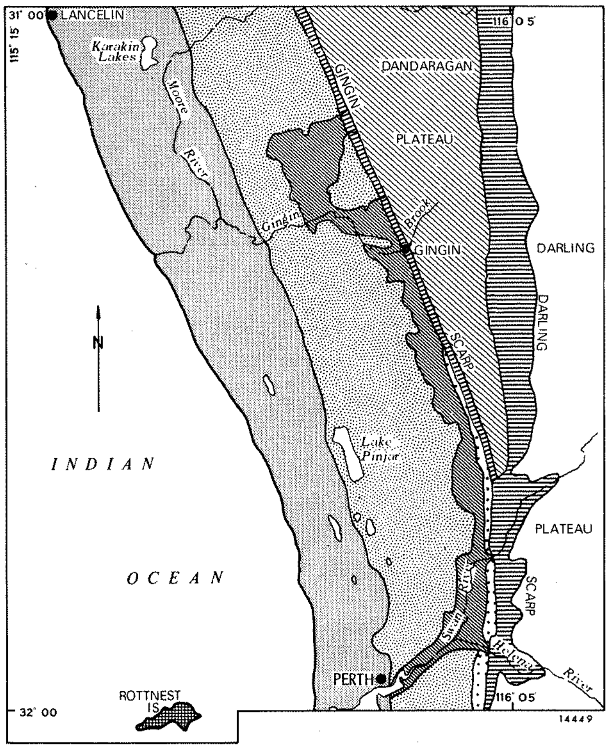

FIGURE 1
PHYSIOGRAPHIC DIAGRAM OF THE SWAN COASTAL PLAIN

0 10 20 30 40 50 km

REFERENCE

- Coastal Belt
- Bassendean Dunes
- Pinjarra Plain
- Piedmont Zone
- Darling and Gingin Scarps
- Dandaragan Plateau
- Rottnest Island

The Bassendean Dunes occur in a 15 km wide zone between the Pinjarra Plain and the Coastal Belt. They consist of low, vegetated hills of quartz sand with seasonal swamps. Chains of swamps parallel the present coast and may reflect old coast lines.

A belt of calcareous sand dunes, calcarenite, kankar and leached siliceous sandhills extending along the coast from Perth to Lancelin forms the Coastal Belt. The carbonate content of the sand decreases from west to east and, as a result, the boundary with the Bassendean Dunes is hard to locate, except in areas where the dunes of the Coastal Belt are at a distinctly higher topographic level. Some of the dunes in the Coastal Belt are more than 60 m high. Mobile patches are present in the recent dunes along the present shoreline. Some permanent lakes, for example Joondalup Lake and Loch McNess, trend parallel to the coast and may represent old lagoons cut off by foredunes from a prograding shoreline.

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Rottnest Island is situated about 18km off the mainland coast, opposite Perth. The island is elongated east-west and its maximum dimensions are 11 km by 4.5 km. It lies at the northern end of two parallel chains of low islands and shallow reefs that represent lines of coastal dunes, formed when the sea level was considerably lower than at present. Rottnest Island is comprised mainly of Quaternary eolianite that is variably lithified and contains minor developments of marine limestone. Present-day beach rock and beach dunes are represented (Glenister and others, 1959).

Rottnest Island has a rolling, sand-dune topography and reaches a maximum elevation of about 45 m. There are no permanent drainage channels, though a number of swamps form in low inter-dune areas during winter and a few lakes occur towards the eastern end of the island. Benches around the coastline and around the margins of the lakes at 0.5, 1.5 and 3.0 m above mean sea level are believed to represent recent still-stands of the sea (Teichert, 1950, 1967; Fairbridge, 1954).

Peaty sediments from 5 fathoms (9.1 m) below present sea level, dated at approximately 7000 years B.P., indicate a low sea level at that time (Churchill, 1959). At such a low sea level Rottnest Island would have been linked with the mainland, implying that separation of the island from the mainland is a youthful geological event.

HISTORY OF INVESTIGATIONS

There are numerous reports pertaining to the geology of the Perth sheet area and only the more important ones are listed in the references. In the Yilgarn Block, most of the early accounts relate to mineral occurrences and no general mapping was done prior to that of Fletcher and Hobson (1932) in the Upper Swan area. Prider (1934, 1944) mapped a sequence of metamorphic rocks in the Toodyay district, part of the "Jimperding Series" of Clarke (1930). Another metamorphic sequence in the Lower Chittering Valley was described by Miles (1938) and named the "Chittering Series". Further mapping in both sequences has been carried out by students of the University of Western Australia, though mapped areas were generally small. The area around Meckering was mapped by Lewis (1970).

Most of the early reports in the Perth Basin were concerned with superficial or shallow deposits and, prior to 1935, knowledge of the geology at depth was restricted to information from water bores extending down to about 600 m. The great thickness of sediments underlying the coastal plain near Perth was not appreciated until gravity investigations in 1935 (Vening Meinesz, 1948). The Commonwealth Bureau of Mineral Resources subsequently carried out a gravity traverse through Bullsbrook (Thyer, 1951), which was followed by a regional gravity survey throughout the Perth Basin (Thyer and Everingham, 1956). The surface geology of the area was mapped by West Australian Petroleum Pty Ltd geologists (Playford and Willmott, 1958).

In recent years seismic work and oil exploration boreholes by West Australian Petroleum Pty Ltd have further clarified the sedimentary structure and stratigraphy of the Perth Basin area. Bouguer anomaly and total magnetic intensity maps for the whole of the sheet area have been prepared by the Bureau of Mineral Resources.

For this survey, the Perth Basin area was mapped by G. H. Low and R. W. Lake between 1965 and 1967 (Low, 1971b); the Yilgarn Block was mapped during 1972 and 1973 by S. A. Wilde (Wilde, 1974), and these notes were first issued, in Record form, in 1975 (Wilde and Low, 1975). Information on the water supplies was prepared by C. C. Sanders.

PRECAMBRIAN GEOLOGY

REGIONAL SETTING

The area east of the Darling Fault forms part of the Yilgarn Block. This is a stable Archaean nucleus, composed of granites and gneisses enclosing a number of elongate "greenstone" belts. The "greenstone" belts of the Eastern Goldfields region consist of layered successions of felsic, mafic and ultramafic igneous rocks with varying, though minor, amounts of sedimentary material and are mainly of low metamorphic grade. In contrast, the sequences exposed in the Perth sheet area are notable for the abundance of metasediments, the complete lack of felsic volcanic rocks, the subordinate amount of mafic ?volcanic rocks and the high grade of regional metamorphism. These rocks occur in two distinct metamorphic belts that extend northward into the Moora 1:250 000 sheet area.

The more extensive eastern belt stretches in a north-northwest direction right across the sheet area and also extends beyond the sheet area to the north, south and east. The rocks are essentially similar to those of the Jimperding "Series", described by Prider (1934 and 1944) from the Toodyay area, and are grouped here as the Jimperding Metamorphic Belt. The western belt occurs immediately east of the Darling Fault and extends from Upper Swan northward beyond Mogumber. This belt of rocks (the Chittering "Series" of Miles, 1938) is here referred to as the Chittering Metamorphic Belt.

These two belts are everywhere separated by granite or gneissic granite; the latter occurring north of Chittering. The granitic rocks in the southwest of the sheet area are extensive and have only local developments of migmatite at their margins. In contrast, the granites occurring in the east and northeast portions of the sheet area are less continuous and intimately admixed with broad zones of migmatite.

An age of 3 084 $\pm$ 191 m.y. has been obtained by pooling certain gneisses from the Yilgarn Block, including samples from the Toodyay and Northam areas (Arriens, 1971). A gneissic sample from the York area gave an age of 2 688$\pm$ 211 m.y. A pooled age of 2 661 $\pm$ 51 m.y. was obtained from the granites of the "Wheat Belt" that intrude these gneisses (giving an isochron of 2 667 $\pm$ 27 m.y. if further pooled with granites from the Eastern Goldfields).

THE LAYERED SEQUENCES

A wide range of lithologies are present in the layered sequences. The predominant rock types are granitic gneisses and schists, with locally abundant amphibolites and quartzites, together with thin units of other varieties of gneiss, banded iron-formation (BIF) and mafic granulite. Intrusive ultramafic rocks occur locally in the sequence. Many of these have been deformed and they only occasionally transgress other rock boundaries.

THE JIMPERDING METAMORPHIC BELT

This belt extends north-northwest across the Perth sheet area for over 120 km and varies in width from 15 to 65 km. Regionally, the strata dip to the east at moderate to steep angles, though there are large areas of subhorizontally dipping strata near Toodyay and York.

Gneisses

*Anb:*The predominant rock type is a fine to medium-grained quartz-feldspar-biotite gneiss. It is usually well banded with distinct biotite-rich layers, but may be locally more massive. Both plagioclase (andesine/oligoclase) and microcline are present, though the relative proportions of these vary. Porphyroblasts of garnet are locally abundant.

Anl: Leucocratic, quartz-microcline-oligoclase (-garnet-biotite) gneiss is interbanded with *Anb*, particularly in the southern and eastern portions of the metamorphic belt. Its boundaries with *Anb* are complex, and are shown in stylized form on the map. Thin units of quartzite and garnet-oligoclase quartzite are locally abundant in *Anl*. The chief rock type is medium to coarse grained and consists of long stringers and lenses of quartz interleaved with a granular aggregate of microcline and oligoclase. Sharply delineated lozenges of feldspar are commonly included in the quartz stringers. The overall texture is typical of granulites. Both feldspars may occur as megacrysts, whilst garnet is a common accessory mineral. Thin bands rich in biotite are locally present and may be accompanied by hypersthene. In such rocks, the amount of oligoclase generally exceeds potash feldspar.

Ana: Augen gneiss occurs in contact with quartzite at Jimperding Hill near Toodyay. It is coarse grained and consists of quartz, microcline, oligoclase and biotite, with large microcline augen. The texture suggest cataclastic deformation along the quartzite/gneiss contact, though Prider (1944) believes that the texture is protoclastic. The augen gneiss is thought to have developed from *Anb*.

Anp: The porphyritic granite gneiss is a coarse-grained quartz-microcline-oligoclase-biotite (-hornblende) gneiss. It differs from the augen gneiss in containing tabular megacrysts of microcline and in having a less distinct biotite foliation. The rock approaches porphyritic granite in appearance, but always retains a gneissic foliation. Its proximity to granite and migmatite suggests that it was a gneiss that underwent metasomatism during emplacement of the granite.

Schists

Outcrop of the schist bands is poor and the rocks are usually overlain by a thick mantle of soil. Where exposed, they are mostly ferruginous or kaolinized. Quartz-mica schist (*Alb*) is the predominant type, with biotite normally in excess of muscovite. It may be interbanded with thin units of quartz-mica-garnet schist (*Alg*), though the latter also forms more extensive areas. The schist band extending from Jimperding Hill to Clackline is andalusite-bearing (*Ala*) in the north; apparently devoid of alumino-silicates in the central portions; and sillimanite-bearing (*Als*) at Clackline. Many schist bands contain alumino-silicate minerals, but only those with abundant concentrations are distinguished on the map.

The muscovite-chlorite phyllitic schist (*Alm*) seems to have been derived from other types by retrograde metamorphism. At Smiths Mill Hill, large sericite flakes appear to have replaced original andalusite crystals.

Other rock units

Aa: Amphibolite occurs as thin, discrete bands within the gneissic sequence and as broader units interbanded with leucocratic quartzo-feldspathic gneiss. Typically, the amphibolites are fine to medium grained and are composed of a xenomorphic granular aggregate of hornblende and plagioclase (andesine/labradorite). Quartz is normally a minor constituent, but ranges to 15 per cent in certain units. Clinopyroxene is present in accessory amounts, but may be locally almost as abundant as hornblende. Some bands contain cummingtonite and not hornblende. The broad amphibolite band, 6 km west of York, is chiefly a brown hornblende-diopside-labradorite gneiss, and similar assemblages occur in the amphibolite units at Bolgart. Some thin bands consist almost entirely of hornblende and are thus hornblendites. In these, occasional cores of clinopyroxene appear to have altered piecemeal to hornblende.

Aqo: Quartzite occurs in massive to flaggy bands that mostly form areas of high relief, owing to their resistance to erosion. They are metamorphosed orthoquartzites, consisting of interlocking grains of quartz with only minor amounts of muscovite, chrome-muscovite, feldspar, sillimanite, or garnet. The green chrome-muscovite is characteristic, though variable in amount. It is most abundant in flaggy units where it coats the foliation surfaces. The foliation probably corresponds to original bedding, but it has certainly been emphasized during later structural deformation, A lineation is common on the foliation planes.

BIF: Thin units of metamorphosed banded iron-formation are present throughout the sequence and are especially abundant east of Northam. The units are generally less than 30 m thick, and form good marker horizons. They may have local topographic expression, but in many places form only trains of rubble. The BIF is usually associated with map units *Anl* and *Aqo,* or with schist adjacent to quartzite. Intense minor folding is a characteristic feature of the bands.

The banded magnetite-bearing quartzite (*Aiq*) is somewhat transitional to the metamorphosed orthoquartzite (*Aqo*) but has centimetre-scale banding caused by concentrations of magnetite.

The unassigned BIF (*Ai*) includes the commoner assemblages of quartz-magnetite-grunerite, quartz-hematite-grunerite and quartz-magnetite-hypersthene-grunerite, as well as units that have not been petrographically examined. Quartzose layers alternate with amphibole-rich and magnetite-rich bands. Fragments of *Ai* in migmatite near Wooroloo indicate that the Jimperding metamorphic rocks were originally much more widespread.

A distinctive suite of strongly magnetic BIFs occurs east of Northam. These quartz-magnetite-hypersthene rocks (*Aiw*) are medium to coarse grained and are not always well banded.

A garnet-bearing BIF (*Aig*) crops out 20 km east of Mogumber. It is poorly banded and consists of an assemblage of quartz-garnet-hypersthene-hornblende-magnetite. It has affinities with the mafic granulites.

Ahg: The mafic granulites are a rather diverse group of rocks interbanded in the gneissic sequence. Some are well banded and appear similar to BIF. They differ from *Aig* in having considerably less magnetite and quartz. Typical assemblages are hypersthene-diopside-brown hornblende-plagioclase (– magnetite-quartz), and hyperstene-garnet-anthophyllite-magnetite-quartz. Rocks of this type crop out near Wongamine and Grass Valley.

More basic varieties consist of diopside-brown hornblende-plagioclase and hypersthene-diopside-brown hornblende-plagioclase assemblages. They are not usually banded and may appear similar to the amphibolites in the field. Megacrysts of hornblende are occasionally present, as in the unit 1 km north-east of Jennapullin.

Ultramafic granulites are not common. The assemblages hypersthene-diopside-brown hornblende and hypersthene-brown hornblende (– spinel) occur in association with basic granulites at Mount Bakewell, near York (Stephenson, 1970). In a road cutting, 3 km south of Bolgart, diopside-brown hornblende rocks are interbanded with hornblendite, hypersthene-diopside-brown hornblende and diopside (—magnetite) assemblages. These rocks are well banded and occur in a sequence of amphibolites. At 2 km west-northwest of Grass Valley, a thin band of hypersthene-quartz rock occurs. Quartz is not abundant and the rock is essentially hypersthenite, though related to the granulites.

Au: Ultramafic rocks are intrusive into the gneissic sequence, but are usually sub-concordant and form part of the layered succession. They are generally foliated and thus predate the final deformation. No subdivision has been attempted on the map, owing to their variable mineralogy. The rocks are altered and occur chiefly as serpentinite and talcose rocks, and as serpentine-talc, serpentine-tremolite, tremolite-actinolite, and tremolite-chlorite assemblages. Locally, silicified ultramafic rocks have developed, for example, at Mount Bakewell. A fresher peridotite occurs at Nunyle, 6 km east of Toodyay. It is mainly a bronzite peridotite with minor hornblende, bronzitite, serpentinite and associated rodingite (Elkington, 1963). In contrast, study of the margins of the talcose ultramafic, 9 km south-southwest of Bolgart, reveals that the original rock was a clinopyroxenite. Both peridotites and pyroxenites were therefore present in the Jimperding Metamorphic Belt.

Ci: Thin units of cordierite-bearing gneiss within the gneissic sequence are not extensive and are shown as mineral occurrences on the map. These include cordierite-anthophyllite, cordierite-quartz-biotite, cordierite-quartz-garnet-sillimanite-biotite, and cordierite-hypersthene-quartz-biotite assemblages. Most of the cordierite-bearing rocks appear to be paragneisses, though Prider (1940) suggests that the cordierite-anthophyllite rocks near Noondeening Hill resulted from the intrusion of a hypersthenite magma.

Cs: Small areas of calc-silicate rock occur in the layered succession near Toodyay and are similarly shown as mineral occurrences on the map. These rocks comprise assemblages of diopside-grossular-epidote-quartz.

There are also minor developments throughout the metamorphic belt of many rock types, especially amphibolite, that are too small to indicate on the map.

THE CHITTERING METAMORPHIC BELT

A series of metamorphic rocks extends due north from Bullsbrook East for about 75 km to the northern limit of the Perth Sheet. The average width of the belt is 10 km. The rocks have a northerly regional strike and dip steeply to east or west. The sequence consists of various gneisses and interbanded schists.

Gneisses

Anb: The chief rock type is banded quartz-feldspar-biotite gneiss, essentially similar to the type occurring in the Jimperding Metamorphic Belt. The biotite-rich layers are often extensive and increase in width toward interbanded schist units.

Ana: Two well-marked bands of augen gneiss are present. They contain microcline megacrysts and are petrographically similar to those described previously. The texture appears to be the result of cataclasis. This is also suggested by the fact that the southern unit is along the northern extension of the Swan Gorge mylonite zone, whilst the unit at Mogumber and Wannamal is associated with thin mylonite bands and is near to cataclastically-deformed granite.

Anc: In the northern part of the belt, an interbanded sequence of melanocratic quartz-hornblende-biotite-garnet-plagioclase gneiss and leucocratic quartz-feldspar gneiss forms the most westerly unit of the metamorphic belt. The melanocratic gneiss contains olive-brown biotite and dark-green ferrohastingsite. It ranges to an amphibolite consisting entirely of a xenomorphic-granular aggregate of amphibole and plagioclase. The leucocratic gneiss consists of potash feldspar, plagioclase and quartz, with minor biotite and magnetite. Zones of cataclasis, resulting in mylonite and blastomylonite, occur throughout the sequence and appear to increase northward to Mogumber. The eastern contact with *Ana* is sharp.

And: A thin band of melanocratic quartz-feldspar-hornblende-biotite gneiss and schist occurs in the eastern part of the belt from Wannamal south to Bindoon. The gneissic bands contain megacrysts of microcline, oligoclase and biotite in a fine-grained matrix of quartz, feldspar, biotite and hornblende. The schists are richer in biotite and lack megacrysts.

Anf: There is an extensive development of quartz-feldspar-biotite granofels in the Chittering area. The rock is a fine-grained to medium-grained, blue, melanocratic gneiss that is poorly banded, but has a strong biotite lineation. It consists of a granoblastic aggregate of quartz, microcline and oligoclase with minor biotite.

The relative proportions of microcline and oligoclase vary considerably. Biotite normally forms individual crystals but may occur as cuspate wisps or, more rarely, as distinct layers. The granofels is locally interbanded with thin units of *Anb*.

Schists

Numerous thin units of schist are intercalated with the gneisses. Many are discontinuous, partly as a result of poor outcrop and partly because of their lensoid form. Several more extensive bands crop out south of Bindoon. The rocks are chiefly quartz-mica schist (*Alb*). The relative amount of biotite and muscovite varies, whilst the biotite is commonly altered to chlorite. Interbanded units of *Anb* are common. The schist band 4 km east of Mogumber passes northward into a more gneissose rock with discontinuous micaceous wisps defining a strong lineation.

Traces of sillimanite, kyanite and, more rarely, staurolite and garnet, may occur in *Alb*. Where kyanite or sillimanite are abundant and the schist bands are of sufficient size to be shown on the map, they are distinguished as kyanite schist (*Alk*) and sillimanite schist (*Als*), respectively. A single band of staurolite schist (*Aln*) occurs 1 km east of Chittering Lake, whilst there is a smaller outcrop (shown as a mineral occurrence) at Lower Chittering.

Other rock units

Aa: Amphibolite is not abundant, being restricted to two main bands west of Bindoon. The northern band crops out at Mooliabeenee Hill where medium-grained hornblende-plagioclase amphibolite is interbanded with leucocratic quartz-feldspar gneiss. The southern unit is exposed in a roadway 2 km further southwest, where amphibolite, containing long needles of hornblende, occurs with buff, quartz-feldspar granofels and hornblende-bearing gneiss.

In the Chittering Valley, shearing of the margins of certain dolerite dykes has produced amphibolite (Mong, 1964).

Quartzites have been recorded from the Chittering Metamorphic Belt (Geary, 1950; Jones, 1950 and Mong, 1964), but they are extremely thin and do not form mappable units. Rocks approaching quartzite in megascopic appearance form part of the granofels (*Anf*) sequence. However, thin sections reveal that feldspar is generally as abundant as quartz. Metamorphosed orthoquartzite similar to that occurring in the Jimperding Metamorphic Belt has not been recorded.

MIGMATITE

The term migmatite is used here to describe gneissic rocks intimately admixed with a granitic component. The granite may occur as veins subparalleled to the foliation or as more extensive areas that cut irregularly across the gneissic palaeosome. The original metamorphic foliation is often strongly contorted and disrupted. The granitic component is not everywhere obviously intrusive and may form diffuse veins that transgress a wispy metamorphic foliation. Some of this material has formed *in situ*, and appears to have developed first at the hinges of minor folds within the gneiss.

Am: Migmatite occurs as a narrow, sporadically developed marginal zone to the granitic rocks in the southern part of the Perth sheet area. It also occurs within the granite area and is particularly extensive around Wooroloo and near the Darling Scarp, where it forms a number of subparallel, north-northeast trending zones. In the northern part of the sheet area migmatite is more extensive and forms a broad, irregular zone between the layered succession and the granitic rocks.

The migmatite of the Toodyay area is not directly related to intrusive granite but has resulted from mobilization of the gneisses. Migmatite and *Anp* are closely associated, the latter grading into migmatite with an increase in the amount of granitic neosome.

Amh: Certain portions of the migmatite containing abundant amphibole crystals, together with bands and "xenoliths" of amphibolite, appear on the map as *Amh.* The zones near York and Coondle are along strike extensions of amphibolite units and were probably derived from these by mobilization. The large area at Clackline is away from known amphibolite occurrences. Here, blocks of amphibolite are enclosed in a contorted granitic medium. Discrete areas of porphyritic hornblende granite occur within this migmatite, but are too small and irregular to indicate separately on the map. They appear to cut the migmatite, but were probably derived from it at a lower structural level.

GRANITIC ROCKS

The plutonic granitic rocks were distinguished in the field on the basis of their textures. Each unit varies somewhat in composition, with a maximum range from granodiorite, through adamellite, to granite. The rocks constitute a discrete batholith in the southern portion of the sheet area, where they have sharp, intrusive contacts with the layered succession. The granitic rocks of the eastern and northern areas are associated with more extensive migmatite and may have sharp or diffuse contact relations. The various textural types are irregularly interdeveloped.

Agg: The leucocratic adamellite is fine to medium grained, with marked variations in the grain size. Veins and irregular areas of pegmatite are abundant and often associated with aplite. The rock has an allotriomorphic granular texture and consists of oligoclase, microcline and quartz, with minor biotite and accessory muscovite and epidote. It is almost invariably associated with migmatite and in many places occurs between this and other granitic rocks. Gneissic xenoliths are common near migmatite contacts and the adamellite may have a weak biotite foliation. Northwest of Calingiri, patches of *Agg* within migmatite contain large garnets that show marginal alteration to biotite. This feature, together with the overall distribution, suggests that *Agg* may have developed from leucocratic gneisses of the Jimperding Metamorphic Belt under the influence of granite emplacement.

Age: The even-grained granitic rocks are fine-grained to coarse-grained and mesocratic. They range in composition from granodiorite to granite, but true granite is rare. The rocks are homogeneous on a regional scale but reveal much minor variation in well exposed quarry faces for example in the Boya area. The chief constituents are andesine/oligoclase, microcline, quartz and biotite, the texture is allotriomorphic granular, with a tendency for microcline to form large interstitial areas, up to 6 mm in diameter, which enclose a number of smaller plagioclase crystals; myrmekite is often present here. Xenoliths of country rock occur near contacts with migmatite and the layered succession, but are nowhere abundant. There may be a weak foliation defined by biotite and/or the felsic minerals which, close to the granite contacts, is generally subparallel to the regional metamorphic trend, but elsewhere is more random. Near the Darling Scarp, a strong shear foliation, defined by biotite and epidote, parallels the mylonite zones.

Agp: Grey porphyritic granite forms a number of small irregularly shaped areas within the granite complexes. Contacts with the country rock and adjacent *Age* are generally sharp. Tabular megacrysts of microcline microperthite average 1.5 cm in length and occur in an allotriomorphic granular aggregate of microcline, oligoclase and quartz, with accessory biotite and hornblende. The megacrysts vary in abundance and are commonly aligned. The granite south of York and at Bakers Hill contains up to 15 per cent hornblende. Mafic schlieren are abundant and the hornblende probably resulted from contamination by amphibolite xenoliths. Thin veins and irregular areas of pegmatite and aplite cut the porphyritic granite. Near York, Konnongorring and Uberin Rock, veins of fine to medium-grained adamellite traverse the granite. However, at Walyormouring Lake, veins of porphyritic granite cut *Age*. This suggests at least two periods of intrusion of *Age* and/or *Agp*.

Agm: Although the junctions between *Age* and *Agp* are sharp, there are areas where the two types are intimately admixed and cannot be separated on the map. Such areas of mixed granite form part of the *Agm* unit. It is generally impossible to determine the order of intrusion, but scanty evidence from several areas suggests that *Age* intrudes *Agp*. However, most of the mixed granite areas (*Agm*) also have portions of *Agg* and an extensive development of pegmatite and aplite. Gneissic xenoliths and rafts are abundant near migmatite contacts and it would appear that such areas formed from a complex interaction between intrusive granite and the migmatitic gneisses.

Agv: Fine to medium-grained granitic rocks with scattered megacrysts of potash feldspar are particularly extensive in the southern portion of the sheet area. They are found associated with *Age* and *Agp* and appear to represent a transitional phase between these two varieties. The rocks are mesocratic and range from adamellite to granite. They are texturally and compositionally similar to *Age* except for the occurrence of microcline megacrysts. Only rarely are the megacrysts aligned and they are mostly ragged, with numerous inclusions of plagioclase. A few mafic schlieren and clots of biotite are present in rocks near the Avon River. The rocks grade into *Agp* with an increase in both size and abundance of the megacrysts, and into *Age* as these decline.

Agn: A large, discrete mass of foliated gneissic granite occurs in the Bolgart-Mogumber-Bindoon area. Strong cataclasis is evident, though the intensity of the foliation and abundance of epidote shears decreases eastward. Indeed, the rock near Bolgart and Julimar Brook, although forming part of the same granitic intrusion, is a medium-grained granite with only a weak foliation and has been shown as *Age* on the map. Where least deformed, *Agn* consists of an allotriomorphic granular aggregate of microcline, orthoclase, albite/oligoclase and biotite. The orthoclase is perthitic and tends to enclose plagioclase. Further to the west, the more deformed granite is coarser grained and consists of perthitic orthoclase, albite, quartz and biotite. The perthite often forms elongate aggregates and has corroded plagioclase. Quartz has slightly undulose extinction and occurs as stringers parallel to the perthite clusters. Biotite forms cusplike aggregates that partially enclose compound felsic areas. The highly deformed gneissic granite consists largely of perthite and quartz with minor albite and biotite. The quartz has a strongly undulose extinction and is criss-crossed by thin bands of granulation. Zones of complete quartz granulation and partial granulation of perthite occur locally and there is a tendency for areas of perthite enclosed in quartz to be rounded.

Around Bindoon and Chittering, the gneissic granite is commonly blue and much finer grained. It has a mortar texture of rounded grains of undulose quartz and potash feldspar in a matrix of graphically intergrown potash feldspar, plagioclase and quartz. Abundant biotite forms wispy aggregates that define a crude foliation. Locally, only the quartz megacrysts are distinct and the matrix is so fine grained that the rock becomes a blastomylonite.

DIORITIC AND SYENITIC ROCKS

A number of small outcrops of rock ranging in composition from quartz diorite, through monzonite (*Agd*), to syenite and quartz syenite (*Ags*) occur scattered throughout the Perth sheet area. With the exception of dyke-like intrusions at

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Grass Valley and Northam, they are associated with migmatite or mobilized gneiss of the Jimperding Metamorphic Belt. There are marked variations in grain size within small areas and amphibolite xenoliths are invariably present.

Diorite crops out near the Avon River, 4 km west of Toodyay. It consists of hornblende and plagioclase, with minor quartz. Xenoliths of amphibolite and hornblendite are abundant and many are net-veined by the diorite. Appinite veins are locally present.

The monzonites and syenites consist of microcline, oligoclase, augite and hornblende, with minor quartz, sphene and apatite. Some of the rocks are even grained and occur as irregular patches in close proximity to amphibolite or hornblende-bearing gneiss. However, more gneissose syenitic rocks also occur, with a foliation marked by stringers of mafic minerals, blades of quartz and microcline, or differences in grain size. The large syenite body at Katrine, which is of this type, is interbanded with leucocratic quartz-feldspar gneiss (*Anl*). Its texture is identical to these gneisses and there are not intrusive contacts. Streaks of amphibolite occur near the northern margin.

Although some of the dioritic and syenitic rocks are pre- and some post-deformation their origin was probably similar. Their association with migmatite, amphibolite and mobilized gneiss suggests that they resulted from potash metasomatism and hybridization of an amphibolite-quartzo-feldspathic gneiss sequence.

The syenite at Grass Valley is texturally and compositionally similar to a syenite dyke occurring in migmatite, 2 km west of Northam. The latter is subhorizontal, 1 to 2 m thick and has distinct chilled margins. The margins consist of a fine-grained aggregate of microcline, oligoclase, green clino-pyroxene and hornblende, with abundant sphene and apatite. The mafic minerals are of similar size in the centre of the dyke, but are enclosed in plates of microcline more than 5 mm long.

MINOR INTRUSIVE ROCKS

Granitic dykes and veins (g)

A number of fine-grained or medium-grained, black and white granitic dykes occur in the vicinity of York. They are only a few metres wide and occur within the gneissic sequence. Biotite and/or hornblende are generally present.

Smaller dykes and veins of granite and adamellite are abundant around the plutonic intrusions. They are fine-grained and range to aplite. A notable feature is their grouping about an easterly strike direction, evident at Clackline, Meenar, Goomalling and Konnongorring. Some veins also occur within *Agp* and *Agm*, for example, at Uberin Rock.

Veins of pegmatite and associated aplite are common in the gneisses and migmatite. They are subparallel to the metamorphic banding and, at Konnongorring, are at right angles to the fine-grained granitic veins.

Dioritic dykes (di)

A small number of fine to medium-grained dykes within the tonalite-diorite-monzonite compositional range occur in the Jimperding Metamorphic Belt and the nearby migmatite and granitic areas. The dykes are generally less than 10 m wide and are unfoliated. Their age is uncertain, though the dyke at Walyormouring Lake cuts *Age*.

Doleritic Dykes

Tholeiitic quartz dolerite dykes intrude all the Archaean rocks throughout the sheet area. They are particularly prominent in the granitic terrains and appear to increase in abundance towards the Darling Scarp. The dykes are generally around 2 to 10 m thick, but range up to 200 m maximum thickness. The smaller dykes are mostly fine grained and melanocratic. Material of this type also forms the margins to the coarser grained gabbroic varieties, though some of these dykes have no finer grained margins. Most dykes, especially in the western part of the area, show some alteration. They consist of saussuritized plagioclase, augite, hornblende and minor quartz, with accessory epidote, sphene and chlorite. Near the Darling Scarp, certain dykes have sheared margins, whilst at places in the Chittering Valley, the dykes are completely sheared (Mong, 1964).

Cross-cutting relations indicate several relative ages (Martin, 1961), though there may have been only one general period of dyke intrusion. The larger dykes have an overall northerly trend in the western part of the area, whilst easterly and east-northeasterly trends are more prominent in the east. A Rb-Sr age of 560 to 590 m.y. has been obtained from sheared and metasomatized dyke margins (Compston and Arriens, 1968).

A distinctive suite of fine-grained, melanocratic, plagioclase-phyric, basaltic dolerites occurs in the eastern portion of the sheet area. These dykes have not been distinguished separately on the map. They are fresh and consist of labradorite and augite phenocrysts in an aphanitic to fine-grained groundmass of plagioclase, augite, quartz, dendritic iron ore and occasional devitrified glass. Most of these dykes have a northeasterly trend.

A set of unusual xenolithic dolerite dykes (*dx*) is similarly restricted to the eastern part of the sheet area. The dykes trend northeast, with the exception of two north-northwest-trending dykes at Wongamine and Northam. They have been described by Lewis (1969, 1970), who attributes the abundance of granitic zenoliths to intrusion of dolerite along shear-zones. The doleritic matrix to the xenoliths is similar to the plagioclase-phyric dolerites.

Quartz dykes and veins (q)

Innumerable small, pre- and post-tectonic quartz veins are present in all Archean rock types. A number of quartz dykes also occur, the largest extending for 30 km from Botherling south to the Salt River. Several north-northeast-trending quartz dykes are associated with this intrusion near Burabadji. Some lensoid quartz "blows" are present in the schist unit east of Cockman Bluff, in the Chittering Valley. Several other quartz dykes and veins throughout the sheet area are associated with lines of faulting or shearing.

METAMORPHISM

The metamorphic mineral assemblages have been used to roughly delineate regional metamorphic facies zones on the structural map (Fig. 2). The Jimperding and Chittering Metamorphic Belts have quite distinct mineral assemblages and there are also differences within each belt.

The Jimperding Metamorphic Belt contains schists rich in andalusite and sillimanite, and generally poor in kyanite. Cordierite is a rare but widely distributed mineral in certain gneisses. The plagioclase in the amphibolites is calcic and often associated with cummingtonite, whilst orthopyroxene is common in the BIF and mafic granulite bands. These minerals indicate low pressure conditions of the andalusite-sillimanite facies series (Miyashiro, 1961) with a range from amphibolite to granulite facies metamorphism. The quartz-microcline-oligoclase (—garnet-biotite) assemblage of the leucocratic gneisses (*Anl*) is also characteristic of the granulite facies, whilst the rocks are texturally similar to the classic granulites of Saxony.

In contrast, the abundance of kyanite and sillimanite, together with minor staurolite, in the schists of the Chittering Valley; the calcic composition of the plagioclase in the amphibolitic rocks; and the scattered occurrence of garnet throughout the quartz-feldspar-biotite-gneiss, indicate amphibolite facies conditions within the kyanite-sillimanite metamorphic facies series of Miyashiro (1961). This facies

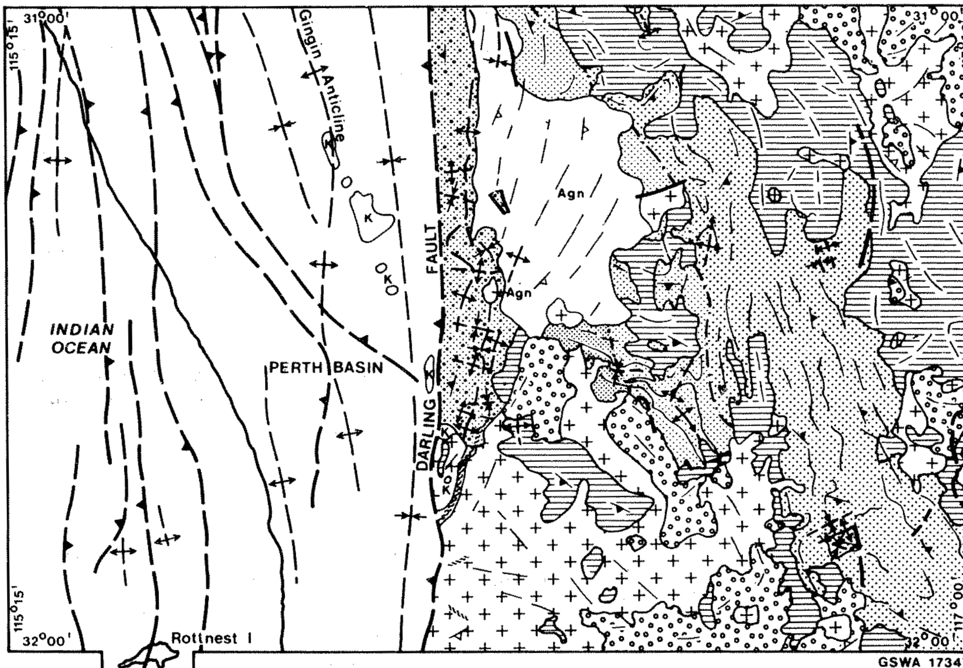
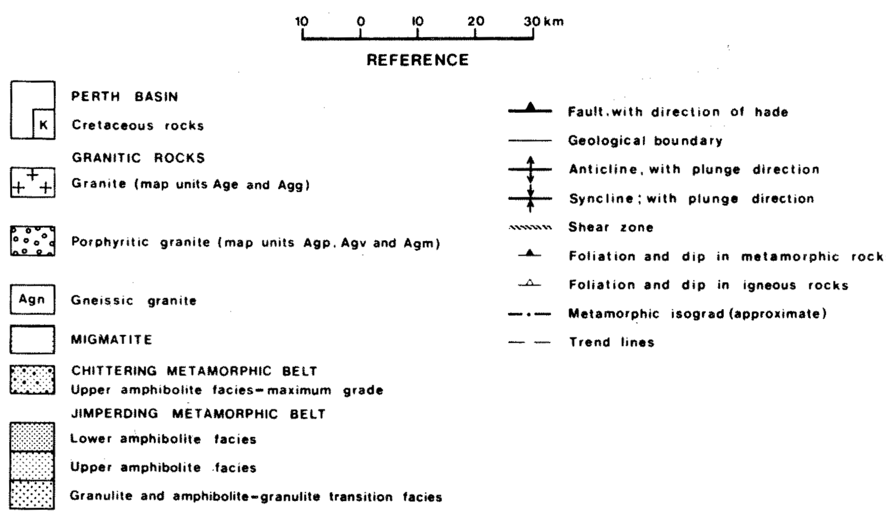


FIGURE 2
STRUCTURAL MAP OF THE PERTH SHEET SHOWING METAMORPHIC ISOGRADS



Faults in Perth Basin from seismic data on the Cattamarra Reflector

series is characteristic of moderate to high pressure. However, the occurrence of chloritic schists and rocks rich in epidote indicates lower temperatures and a range down into the greenschist facies. Such rocks are only developed locally and appear to have resulted from retrograde metamorphism associated with shear zones sub-parallel to the trend of the Darling Fault.

The metamorphic zones shown in Figure 2 have been extended and slightly modified from Stephenson (1970). Within the granulite facies zone there are areas that correspond more nearly to the amphibolite-granulite transitional facies (Turner, 1968). These have not been separated, owing to the lack of detailed information, except for a large area west of York that occurs between the granulite facies isograd and the migmatite zone surrounding the granitic rocks. Relict cores of pyroxene in many amphibolites and hornblendites suggest that much of the Jimperding Metamorphic Belt attained granulite facies conditions at some stage and that the present amphibole facies zones could reflect later retrogressive effects. The later development of migmatite and intrusion of the granitic rocks could have been important in this respect.

The ultramafic rocks within the Jimperding Metamorphic Belt only rarely retain their original mineralogy and are usually altered to greenschist facies assemblages.

RELATIONS BETWEEN THE JIMPERDING AND CHITTERING METAMORPHIC BELTS

The various features described in previous sections indicate that there are fundamental differences between the Jimperding and Chittering Metamorphic Belts and that they may not be equivalent in age.

The important differences are listed in Table I.

Table I: Comparison between the Jimperding and Chittering Metamorphic Belts

Jimperding Belt	*Chittering Belt*
1. Numerous bands of BIF, orthoquartzite and amphibolite	No BIF or orthoquartzite; rare amphibolite
2. Large areas of leucocratic quartz-feldspar-garnet gneiss	No quartz-feldspar-garnet gneiss
3. Presence of ultramafic rocks	No ultramafic rocks
4. No occurrence of granofels	Extensive unit of granofels
5. Widespread granulite facies metamorphism	No granulite facies metamorphism
6. Within andalusite-sillimanite metamorphic facies series	Within kyanite-sillimanite metamorphic facies series

There are no isotopic age dates on the main Chittering Metamorphic Belt rocks and data for the Jimperding Metamorphic Belt are sparse. However, the lack of evidence for granulite facies rocks in the Chittering Valley, even allowing for the later, extensive retrograde effects, could imply a fundamental age difference between the belts. There is some evidence to suggest that, although only parts of the Jimperding Metamorphic Belt are now of granulite facies, most of the rocks at some time approached or attained this grade of metamorphism and that present differences may be due to a westward increase in retrograde effects. Further, hypersthene-bearing BIFs of granulite facies grade occur less than 10 km from the Darling Fault north of Gillingara, in the Moora 1:250 000 sheet area (J. D. Carter, unpublished data). These rocks are of Jimperding type and are apparently unaffected by northerly shearing in the area.

It is tentatively suggested that the rocks of the Chittering Metamorphic Belt may be younger than those of the Jimperding Metamorphic Belt. They occur close to the Darling Fault and thus have a similar distribution to the Middle or Upper Proterozoic rocks of the Cardup and Moora Groups (Low, 1972a and 1972b, respectively). The position of these three distinct groups of strata suggests possible marginal accretion onto the early Archaean nucleus of the Yilgarn Block, of which the Jimperding Metamorphic Belt forms part. This suggestion was also made by Wilson (1958), although on somewhat different grounds.

STRUCTURE OF THE YILGARN BLOCK

The general structure of the area is illustrated in Figure 2.

Folding

The structure of the Jimperding Metamorphic Belt is complex and difficult to interpret. In the portion east of York and Northam, and its northward extension through Bolgart and Calingiri, the structure is superficially simple: a zone of gneisses, with abundant BIF and quartzite, trends north-northwest and has a regional dip to the east. A strong lineation generally plunges at moderate angles to the south-southeast. However, paucity of outcrop, the lensoid shape of many units and the complexity of minor structures mean that individual horizons cannot be traced over large distances. At Jennapullin, a mafic granulite band is isoclinally folded about north-trending axes with the minor fold closures plunging steeply (70-85°) to the north. Shearing-out of limbs parallel to the axial trend and transposition of structures occurs. Similar features are evident south of Bolgart, where occasional transposed fold cores in quartzite and amphibolite plunge steeply to the north or south. The distribution of strata in the Bolgart-Wattening area also suggests that local variations in plunge occur.

It would appear from the minor structures that, although there is a continuity of broad lithological zones in the eastern part of the belt, the rocks have undergone intense isoclinal folding, accompanied by shearing-out of limbs and transposition. A series of later east-trending cross-folds probably accounts for variations in plunge.

In the Toodyay and York area, the metasediments have an easterly trend and thus strike almost at right angles to the trend in the eastern part of the belt. Quartzite is dominant in both areas and its foliation is subhorizontal over much of the outcrop. The major folding varies from open to isoclinal, with evidence of overturning (Prider, 1944; Stephenson, 1970). The earliest phase is now represented only by rootless isoclines. At least three, and possibly four, phases of folding have affected the rocks and several interpretations of the data are possible. A structural interpretation of the Toodyay area is presented in Figure 3. The relation between these east-trending zones and the north-northwest-trending rocks further to the east is not clear, but there is evidence of strong regional shearing-out of structures east of Toodyay.

A further complicating factor is the development of migmatite and local mobilization of the granitic gneisses. In general, the regional north-northwest trend of the metamorphic rocks tends to swing approximately easterly in the migmatite zones, especially where marginal to intrusive granites. The predominant foliation in these granites is also easterly. Although the intrusion of the granites is post-metamorphic, there is a marked parallelism of the granite contact and the metamorphic units between Clackline and the Malkup area. It is possible that the emplacement of granite had some effect on the structural style of neighbouring areas.

In the Chittering Metamorphic Belt, the metamorphic foliation (S_1) is subparallel to the lithological banding. The predominant trend is northerly with steep dips to east or west. Minor folding is complex within the schist units and the bedding in some places is at an angle to the schistosity. A strain-slip cleavage (S_2) is locally developed, but its regional significance is not known.

The earliest and main phase of folding (F_1) produced a series of north-trending, tight to isoclinal folds. A number of fold axes are present in the lower and middle Chittering Valley but, to the north, only one major anticlinal fold has been recognized. Congruent minor folds suggest some overturning to both east and west. It is not possible to match lithologies either side of the fold axes and probably many more isoclinal folds remain undetected.

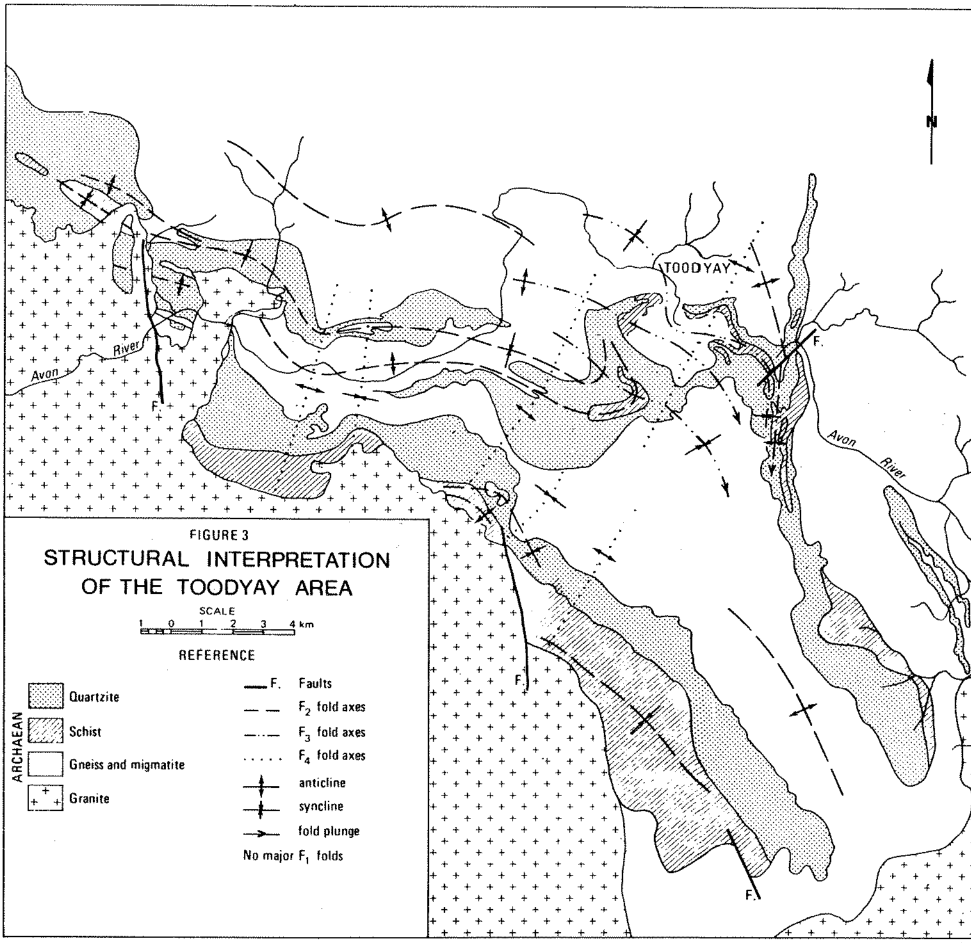


FIGURE 3
STRUCTURAL INTERPRETATION OF THE TOODYAY AREA

A series of easterly trending cross-folds (F_2), first recognized by Geary (1950) at Wattle Flat, occur throughout the belt. They generally have little effect on the isoclinal folds, except for an open-style folding of the associated lineation. An exception occurs 5 km southwest of Bindoon, where an anticlinal cross-fold appears to have caused a local westerly deflection of the lithologies and F_1. Again, many more cross-folds than are shown in Figure 2 are probably present.

An important feature is the trace of both F_1 and F_2 fold axes in the cataclastic gneissic granite (*Agn*). The F_2 folds cause variations in the plunge of the distinctive biotite lineation. That the granite intrusion was pre or syn-F_1 is further suggested by the subparallelism of its contacts with the trend of the metamorphic units.

Faulting

Few definite faults were recognized in the Precambrian rocks of the sheet area, but it is likely that many more exist. Most of the faults have a northeast to northwest trend, but directions of displacement were hard to determine. Many of the larger quartz dykes appear to follow faults or crush and shear zones, as in the Malkup area (Cole and Gloe, 1940) and southeast of Mogumber. In the latter area, broad zones of intense quartz-veining occur within *Agn* and partially coincide with its eastern margin. The area of *Age* west of Bolgart is similarly terminated on its northern side by a quartz-veined fault. A number of shear zones in the granite between the Swan River and Kalamunda, striking 060° or 120°, have reduced the granite to quartz-sericite schist (Whincup, 1970).

A north-northeast-trending shear zone is followed by the Swan River immediately east of the Darling Scarp. The original rock has been intensely mylonitized but appears to have been migmatite. A few unaltered pods of granitic gneiss are totally enclosed in strongly foliated mylonite. The adjacent granite has a strong shear foliation and contains abundant epidote. The northeastward continuation of this shear zone into the Chittering Metamorphic Belt is represented by the mylonitic "feldspathic quartzite" of Miles (1938).

Bands of mylonite, blastomylonite and sheared rock occur in the western portion of the Chittering Metamorphic Belt, parallel to the Darling Fault. Near Mogumber, the metamorphic grade of the mylonite bands is similar to that of the adjacent gneisses, indicating that the shearing was pre- or syn-metamorphic. At Bullsbrook, the deformation postdates the granite intrusion, whilst in the Chittering Valley, some of the dolerite dykes have been extensively sheared. It seems likely that the present Darling Fault runs subparallel to an ancient zone of north to north-northeast shearing that has been re-activated at various times.

A marked aeromagnetic anomaly trending 035° extends northeastward from South Chittering to about 16 km west of Bolgart. Exposure is poor, but the surface rocks are chiefly migmatite and gneissic granite (*Agn*). The lineament is subparallel to shear foliations in the adjacent rocks and to a fault postulated by Wilson (1958) in this area. The lineament is also approximately coincident with the southeastern limit of the cataclastically deformed granite.

Recent fault scarps in the area were produced at Meckering (1968) and Calingiri (1970) as a result of earthquakes, though little surface trace of the later fault is evident (Everingham and Parkes, 1971). The arcuate fault scarp at Meckering (Everingham, 1968; Gordon, 1971) is still a marked feature in the area and was probably the result of east-west compression. The fault dips 45° east. Both these faults lie within a seismically active zone termed the Yandanooka-Cape Riche Lineament (Everingham, 1966). Epicentres of numerous earthquake shocks are spread over a fairly broad zone some 50 km in width, mostly within the Jimperding Metamorphic Belt. However, if the events at Meckering and Calingiri are a guide, the more intense seismic activity is possibly associated with the contact zone between the Jimperding Metamorphic Belt and the migmatite and granite complex to the northeast.

PHANEROZOIC GEOLOGY

INTRODUCTION

Phanerozoic sedimentary rocks are present in the Perth Basin, an elongate structure which extends for almost 1 000 km along the western side of the Australian continent (Playford and others, 1976). The basin varies in width from 80 to 175 km and is bounded on the east by the Darling Fault. The western limit is not well defined and the basin extends offshore to the edge of the continental shelf. The total thickness of sedimentary rocks may exceed 15 000 m. The structure of the basin is dominated by north-trending faults, the chief of which is the Darling Fault. At Bullsbrook East, Cretaceous rocks overlap the Darling Fault for short distances and thus post-date the main period of movement along the fault.

Cainozoic rocks crop out in both the Perth Basin and the Yilgarn Block.

PALAEOZOIC ROCKS

There are no outcrops of Palaeozoic rocks in the Perth sheet area and they have not been detected in subsurface drilling. However, rocks of this age have been recorded from elsewhere in the Perth Basin and it appears likely that they may be represented at depth.

The Tumblagooda Sandstone (Clarke and Teichert, 1948) crops out along the Murchison River and is believed to be of Ordovician-Silurian age. Ingram (1967) reported the presence of reworked *remanié* Upper Devonian spores in the Otorowiri Siltstone Member of the Yarragadee Formation (Lower Cretaceous), penetrated in the Arrowsmith River water bores, 290 km north of Perth.

Permian sediments are exposed in the northern part of the Perth Basin and have been found in the subsurface at Hill River, about 190 km north of Perth, and at Busselton, a similar distance south of Perth. They may also be present in the subsurface of the Perth Sheet area.

MESOZOIC ROCKS

Triassic

Although rocks of Triassic age do not crop out in the Perth sheet area,they are present in the central part of the Perth Basin at Hill River, in Cadda No. 1 well (190 km north-northwest of Perth), and in Pinjarra No. 1 well (88 km south of Perth). They probably occur in the subsurface of the Perth sheet area.

Jurassic

Jurassic formations are not exposed in the Perth sheet area but are present in the subsurface from Gingin to the Rottnest area, where they may attain a total thickness of 5 000 m. Formations identified in this area, from wells drilled for oil and water, include the Lower Jurassic Cockleshell Gully Formation (continental sandstone, siltstone, claystone and shale, with an upper coal-bearing unit), the Middle Jurassic Cadda Formation (a marine to paralic sequence of shale, siltstone and sandstone, with lenticular limestone and calcareous beds) and the Middle to Upper Jurassic Yarragadee Formation (continental sandstone and siltstone, with minor shale, claystone and conglomerate) (McWhae and others, 1958). The Yarragadee Formation has been shown to extend into the Lower Cretaceous in the offshore wells opposite Perth (Bozanic, 1969a).

Cretaceous

Kb: The Lower Cretaceous Bullsbrook Beds (Walkom, 1944) are exposed along the Darling Scarp, immediately east of Bullsbrook East. They consist of a weathered and partly lateritized alternating sequence of poorly sorted sandstones and siltstones, with minor lenses of conglomerate. Some plant remains are present. The beds were laid down in a valley incised into the Darling Scarp and unconformably overlie Archaean gneissic granite. They are apparently overlain by rocks of the Osborne Formation.

Warnbro Group: Two formations of the Lower Cretaceous Warnbro Group (Cockbain and Playford, 1973) crop out in the Perth sheet area. The Leederville Formation (*Kl*) (Playford and Cockbain, 1973) is exposed in a number of scattered outcrops along the eroded edge of the escarpment near Gingin. The formation has been penetrated in the subsurface for a maximum thickness of 1 181.4 m in the offshore Gage Roads No. 1 well. It consists of inter-bedded sandstone, shale and siltstone, with minor conglomerate. It is a shallow marine to continental sequence that becomes more marine offshore. The Leederville Formation lies unconformably over the Yarragadee Formation and is unconformably overlain by the Dandaragan Sandstone or the Osborne Formation.

The Dandaragan Sandstone (*Kd*) (Fairbridge, 1953) crops out discontinuously northwestward from Gingin. It is a massive to thickly bedded feldspathic sandstone unit up to 33 m thick. No diagnostic fossils have been found, but the unit is believed to be of Early Cretaceous age because of its stratigraphic position. It may be laterally equivalent to part of the Osborne Formation.

Coolyena Group: The Coolyena Group (Cockbain and Playford, 1973) consists of strata ranging from Early to Late Cretaceous in age. The lowermost unit, the Osborne Formation (*Ko*) (McWhae and others, 1958), consists of interbedded glauconitic sandstone, siltstone, shale and claystone. It crops out in weathered exposures in the Muchea-Bullsbrook area. It has also been penetrated in a number of water bores in the Perth area and in the Gingin No. 1 well, where it is 54.8 m thick. The type section is in the King Edward Street bore, Osborne Park (lat.31°54′S, long.115°49′E) from 36.6 m to 135.5 m (depth from surface). The formation is of Albian-Cenomanian age (Passmore, 1969).

The Osborne Formation and the Dandaragan Sandstone are overlain, probably conformably, by an Upper Cretaceous succession consisting (in ascending order) of the Molecap Greensand, the Gingin Chalk, and the Poison Hill Greensand. These formations crop out in the vicinity of Gingin along the eroded edge of the Gingin Scarp.

The Molecap Greensand (*Kum*) (Fairbridge, 1953) consists of glauconitic sandstone up to 12 m thick. The type section is in the Molecap Hill quarry near Gingin (lat.31°22′S, long.115°54′E). Phosphate nodules are present in a thin zone near the top of the section. Teichert and Matheson (1944) found ichthyosaur and plesiosaur bones, whilst pelecypods and belemnites are reported from the formation at Gingin. Late Cretaceous microplankton were recorded by Deflandre and Cookson (1955), and this dating has since been confirmed by B. S. Ingram (pers. comm., 1974), who considers that the formation may range in age from Late Cenomanian to Santonian.

The Gingin Chalk (*Kug*) (Glauert, 1910) consists of slightly glauconitic chalk that contains thin beds of greensand in some areas. It is 18.9 m thick in the type section in McIntyres Gully, 1.6 km north of Gingin (lat.31°19′S, long.115°54′E), but locally pinches out against the unconformity with the Leederville Formation. Scattered outcrops occur from about 6 km south of Gingin to beyond the northern boundary of the sheet area.

The Gingin Chalk is rich in fossils, including the Santonian (Middle Senonian) foraminifers *Globotruncana marginata,* the *G. lapparenti* group and *Rugoglobigerina* spp. (Belford, 1960). Other fossils and references are given in McWhae and others (1958).

The Poison Hill Greensand (*Kup*) (Fairbridge, 1953) is a strongly lateritized glauconitic sandstone that crops out north of Gingin. The formation rests conformably on the Gingin Chalk and is overlain by laterite and Quaternary deposits. The type section is at Poison Hill (lat.31°18′S, long.115°53′E), 7.5 km north-northwest of Gingin. Drilling has shown that the formation is at least 41 m thick at Poison Hill (Low, 1965). It is poor in fossils, though a sample from a shot-hole near Mindarra (lat.31°04′S, long.115°47′E) yielded an assemblage of foraminifers including *Dentalina confluens, Haplophragmoides* sp., *Verneuilina parri* and *Spiroplectammina grzybowskii,* of Senonian (possibly Campanian) age (A. E. Cockbain, pers. comm., 1974).

Rocks referred to as the Lancelin Beds (Edgell, 1964) underlie Quaternary sands in the Lancelin No. 2B water bore (lat.31°04′00″S, long.115°19′20″E) between 32 m and 45.7 m (total depth). They consist of light-grey marl with some glauconitic lenses. The unit is similar to the Gingin Chalk, but is considered to be younger owing to the presence of the Campanian foraminifers *Bolivinoides granulatis* and *Neoflabellina praereticulata* (Edgell, 1964).

CAINOZOIC ROCKS

The Cainozoic deposits have been mapped on the basis of their lithology and morphological features. Their genesis is complex and the distinction between Tertiary and Quaternary deposits is often doubtful in the field. East of the Darling Fault, no subdivision of the Quaternary is implied by the second letter of a "Q" unit symbol. The relationship of the units in this area is illustrated in Figure 4.

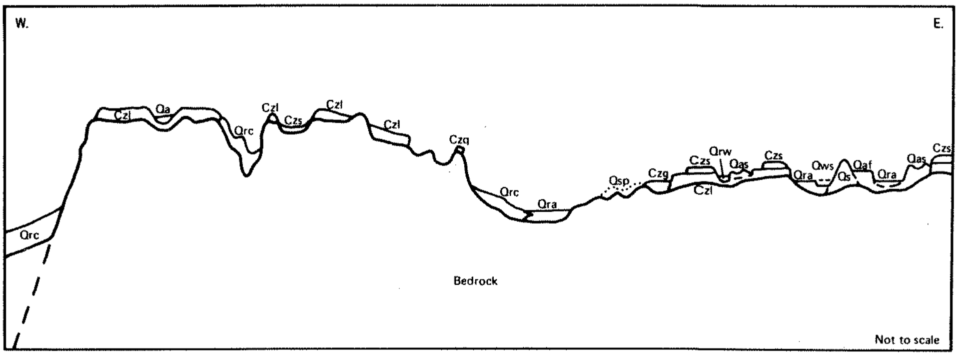


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FIGURE 4

CAINOZOIC ROCK UNIT RELATIONSHIPS EAST OF THE DARLING SCARP

PERTH SHEET SH 50-14 AND PART OF SH 50-13

Cainozoic Symbols as on Map Reference

Tertiary

In the Perth Basin, the Kings Park Shale (Fairbridge, *in* Coleman, 1952) is known in the subsurface and extends from the Perth area as far west as Rottnest Island. It is a unit of grey, calcareous, glauconitic shale and siltstone, with minor beds of sandstone and limestone. The Kings Park Shale apparently fills an ancient drainage channel and rests with angular unconformity on the Yarragadee, Leederville or Osborne Formations. It is overlain unconformably by Quaternary deposits.

The type section is in the Kings Park No. 2 artesian bore (lat.31°58′30″S, long.115°50′30″E) between 36.6 m and 302 m (total depth). The thickest known section (599 m) is in the Rottnest Island artesian bore. The formation is locally rich in fossils, and foraminifers indicate a Paleocene age (McGowran, 1964).

Sediments of Tertiary age appear to be widespread offshore. A sandstone-siltstone unit penetrated between 63.8 and 365.3 m in Quinns Rock No. 1 well is of probable Late Eocene age (Bozanic, 1969a), whilst a unit of dolomite with some chert and sandstone, encountered above 619 m in Gage Roads No. 1 well, is believed to be of Late Miocene age (Bozanic, 1969b).

Czl: The most extensive deposit in the Perth sheet area is laterite. Its age is uncertain but it was probably formed, at least in part, during the Tertiary (Prider, 1966). However, Pleistocene deposits are lateritized throughout much of the Perth Basin and this indicates some laterite formation during the Quaternary (Playford, Cockbain and Low, 1976). It is associated with abundant sand on the Dandaragan Plateau and in the eastern part of the sheet area. On the Darling Plateau, the laterite is generally massive and cemented, and may be pisolitic or vesicular. It averages about 4 m in thickness and the upper portions may consist locally of uncemented pisolites. The laterite surface is flat to undulating and has been strongly dissected by streams, especially south of the Avon River. This laterite has formed *in situ* from the weathering of underlying rocks and passes downward through a pallid zone of variable thickness into weathered bedrock. Only local redistribution has occurred. East of the zone of massive laterites (Mulcahy, 1967) the unit is developed more sporadically. A number of deposits have formed on colluvial slopes above alluvium and are chiefly lateritized sands. It is not certain whether these deposits are coeval with the massive laterites.

Czq: A special type of siliceous duricrust is developed over some of the larger quartzite units. It corresponds to the main laterite surface but is not ferruginous. It consists of a pavement of white quartzite rubble and *in situ* quartzite.

Czs: Overlying the laterite, particularly in the eastern part of the sheet, are deposits of yellow, grey or white sand of variable thickness. There has been some redistribution of this material into eolian dunes. Where it overlies the massive laterite of the Darling Range the unit is much less extensive, is grey or white but not yellow, and is invariably associated with the drainage courses.

Czg: A unique deposit, shown on the map as *Czg,* occurs 6 km south of Calingiri. It is a subhorizontal, flaggy "silcrete" that contains large quartz and kaolinized feldspar fragments in a cemented sandy matrix, and is associated with sand rich in quartz cobbles. The exact age of the deposit is unknown but it has been lateritized in part. It occurs on the drainage divide between the Moore, Avon and Mortlock systems and may represent the product of a pre-Pleistocene drainage system (Balleau, 1972a).

Czf: A compact, partially lateritized, gritty sandstone is associated with *Czg* and also occurs at the head of present drainage channels in the Calingiri area. It overlies *Czg* 5 km east-southeast of Wyening Mission.

Czc: A deposit of unsorted conglomerate partly fills an abandoned section of the Swan River valley at Walyunga, 9 km southeast of Bullsbrook, and also crops out in a valley 4 km farther east. At Walyunga, the unit is exposed over 65 ha and is up to 45 m thick. It consists of irregularly-shaped clasts, ranging to large boulder size, in a matrix ranging in grade from clay to coarse sand. The sand grains are predominantly angular and the highly weathered clasts are devoid of striae. The deposit rests unconformably on Archaean granite and migmatite and is overlain unconformably by the Pleistocene Yoganup Formation and Ridge Hill Sandstone. A doubtful outcrop of Leederville Formation (Lower Cretaceous), too small to show on the map, appears to overlie the conglomerate in the northwest. This, and the unsorted nature of the conglomerate, led to the tentative suggestion that it may be a tillite of possible Permian age (Low, 1971b). However, similar deposits south of the sheet area are considered to be of Tertiary age (the *Harvey Beds* of Playford, Cockbain and Low, 1976), though Churchward and Bettenay (1973) suggest that they may even be Mesozoic.

QUATERNARY

Perth Basin

Quaternary to Recent deposits cover most of the Perth Basin in the sheet area, with the exception of the few Mesozoic outcrops. The Quaternary deposits are usually less than 60 m thick and consist principally of shoreline and associated dune deposits, together with mainly fluviatile beds underlying the Pinjarra Plain and colluvium in the Piedmont Zone.

The Ridge Hill Sandstone (*Qph*) (Prider, 1948) is a littoral facies consisting of a leached shoreline sand with a thin basal conglomerate. It is found in isolated patches along the face of the Darling Scarp at heights ranging from 75 m to 90 m. The principal occurrence is at Ridge Hill (lat.31°56′S, long.116°02′E). The formation is of early Pleistocene age.

The Yoganup Formation (*Qpr*) (Low, 1971a) is a shoreline deposit that includes a basal beach conglomerate and a foredune. Any carbonate originally present has been leached out and the unit is variably lateritized. It occurs in a similar manner to the Ridge Hill Sandstone, but its base lies at elevations ranging from 35 to 45 m above sea level. The type section is in Westralian Sands Ltd's excavations for heavy mineral sands at Yoganup (lat.33°40′S, long.115°35′E), where it overlies the Leederville Formation. No fossils have been found in the Yoganup Formation but, because of its stratigraphic position, degree of alteration and dissection, and its elevation above sea level, it is probably of Middle Pleistocene age.

The Guildford Formation (*Qpa*) (Baker, 1954; Low, 1971a) has been described by Aurousseau and Budge (1921) and Fairbridge (1953) under the name Guildford Clay. The unit consists of interbedded alluvial sands and clays, calcareous in places, with thin lenses of basal conglomerate. A thin band containing marine fossils (*Anadara, Dosinia,* etc.) occurs at a height of about 4.5 m above low-tide level in the brick clay pits at Caversham (lat.31°53′S, long.115°58′E). The clay is rich in gypsum crystals for about 60 cm above the fossil bed.

The type section of the Guildford Formation is in the West Guildford artesian bore (lat.31°54′30″S, long.115°57′20″E) from the surface down to 32.99 m (Low, 1971b). The formation unconformably overlies the Kings Park Shale, the Osborne Formation or the Leederville Formation, and is overlain by younger Quaternary alluvium or dune sand. It is probably of Middle or Late Pleistocene age.

Dune sand and coastal deposits in the Perth Basin range from Pleistocene to Recent in age and are grouped as the Bassendean Sand (*Qpb*) (Playford and Low, 1972; Low and others, 1970), the Coastal Limestone (*Qpc*) (Saint-Smith, 1912) and the Safety Bay Sand (*Qrs*) (Passmore, 1967; Low and others, 1970).

The Muchea Limestone (*Qpm*) (Glauert, 1911) is a chalky kankar-type deposit developed at or near the surface in small isolated patches along the eastern side of the Swan Coastal Plain.

Shell beds (*Qro*) on the bottom and around the margins of salt lakes on Rottnest Island represent marine incursions into the Coastal Limestone, perhaps dating back to the late Pleistocene (Teichert, 1950; Glenister and others, 1959).

Small areas of lacustrine clay, silt and marl, with shell beds (*Qrg*) occur on the western bank of the Swan Estuary.

There are other alluvial, colluvial and lacustrine deposits, all of which, except for colluvium derived from Cretaceous rocks (*Qm*), also occur on the Yilgarn Block to the east and are described below.

Yilgarn Block

In the northeast portion of the sheet area, buff sand with distinct bands and lenses of ferruginous pisoliths (*Qsp*) forms a thin mantle over rock. The relief and photo pattern are similar to soil-covered areas, and dykes can often be detected beneath the deposits. Areas of *Qsp* are particularly abundant around the Moore, Avon and Mortlock drainage divides and usually flank drainage channels, giving way upslope or laterally to laterite or rock outcrop. The deposits appear to be redistributed residual products whose position is closely related to an early Quaternary drainage system.

Hummocky deposits of bright yellow sand (*Qs*) occur marginal to alluvial areas in Salinaland. They are probably of eolian origin. Similar yellow sand also overlies laterite in much of this area. Older sandy alluvium (*Qaf*) and reworked sand (*Qas*) associated with old stream channels are extensive upstream of the more recent alluvium of the Mortlock drainage system and near the drainage divides. The older alluvium has a flat surface and is dissected, whereas *Qas* has an undulose surface and is often traversed by dunes. The more recent alluvium (*Qra*) has a fairly flat surface and lies above the normal level of the present streams. It is particularly extensive around the Mortlock River (North Branch) and in association with the salt lake system.

Salt lake deposits (*Qwś*) occur in the broad alluvial areas of Salinaland and with *Qas* in the eastern portion of the Mortlock drainage system. Minor salt lakes have also developed in sand over laterite north of Meckering.

Swamp and lacustrine deposits (*Qrw*) are generally associated with *Qas* to the west of the Mortlock River (North Branch). They also occur with thin bands of alluvium and colluvium (*Qa*) developed on the laterite of the Darling Range. The deposits form rounded clay pans and swamps. Lacustrine deposits also occur along the Brockman River between Chittering and Mogumber and are particularly extensive on the Swan Coastal Plain.

In the eastern part of the sheet area, colluvium (*Qrc*) consists of shallow dipping sheets of sand on valley sides upslope from alluvium and below rock or laterite outcrops. In areas of more active erosion to the west, colluvium occurs between valley alluvium and rock outcrop (separated from both by a marked change of slope) and also occurs as scree deposits in valleys that are actively incising the laterite surface of the Darling Range.

In the eastern part of the sheet area, bedrock is often largely or almost completely obscured by soil. However, occasional outcrops and rock fragments enable the underlying rock type to be determined. Such areas are denoted on the map by a special overprint (see map reference).

STRUCTURE OF THE PERTH BASIN

The Perth Basin, a narrow, longitudinal basin filled with predominantly Mesozoic sediments, is bounded on the eastern side by the Darling Fault. The sediments may attain a thickness of 15 000 m (Rae, 1965). The Darling Fault has dominated the structure and stratigraphy of the Perth Basin, probably since the Silurian, by a series of west-block down displacements, resulting in a half-graben structure (the Dandaragan Trough) in the on-shore area (see cross-section A-B on the map).

West and southwest of Rottnest Island lies a broad, deep trough from which the basement rises steeply to form the western edge of the Perth Basin, some 80 km from the mainland coast. Northwest of Rottnest, the basin narrows markedly where a postulated fault (the Harvey Fault), trending north-northwest from the vicinity of Harvey, meets the basin margin (Hawkins and others, 1965).

The Darling Fault had its greatest movement during the period from the Late Triassic to the Early Cretaceous. During the Late Jurassic, a north-trending arch developed between the present coastline and Rottnest Island. Subsequently, the crestal portion of this arch collapsed, forming a keystone graben (the Rottnest Trench) that extends through Rottnest to the offshore area near Yanchep. The Vlaming Sub-Basin lies offshore between the Rottnest Trench and the Edwards Island Block (Jones and Pearson, 1972).

North and north-northwest structural trends in the basement are reflected by similarly aligned folds and faults in the Phanerozoic deposits. No major faulting is known above the Neocomian unconformity at the base of the Warnbro Group, though flexures and minor faults in the Leederville Formation also follow the general trend. Seismic reflection data from the Cattamarra Coal Measures Member of the Jurassic Cockleshell Gully Formation have been used to establish the position of the major faults (Fig. 2). All the faults are thought to have normal displacements.

ECONOMIC GEOLOGY

Mineral production from the sheet area has been negligible, except for industrial and building materials such as clay, limestone and aggregate. A little gold and lateritic iron-ore have been produced and minor occurrences of other minerals are recorded.

METALLIC MINERALS

Gold (Au)

Shafts and adits were sunk for gold at Chittering, Bolgart, Wongamine, Grass Valley and Jimperding Hill. Total recorded production amounted to 10 170 g of lode gold from Jimperding Hill, together with 7 371 g of alluvial gold from Jimperding Hill and Wongamine. The lode gold was extracted from quartz-veined aluminous schist and appears to have been concentrated at the base of the laterite profile. The alluvial workings at Bolgart, Wongamine and Grass Valley were in eluvial and colluvial deposits in close proximity to BIF. The shaft at Chittering was sunk through quartz-veined schist.

Tungsten (W)

Scattered boulders of wolfram occur 6 km north-northwest of Grass Valley (Blatchford, 1918). The country rock is leucocratic granitic gneiss (*Anl*) and quartzite (*Aqo*), together with tourmaline-bearing ?vein quartz. Traces of reinite (ferrous tungstate) have been found associated with the gold at Jimperding Hill (Simpson, 1950). The deposits are not economic.

Molybdenum (Mo)

The first discovery of molybdenite in Western Australia was at Swan View (Miles, 1944). It occurs with pyrite and epidote in shear zones through *Age*. There are also several small occurrences in the Spencers Brook area. Simpson (1952) records mining of the deposit in the Mokine railway cutting, though no production figures are available.

Iron (Fe)

The first production of iron ore in the State was from lateritized BIF at Clackline. Between 1899 and 1907, recorded production was 18 545 t, though Hobson (1946) indicates that larger quantities were mined. The ore is highgrade limonite and was treated at the Fremantle Smelting Works. Some ore from the Wundowie-Coates Siding area was also treated at Fremantle, though most of the 82 273 t produced from this area was smelted at Wundowie between 1948 and 1955.

Several of the larger quartz-magnetite-hypersthene BIF bands east of Northam have been drilled and tested for magnetite, but have not been mined.

Vanadium (V)

A lateritized gabbroic intrusion at Coates Siding contains vanadium-bearing titaniferous magnetite. The intrusion trends west-northwest but has little surface expression except for some relict textures in the laterite. Drilling has revealed cumulate textures and a compositional range from gabbro to anorthosite. This gabbro intrusion is the only one of its type known in the Perth sheet area. The fresh rock contains an average of 0.54 per cent V_2O_5 and published ore reserves for the prospect amount to more than 227 000 of V_2O_5.

Bauxite (Bx)

Bauxitic laterite is extensive on the Darling Plateau. Portions of the Alcoa mineral lease MLI SA and the Alwest Agreement area extend northward into the Perth sheet area. The Pacminex deposits are centred on the area east of the lower Chittering Valley. A bulk sample from here has been tested and over 100 million tonnes of bauxite at around 32 per cent available alumina have been indicated in the area.

Rutile (R)

At Yulgering Well, 8 km northeast of Calingiri, a small concentration of rutile was dicovered in colluvium overlying migmatite (Jutson, 1912). Individual crystals reach 4 cm in length, but the amount of material is small.

Potentially economic deposits of heavy mineral sands occur in the Perth Basin in the Gingin, Muchea and Bullsbrook areas. They are associated with fossil strand lines and beach dune systems that can be equated with the Yoganup Formation. The Gingin deposit has inferred reserves of 2.3 million t of heavy mineral concentrate.

INDUSTRIAL ROCKS AND MINERALS

Vermiculite (Ve)

Vermiculite of varying quality is present in minor amounts throughout the area. Small lenses occur in the broad schist unit, 8 km northeast of Bullsbrook East. It is also recorded from a serpentinite at Goomalling (Simpson, 1950).

Asbestos (Aa)

At Goomalling, asbestiform anthophyllite is associated with a talc-serpentine band within migmatite. Two prospecting areas were worked in 1922, but no production was recorded.

Talc (T)

Both talc and asbestos occur in minor amounts in certain altered ultramafic intrusions. The only talc deposit worked is situated 9 km south-southwest of Bolgart. The recorded production is 275 t between 1946 and 1952, although the deposit is still worked sporadically (Berliat, 1955).

Kyanite and sillimanite

Concentrations of almost pure kyanite and sillimanite occur as lenses in the schists and gneisses of the Chittering Metamorphic Belt. Large quantities of kyanite (at Wattle Flat) and sillimanite (at Goyamin Pool) are available but would require crushing and special beneficiation. Sillimanite is also a constituent of many schists in the Jimperding Metamorphic Belt. The only recorded production is 2 t of sillimanite from Clackline in 1948.

Clay (Cl)

Large quantities of clay have been obtained from the sheet area and abundant supplies are available.

In the Perth Basin, ceramic and brick clays occur in the Guildford Formation (*Qpa*) in the valleys of the Swan and Helena Rivers, and have been quarried extensively at a number of places. North of Upper Swan, transported clays are limited in extent and confined to the vicinity of Ellen Brook. Alluvial deposits along the Moore River are mostly sandy. Bauxitic clay suitable for cement manufacture has been obtained from Maida Vale.

East of the Darling Fault, structural clay is obtained from the pallid zone, formed during lateritic weathering of the granitic rocks. Most quarries are close to the Darling Scarp. Recorded production of structural clay is 117 161 t to the end of 1972. Fireclay is obtained from the pallid zone and from weathered aluminous schists. Production of fireclay from weathered granitic rocks in the Glen Forest-Mahogany Creek area amounted to 236 045 t to the end of 1972. A small quantity of fireclay (1 670 t to 1972) has also been produced from the pallid zone overlying porphyritic granite, 2 km south-southeast of Clackline. To the end of 1972, 108 486 t of fireclay were produced from weathered sillimanite-bearing schists at Clackline. Smaller amounts of clay have been obtained further north along this schist belt, but the material is generally less aluminous than at Clackline.

Total production of clay from the Perth sheet area has been much greater, but no exact figures are available.

Kaolin (Ck)

A small amount of residual kaolin for use as a filler material has been obtained from the pallid zone of the laterite profile at Glen Forest. Recorded production was 2 786 t prior to 1952.

A flooded claypan (*Qrw*), 17 km west of Goomalling, has yielded 29 176 t of good quality ceramic clay up to the end of 1972. Four clay horizons up to 2 m thick are interstratified with unconsolidated sand and grit. The deposits are probably of lacustrine origin. A number of similar claypans between Goomalling and Bolgart are potential sources of ball and semi-ball ceramic clay.

Shale (Sh)

Quartz-mica schist obtained from the Chittering Metamorphic Belt, 3 km south of Bullsbrook East, is used for brickmaking, Shale suitable for brickmaking is also obtained from the Osborne Formation, about 4 km east of Muchea. It is variably sandy and carbonaceous and ranges from off-white to dark brown. Similar lithologies occur in scattered outcrops of the Leederville Formation in the vicinity of Gingin and further northwards.

Diatomaceous earth (Dt)

A number of the lakes and swamps on the Bassendean Sand contain diatomaceous material, up to 1.5 m thick in places. All the deposits carry varying quantities of organic matter and quartz sand, which prove a handicap to economic exploitation. Diatomaceous material has been obtained from the Gnangara and Badgerup localities. Some of the material from Lake Gnangara, when calcined, contains over 90 per cent silica and has a weight of approximately 260 kg/m^3 (Carroll, 1949).

Glauconite (Gl)

Glauconite occurs in the Molecap and Poison Hill Greensands (Upper Cretaceous) and in the Osborne Formation (Cenomanian-Albian). The Molecap and Poison Hill Greensands carry up to 5.4 per cent K_2O, below a weathered surface zone (Low, 1965). The potash content of the greensands at Gingin (Poison Hill Greensand and Molecap Greensand) and at Bullsbrook (Osborne Formation) was investigated by the Geological Survey and the Commonwealth Scientific and Industrial Research Organization during 1964. In the holes drilled at Gingin, the Molecap Greensand was found to contain up to 3.6 per cent K_2O, and at Bullsbrook the Osborne Formation was found to contain up to 3.0 per cent K_2O (Low, 1965). The deposits are not economic at the present time.

Some 32 500 t of greensand were mined from the Molecap Hill quarry near Gingin between 1932 and 1960, and from this, 6 570 t of glauconite concentrate were exported to England for water-softening purposes. This indicates an average grade of about 20 per cent.

Phosphate (Ph)

A thin band of phosphatic nodules (corprolite) occurs near the top of the Molecap Greensand (Upper Cretaceous) at Molecap Hill near Gingin. Some of this material was quarried from the northeastern slope of the hill, but was found to be too thin for profitable exploitation (Feldtmann, 1934). The phosphate occurs as apatite, dufrenite and vivianite (Simpson, 1948).

Peat (P)

Peat of variable quality and ranging in thickness up to 4.5 m is found in many of the small interdune swamps on the Bassendean Sand and the Coastal Limestone (Esson, 1926). It is currently in demand to improve soils for gardening. Some of this material is of semi-lignite grade.

Salt

The earliest saltworks in the State were established on Rottnest Island where a few inches of salt collect each summer on a dried-up arm of a salt lake. The crude dry salt averaged 98 per cent NaCl and was recrystallized for domestic use.

Petroleum

Eight test wells have been drilled in the Perth sheet area to date and details of these are given by Playford and Low (1971). Gingin No. 1 and Gingin No. 2 produced gas and condensate, whilst Gage Roads, No. 1 (offshore) had a minor show of oil. The remaining wells, Quinns Rock No. 1, Badaminna No. 1, Roe No. 1, Gage Roads No. 2, and Charlotte No. 1, were dry.

Production testing of Gingin No. 1 yielded 50×10^3 m^3/day of gas with 36 barrels/day of condensate and 4.5 barrels/day of water from the Cockleshell Gully Formation (Lower Jurassic). It was completed as a gas and condensate well over the intervals 3 866 to 3 880 m and 3 949 to 3 962 m. Gingin No. 2 was drilled 4 km south-southeast of Gingin No. 1 to evaluate this discovery. Gingin No. 2 was completed as a potential gas and condensate producer after flowing a maximum of 110×10^3 m^3/day with 270 barrels/day of condensate from the interval 4 256 to 4 482 m. This yield fell substantially with prolonged testing.

In Gage Roads No. 1, 35.5 km offshore to the west of Perth, hydrocarbon shows were found in a sand in the Leederville Formation (Lower Cretaceous) over the interval 1 743 m to 1 794 m, and in the Yarragadee Formation (Lower Cretaceous section) over the interval 2 618 to 2 646 m (Bozanic, 1969b). The petroleum potential in the Perth sheet area, especially offshore, is regarded as moderate.

Chalk (Lm)

Chalk has been quarried at various times from the Gingin Chalk (Upper Cretaceous) at One Tree Hill and Molecap Hill, near Gingin. It was found to be too variable in composition and too high in free silica for Portland cement or high-grade lime, but it has been used as a soil dressing from time to time.

Lime and limestone (Ls)

The Coastal Limestone from Perth to Lancelin is quarried for use as road-making material. Closer to Perth, calcarenite in the Coastal Limestone has been used for building material (mainly foundations), while lime-rich patches have been utilized as a source of industrial and builders lime. The bulk of the reserves of industrial limestone ($CaCO_3$ content above 80 per cent) in the Perth metropolitan area occur between Perth and Lancelin. Large reserves of material, 70 to 80 per cent $CaCO_3$ in grade, are also available (McMath, 1954; de la Hunty, 1966; Baxter and Rexilius, 1974) although many high grade deposits could be sterilized by urban development.

Thin lacustrine limestone cropping out between Bullsbrook and Gingin (Muchea Limestone—Pleistocene) may have a local and limited agricultural use.

The extensive shell beds (mainly *Ostrea angasi*) of the Swan River estuary were worked in the past as a source of lime for cement manufacture. Production ceased about 1957.

Building stone (Bs)

Local stone, especially cemented laterite and granitic rock, has been used for home construction in past decades, and to a lesser extent is employed at the present time. Porphyritic granite 6 km south of York has been quarried for facing stone. Extensive use is made of laterite and granite in landscape gardening.

The quartzite band extending southward from Jimperding Hill to Clackline is quarried sporadically along its length for building and facing stone ("Toodyay Stone"). Portions of this unit are fissile along planes crowded with green chrome mica. The best quality facing stone has extremely smooth partings devoid of crenulations. The main quarry is situated 9 km south-southwest of Toodyay.

A porous, granular, cream-coloured rock from the Coastal Limestone is well suited as a building stone and has been used in many Perth and Fremantle buildings. Rock from the Coastal Limestone has also been used in breakwaters.

Aggregate, ballast and road metal

There are abundant supplies of rock suitable for crushed aggregate (Rc) and large quarries have been opened up along the Darling Scarp close to the Perth metropolitan area. Railway ballast has been provided by quarries in close proximity to the railway lines. Innumerable small workings in weathered granitic rocks (Rm) and uncemented pisolitic laterite (Gr) provide gravel for road making.

Sand

Large quantities of sand (Sd) are available, especially in the Perth Basin and in the eastern part of the sheet area where it overlies laterite.

Abundant supplies of unbonded silica sands occur in the Bassendean Sand (*Qpb*). These sands are usually clean and well graded and, from selected localities, uniform sand in the range of A.F.A. grain fineness 30 to 50 has been obtained. This sand is highly satisfactory for steel and cast-iron work. Suitable deposits of fine sands are not known at present in the vicinity of Perth, but eolian sand around the larger lakes and swamps in the northern part of the mapped area offers possibilities.

Naturally bonded moulding sands (loam) are known from the Guildford Formation (*Qpa*) in the vicinity of Guildford, though the deposits are variable in grade (Miles and Stephens, 1950).

Many commercial pits are operated in the Bassendean Sand for the supply of building sand. Sand from two localities south of Perth has proved suitable for the production of sandlime brick and similar deposits may be expected in the Bassendean Sand north of Perth.

Sand deposits (Sg) around the shore of Gnangara Lake contain a white even-grained sand comparable in quality with the Fontainbleu and other famous glass sands. These have already been utilized for the production of table glass and other white ware. Even-grained sand with low iron content suitable for window, mirror, and bottle glass is common in the Bassendean Sand.

WATER SUPPLIES

Aspects of the hydrogeology of the mapped area have been described by Maitland (1903), Foreman (1933), McMath (1952), Berliat (1961), Morgan (1964, 1965), Whincup (1966), Sanders (1967), Balleau (1972a) and in numerous file reports of the Geological Survey. The main features are illustrated in Figure 5.

SURFACE WATER

Most rivers and streams in the Perth sheet area are intermittent and brackish and are unsuitable for irrigation or domestic use. The Helena River, the only one draining an entirely forested catchment, is fresh. It is dammed at Mundaring and

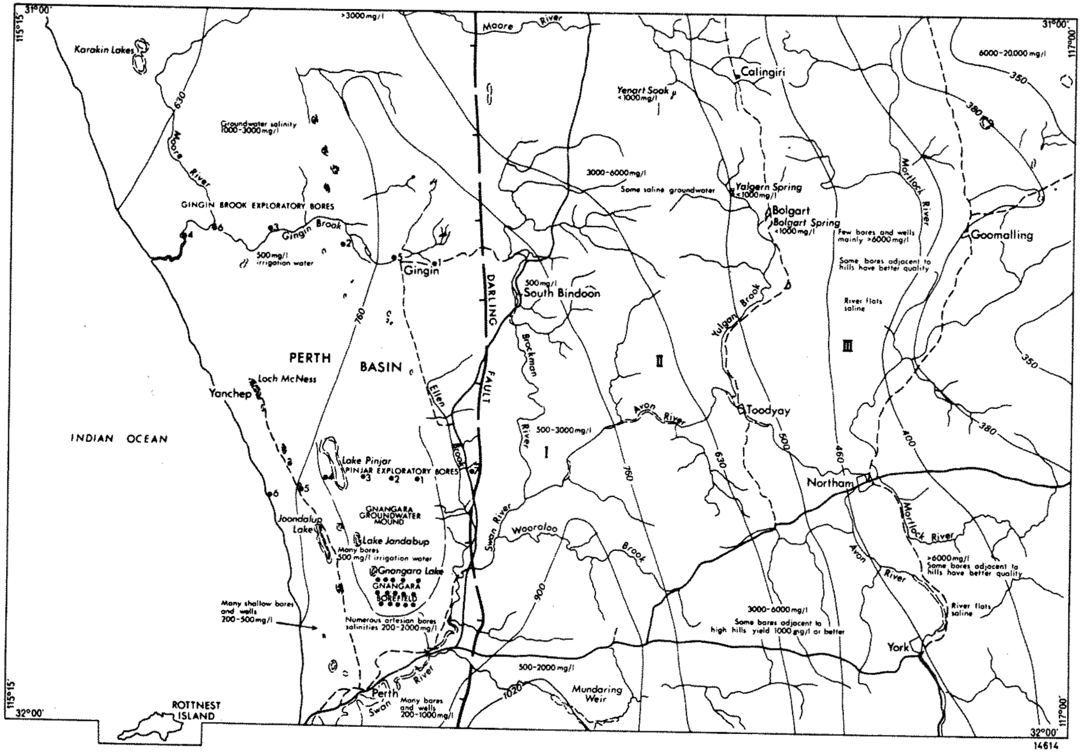

FIGURE 5

WATER SUPPLIES

PERTH SHEET SH 50-13 & 14

SCALE

10 0 10 20 30

KILOMETRES

REFERENCE

- Highway
- Main road
- Townsite
- 350 Rainfall in millimetres per year
- River, creek
- Lake, claypan
- Spring
- 200 mg/l Salinities of groundwater in milligrams/litre total dissolved solids
- •2 Exploratory bores Perth Basin

YILGARN BLOCK – GROUNDWATER PROVINCES

Darling Scarp	I	Many shallow bores, mostly low yields 500-3000 mg/l T.D.S. Domestic, irrigation and stock
Eastern Lateritic Plateau and Northern Scarp	II	Few bores, low yields. 3000-6000 mg/l T.D.S. Some better quality water in favourable positions, mainly stock
Eastern Plateau	III	Few bores. Low yields >6000 mg/l T.D.S. Stock

the water is pumped to the Eastern Goldfields and supplies towns in the "Wheat Belt" on route.

The Swan-Avon River, Ellen Brook and Gingin Brook are the only perennial streams within the sheet area. The longest river system is the Swan-Avon, which drains mainly agricultural areas up to 160 km east of the Darling Scarp. It flows at a greatly reduced rate during the summer and is too brackish for town water supply.

Perth's main water supply comes from dams on the Canning, Serpentine and South Dandalup Rivers, south of the sheet area.

GROUNDWATER

Groundwater occurrence varies with rainfall and geomorphology. Three main hydrological provinces can be recognized on the Yilgarn block. These are based largely on the rainfall pattern, though the boundaries are somewhat arbitrary (Fig. 5). Four provinces that are closely tied to the geology and geomorphology can be recognized in the Perth Basin (cf. Fig. 1).

Yilgarn Block

Darling Scarp: This province has a reliable rainfall of 760 to 1 000 mm per year and is characterized by streams that deeply incise the laterite surface. Small amounts of potable groundwater, generally at yields of less than 15 m^3/day, are available from bores and wells sunk through the laterite profile to bedrock. Those sited in valleys or on hill slopes may give larger supplies, but the salinity is higher and may range up to 3 000 mg/l total dissolved solids (t.d.s.). Groundwater in the Avon valley is often more brackish.

In a portion of the Bindoon-Chittering area, shearing and fracturing has increased the permeability and porosity of the water-bearing bedrock, permitting pumpage of up to 1 000 m^3/day of groundwater containing 500 mg/l t.d.s. This water is used for domestic purposes and irrigation of market gardens and orchards.

Eastern Lateritic Plateau and Northern Scarp: This province lies in the 500 mm to 760 mm rainfall velt, where the laterite surface is often relatively undissected. Groundwater is less common than in the area to the west and is often brackish. Favourably sited bores or wells may yield up to 15 m^3 per day of 3 000 to 6 000 mg/l t.d.s. groundwater. Locally, a bore put down to bedrock from the higher laterite-capped hills may intersect potable water. Bore depths range from 10 to 30 m.

In the northern part of the area, residual sands (*Qas*) up to 30 m thick overlie laterite and contain shallow, fresh groundwater. At Yenart Soak, near Calingiri (Balleau, 1972b), at least 0.41×10^6 m^3 of potable water are in storage and an annual pumpage of 14.5×10^3 m^3 could be met. Similar sands provide the water for Bolgart township and other reservoirs probably exist along the upper portions of the Avon, Mortlock and Moore drainage systems.

Eastern Plateau: This province has an annual rainfall of 350 mm to 500 mm and is an area of mature topography. Groundwater is common only along broad, alluvial valleys, and is usually brackish to saline. Locally, stock quality water of about 6 000 mg/l t.d.s. or better occurs where conditions of infiltration, percolation and groundwater accumulation are favourable. Such zones are usually in residual sands on hill slopes and in areas of fractured bedrock. Experience is required in finding usable groundwater. Producing bores are commonly up to 30 m deep with the water table standing at 5 to 10 m depth.

Perth Basin

Unconfined groundwater: The main groundwater provinces are as follows:—

The Piedmont Zone of alluvial fan material consists of lenticular conglomerate, gravel, sand and clay beds and yields local supplies of potable water. Many bores have silt problems and yield less than 10 m^3/day.

The Pinjarra Plain (corresponding to the outcrop of the Guildford Formation) contains limited capacity aquifers in lenticular beds of gravel, sand and loam. Salinity increases toward the end of the dry season, and with heavy pumping.

The Bassendean Sand has seasonal swamps that become dry in summer owing to evaporation and the decline of the water table. Salinity may rise to 1 000 mg/l t.d.s. during summer (Morgan, 1964). The water table ranges from zero to 30 m below ground level and useful supplies are obtained from bores in many localities. Large groundwater resources in the Gnangara area are being utilized to supplement Perth's water supply (Balleau, 1972a) and similar reserves as far north as Gingin may be brought into production during the next decade.

Coastal Limestone Belt: Here the water table cuts the surface in seasonal swamps and permanent lakes between sand ridges that overlie the limestone. Bores and wells up to 30 m deep draw good quality water from porous and permeable sands for domestic and market gardening purposes. Coastal sand dunes at Lancelin are considered capable of supplying ample water of suitable quality for the town requirements (Morgan, 1965) and adequate supplies are probably available at Guilderton.

Confined groundwater: Pressure water exists in Cretaceous and Jurassic aquifers in the Perth Basin and has been utilized for many years at Perth, Guildford, Midland Junction (Maitland, 1903; Forman, 1933) and Pearce (Whincup, 1966). The pre-Cretaceous beds dip at low angles to the southeast, while the overlying units are essentially flat. Forman (1933) identified three pressure-water horizons on the basis of water analyses, water temperatures and static heads. Two of these are in the Leederville Formation and the third in the Yarragadee Formation. The deepest aquifer is at 563 m below ground level. Up to 14.5 x 10^3 m^3/day have been produced from the Yarragadee Formation in the Loftus No. 2 bore. The Osborne Formation also carries pressure water in parts of the Perth metropolitan area.

Seven exploratory bores in an east-west line from Bullsbrook to the coast, drilled by the Mines Department in 1964-1965, encountered pressure aquifers in the Yarragadee Formation (Upper Jurassic), Leederville Formation (Lower Cretaceous), and Osborne Formation (Cenomanian-Albian) (Whincup, 1966). A shallow unconfined aquifer was also found in Quaternary sands. In this area, the salinity usually increases with depth, though the Leederville and Yarragadee Formations are capable of yielding large supplies of good quality water.

A similar east-west line of six water bores, drilled in 1965-1966 near Gingin, found large supplies of pressure water ranging from domestic to stock quality in the Yarragadee Formation, Leederville Formation, and Molecap Greensand (Upper Cretaceous) down to 730 m. The water is generally more saline than in Mesozoic units further south, though hydraulic connection between the Perth and Gingin areas is possible. A shallow, unconfined Quaternary aquifer of good quality water also exists in this area (Sanders, 1967).

Recharge to these pressure aquifers apparently occurs along the foot of the Darling Scrap and results from the downward percolation of rainfall through the Quaternary units and from leakage from the Moore River, Gingin Brook and other streams on the coastal plain. The relative importance of each of these recharge resources is uncertain at present.

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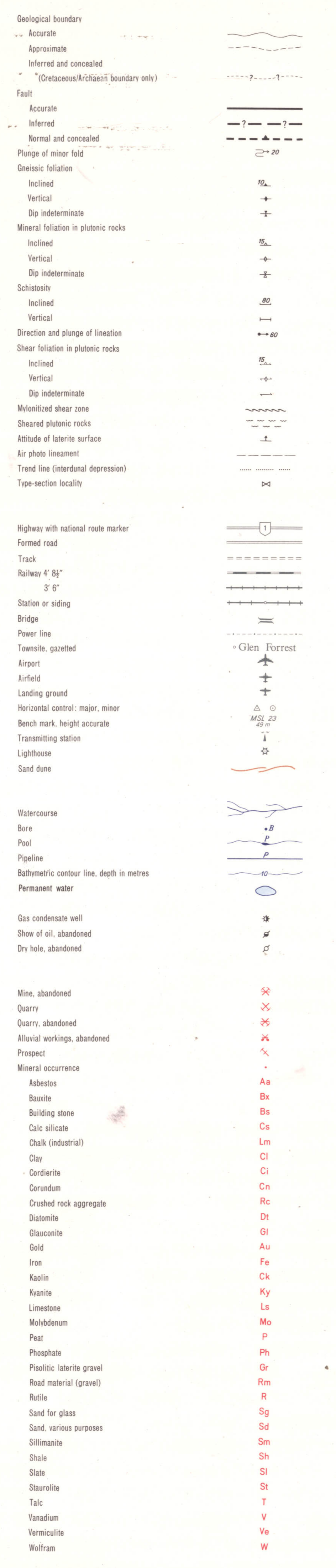
PERTH

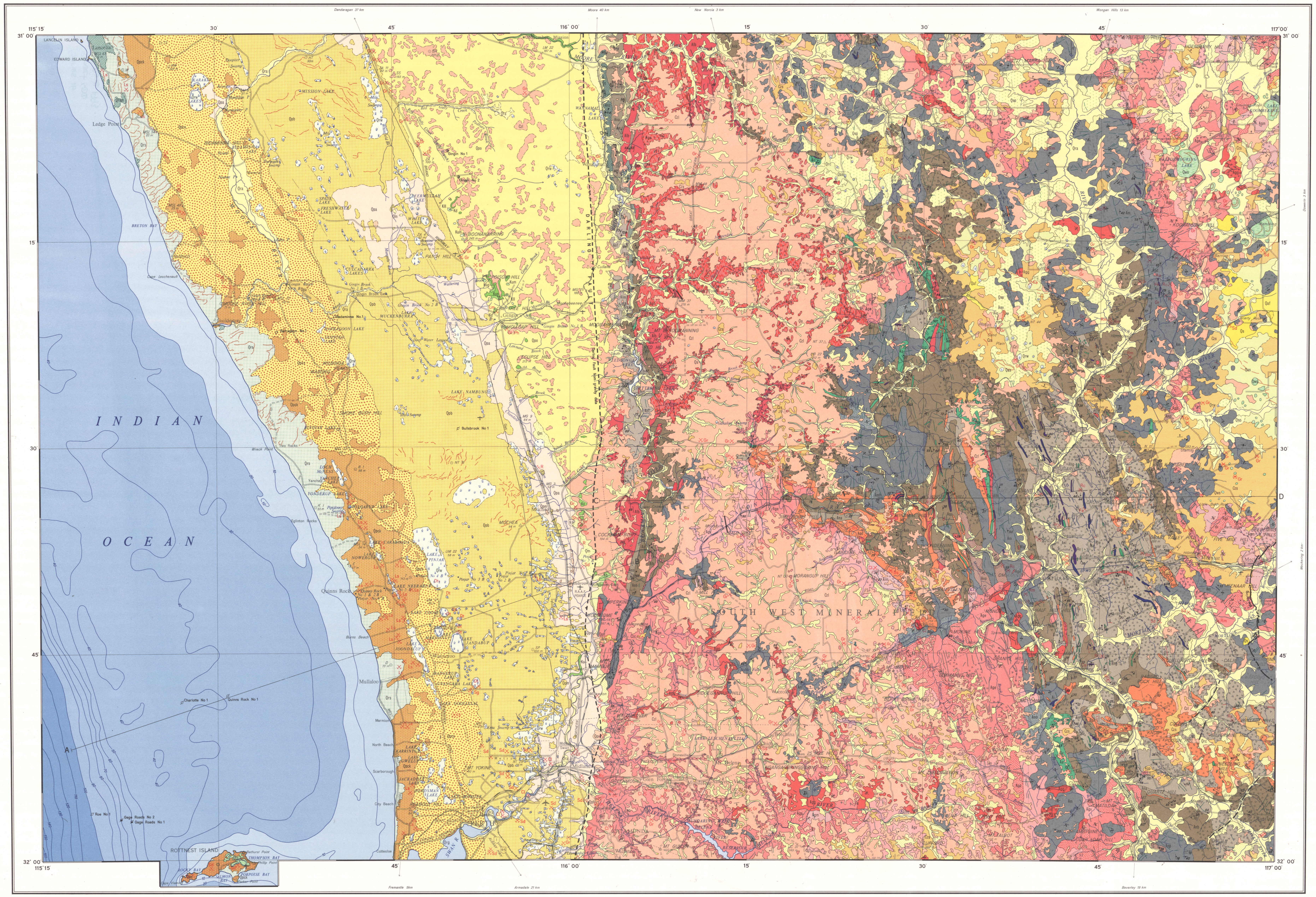
AUSTRALIA 1 : 250 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SH 50 - 14 AND PART OF SHEET SH 50 - 13

SYMBOLS





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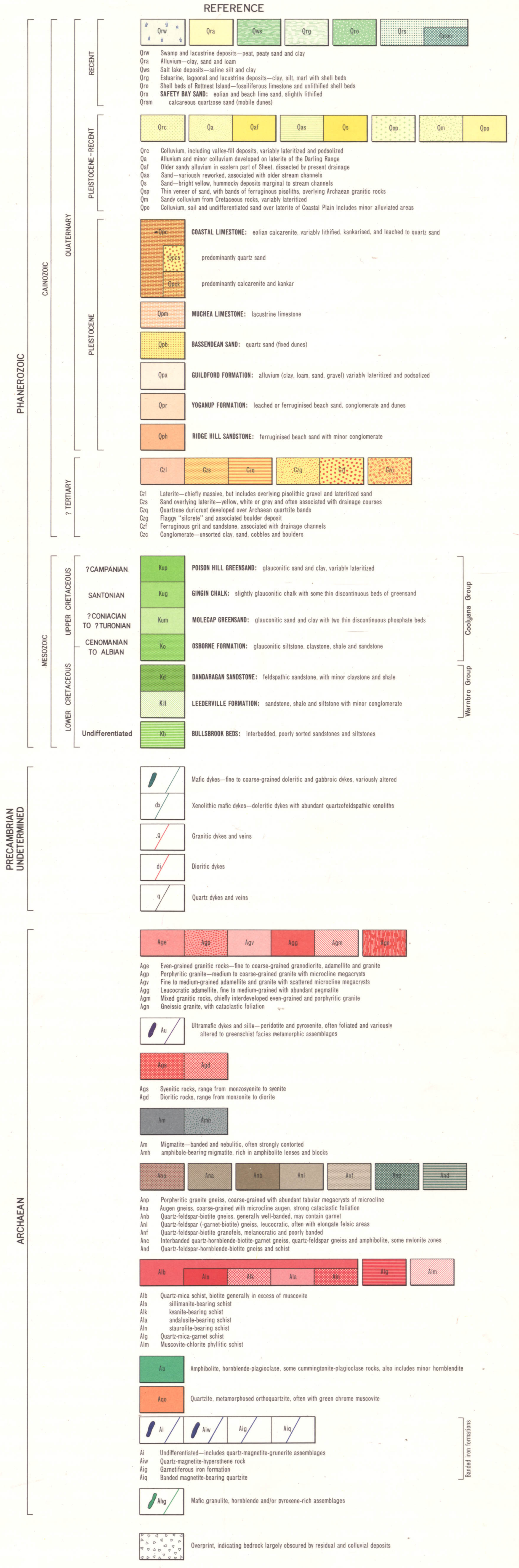
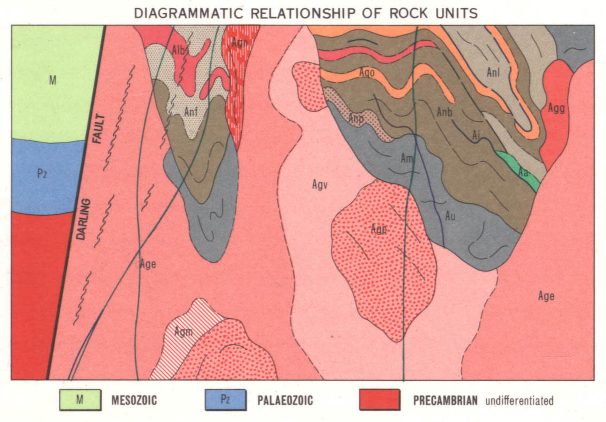
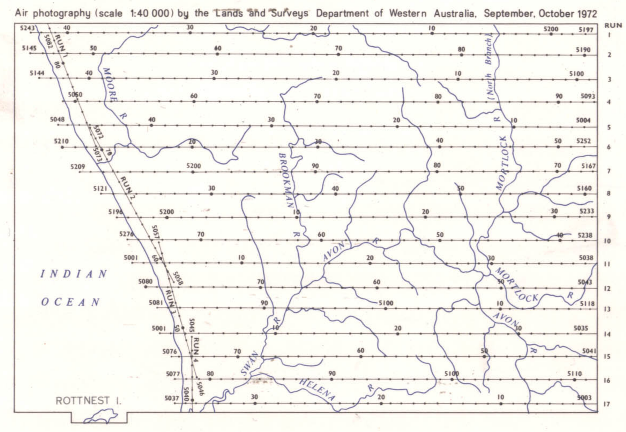


DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



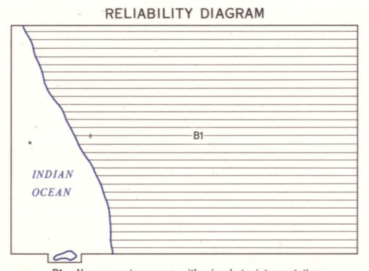
FLIGHT DIAGRAM



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. A. MENSAROS, M.L.A.
MINISTER FOR MINES
J. H. LORD, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1 : 250 000

TRANSVERSE MERCATOR PROJECTION
ZONE 1 AUSTRALIA SERIES

INDEX TO ADJOINING SHEETS

HILL RIVER SH 50 - 9	MOORA SH 50 - 10	BENCUBBIN SH 50 - 11
INDIAN OCEAN	PERTH SH 50 - 14	KELLERBERRIN SH 50 - 15
	PINJARRA SI 50 - 2	CORRIGIN SI 50 - 3

Geology by: Perth Basin—G. H. Low and R. W. Lake 1965-67
Yilgarn Block—S. A. Wilde 1972-73
Printed by Mercury-Walch, Hobart, Australia

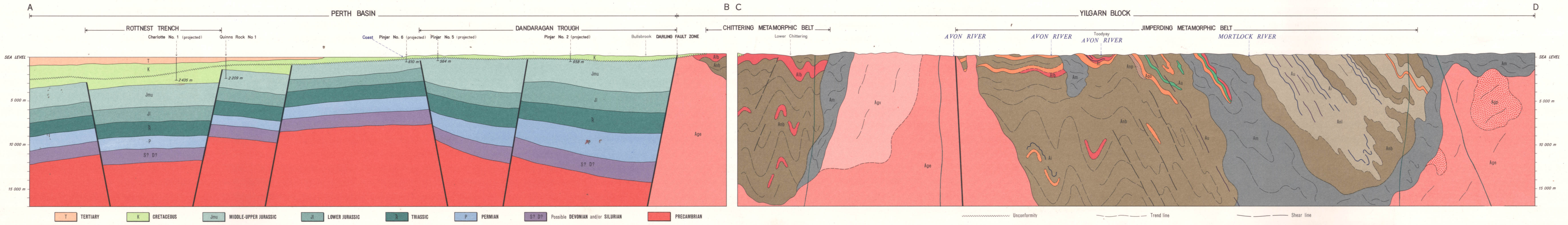
DECLINATION DIAGRAM

The lines indicate magnetic declination, 1970.
+ means declination is east and correction must be added to compass bearing to give true bearing.
− means declination is west and correction must be subtracted from compass bearing to give true bearing.
Annual change is −1' westerly

DIAGRAMMATIC SECTIONS

NATURAL SCALE

SECTION A - B — SECTION C - D



PERTH
SHEET SH 50 - 14 AND PART OF SH 50 - 13

FIRST EDITION 1978