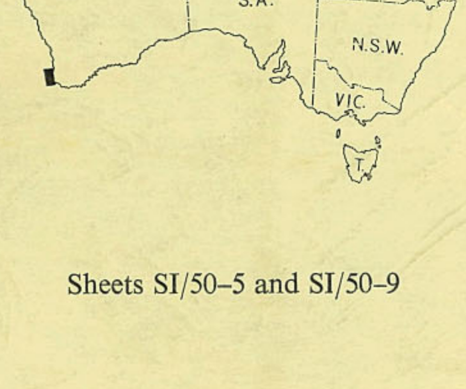
1 : 250,000

# GEOLOGICAL SERIES

EXPLANATORY NOTES

# BUSSELTON
## AND
# AUGUSTA
## WESTERN AUSTRALIA




Sheets SI/50–5 and SI/50–9

# WESTERN AUSTRALIA
# INDEX TO GEOLOGICAL MAPS
# 1:250,000 OR 4 MILE SCALE

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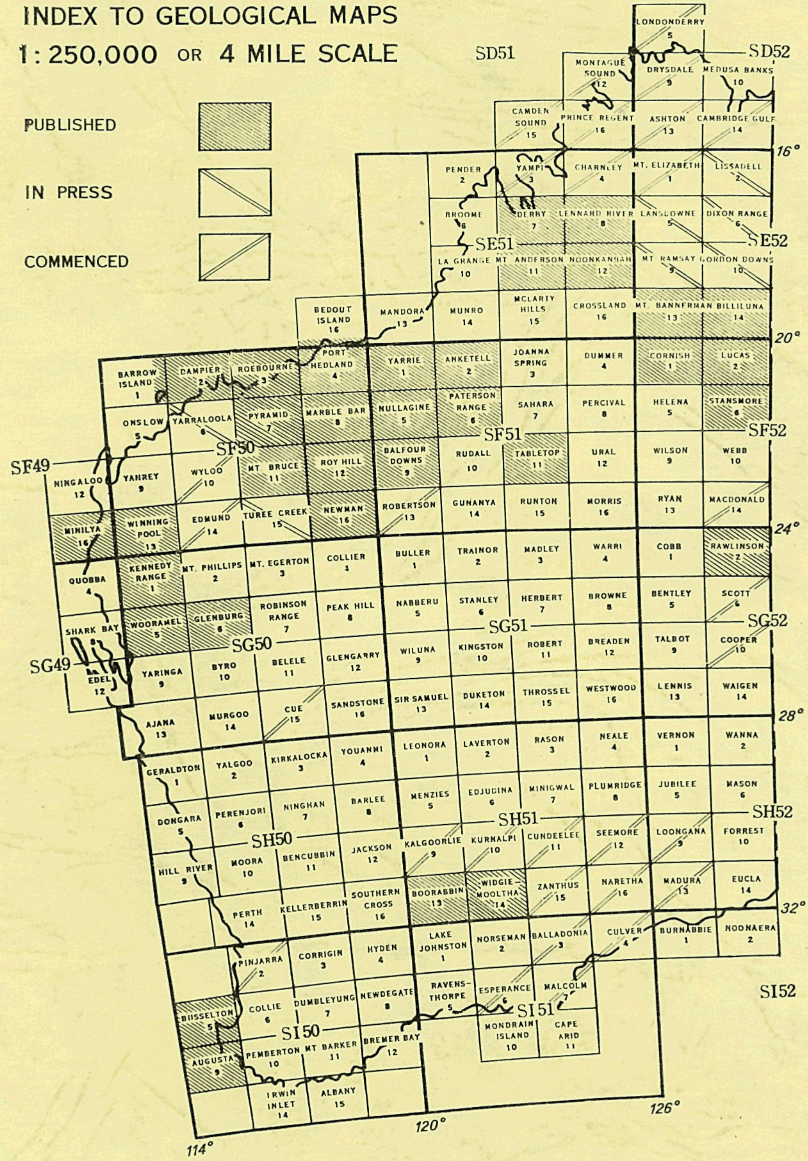

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1:250,000 GEOLOGICAL SERIES

EXPLANATORY NOTES

# BUSSELTON

AND

# AUGUSTA

## WESTERN AUSTRALIA

Sheets SI/50-5 and SI/50-9

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*Compiled by D. C. Lowry*

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*Under Secretary*: I. R. BERRY

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

*Director*: J. H. LORD

# Explanatory Notes on the Busselton and Augusta Geological Sheets

*Compiled by D. C. Lowry*

## INTRODUCTION

The Busselton and Augusta 1:250,000 Sheets, S1/50-5 and S1/50-9, are bounded by latitude 33° and 35° S and by longitudes 114° and 115° 30′ E. The main towns of Busselton and Augusta are 147 and 205 miles by road south of Perth.

### PHYSIOGRAPHY

The area can be divided into four physiographic provinces (see Figure 1): the Leeuwin-Naturaliste Ridge, the Swan Coastal Plain, the Blackwood Area, and the Scott Coastal Plain.

The Leeuwin-Naturaliste Ridge is composed of Precambrian crystalline rocks capped by laterite and sand. Along the coast, dune sand and limestone, overlying the Precambrian rocks, rise to 750 feet above sea level. The coast between Capes Leeuwin and Naturaliste has a rugged retrograding shoreline with small sandy bays between promontories of gneiss and limestone. Numerous caves are developed in the limestone and many of them have abundant calcite formations (stalagmites, stalactites, helictites, and flowstone). Four of the caves have been opened for public inspection: Jewel Cave near Augusta, Lake and Mammoth Caves near Witchcliffe, and Yallingup Cave.

The Swan Coastal Plain is underlain by Quaternary alluvium and littoral dunes. Along the coast of Geographe Bay there is a narrow belt of active dunes with lagoons on the landward side. The plains rise gently from the coast to an altitude of about 150 feet at the foot of the Whicher Scarp. This scarp, which separates the Swan Coastal Plain to the north from the Blackwood Area to the south, is an arcuate feature with a relief ranging from about 300 feet in the east to about 100 feet in the west. It runs from the Darling Scarp (east of the mapped area) to the Leeuwin-Naturaliste Ridge. The Whicher Scarp was once thought to be a fault scarp, but it is now believed to have been formed by marine erosion during the Pleistocene.

The Blackwood Area consists of undulating hills of Mesozoic sedimentary rocks capped with laterite and sand. The maximum elevation of about 500 feet is reached in the Whicher Range immediately south of the Whicher Scarp.

The Scott Coastal Plain is a low-lying swampy region, with remnants of dunes which form scattered hills and ridges, and a belt of lithified and active dunes along the coast. The swamps have resulted from blocking of the drainage by coastal dunes. The coast of Flinders Bay is actively prograding at present.

The Swan Coastal Plain and part of the Leeuwin-Naturaliste Ridge are cleared for dairying and for grazing beef cattle. The Blackwood Area is covered with jarrah forest (mainly State owned) which supports an important timber-milling industry. The eastern fringe of the dune limestone, between Margaret River and Augusta, supports karri forest, and the dune limestone opposite the eastern part of the Geographe Bay bears a tuart forest. Elsewhere the dune sand and limestone is generally scrub covered and undeveloped.

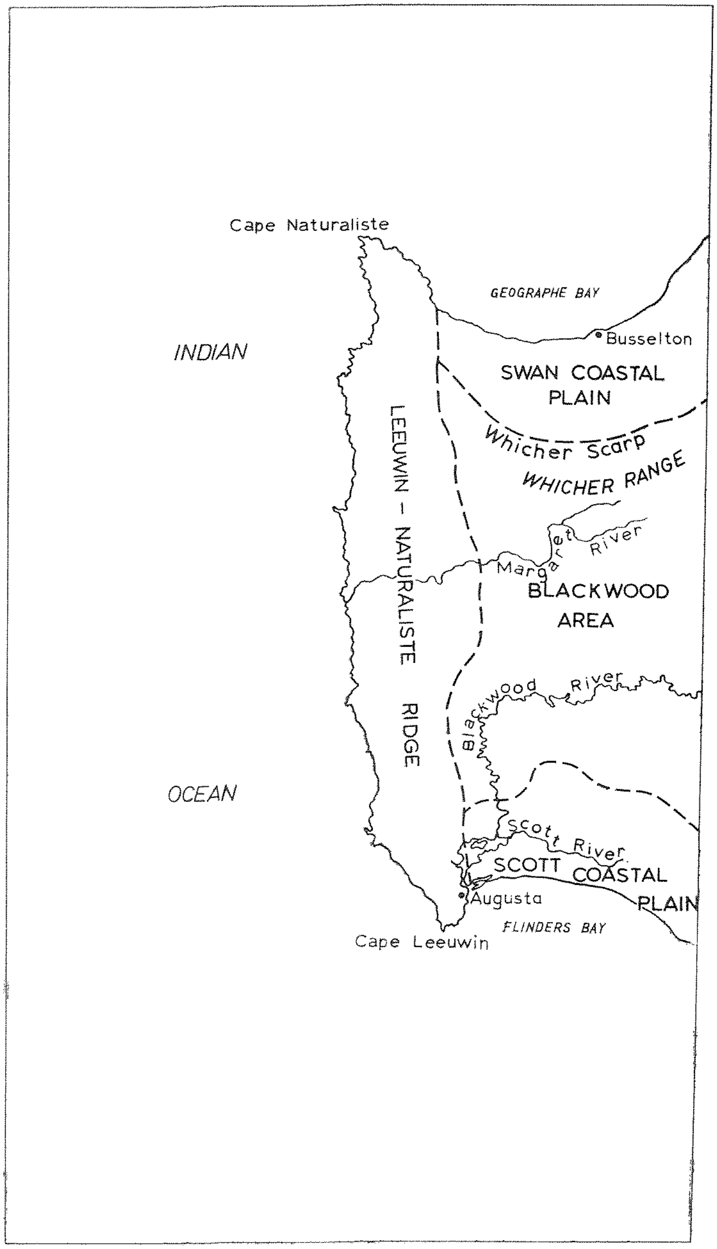


FIGURE 1

PHYSIOGRAPHIC PROVINCES

BUSSELTON AND AUGUSTA SHEETS S1/50-5, S1/50-9

SCALE OF MILES

10 0 10 20 30

The climate is warm with a high rainfall which is largely restricted to the winter months (see Table 1). Only three rivers (the Margaret, Blackwood and Scott Rivers) flow permanently.

TABLE 1

CLIMATIC DATA FOR THE BUSSELTON-AUGUSTA AREA

(based on records of 56 years or more)

| — | Mean rainfall (inches) | | | Average daily mean temperature (°F) | |
|---|---|---|---|---|---|
| | November–March | April–October | Total | November–March | April–October |
| Busselton .. .. .. | 3.10 | 29.68 | 32.78 | 67.1° | 56.4° |
| Cape Leeuwin .. .. | 4.58 | 33.96 | 38.54 | 66.2° | 59.3° |
| Cape Naturaliste .. .. | 4.94 | 27.35 | 32.29 | 66.9° | 58.2° |
| Margaret River .. .. | 4.58 | 41.51 | 46.09 | .. | |

### GEOLOGICAL INVESTIGATIONS

An early account of the geology of the dune limestone between Capes Leeuwin and Naturaliste was given by Simpson (1902). Saint-Smith (1912) later described the whole of the area covered by the Busselton-Augusta Sheet. Since then, particular aspects of the geology have been described by various workers: the dune limestone by Fairbridge and Teichert (1953), the iron ore by de la Hunty (1962) and Gregson (1962), the heavy mineral sands by McMath (1951), Low (1960), and Welch (1964), and the Mesozoic sedimentary rocks by Fairbridge (1953).

In 1963, R. C. Horwitz and I. Gemuts mapped the Precambrian rocks of the Busselton-Augusta Sheet, and D. C. Lowry mapped the younger sediments under the supervision of P. E. Playford. Horwitz prepared the parts of these notes dealing with the Precambrian rocks and he made use of petrological notes by Gemuts.

## STRATIGRAPHY

### PRECAMBRIAN

Crystalline rocks of Precambrian age are restricted to the Leeuwin Block. Outcrops are best on the coast, and along Hardy Inlet and the Margaret River.

Wilson (1958) has separated the Leeuwin Block crystalline rocks from most of the Archaean of the Precambrian of Western Australia and suggests that the Leeuwin Block has been affected by a younger Precambrian metamorphism.

Four layered units have been distinguished. Their order of superposition along the coast in the Cape Leeuwin region is (from lowest to highest): coarse-grained granulite, granite-gneiss, basic granulite, and medium-grained granulite. The granite-gneiss occurs elsewhere at different stratigraphic levels and locally intrudes the other units. It is thus best considered as the youngest unit.

As noted by Prider (1954), there are no basic dykes in the region.



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TABLE 2

STRATIGRAPHIC COLUMN—BUSSELTON AND AUGUSTA 1 : 250,000 GEOLOGICAL SHEETS

| Age | Map Symbol | Name or short Description | Thickness | Lithology | Remarks | Stratigraphic Relationships |
|---|---|---|---|---|---|---|
| Recent | Qra | Alluvium | 20 feet (maximum) | Mud, silt, and sand | Formed along major river courses | Unconformable on Mesozoic and Precambrian rocks |
| Recent | Qrg | Lagoonal and estuarine deposits | 20 feet (maximum) | Dark mud and silt | Formed parallel to Geographe Bay coast | Unconformable on Mesozoic and Precambrian rocks |
| Recent | Qrs | Sand dunes and beach ridges | 200 feet (maximum) | Calcareous sand with heavy mineral deposits in some areas | Mined for ilmenite at Wonnerup | Unconformable on Mesozoic and Precambrian rocks; disconformable on Coastal Limestone |
| Recent-early Pleistocene | Ql | Laterite and associated podzolic quartz sand | 15 feet (maximum) | Massive and pisolitic ferruginous laterite and quartz sand | In most areas, sand which formerly overlaid the laterite has been eroded and redeposited in valleys | Formed on Mesozoic and Precambrian rocks |
| Late Pleistocene | Qpc | Coastal Limestone | 500 feet (maximum) | Eolian calcarenite with minor occurrences of fossil soil and beach conglomerate | | Unconformable on Mesozoic and Precambrian rocks |
| | Qph | Shelly limestone member | 20 feet (maximum) | Shelly limestone | | |
| Late-middle Pleistocene | Qpa | Podzolised alluvium | 20 feet (maximum) | Podzolic quartz sand | Ferruginous laterite is developed beneath the surface and is adjusted to the present water table | Unconformable on Mesozoic and Precambrian rocks |
| Late-middle Pleistocene | Qpb | Podzolised beach ridges and foredunes | 50 feet (maximum) | Podzolic quartz sand | Ferruginous laterite is developed close to the present water table | Unconformable on Mesozoic and Precambrian rocks |
| Late-middle Pleistocene | Qpd | Podzolised sand dunes | 50 feet (maximum) | Podzolic quartz sand | Ferruginous laterite is developed close to the present water table | Unconformable on Mesozoic and Precambrian rocks |

TABLE 2—*continued*

| Age | Map Symbol | Name or short Description | Thickness | Lithology | Remarks | Stratigraphic Relationships |
|---|---|---|---|---|---|---|
| Lower Cretaceous (Albian-Aptian) | | Quindalup Beds | 110 feet (maximum) | Glauconitic sand, silt, and shale | Does not crop out | Probably overlies and interfingers with the Yarragadee Formation |
| Lower Cretaceous | Klb | Bunbury Basalt | 40 feet (maximum) | Tholeiitic basalt | Subsurface limits inferred from geophysical surveys | Underlaid and overlaid by Yarragadee Formation |
| Lower Cretaceous—Upper Jurassic | | Yarragadee Formation | More than 1,712 feet | Sandstone, siltstone and shale | Does not crop out | Upper part laps on to Precambrian rocks on margin of basin. Relationship to older sediments of Perth Basin is unknown |
| Precambrian | pCg | Granite-gneiss | In sheets of 1,000 feet (maximum) | Medium-grained, pink foliated potash feldspar and plagioclase, biotite, quartz rock | Occurs in sheets | Intrusive into Precambrian rocks: broadly concordant, locally discordant |
| | pCm | Medium-grained granulite | 2,000 feet (minimum) | Banded and foliated grey, medium-grained granitic rock | | Highest unit in region. Concordant and possibly interfingering with coarse-grained granulite |
| | pCb | Basic granulite | In bands of the order of 100 feet | Medium-grained, banded amphibole and amphibole-pyroxene rock | Could be a metamorphosed basic igneous rock, in which case it is older than pCg and younger than pCm | Concordant. In between coarse-grained granulite and medium-grained granulite |
| | pCc | Coarse-grained granulite | 200 feet (minimum) | Banded coarse-grained white rock with dark bands and segregations | | Lowest unit in region |

*Coarse-grained granulite*

The coarse-grained granulite is foliated and has coarse dark bands and segregations. In the hand specimen it is a white, saccharoidal rock with biotite and amphibole defining the folia. Thin-sections show that coarse plagioclase feldspar (bytownite) is predominant and is associated with dark-brown hornblende and sphene. The dark bands are composed of dendritic hornblende and black opaque minerals.

The unit is more than 200 feet thick and is overlain by granite.

*Basic granulite*

The basic granulite is a dark, banded rock. It occurs in bands each about 100 feet thick. It is a medium-grained amphibole and amphibole-pyroxene rock; orthopyroxene occurs in areas with the highest grade of metamorphism.

In the Cape Leeuwin region the basic granulite occurs as a single band above the granite; further north, it occurs as several bands which appear to be restricted to the lower part of the medium-grained granulite.

Wilson (1958) examined this unit at Bunker Bay (east of Cape Naturaliste) and suggested that it might be a metamorphosed basic intrusive rock. If this is correct, the basic granulite is younger than the other granulites, but older than the granite-gneiss.

*Medium-grained granulite*

The medium-grained granulite is a grey rock, granitic in composition and well foliated and banded. Some bands are richly garnetiferous. It is more than 2,000 feet thick, and is the highest unit exposed, forming, with the granite-gneiss, the bulk of the Precambrian in this region.

*Granite-gneiss*

Granite-gneiss is widely distributed throughout the area. It usually occurs as concordant bodies. However, locally it can be discordant and intrusive, for example at Cowaramup Bay, where it contains numerous xenoliths of basic granulite. At the contact with these rafts the granite-gneiss is contaminated and more melanocratic.

The granite-gneiss is a pink biotite rock, usually well foliated. In thin section, the rocks are seen to be composed mainly of potassic feldspar and perthite with subordinate plagioclase. The quartz is granulated and strained. A specimen from a locality where the granite-gneiss is intrusive shows a predominance of potassic feldspar, minor plagioclase, and subordinate "basketwork" perthite; quartz is ubiquitous and myrmekitic intergrowths usually occur at the quartz-feldspar interface. Brown hornblende, magnetite, and cordierite are accessories.

Granite-gneiss is present as a sheet at the top of the coarse-grained granulite; other sheets occur throughout the sequence above this contact. North of Augusta, along Hardy Inlet, a single pod of granite-gneiss was observed in the coarse-grained granulite. The main sheets are about 1,000 feet thick.

## JURASSIC—CRETACEOUS

*Yarragadee Formation*

Sedimentary rocks of Upper Jurassic to lower Cretaceous age, correlated with the Yarragadee Formation, underlie the Quaternary deposits of the southern part of the Perth Basin. The rocks do not crop out in the area and are known only from bores and wells.

The rocks are weakly lithified sandstone, siltstone, and shale, with minor lignite and pyrite. The thickest section penetrated is 1,712 feet thick in the Abba River No. 1 Bore. Balme (*in* Low, 1958, p. 31) found a Lower Cretaceous microflora in the upper part of the bore and an Upper Jurassic microflora in the lower part. Palynological examination of samples from two wells (9 miles east and 9 miles northeast of Margaret River) by Edgell (1963b) showed that the sediments there are non-marine and of Lower Cretaceous age. The formation is believed to be largely a fluviatile deposit, but the upper (Lower Cretaceous) part also includes paralic sediments. It probably overlies a thick sequence of Middle to Lower Jurassic, Triassic, and Palaeozoic rocks.

The Mesozoic stratigraphy of the southern part of the Perth Basin was first outlined by Fairbridge (1953), who proposed the name Capel River Group for the sequence comprising the Donnybrook Sandstone, Blackwood Shale, Fly Brook Shale, and Warren River Sandstone. According to this subdivision, the Mesozoic sediments of the mapped area would probably belong to either the Fly Brook Shale or the Blackwood Shale. However, these two units are poorly defined and seem to be lithogically indistinguishable. The only valid formation in Fairbridge's Capel River Group appears to be the Donnybrook Sandstone, which occurs to the east of the mapped area. Therefore the group name and the other formation names have not been used. The sequence is referred to the Yarragadee Formation, a thick continental and paralic deposit defined in the northern part of the Perth Basin (McWhae and others, 1958).

*Bunbury Basalt*

The Bunbury Basalt is a tholeiitic basalt flow which occurs in a north-south belt along the eastern side of the Perth Basin south of Bunbury, and extends westwards into the southern part of the mapped area. It has been examined petrologically by several workers, including Edwards (1938) and Trendall (1963). The basalt crops out in two small areas on the Busselton-Augusta sheet; at Scott River, and on Hammersley Road, 12 miles to the northeast. These outcrops are in the form of scattered boulders lying in soil, but better exposures, to the east of the mapped area (e.g. at Black Point), reveal well-developed columnar jointing. The subsurface distribution of the basalt has been inferred from aeromagnetic and gravity surveys (Felcman and Lane, 1963). The basalt has been encountered in Abba River No. 3 Bore between 179 and 219 feet, and in three seismic shot holes 6 miles north of Lake Gingilup.

In hand specimen, the basalt is dark grey, and is commonly porphyritic and vesicular. In thin-section, the rock is seen to be either porphyritic or microporphyritic. The phenocrysts are glomerocrysts of andesine crystals with oscillatory zoning in the composition range $An_{56-62}$, and having a marginal zone of labradorite (about $An_{45}$). The groundmass is made up of laths of labradorite, grains of pyroxene (pigeonite where determinable), glass, and opaque minerals (Trendall, 1963).

The Bunbury Basalt may represent a single lava flow which spread across the southern part of the Perth Basin. The outcrop at Scott River is separated from the main body of basalt. However, as the two bodies are petrologically very similar, they were probably once continuous and were separated by erosion. The age of the Bunbury Basalt has been determined as Lower Cretaceous by palynological methods. The most precise determination is that of Edgell (*in* Emmenegger, 1963) from the Eaton No. 1 Bore, where he found that the sediments both above and below the basalt had the same microflora which is "Lower Cretaceous, possibly Upper Neocomian" in age.

*Quindalup Beds*

The name Quindalup Beds is proposed for the glauconitic sediments encountered in bores and wells 12 miles west of Busselton. Insufficient is known of the lithology and stratigraphic relationships of the unit to name it as a formation. The name is taken from the Quindalup railway siding and the type section is designated as the beds between 10 feet and 25 feet in the well on Sussex Location 182, situated 1.8 miles north-northeast of the siding. The section in the well (after Simpson, 1951) is as follows:

0-10 feet: Quartz sand, white and yellow

10-17 feet: Greensand, composed of glauconite, siderite, and calcite, with minor quartz and garnet. (1.86 per cent acid-soluble potassium oxide).

17-21 feet: Glauconitic clay, composed of glauconite and kaolin. (4.2 per cent acid soluble potassium oxide).

21-25 feet: Greensand, composed of glauconite and quartz with minor kaolin. (2.22 per cent acid-soluble potassium oxide).

Descriptions by property owners and drillers indicate that the glauconitic sediments (mostly shale and siltstone, with some sandstone) attain a maximum thickness of 110 feet. The unit is known from an area of about 3 square miles. It appears to grade laterally into dark shale. There is an isolated occurence of a glauconitic sand in a bore 5 miles to the south over the intervals 26 to 29 feet and 32 to 46 feet which may represent the Quindalup Beds, although there are no reports of glauconite in bores in the intervening area.

A sample of glauconitic silt, from a depth of 15 feet in a well 1,200 yards southwest of the type section, was examined by Edgell (1964), who reported microplankton, spores and pollen indicating an Albian to Aptian age. The unit is overlain by 10 to 20 feet of Quaternary sand, and is thought to be underlain by, and to interfinger with, the Yarragadee Formation.

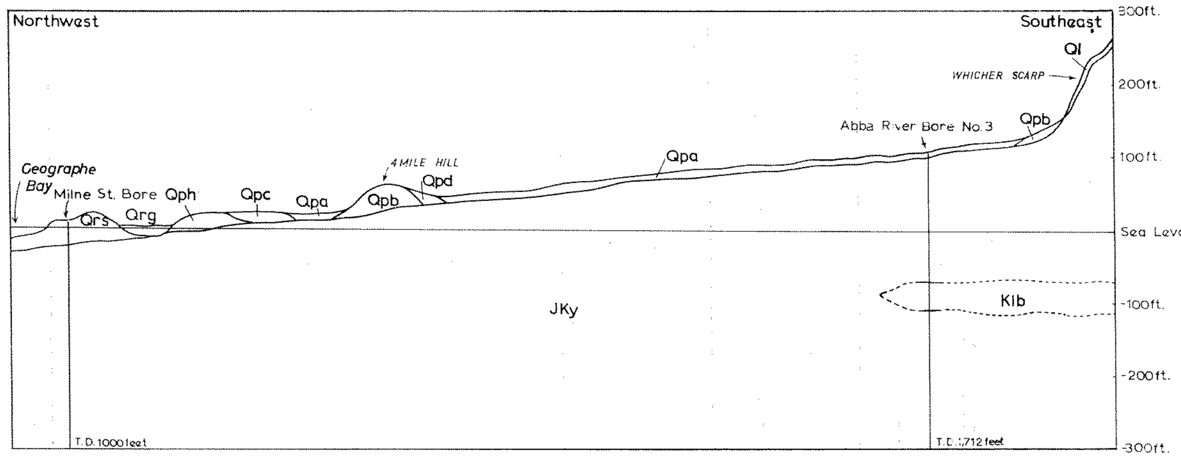
## PLEISTOCENE

### *Podzolised sand dunes*

Podzolised sand dunes are found 1 to 9 miles inland in belts parallel to the coast of Flinders Bay and Geographe Bay, and also occur in a small area 5 miles northwest of Augusta, parallel to the Leeuwin-Naturaliste coast. The dunes are now composed of leached, well-rounded quartz sand which overlies ferruginous laterite developed close to the present water table. They are thought to have formed in the middle and late Pleistocene.

The dunes can still be recognised by their topography, although they have been modified by streams which have cut through the dunes, and by rain and groundwater which have reduced the relief by dissolving out calcium carbonate. These older dunes are believed to have once been strongly calcareous, resembling the dunes forming at present, and the quartz sand that remains after leaching of the calcium carbonate may be only a small part of the original volume of the dunes.

The podzolised dunes on the Swan Coastal Plain are associated with a series of podzolised Pleistocene beach ridges and foredunes. There is a large area of podzolised dune sand parallel to the coast of Flinders Bay, but the ancient strand line associated with it has not been recognised.




REFERENCE

| | | |
|---|---|---|
| RECENT | Qrs | Sand dunes and beach ridges |
| | Qrg | Lagoonal and estuarine deposits |
| RECENT TO EARLY PLEISTOCENE | Ql | Laterite and associated quartz sand |
| LATE PLEISTOCENE | Qpc | Coastal Limestone |
| | Qph | shelly limestone member |
| LATE TO MIDDLE PLEISTOCENE | Qpa | Alluvium (Now podzolised) |
| | Qpb | Beach ridges and foredunes (Now podzolised) |
| | Qpd | Dunes (Now podzolised) |
| LOWER CRETACEOUS | Klb | Bunbury Basalt |
| UPPER JURASSIC TO LOWER CRETACEOUS | JKy | Yarragadee Formation |

FIGURE 2

DIAGRAMMATIC CROSS SECTION THROUGH THE SWAN COASTAL PLAIN SOUTHEAST OF BUSSELTON

SCALE RELATIONSHIP: $\frac{V}{H} = \frac{40}{1}$

HORIZONTAL SCALE (MILES): 0, 1, 2, 3 Miles, 4 Miles

VERTICAL SCALE (FEET): 0, 100, 200, 300, 400, 500 Feet

*Podzolised beach ridges and foredunes*

A series of beach ridges and associated foredunes accumulated during successively lower still-stands of sea level during the Quaternary. The deposits are preserved in narrow bands on the Swan Coastal Plain parallel to the coast of Geographe Bay and range up to 250 feet above present sea level (see Figure 2 and Table 3). Since their accumulation, all but the two youngest bands have been leached (podzolised) by acid groundwater, in the same manner as the Pleistocene dunes. The succession of deposits provides an interesting record of the progressive alteration of the initially calcareous sand (see Table 3). There is no corresponding set of littoral deposits discernible on the Scott Coastal Plain although there is a possible occurrence of a single foredune, north of Lake Gingilup, at an altitude of about 90 feet.

TABLE 3

QUATERNARY BEACH RIDGES AND FOREDUNES OF GEOGRAPHE BAY

| Approximate Elevation | Lithology | Location | Comments and References |
|---|---|---|---|
| 0–5 feet | Unconsolidated calcareous sand | On the present coast | Mined for ilmenite at Wonnerup. " Quindalup System " of McArthur and Bettenay (1960). Described in these notes under " Recent dune sands and beach ridges " |
| 10-15 feet | Shelly limestone | 1½ miles south of Busselton | Correlated with " Spearwood System " of McArthur and Bettenay (1960). Described in these notes under " Coastal Limestone " |
| 25 feet (approximately) | Podzolic quartz sand overlying laterite or ferruginous sandstone | Prominent ridge on eastern of Geographe Bay, running close to Ludlow | Mined for ilmenite at Capel, 3 miles east of the mapped area. Correlated with " Bassendean System " of McArthur and Bettenay (1960). See also Welch (1964) |
| 60 feet (approximately) | Podzolic quartz sand overlying laterite or ferruginous sandstone | 1½ miles south of Quindalup Railway Siding | Developed on western side of Geographe Bay |
| 130–150 feet | Podzolic quartz sand overlying laterite. Ilmenite largely altered to leucoxene | Developed along foot of Whicher Scarp | Mined at Yoganup, 5½ miles east of the mapped area. Correlated with " Ridge Hill Shelf " of McArthur and Bettenay (1960). See Welch (1964) and Morgan (1964) |
| 250 feet (approximately) | Laterite | Part way up Whicher Scarp | Erosional remnants too small to map. " Middle Escarpment Shoreline " of Welch (1964) |

The physiographic conditions existing in Geographe Bay at intervals during the Quaternary were favourable for the concentration of heavy minerals in the beach ridges and foredunes. Ilmenite is the dominant heavy mineral, but there are also garnet, zircon, monazite, and traces of rutile, epidote, cassiterite, sillimanite, spinel, staurolite, tourmaline, and kyanite.

The internal structure of the deposits can be seen in excavations for heavy minerals at Capel and Yoganup (3 miles and 5½ miles east of the mapped area). At these localities a basal beach conglomerate is overlain by 2 or 3 feet of concentrated mineral beach sand, and this in turn is overlain by about 20 feet of less-concentrated foredune mineral sand. The basal conglomerate in the Yoganup pit is made up of pebbles and cobbles of weathered quartzite. The conglomerate at Capel includes boulders of kaolinised Bunbury Basalt in addition to cobbles of quartzite.

Abundant mollusc casts occur in deposits isolated from the main beach ridges at two localities. Seven miles southwest of Busselton, at an altitude of 80 feet, they occur in a massive vesicular sandy laterite, and 5 miles southwest of Busselton, at an altitude of about 30 feet, they occur in a ferruginous sandstone. The shells probably accumulated as a beach deposit, and Edgell (1963a) regarded them as being Quaternary in age. The region is tectonically stable and it is likely that the strand-line movements were purely eustatic, so that comparison with elevated deposits and terraces in other countries could provide an accurate dating of the various beach ridges. Unfortunately the elevation data on the still-stands, represented by the Quaternary deposits of the Busselton area, are not sufficiently precise to make such correlations with confidence. However, it is possible that the four lowest deposits correlate with the Flandrian, Epi-Monastirian, Late Monastirian, and Main Monastirian interglacial sea levels of the European standard. The Yoganup deposit may correlate with the Milazzian or Tyrrhenian sea levels, and the highest (unmapped) deposit with the Sicilian sea level. If this is correct, the mapped podzolised beach ridges and foredunes range in age from the Mindel-Riss Interglacial period to the end of the Riss-Würm Interglacial period.

*Podzolised alluvium*

Part of the Swan Coastal Plain and some small terraces along the Blackwood River are built of Pleistocene alluvium which has later been podzolised. The surface is covered with quartz sand (usually fine to medium-grained, and subangular), and below the surface a ferruginous laterite is developed close to the present water table. The Swan Coastal Plain appears to be underlain by about 20 feet of sand, silt, and clay, but the thickness of these deposits is uncertain because the boundary between the alluvium and the underlying Yarragadee Formation is difficult to recognise.

Deposition of alluvium on the plains has probably occurred intermittently since the sea last retreated from the Whicher Scarp, that is, since the Mindel-Riss Interglacial period.

*Coastal Limestone*

The Coastal Limestone consists dominantly of eolian calcarenite, but also included in this unit are minor occurrences of marine limestone, fossil soil, and beach conglomerate. A shelly limestone near Geographe Bay is sufficiently widespread to be mapped as a separate member.

The eolianite is best developed along the coast between Capes Leeuwin and Naturaliste, where it is piled on Precambrian rocks to a height of 750 feet above sea level and is possibly as much as 500 feet thick. The limestone is also developed in a belt parallel to the coasts of Flinders Bay and Geographe Bay.

The eolianite is made up of rounded, frosted quartz sand together with 10 to 90 per cent calcium carbonate sand. Minor constituents include feldspar, sponge spicules, and heavy minerals. The carbonate fraction (approximately 5% magnesium carbonate and 95% calcium carbonate) consists of comminuted molluscs and calcareous algae, and foraminifera (Fairbridge, 1953).

The conversion of a loose calcareous sand into a hard limestone begins soon after the dune accumulates. The movement of meteoric water through the sand causes a redistribution of calcium carbonate. The mass of the dune becomes lithified, and below the water table both lithification and cave formation by solution take place (Bastian, 1964).

A hard 'cap rock' of secondary calcium carbonate is exposed in places on the older dune, and elsewhere it is buried to a depth of 10 feet beneath red or grey leached quartz sand. Two conspicuous features of the Coastal Limestone are strong cross-bedding and the occurrence in some areas of hard, ramifying, tubular structures, caused by calcification around tree roots.

Fossil soil horizons are exposed in some of the coastal cliffs and caves, and have been described at Hamelin Bay by Fairbridge and Teichert (1953). They also described a beach conglomerate at Cowaramup Bay (the 'Cowaramup Conglomerate') said to have formed when the sea was 5 to 15 feet higher than present. Similar conglomerates occur at Bunker Bay (up to 30 feet above present sea level) and northwest of Cape Leeuwin (10 feet above present sea level), but it is doubted that these small lenticular bodies warrant the status of formations.

A succession of dunes of different ages within the Coastal Limestone can be recognised at different places along the coast, but correlation from one area to another is not yet possible. The fossils contained in the Coastal Limestone all belong to species found living along the coast and the formation is clearly of Quaternary age. A more precise age of the Coastal Limestone can be deduced from the elevation of wave-cut platforms and marine members, and Fairbridge and Teichert (1953) and McArthur and Bettenay (1960) concluded that the oldest limestone was formed during the First Würm Interstadial period. However, the presence of podzolised beach ridges and dunes that probably date back to the Mindel-Riss Interglacial period show that, although conditions did not permit its preservation, eolian limestone was formed much earlier than the First Würm Interstadial.

Spelean deposits containing the remains of extinct marsupials were found in two caves in the Coastal Limestone near Margaret River: Mammoth Cave (Glauert, 1948) and Strong's Cave (Cook, 1963).

They include *Nototherium, Phascolomys hacaketti* (a wombat), *Thylacoleo* (the 'marsupial lion'), *Zaglossus hacketti* (a large echidna), *Sthenurus occidentalis* (a kangaroo-like marsupial), and *Protemnodon anak* (a large wallaby). The remains of several other marsupials, which are now extinct in the vicinity of the caves but live in other parts of Australia, were also found. They include *Phascolarctos cinereus* (the koala), *Sarcophilus harrisi* (the Tasmanian devil), *Thylacinus cynocephalus* (the Tasmania wolf or tiger), and *Setonix brachyurus* (the quokka).

A member of the Coastal Limestone is distinguished on the map south of Busselton. It is a narrow band of limestone which contains abundant shells of marine molluscs, and in one locality, heads of coral. It is thought to be a beach deposit which was formed when the sea level was about 8 to 15 feet higher than at present, possibly during the Epi-Monastirian high sea level of the Pleistocene.

*Laterite and associated quartz sand*

Laterite and associated quartz sand are widely developed in the Busselton-Augusta area. Limonitic laterite covers hills underlain by Mesozoic and Precambrian rocks, and the sand that once covered the laterite has been washed into the valleys. These areas are mapped as 'Laterite and associated quartz sand, undifferentiated'. The laterite is part of a dissected soil profile that was originally as follows:

0-10 feet: podozolic quartz sand
10-15 feet: ferruginous laterite
15-35 feet: weathered rock
35 feet: unweathered rock

Dissection is deep enough in some places on the Leeuwin-Naturaliste Ridge to expose unweathered Precambrian rock beneath the laterite, but where laterite is developed on Yarragadee Formation, dissection is nowhere sufficient to expose the formation, and the slopes below the laterite are mantled with soil and laterite debris. The laterite is massive and vesicular, or pisolitic.

The age of the oldest dissected laterite in the mapped area is believed to be Pleistocene, contrary to the usual belief that laterite in Western Australia formed in the Tertiary. The dissected laterite conforms to the present topography, and with the possible exception of the lower part of the Margaret River, there has been no major deepening of stream valleys since its formation. In flat parts of the Leeuwin-Naturaliste Ridge (for example near Cowaramup and Witchcliffe), the laterite has undergone little dissection and in some places it occurs close to the water table. Thus in most areas the dissected laterite is thought to have formed during the Pleistocene, but in small parts of the Leeuwin-Naturaliste Ridge a Recent age is more likely. Climate is thought to have a controlling influence on the development of laterite, and as the climate of the area probably fluctuated during the Pleistocene glacial and interglacial periods, conditions suitable for laterite formation are likely to have occurred several times.

Laterite is forming today in many areas of Pleistocene sediments. It is developed at the water table and is overlain by quartz sand formed by podzolisation of the sediment. The origin of the Pleistocene sediments can be deduced from the character of the sand and from the geomorphology of the deposits, and they are subdivided into alluvium, beach ridges, and dunes, The Recent laterite is described in this section in order to illustrate the development of the older dissected laterite, as they are believed to have similar origins.

At Scott River, Recent laterite is particularly well developed in dune sand. It is classed as an iron ore and contains up to 54.6 per cent iron (de la Hunty, 1962). Excavations show that the laterite is about 5 feet thick and is underlain and overlain by sand composed of medium to coarse-grained, well-rounded, frosted quartz grains. The overlying quartz sand is usually a foot or two thick, but in some places it has been washed off. The vesicular laterite encloses small pockets and channels of sand, and it contains limonitic pseudomorphs of charcoal fragments similar to those found in the soil after a present-day forest fire. The upper surface of the laterite is flat and the lower surface interfingers with the underlying sand; these surfaces roughly coincide with the upper and lower limits of the annual fluctuation of the water table. The dunes are believed to have once been calcareous before acid groundwater leached out calcium carbonate and deposited limonite. In other regions, laterite is generally thought to be an illuvial soil horizon formed by the precipitation of iron oxides leached from the material above. However, the development in the Scott River area of a high concentration of iron, in what was once a clean quartz—calcium carbonate sand, shows that lateral movement of groundwater was important in transporting the iron, probably from the older dissected laterite of the Blackwood Area.

Laterite is also developed at the present water table in the Pleistocene alluvium which forms parts of the Swan Coastal Plain and the terraces along the Blackwood River. The laterite developed in alluvium tends to be more clayey and sandy than in adajacent dune sand of the same age. The higher concentration of iron in the dune sand is probably due to its greater permeability; but it could be due to the reaction of the groundwater with the calcium carbonate originally present in the dune sand. The following section through laterite is exposed in a large well 2 miles southwest of Carbunup which is used for irrigation and is regularly pumped dry.

- 0-1 foot: White clayey sand
- 1-3 feet: Mottled light-yellow and grey sandy clay with laterite nodules
- 3-4 feet: Weakly lithified laterite with light-grey sandy clay
- 4-8 feet: Massive vesicular laterite with fossil wood, becoming less strongly lithified towards the top
- 8-22 feet: Light grey medium-grained clayey sand

The lowest level of the water table at this locality during the summer is close to the top of the massive laterite, and in winter it is at the ground surface. Similarly, in other parts of the Busselton Plains, the lowest annual level of the water table (attained in March or April) is at the top of the laterite or within it. The precise relationship varies from one area to another, possibly because of a recent alteration in the water table due to the clearing and draining of the land for farming. Water drawn from wells sunk through laterite is acidic, and hydrated iron oxides are precipitated on aeration of the water.

The close adjustment of the laterite to the present water table in Pleistocene alluvium, dunes, and beach ridges indicates that the lateritisation has occurred during the Recent, and the high iron content of the ground water suggests that the process is continuing at the present time. The process of lateritisation is not fully understood, but it is generally agreed that climate has a controlling influence. The features of the climate in the Busselton-Augusta area (see Table 1) are its warmth and the occurrence of a moderately heavy rainfall restricted to the winter months. It is likely that these conditions are also typical of those under which the older laterite formed.

## RECENT

### *Sand dunes and beach ridges*

Dunes of calcareous sand, which are mobile in some places and elsewhere fixed by vegetation, are developed intermittently along the coast. The largest dune mass is the Boranup Sand Patch near Augusta, which is about 200 feet thick and covers more than 2 square miles. Accumulations of heavy minerals (notably garnet, ilmenite, and zircon) are present in places in the foredunes and beach ridges along the coast of Geographe Bay and between Capes Leeuwin and Naturaliste.

*Lagoonal and estuarine deposits*

Deposits of clay and silt have filled lagoons and estuaries behind the shoreline of Geographe Bay in Recent times. There are several square miles of low-lying land where bores and wells intersect about 20 feet of these deposits, which consist of black mud and silt with lenses of shells and partly decomposed plant remains.

*Alluvium*

Alluvial deposits of Recent age are developed on the flood plains of the large rivers. The deposits are generally about 20 feet thick, but are probably considerably thicker along the lower reaches of the Blackwood River.

## STRUCTURE

There are two main structural elements in the area mapped: the Leeuwin Block of Precambrian rocks, and the Perth Basin. These are separated by the Dunsborough Fault.

### LEEUWIN BLOCK

Gentilli and Fairbridge (1951) referred to the ridge of Precambrian rocks between Capes Leeuwin and Naturaliste as the "Leeuwin-Naturaliste Horst". However, the aeromagnetic survey indicates that there is no fault on the western side. The term 'horst' is therefore inappropriate, and the name "Leeuwin Block" is proposed.

All the Precambrian rocks are tightly folded. Fold axes trend north in the Cape Leeuwin area, swinging to northwest in the north. Reversal of the plunge of folds is frequent, resulting in a pattern of domes and basins.

### PERTH BASIN

The eastern part of the mapped area lies at the southwestern extremity of the Perth Basin, and its structure is broadly known from geophysical surveys conducted by the Commonwealth Bureau of Mineral Resources or by petroleum exploration companies subsidised under the Commonwealth Petroleum Search Subsidy Acts. The reports are as follows: seismic, Lodwick (1962) and Frankovitch (1964); aeromagnetic, Quilty (1963); and gravity, Thyer and Everingham (1956) and Felcman and Lane (1963). Cross-section A-B is based on the detailed surveys of Frankovitch (1964) and Felcman and Lane (1963).

The surveys show that the southern part of the Perth Basin is a graben bounded by the Darling Fault on the east and the Dunsborough Fault on the west. They indicate a maximum thickness in the mapped area of about 20,000 feet of gently dipping or horizontal sedimentary rocks, disrupted by several large faults.

The Dunsborough Fault is believed to be the largest fault in the area. It was first recognised by Woodward (1917) and its existence has since been confirmed by geophysical surveys. The fault has no topographic expression except at its southern end, where it is marked by a small scarp that extends from 5 miles to 10 miles north of Augusta. Felcman and Lane (1963) calculated from gravity data that the throw

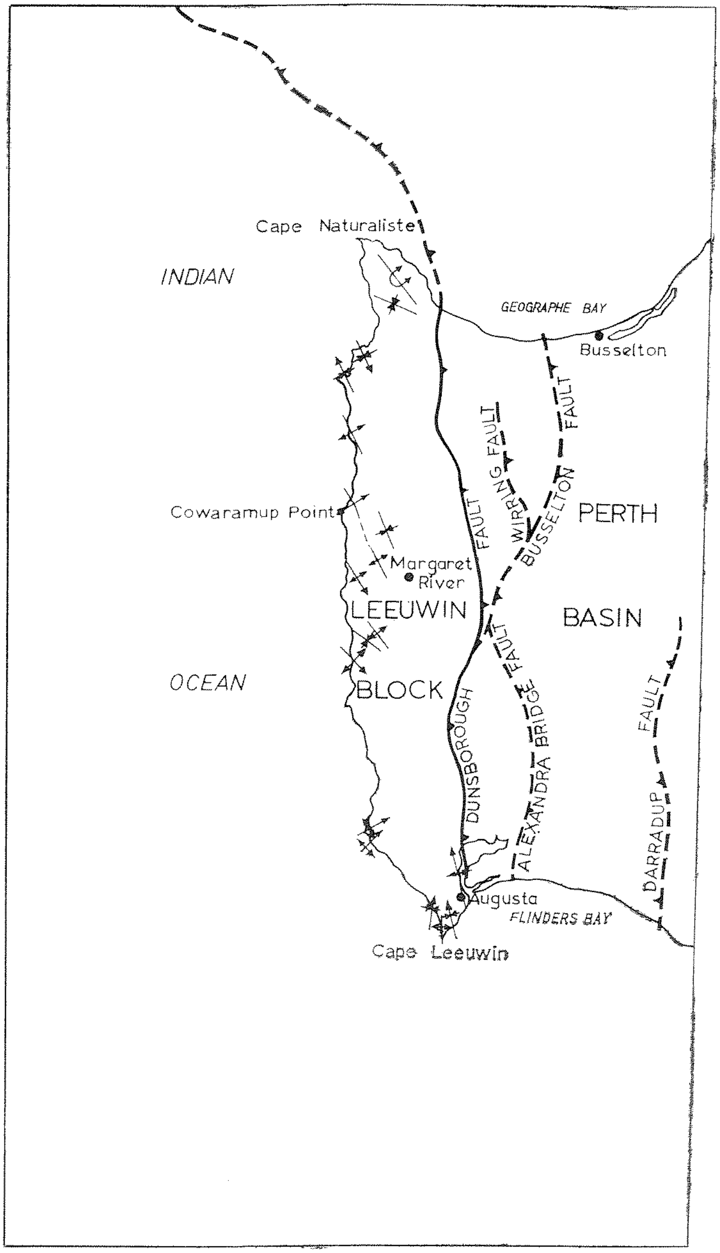
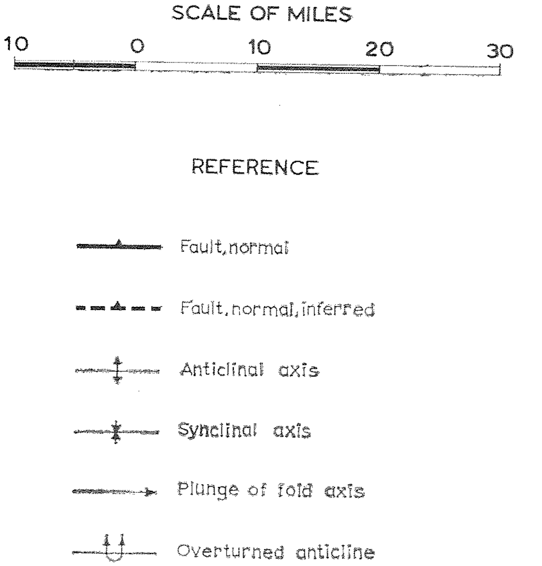



FIGURE 3

## STRUCTURAL SKETCH MAP

BUSSELTON-AUGUSTA SHEETS S1/50-5, S1/50-9



of the fault ranges from about 15,000 feet near Rosa Glen to about 10,000 feet near Augusta.

Near Rosa Glen, the Dunsborough Fault is joined from the north by the Busselton Fault, which for most of its length lies roughly parallel to and 10 miles east of the Dunsborough Fault. Six miles further north, the Busselton Fault is joined by the Wirring Fault, which also has a northerly trend and lies mid-way between the other two faults. The Wirring and Busselton Faults were mapped by Felcman and Lane (1963) and confirmed by the seismic survey of Frankovitch (1964).

South of Rosa Glen, gravity and aeromagnetic data indicate the presence of another fault (the Alexandria Bridge Fault) aproximately parallel to the Dunsborough Fault and 6 miles to the east of it. All these faults are thought to have a normal east-block-down displacement of several thousand feet.

The aeromagnetic survey suggests a large north trending fault with west-block-down displacement passing to the east of Busselton. Gravity and seismic surveys confirm the existence of this fault (the Darradup Fault) in the southern part of the area, and indicate that its throw increases southwards to reach 5,000 feet near Flinders Bay.

The early tectonic history of the Perth Basin in the mapped area is virtually unknown. Deposition of the thick Yarragadee Formation marked an important period of subsidence and deposition from the Upper Jurassic to the Lower Cretaceous. The Bunbury Basalt possibly reached the surface by way of the Darling Fault, and its eruption in the Lower Cretaceous may have marked a period of movement on the fault. Since the Lower Cretaceous there has been no major subsidence in this part of the Perth Basin. Movement on the Dunsborough Fault is believed to have ceased shortly before the close of deposition of the Yarragadee Formation. The younger part of the formation apparently laps over the fault on to the Leeuwin Block; three bores, each about a third of a mile west of the position of the fault as determined by the gravity survey, penetrated between 20 and 70 feet of sediment without reaching basement. There is no evidence of later tectonism, and it seems probable that the area has been stable since the lower Cretaceous.

# ECONOMIC GEOLOGY

## UNDERGROUND WATER

The main regions of farming are the Swan Coastal Plain and the Leeuwin-Naturaliste Ridge. In this area more than 1,400 wells (5 to 30 feet deep) draw supplies of 1,000 to 2,000 gallons per day for stock and domestic use. On the Swan Coastal Plain, the wells draw water from the laterite and the kaolinised zone, or from the underlying Yarragadee Formation. In some instances shallow wells, having poor yields because of low permeability, have been successfully replaced by excavations 10 to 20 feet deep and about 20 yards across. On the Leeuwin-Naturaliste Ridge, wells sometimes obtain water from the laterite and the underlying weathered zone, or, more commonly, from sand that has washed from hillsides and accumulated in the valleys.

In the Perth Basin, water is readily obtained from the Yarragadee Formation. Drilling suggests that the sediments are markedly lenticular. It has not been possible to trace individual aquifers from one bore to another, and the success of a bore depends on whether it intersects a suitable porous sand. More than 120 bores are used for farm supplies and it can be seen from the following data that they have an average depth of about 60 feet, and that the bores have rarely had to be drilled beyond 150 feet to obtain supplies of 1,000 to 2,000 gallons per day.

Depth 30- 50 feet: 39 bores
51- 70 feet: 37 bores
71-100 feet: 20 bores
101-150 feet: 20 bores
more than 150 feet: 7 bores

The quality of water from bores and wells in this part of the Perth Basin is almost always suitable for stock, and is usually suitable for domestic use, although the iron content is sometimes objectionably high. The groundwater of the Leeuwin-Naturaliste Ridge is usually potable, but in one area at least (Augusta township) some wells yield water too saline for domestic use.

Large supplies of water are avilable from the Yarragadee Formation; Busselton is supplied by several bores, each about 500 feet deep, that give artesian flows of up to 15,000 gallons per hour. Geological and hydrological data are available on four exploratory water bores supervised by the W.A. Geological Survey: Milne Street Bore (Passmore, 1962) and Abba River Bores Nos. 1 to 3 (Low, 1958).

Because of the large number of wells and bores in the mapped area, only those mentioned in the text are shown on the map.

## MINERAL BEACH SANDS

Heavy minerals are being mined from small deposits in the Recent beach ridge and dunes near Wonnerup. The ilmenite is sold, and at present the remaining heavy minerals (garnet, and small quantities of zircon and monazite) are being stockpiled. Other heavy mineral deposits of economic value possibly exist in the mapped area: the Pleistocene beach ridges near Capel and along the foot of the Whicher Scarp are being mined a few miles to the east of the map boundary. Ilmenite (for the preparation of paint pigment) is the most important mineral, but zircon, monazite, rutile, and leucoxene are also separated and sold.

## LIMESTONE

Large quantities of calcium carbonate are available along the coast in the form of lime sand and limestone. Haphazard sampling (see Simpson, 1948) indicates that these deposits are suitable for fertiliser, but little else. The lime sands are easier to mine than the limestone, and most sampling has been carried out on sands. It is estimated that there are some 500 million tons of easily won sand having a calcium carbonate content of 74.3 to 83.0 per cent in the largest deposit, the Boranup Sand Patch.

The 'cap rock' on the Coastal Limestone has a much higher proportion of calcium carbonate than the limestone on which it is developed, and is as high as 95.3 per cent at Margaret River, but it is unlikely to be of commercial value because of variations in thickness and grade.

## PETROLEUM

Geophysical surveys carried out in the part of the Perth Basin covered by the map have shown the presence of a considerable thickness of sediments and have indicated that there are several structures with indications of closure (Frankovitch 1964). Not enough is known of the subsurface stratigraphy to predict that suitable source and reservoir rocks are present in the area. However, the stratigraphy is expected to be similar to that in the northern and central parts of the Perth Basin, where petroleum has been discovered (oil and gas at Yardarino, and gas at Arrowsmith and Gingin).

## LATERITE

The Recent limonitic laterite at Scott River is sufficiently rich in iron to have warranted investigation as an iron ore (de la Hunty, 1962; and Gregson, 1962). It appears that there are some 50 million tons of ore containing about 30 to 40 per cent iron, but at present the deposit is not regarded favourably because of the discovery of much larger and richer deposits in the north-west of Western Australia. Pisolitic laterite developed over Mesozoic and Precambrian rocks is taken from many shallow pits in the Busselton-Augusta area for use as road building material.

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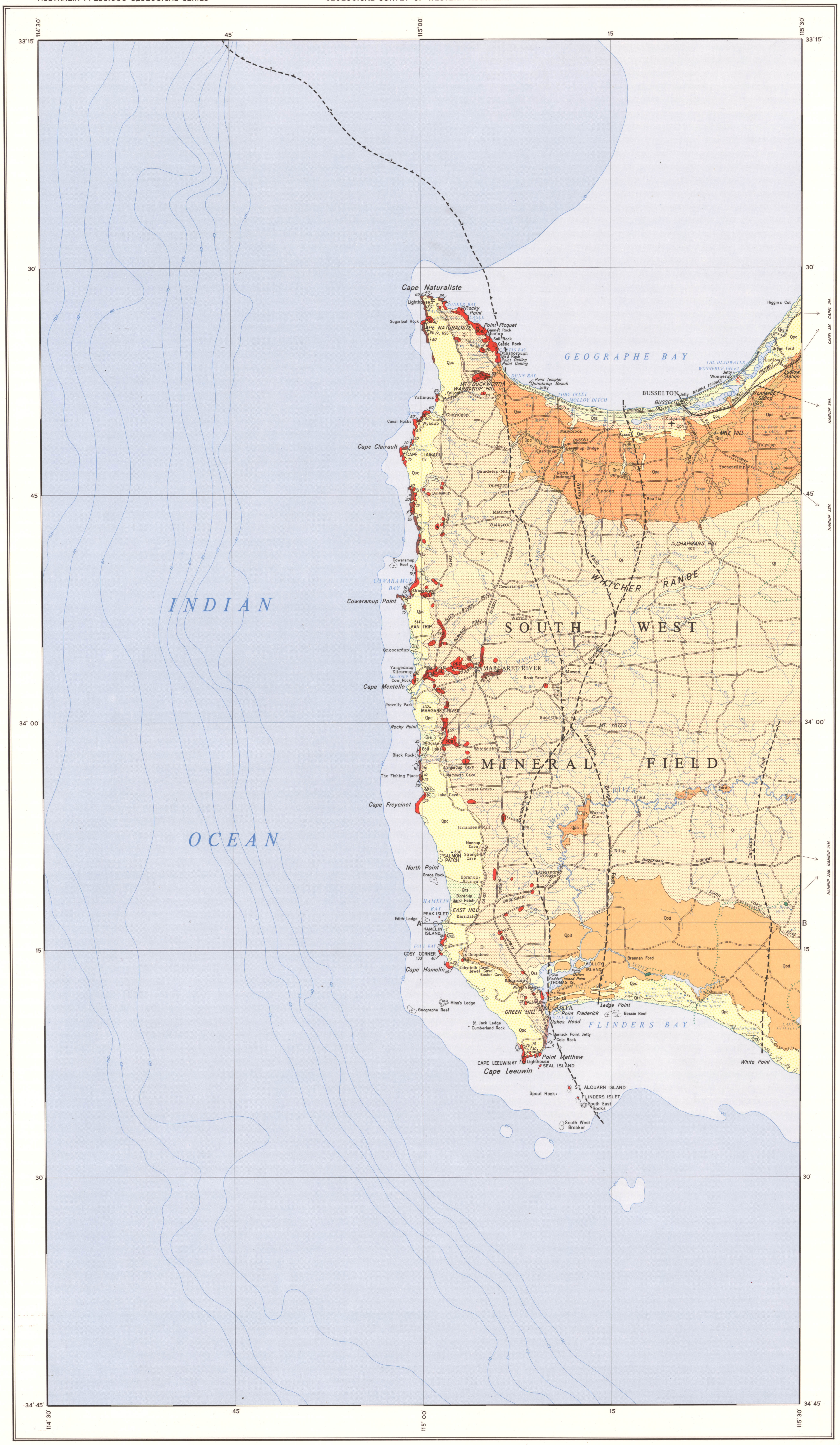
# BUSSELTON AND AUGUSTA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

PORTIONS OF SHEETS SI 50-5 AND SI 50-9




## REFERENCE

| | | | | |
|---|---|---|---|---|
| CAINOZOIC | QUATERNARY | RECENT | Qra | Alluvium : mud, silt and sand |
| | | | Qrg | Lagoonal and estuarine deposits : mud, silt and shell beds |
| | | | Qrs | Sand dunes and beach ridges : fixed and mobile calcareous sand containing heavy mineral deposits in some areas |
| | | RECENT - EARLY PLEISTOCENE | Ql | Laterite and associated quartz sand (undifferentiated) |
| | | LATE PLEISTOCENE | Qpc | COASTAL LIMESTONE : eolian calcarenite with minor occurrences of fossil soil and beach conglomerate |
| | | | Qph | Shelly limestone member |
| | | LATE - MIDDLE PLEISTOCENE | Qpa | Alluvium } Now altered to podzolic quartz sand with underlying ferruginous laterite |
| | | | Qpb | Beach ridges and foredunes containing heavy mineral deposits in some areas } Now altered to podzolic quartz sand with underlying ferruginous laterite |
| | | | Qpd | Sand dunes } Now altered to podzolic quartz sand with underlying ferruginous laterite |
| MESOZOIC | LOWER CRETACEOUS | | Klb | BUNBURY BASALT : tholeiitic basalt flow |
| PRECAMBRIAN | | | p€g | Granite gneiss : mainly potassic, strongly to weakly foliated usually concordant; always present between basic granulite and coarse-grained granulite |
| | | | p€m | Medium - grained granulite : foliated and banded; locally garnetiferous |
| | | | p€b | Basic granulite : dark, banded amphibole and amphibole - pyroxene rocks occurring in thin bands; often as xenoliths in granite gneiss |
| | | | p€c | Coarse - grained granulite : banded and foliated, white with dark banding |

## SYMBOLS

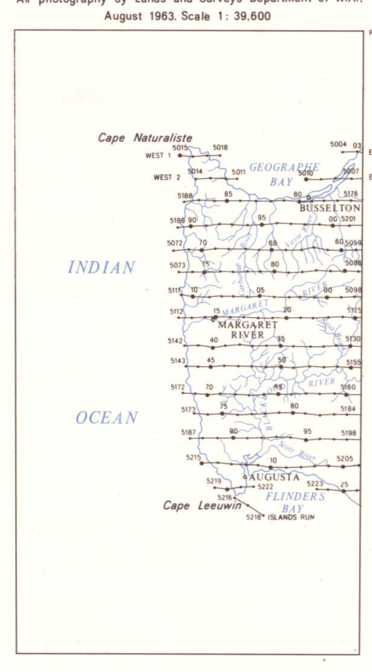
Geological boundary
Inferred concealed boundary of BUNBURY BASALT
Fault, normal and concealed
Fault, normal inferred and concealed
Strike and dip of foliation
Vertical foliation
Horizontal foliation
Foliation and plunge of lineation
Plunge of fold axis
Geological section
Macrofossil occurrence

Highway
Formed road
Track
Railway with station
Town
Locality — • Broadwater
Landing ground
Trigonometrical station, Major, Minor
Tellurometer station — ▲ VAN TRIP
Cave — · Mammoth Cave
Lighthouse
Jetty
Reef, submerged, exposed
Shoal
River or stream
Fathom-line
Drain
Waterfall
Pool
Spring
Well
Bore
Open cut

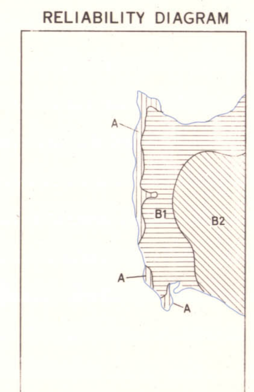
Ilmenite occurrence — Im.

FLIGHT DIAGRAM

Air photography by Lands and Surveys Department of W.A. August 1963. Scale 1 : 39,600



RELIABILITY DIAGRAM



A Detailed mapping
B1 Numerous traverses with air photo interpretation
B2 Air photo interpretation with a few traverses

Geology by D. C. Lowry, R. C. Horwitz and I. Gemuts, 1962 - 1964


Compiled by Geological Survey of Western Australia. Cartography by Geological Drafting Section, Mines Department. Topographic base from compilations by Lands and Surveys Department.
Published by Bureau of Mineral Resources, Geology and Geophysics, Department of National Development, Canberra, A.C.T.
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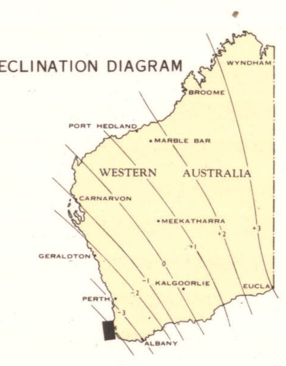
TRANSVERSE MERCATOR PROJECTION

ZONE 1 . AUSTRALIA SERIES

DECLINATION DIAGRAM



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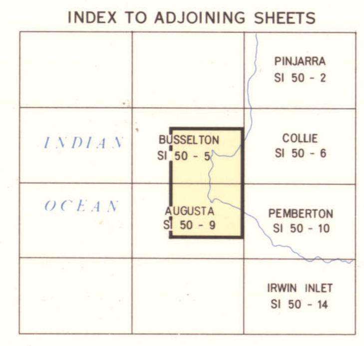
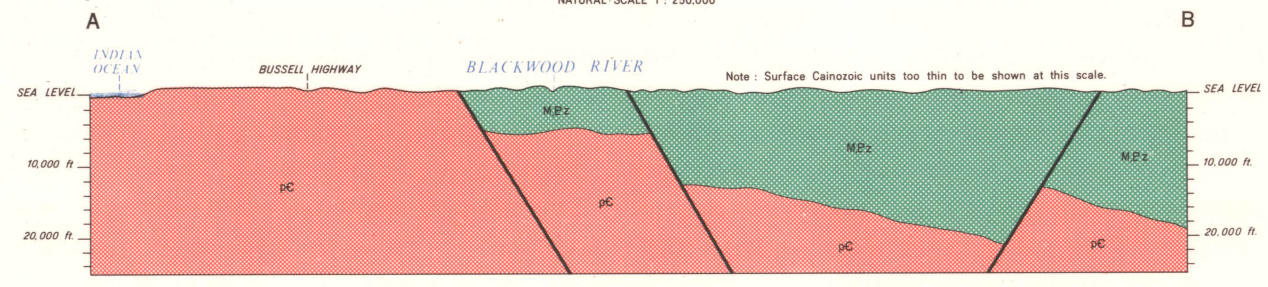
INDEX TO ADJOINING SHEETS




DIAGRAMMATIC SECTION A - B

Generalised from Geophysical Data.
NATURAL SCALE 1 : 250,000




LOWER CRETACEOUS TO ? PALAEOZOIC — Sedimentary and volcanic rocks
PRECAMBRIAN — p€ — Crystalline rocks (undifferentiated)

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BUSSELTON AND AUGUSTA
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