1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

BREMER BAY

WESTERN AUSTRALIA

SHEET SI/50-12 INTERNATIONAL INDEX

WESTERN AUSTRALIA
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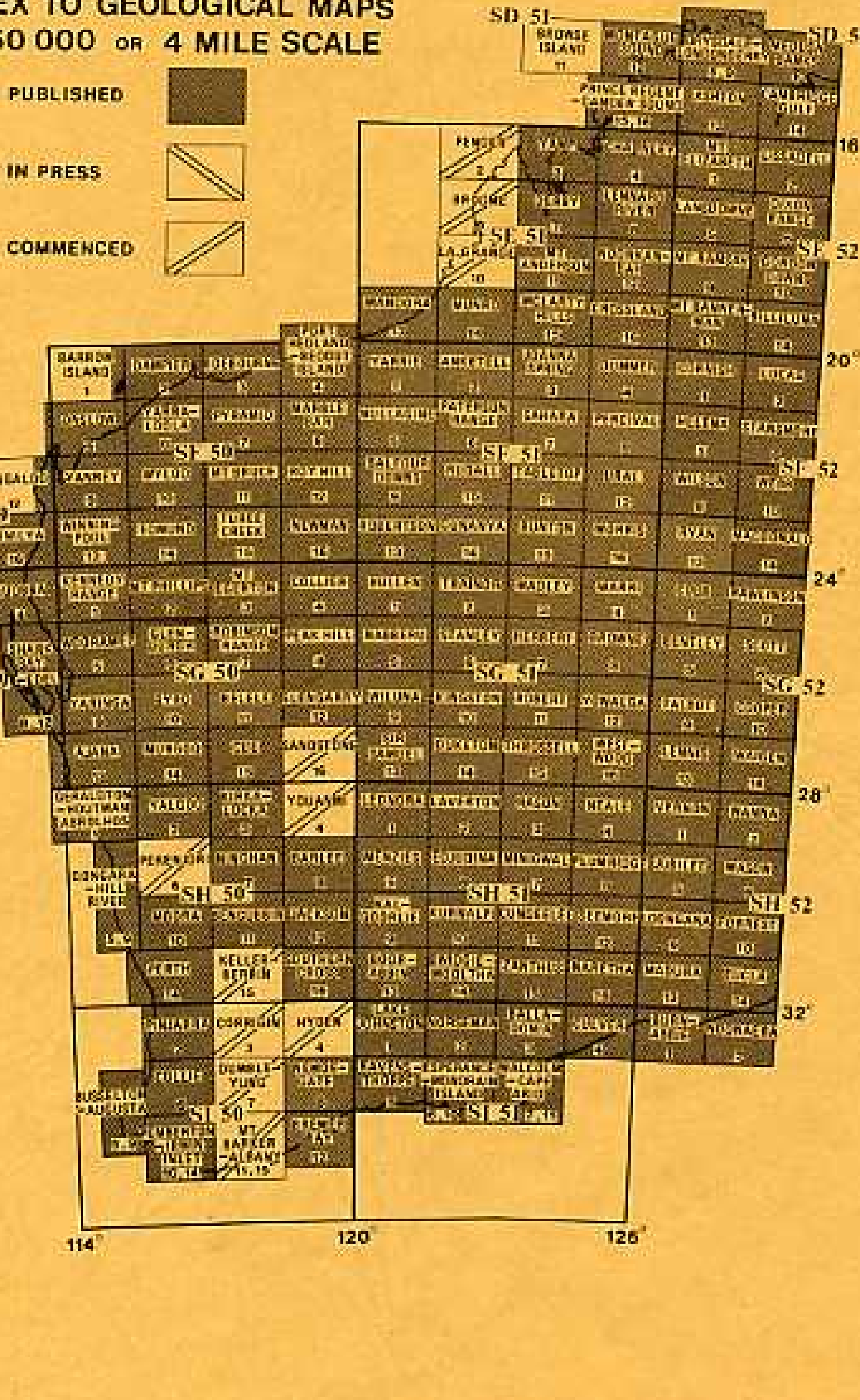

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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BREMER BAY

WESTERN AUSTRALIA

SHEET SI/50-12 INTERNATIONAL INDEX

COMPILED BY R. THOM AND R. J. CHIN

PERTH, WESTERN AUSTRALIA 1984

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Explanatory Notes on the Bremer Bay Geological Sheet

Compiled By R. Thom and R. J. Chin

INTRODUCTION

The BREMER BAY* 1:250 000 Sheet, SI 50-12 of the International Series, is bounded by latitudes 34° and 35° S and longitudes 118°31' and 120° E. Two-thirds of the sheet is covered by the Southern Ocean, which meets the mainland in a scalloped coastline of rocky headlands separated by sandy beaches.

BREMER BAY lies at the southern end of the "Wheat Belt". The western two-thirds is under cultivation for crops and sheep grazing and is serviced by numerous sealed and graded roads. The South Coast Highway, which passes through BREMER BAY, connects Jerramungup (pop. 225 in 1976 census), which is 10 km beyond the northern sheet boundary, with Albany (pop. 13 000), which is 60 km beyond the western boundary. The only populated centre on BREMER BAY is the small settlement of Bremer Bay, which serves the surrounding farming area and which, because of its proximity to the coast and to the Fitzgerald River National Park, has a seasonal influx of fishermen and tourists. Gairdner South has a primary school, and there is a general store at Wellstead.

The eastern third of BREMER BAY forms part of the Fitzgerald River National Park, within which tracks are generally rough and may be impassable in wet weather. Access to much of the coastal fringe is by long winding tracks through coastal sand deposits.

BREMER BAY lies within the South West Mineral Field, but has few known mineral resources. Mineral occurrences such as lignite, montan wax, manganese, and heavy minerals have been investigated from time to time, but have been judged uneconomic.

BREMER BAY encompasses the junction between the southern part of the Yilgarn Block (a stable Archaean craton) and the Albany-Fraser Province (a Proterozoic mobile belt). The Pallinup River on the west side of BREMER BAY has exposed a southward transition from granite-gneiss terrain typical of the southwestern part of the Yilgarn Block to granite-gneiss terrain of the Albany-Fraser Province. On the eastern side of BREMER BAY the Archaean-Proterozoic transition in the basement is largely concealed by Mount Barren Group sediments. This Proterozoic succession, which spans the adjoining corners of BREMER BAY, NEWDEGATE and RAVENSTHORPE, documents a complex metamorphic and structural history which may be shared by gneisses of the mobile belt. The Mount Barren Group sediments exposed on BREMER BAY record only part of this history.

PREVIOUS INVESTIGATIONS.

One of the earliest investigations was carried out by Roe (1852), who reported on lignite within the Plantagenet Group in the Fitzgerald River. Many subsequent investigations prompted by his report were summarized by Cockbain and van de Graaff (1973).

* Sheet names are in full capitals to distinguish them from like-named places.

The first regional reconnaissance was by Clarke and others (1954), who recognized a difference between the regional trend of the main part of the Western Australian Shield and that of the gneisses of the coastal strip. They noted that the trend changes at about latitude 33°30' S, but offered no explanation for the change. In the course of their investigations they visited several localities within BREMER BAY and described the petrography of various rocks.

Thrusting within the Mount Barren Group was first suggested by Roe (1852, p. 42) who, noting that metasediments at two localities near Mid Mount Barren have contrasting orientation, accounted for the sudden change " . . . by supposing that the Middle Mount Barren ranges had been thrust up from below at a period subsequent to that which formed the country around them." Recent mapping has confirmed that thrusting is present at this locality.

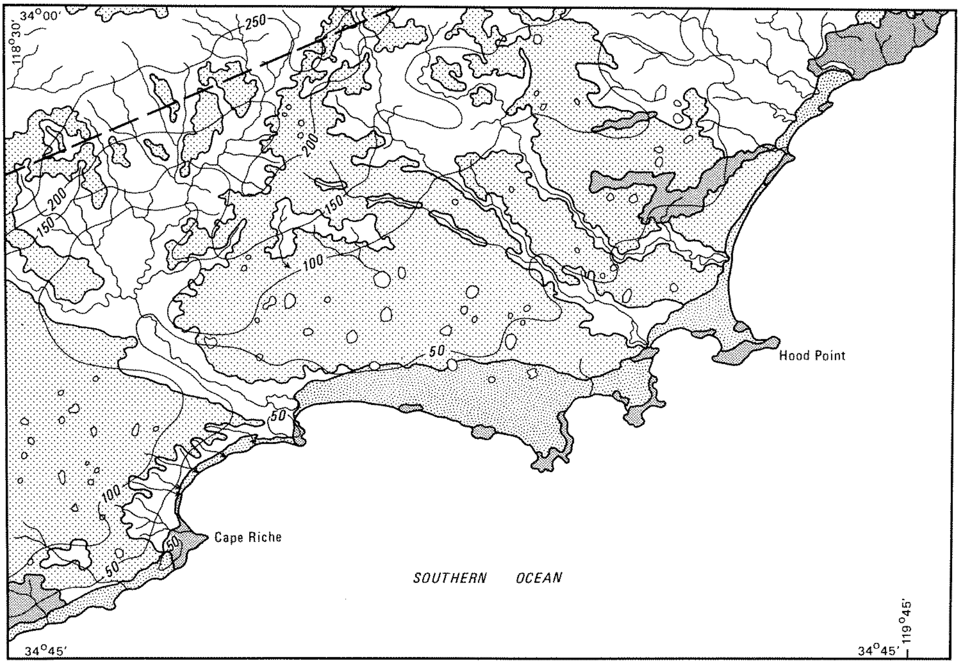
A hundred years after Roe, further evidence for thrusting in the Mount Barren Group was noted by McMath (1954) and Wilson (1952). McMath, reporting on field work carried out in 1951, suggested that the Mount Barren Group is thrust along its base over Archaean rocks, which acted as a foreland. Early in 1952, Wilson examined a zone of phyllonite and "thrust quartz" in the Fitzgerald River valley, which he attributed to intense thrusting of the Mount Barren Group over the Archaean granitic basement. Wilson also reported that " . . . the charnockitic rocks at Doubtful Island Bay appear to have been thrust over the highly sheared southern flank of the Mount Barren Group." This thrust fault, named the Bremer Fault (Wilson, 1958), has appeared in subsequent publications by various authors (Wilson, 1959, 1969; Geological Society of Australia, 1971; Australia B.M.R., 1976), and its validity is discussed below in the section on faulting.

R. T. Prider and A. F. Wilson initiated geochronological studies in the area: allanite from pegmatite which intrudes gneiss at Doubtful Island Bay gave an age of about 1 400 m.y., and biotite from the same gneiss gave an age of 970 m.y. (Prider, 1955; Wilson and others, 1960). These, together with similar ages from the Fraser Range area east of Norseman, led to the idea of a "Grenville" type of orogenic belt welded to the Western Australian Shield (Wilson, 1960). This orogenic belt is now called the Albany-Fraser Province.

More recently, Stephenson and others (1977) included gneiss at Cape Riche in a geochronological study of part of the south coast. Baxter (1977) investigated some of the heavy-mineral deposits, and Thom (1980) has reported on clastic dykes in the area.

PHYSIOGRAPHY

In the central part of BREMER BAY, sandplain overlying horizontal beds of Plantagenet Group forms monotonous interfluvial plains containing numerous swamps, lakes and short ephemeral streams (Fig. 1). Northwards, beyond the present limit of the Plantagenet Group, is Archaean granite-gneiss terrain, much of which is more than 150 m above sea level, so that individual summits, though commanding extensive views across the countryside, rise only gently from the surrounding hilly terrain. The south coast is fringed by elongate hills of limestone and dune sand, and prominent rocky headlands of Proterozoic gneiss rise sharply from the sea to an elevation of a hundred metres or more.



GSWA 19330

FIGURE 1

PHYSIOGRAPHIC MAP

BREMER BAY SHEET SI 50-12

0 20 km

REFERENCE

- Hills of Precambrian basement
- Sandplain
- Colluvium, minor alluvium and outcrop in drainage valleys and catchments
- Coastal deposits, mainly sand, limestone and minor outcrop
- Approximate northern limit of outcrop of Plantagenet Group
- 50 Generalized topographic contours, in metres
- Watercourse
- Lake, swamp, coastal inlet

29680—2

The Fitzgerald River National Park, which occupies the eastern third of BREMER BAY, as well as parts of NEWDEGATE and RAVENSTHORPE, is notable for its attractive and varied scenery. Rugged peaks of Proterozoic quartzite and flat-topped mesas of Tertiary siltstone and spongolite rise above extensive, undulating heathland over Proterozoic schist.

Major drainages, in particular the Pallinup, Gairdner, and Fitzgerald rivers, flow southeastwards across BREMER BAY to the Southern Ocean. In the north, the dendritic headwaters of these rivers have exposed much of the granite-gneiss terrain, but farther south, where Precambrian basement is thickly blanketed by the Plantagenet Group, bedrock remains unexposed in all but the Pallinup River.

The physiography of the region has been described by Jutson (1950), Clarke and Phillipps (1953), and Cope (1975), and the vegetation has been mapped by Beard (1976).

CAINOZOIC GEOLOGY

GENERAL

Cainozoic units on BREMER BAY fall into three broad groups:

(a) Coastal units, consisting of dune sand and beach sand without vegetation (*Qf*), sand with vegetation (*Qn*), and coastal limestone (*Qpl*).
(b) Sandplain (*Czs*), which forms extensive interfluvial plains containing numerous swamps (*Qrp*). In the headwaters and valleys of rivers and streams, the sandplain has been reworked to form colluvium (*Qc*), and locally has been eroded to expose duricrust and weathered rock (*Czl*), which everywhere underlies the sandplain.
(c) The Plantagenet Group (*Tp*) and its alluvial wash (*Qa*).

These units are described on the map reference and only the Plantagenet Group is described here in more detail.

PLANTAGENET GROUP

The Plantagenet Group (*Tp*) covers about half of BREMER BAY and, although largely obscured by sandplain, is well exposed in cliffs bordering major drainages and in coastal cliffs near the mouth of the Pallinup River. The Plantagenet Group, which extends along the south coast of Western Australia from Northcliffe to Cape Arid, lies within the Bremer Basin (Playford and others, 1975). The group has been divided into a lower unit of marine and non-marine sediments—the Werillup Formation, and an upper unit of marine sediments—the Pallinup Siltstone (Cockbain, 1968). Both formations are present on BREMER BAY, but are not shown separately on the map.

Although mostly obscured by the Pallinup Siltstone, the Werillup Formation is exposed in the Fitzgerald River and has been described by Cockbain and van de Graaff (1973). Lignite and montan wax occur within this formation, and their economic potential is considered below, in the section on economic geology. The Werillup Formation in the Pallinup River near Fresh Water Pool consists of poorly sorted, well-bedded sandstone and conglomerate, containing well-rounded clasts of quartz up to 0.1 m across. The Werillup Formation contains a rich microflora which indicates a late Eocene age (Cockbain, 1968).

The Pallinup Siltstone is mainly horizontally bedded white, brown, or red siltstone and spongolite; and at its type section, the cliff on the north side of Beaufort Inlet near the mouth of the Pallinup River, the formation is 47 m thick (Cockbain, 1968). The Pallinup siltstone has a rich and varied fauna which is locally abundant, but usually poorly preserved. At an exposure 2 km northeast of John Cove, the following macrofossils were collected:

> Nautiloids (c.f. *Cimomia felix*); sponges; bivalves (*Spondylus*); bryozoan (membraniporid); gastropods (volutid, vermetid, and pleurotomarid); and echinoids (cidarid and spatangid).

Conglomerate at the unconformity between the Plantagenet Group and the Precambrian basement at Hummocks Beach (Kay and others, 1963) has been assigned to the Pallinup Siltstone (Cockbain, 1968). Quilty described the Pallinup Siltstone at Cheyne Bay (Hodgson and others, 1962).

PRECAMBRIAN GEOLOGY

INTRODUCTION

Roughly half the basement on BREMER BAY is Archaean granite and gneiss, and the other half is Proterozoic granite and gneiss. The Proterozoic gneiss seems mainly derived from Archaean rocks, and there are progressive regional changes in character within the Proterozoic gneiss. The area has been divided into five tectonic zones which are described in an order corresponding to an increase in complexity or intensity of metamorphic history (Fig. 2) from north to south.

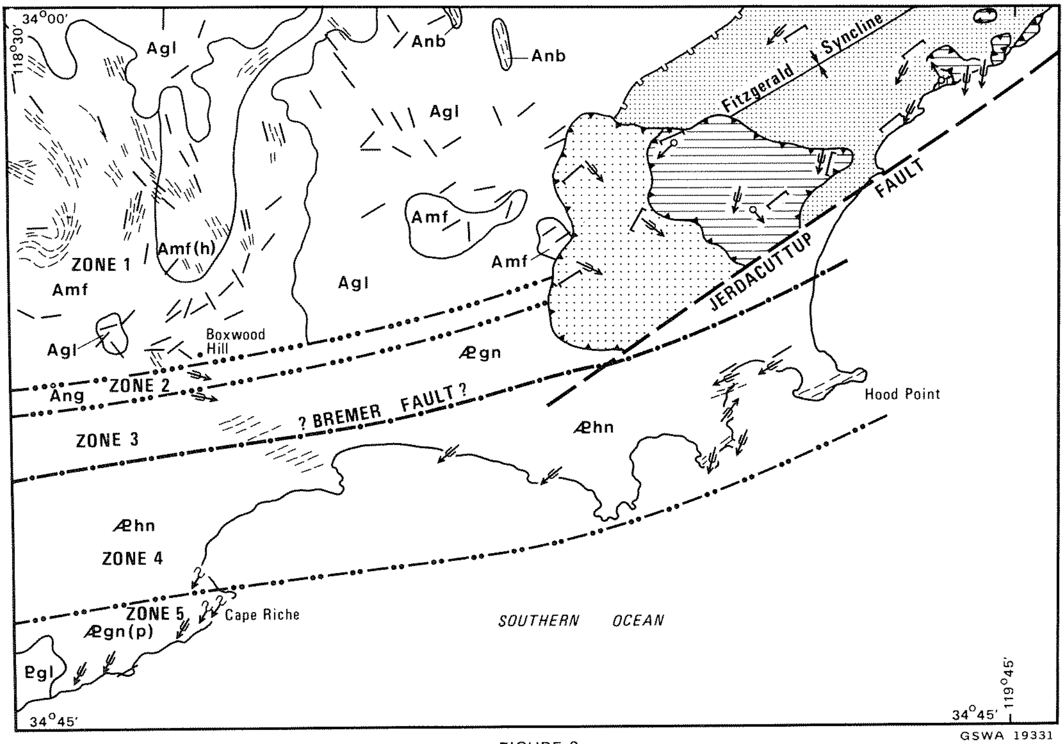
A summary of regional geochronology precedes the descriptions of the tectonic units.

GEOCHRONOLOGY

There have been no isotopic age determinations for Archaean rocks on BREMER BAY, and existing determinations for granitic and gneissic rocks scattered throughout the southwest of Western Australia present a considerable range of dates. Sixty-one pooled "Wheat Belt" granites give a date of 2 661 $\pm$ 51 m.y.; gneisses from the York, Bruce Rock, Corrigin and Brookton areas give dates between 2 600-2 700 m.y.; and 23 pooled gneisses from the Northam, Toodyay, Dale Bridge and Canning Dam areas give a date of 3 084 $\pm$ 191 m.y. (Arriens, 1971). These indicate the range of dates that might be expected for similar rocks on BREMER BAY. All Rb-Sr age determinations in this report are quoted directly from the sources of information, and have not been corrected to the new constant ($\lambda = 1.42$).

On NEWGATE, east-northeasterly trending mafic dykes near Ravensthorpe have been dated at 2 500 $\pm$ 100 m.y. (Giddings, 1976), and this age may be applied to dykes of this trend on BREMER BAY.

Several dates have been obtained for rocks within the Albany-Fraser Province on BREMER BAY. Wilson and others (1960) obtained an uncorrected U-Pb chemical age of 1 390 m.y. for allanite in pegmatite which cuts gneiss at Doubtful Island Bay; biotite from the same gneiss gave an age of 970 m.y. The first of these is consistent with dates throughout the Albany-Fraser Province, which indicate a major tectonothermal event between about 1 200—1 400 m.y. (Compston and Arriens, 1968; Arriens and Lambert, 1969; Doepel, 1975). The biotite age may reflect uplift



GSWA 19331

FIGURE 2

TECTONIC SKETCH MAP

BREMER BAY SHEET SI 50-12

0 — 20 km

REFERENCE

PROTEROZOIC

Mount Barren Group

- Allochthonous quartzite
- Allochthonous schist
- Autochthonous schist
- Autochthonous quartzite

Albany - Fraser Province

- Ꝑgl — Post-tectonic granitoid : porphyritic adamellite
- polygenetic gneiss:
  - Ꝃgn(p) — Foliated gneiss, banded and unbanded, and augen gneiss with penetrative Proterozoic foliation and abundant minor folds. Upper amphibolite facies
  - Ꝃhn — Foliated gneiss, banded and unbanded, with penetrative Proterozoic foliation and abundant minor folds. Granulite facies
  - Ꝃgn — Foliated gneiss, banded and unbanded, with penetrative Proterozoic foliation and east-northeasterly alignment of banding. Amphibolite facies

ARCHAEAN

Yilgarn Block

Boxwood Hill Gneiss Belt

- polygenetic gneiss:
  - Ang — Foliated gneiss, banded and unbanded, locally overprinted by Proterozoic foliation

Granite-gneiss terrain

- Agl — Post-tectonic granitoid: porphyritic and seriate adamellite
- Amf(h) — Migmatite and gneiss, older phases are recognizably granulite facies
- Amf — Migmatite and gneiss
- Anb — Banded gneiss, including metasedimentary relics

Symbols:

- Approximate northern limit of granulite facies metamorphism and abundant minor folds
- Tentative southern limit of granulite facies
- Approximate northern limit of penetrative Proterozoic foliation in gneiss
- Approximate northern limit of abundant compositional banding in gneiss
- Structural trends
- Unconformity
- Facing (cross-bedding)
- Thrust
- Trend of Archaean foliation
- Strike and dip of Proterozoic cleavage
- Minor folds, with plunge direction
- Asymmetric fold with plunge

after the close of metamorphism in the Albany-Fraser Province (Stephenson and others, 1977). The Albany Adamellite has been dated at 1 100 ± 50 m.y. (Turek and Stephenson, 1966), and this may be the age of prophyritic granite of similar appearance which intrudes deformed gneiss west of Cape Riche.

ARCHAEAN GEOLOGY

Southwest Yilgarn Block

Archaean rocks with the north-northwesterly structural trend typical of the southwestern part of the Yilgarn Block are restricted to northwestern BREMER BAY. Southward, structural trends become variable and trend more easterly, because of either macroscopic folding or overprinting associated with the Boxwood Hill Gneiss Belt. Despite these changes in structural trend, the rock types remain essentially the same throughout the zone.

The unit (*Agg*), which extends in an arc from the Pallinup River to the Gairdner River, consists mainly of homogeneous medium-grained recrystallized granodiorite and, less commonly, recrystallized adamellite. Even-grained types are most common, but seriate and sparsely porphyritic varieties have been noted. It (*Agg*) contains blocks of older granitoid gneiss and metasedimentary gneiss.

High-grade static metamorphism has imposed a granoblastic texture, but the early gneissic foliation is preserved as disc-shaped lenses of small, randomly oriented biotite plates. Only rarely is this fabric overprinted by cataclastic deformation. Clinopyroxene, a rare constituent, is commonly altered to actinolite and hornblende. Whether this mineral is primary or metamorphic is uncertain. Partial alteration of biotite to muscovite and chlorite, and sericitization and saussuritization of feldspar, are effects common to all Archaean rock types on BREMER BAY.

Metamorphosed agmatite (*Amf*) is mostly derived from granodiorite-adamellite (*Agg*) by the injection of, and partial assimilation by, leucocratic granite and adamellite, which are themselves now recrystallized. The proportion of the intruding phase, or neosome, varies considerably, from areas with little veining to areas where the neosome forms homogeneous bodies up to 300 m across containing a few rafts of older gneiss. In most cases, the older gneiss phase, or palaeosome, forms sharply bounded angular blocks showing little relative rotation. In the upper reaches of a creek 18 km west-southwest of Saltbush Hill, the palaeosome is partially absorbed into the neosome so that the contacts between them are poorly defined. The neosome contains nebulous swirls and bands of biotite resulting from the incorporation of older material. Although granodiorite-adamellite (*Agg*) is the commonest palaeosome in the agmatite, other rocks such as compositionally banded gneiss (*Ang*), metasedimentary gneiss, amphibolite, quarzite, metamorphosed banded iron-formation, and ultramafic rocks, are sparsely distributed throughout the leucocratic phase and are common, for example, at a locality 20 km northwest of Boxwood Hill. Where the neosome occurs as veins these have an overall random orientation but locally they may follow the gneissic foliation. Biotite clots, which are common in the neosome, form a primary flow foliation parallel to vein margins.

The neosome is mostly leucocratic adamellite, but alkali granite and leucogranite also occur. All of these show the same granoblastic texture as the palaeosome but lack hypersthene. Garnet, hornblende, and clinopyroxene are common accessory minerals. Grain size is variable, ranging from fine grained to coarse grained and pegmatitic.

The agmatite is extensively intruded by interconnecting lobes of porphyritic granite and adamellite (*Agl*) which form part of the extensive post-tectonic granitoid terrain of the southwest Yilgarn Block. Contact relationships indicate the presence of more than one intrusive phase of porphyritic adamellite, and this partly explains the variations in composition and texture. The porphyritic granite and adamellite unit (*Agl*) is moderately to strongly porphyritic and, depending on the abundance of microcline phenocrysts, ranges in composition from granite to adamellite. Phenocrysts, commonly up to 50 mm long, are enclosed in a medium- to coarse—grained groundmass of quartz, perthitic microcline, oligoclase, and biotite. Characteristically, the primary igneous texture is weakly recrystallized and weakly deformed, and phenocrysts are fractured and recrystallized at their margins.

Intrusive contacts between the porphyritic adamellite and older gneiss lack deformation or shearing, and their irregularity in plan indicates that emplacement was independent of structures in the country rock. There is flow alignment of phenocrysts parallel to some contacts, although alignment is weak away from the margins of the intrusion. Xenoliths are rare and generally small (less than 1 m across), but there are numerous clots of intergrown biotite, clinopyroxene and, rarely, orthopyroxene. These may represent xenolithic contaminants from assimilated granulite country rock.

Porphyritic granite exposed at a locality 2 km southwest of Hegarty Hill and at Saltbush Hill has a more leucocratic composition than elsewhere; phenocrysts are fewer and smaller (up to 30 mm) and recrystallization is more extensive. Contact relationships indicate that this may be an older phase of porphyritic granite.

Where phenocrysts in the porphyritic adamellite become sparse or small and the texture tends towards even-grained, the rock is distinguished as *Agv*. This rock occurs to the south and east of the main areas of porphyritic adamellite and the two adamellites, which may be variants belonging to the same intrusive event, are separated on the map by an arbitrary boundary.

A small body of hornblende granodiorite (*Agz*) occurs on the northern boundary of BREMER BAY. This is a coarse-grained, igneous-textured rock composed mainly of saussuritized plagioclase, quartz, microcline, hornblende, and biotite. The boundary of this body has not been accurately outlined, and its relationships with other granitoids have not been determined.

Zone 2—Boxwood Hill Gneiss Belt

Banded gneiss, (*Ang*), which is generally uncommon in the Archaean granite-gneiss terrain on BREMER BAY, is common in the Pallinup River from Boxwood Hill southwards (Fig. 2, zone 2), although it loses its Archaean structure as it becomes overprinted by the Proterozoic tectonism of the Albany-Fraser Province to the south. In consequence, the zone distinguished as Archaean banded gneiss is narrow, and its extent and metamorphic state prior to overprinting in the Proterozoic are unknown.

The appearance of compositionally banded gneiss at Boxwood Hill is so abrupt that its occurrence there may be fault controlled, and the presence of a zone of sheared gneiss immediately to the north lends some support to this idea. The origin of the compositional bands is uncertain: in some cases adjacent layers are of strongly contrasting composition, but elsewhere adjacent layers differ only in the distribution of mafic minerals. The banding is parallel to biotite entrainments (i.e. recrystallized Archaean foliations) either in a single sample which contains both banding and foliation, or on the regional scale (Fig. 2). If the banded gneiss is derived from sediments, these were Archaean in age, as the gneissic layering is cut by mafic dykes assigned to the 2 500 m.y.-old suite (*see* section on geochronology).

To distinguish it from the north-northwesterly trending Archaean gneiss, the east-northeasterly trending zone of banded gneiss is here named the Boxwood Hill Gneiss Belt. The locus of abrupt change at Boxwood Hill may be a major fault, thrust, or unconformity and is a convenient boundary (for purposes of discussion) to the Yilgarn Block. Although the zone has the structural trend of the Albany-Fraser Province, it is older than the tectonism associated with the Albany-Fraser Province and lacks the Proterozoic structures that characterize this province.

Typical compositionally banded gneiss from the Boxwood Hill Gneiss Belt has a granoblastic to lepidoblastic texture with seriate and interlobate grains, and adamellite to granodioritic composition. The plagioclase is saussuritized and the biotite has been recrystallized into aggregates of small grains. Compositional layering is defined by alternating biotite-rich and biotite-poor layers.

Another type of gneiss in this zone has weak layering or foliation defined by the entrainment or clustering of biotite clots. It contains quartz, plagioclase (generally saussuritized), some microcline, biotite, and in some cases hornblende. Indications of retrograde hypersthene point to a previous Archaean granulite-facies metamorphism. Textures are generally granoblastic or lepidoblastic, with seriate and interlobate mineral grains.

Summary of Archaean tectonism

The oldest of the banded gneisses (*Ang*) are of uncertain origin, and their age relationship to the greenstone belts is unknown. Rafts and blocks of metasediment, amphibolite, and ultramafic rock, distributed throughout the Archaean on BREMER BAY, are assumed to be derived from the disruption of pre-existing layered greenstone sequences during emplacement of granodiorite and adamellite. Subseqent metamorphism transformed the granodiorite and adamellite to foliated gneiss (*Agg*) with north-northwesterly structural trend. Macroscopic folds formed during this event have been disrupted by intrusion of the leucocratic granite and adamellite that formed the neosome of the agmatite (*Amf*). These events were followed by static metamorphism, which recrystallized the neosome of the agmatite to granofels or granoblastic gneiss, and which recrystallized the foliations in the older gneisses to biotite and hornblende entrainments within which individual biotite plates and hornblende grains have random orientation. The porphyritic adamellite (*Agl*) and its variant (*Agv*) were intruded into these older rocks, and the whole area was subjected to retrograde metamorphism which resulted in weak recrystallization of the post-tectonic granitoids.

Before emplacement of the east-northeasterly trending mafic dyke suite, a zone of east-northeasterly trending Archaean gneiss (Boxwood Hill Gneiss Belt) was established, either by a separate gneiss-forming event or by rotation, faulting or thrusting of older banded gneiss. The maximum age for this event is uncertain. There is no clear evidence that the porphyritic granite around Jerramungup was the parent of the augen gneiss in the Pallinup River, although on present evidence this seems a reasonable view and would indicate a maximum age for the Boxwood Hill Gneiss Belt of about 2 600-2 700 m.y. (*see* section of geochronology). The Boxwood Hill Gneiss Belt truncates the north-northwesterly trending structures of the south-western part of the Yilgarn Block and therefore post-dates them.

Mafic dykes

Mafic dykes belonging to an east-northeasterly trending suite are ubiquitous within the Archaean on BREMER BAY, where they have a low metamorphic grade. Typically they have a relict igneous texture and contain saussuritized plagioclase, hornblende after pyroxene, minor ilmenite, accessory apatite, with secondary epidote and chlorite after hornblende. East-northeasterly trending dykes near Ravensthorpe have been dated at 2 500 ± 100 m.y. using Rb-Sr techniques (Giddings, 1976).

East-northeasterly trending mafic dykes are numerous in the Boxwood Hill area, where they have a foliation slightly oblique to dyke margins. Southwards, as the foliation becomes more marked, the metamorphic grade in the dykes increases consistently with the appearance of a penetrative foliation within the host gneiss and an increase in its metamorphic grade. The dykes and the gneiss appear to have been metamorphosed simultaneously, and intrusion of the dyke suite at 2 500 ± 100 m.y. sets a maximum age for this metamorphism. It may have been the 1 200-1 400 m.y. tectonothermal event documented isotopically throughout the Albany-Fraser Province (*see* section on geochronology). Dykes cut the fabric (compositional layering, foliation and augen structure) in the gneisses of the Pallinup River, and establish a minimum age for the formation of the gneissic foliation.

In zone 3 of the Pallinup River section, both the mafic and the compositionally banded gneiss lack penetrative folding on the mesoscopic scale, and it seems reasonable to suppose that in the coastal gneisses (zones 4 and 5), which have penetrative mesoscopic folding, the mafic dykes of the east-northeasterly trending suite will also be deformed. Most mafic bodies in zones 4 and 5 are amphibolite or mafic granite, which occur as folds, boudins, rafts and persistent dyke-like bodies. Although those that cross-cut the foliation and those that have relict chilled margins were doubtless intruded as dykes, there is evidently more than one generation of mafic rock within the coastal gneiss, and on present information the east-northeasterly trending dyke suite in the Pallinup River cannot be confidently identified on the coast.

Several unmetamorphosed dolerite dykes were recognized within the Pallinup River. These igneous-textured dykes have a northwesterly trend and clearly cross-cut foliated dykes of the east-northeasterly suite. Similar unmetamorphosed dykes of northwesterly trend were noted by Clarke and others (1954) on the coast. As these dykes post-date the main metamorphism of the Albany-Fraser Province, they have an age less than about 1 200 m.y. These later mafic dykes are not distinguished separately on the map.

Proterozoic gneiss

On BREMER BAY, gneiss of the Albany-Fraser Province is considered to be a product of Proterozoic tectonism acting on Archaean rock similar to those of zones 1 and 2 previously described. The prefix (ÆP) is used in recognition of both the Archaean origin of these rocks and their strong Proterozoic tectonic overprint, but in the text they are consistently referred to as Proterozoic rocks. Three zones (designated 3, 4 and 5) of Proterozoic gneiss have been distinguished on BREMER BAY according to their metamorphic grade and structural style (Fig. 2) and these are described below.

Zone 3: The most northerly zone (zone 3) is characterized by amphibolite-facies metamorphism; penetrative east-northeasterly trending foliation; consistent east-northeasterly alignment of gneissic banding; and lack of mesoscopic folding. The banding, which is cut by mafic dykes, is regarded as Archaean in age; but the foliation, which is also present in the mafic dykes, is considered to be Proterozoic. If the consistency of orientation of the banding, which is inconsistent in zone 2, is the result of folding in the Proterozoic, the foliation may be axial-planar to these folds.

The boundary between zone 2 (Boxwood Hill Gneiss Belt) and zone 3 is arbitrary because Proterozoic foliation is locally present in the Archaean zone 2, particularly in mafic dykes. The intensity of the foliation increases southwards throughout both zones, and the junction between zone 2 and zone 3 is placed at about Yungunup Pool, where the foliation becomes penetrative in the gneiss.

Most of zone 3 in the Pallinup River is foliated gneiss (*Ægm*), which may be either banded or unbanded. In detail, the Proterozoic foliation is oblique to the Archaean foliation and banding in the gneiss. Mesoscopic folds are uncommon, and most of those that are present are demonstrably Archaean (i.e. before the intrusion of the dyke suite) in age. A few folds and lineations which plunge at moderate angles to the east-southeast are thought to be Proterozoic. The foliated gneiss (*Ægn*) from the Pallinup River is granoblastic to lepidoblastic in texture, with seriate and interlobate grains, and is of adamellitic to granodioritic composition, with a strong fabric defined by thin layers of aligned biotite.

Two narrow bands of augen gneiss (*Ægp*) were noted in zone 3. The widest band is 70 m across and contains lozenge-shaped augen of microcline in a granoblastic, equigranular, interlobate-textured groundmass of quartz, plagioclase, microcline and biotite, with some hornblende and opaque minerals.

Two narrow bands of metamorphosed conglomerate (*Ægs*) occur with the gneiss. At the northernmost locality, well-rounded pebbles of granitoid (including granodioritic granofels) are set in a matrix of biotite and chlorite schist. Although the pebbles show no obvious strain, the matrix of the conglomerate is deformed. At the southernmost locality, a 10 m-wide band of mafic schist consists mainly of anthophyllite and plagioclase with pebbles of granitoid and quartz.

Generally, the foliated gneiss (*Ægn*) in the Pallinup River shows amphibolite-facies metamorphism, although there is evidence in some gneiss of retrogression from granulite facies, perhaps reflecting the Archaean metamorphic grade of the gneiss. The metamorphic effects of Proterozoic overprinting may be studied in isolation in the mafic dykes, which have no Archaean metamorphic prehistory.

Zone 4: The next zone southwards, zone 4 (Fig. 2), is characterized by granulite-facies metamorphism and abundant mesoscopic folds in the gneisses. The northern boundary is regionally delineated on the basis of the metamorphic grade, and it coincides with a distinct change in magnetic characteristics (Australian Bureau of Mineral Resources, Total Magnetic Intensity Map, Bremer Bay 1:250 000 sheet, 1979). It also coincides with the Bremer Fault, the existence of which was proposed by Wilson (1952), but not confirmed by the present survey.

Most of the gneiss in zone 4 is grouped under the symbol *Æhn*. This includes granodioritic gneiss which has a strong penetrative foliation and variably developed banding. The foliation, which is usually defined by aligned plates of biotite or the entrainment of hornblende, is parallel to the axial planes of folds in the layering. The penetrative biotite foliation may itself be deformed into southwesterly plunging asymmetrical folds with local development of axial-planar foliation.

The symbol *Æhn* also includes migmatite, which at John Cove occurs in discrete zones a few metres wide and contains mafic granulite blocks whose gneissic foliation is cut by the enclosing recrystallized neosome. Fold hinges within the mafic block are truncated against the country rock at the edge of the migmatite zone. The folds within these blocks therefore predate the migmatite event and predate the ubiquitous folds within the gneissic country rock.

At James Cove, granodiorite gneiss has a layering defined by alternating biotite-rich and biotite-poor zones about 10 mm thick, which are continuous for many metres. Occasional, thin, concordant, mafic layers are commonly boudinaged or folded, and the penetrative foliation in the gneiss is axial-planar to these folds. The mafic layers generally have straight, clean-cut margins, but many mafic bodies are concordant and there is no conclusive evidence that they were once dykes. A typical sample of granodiorite gneiss from James Cove has a granoblastic, seriate texture and consists of interlobate grains of quartz, plagioclase (antiperthitic in patch form) and K-feldspar (perthitic in stringlet form), with some biotite, hypersthene and minor opaques. The rock has a layering and a strong foliation defined mainly by biotite.

Between Point Irby and Bremer Bay, the gneiss (*Æhn*) is more migmatitic. Typically, it consists of a palaeosome of fine- to medium-grained biotite granodiorite which is extensively veined, assimilated and rafted by a neosome of medium-grained, leucocratic granodiorite. The relative proportions of these phases vary considerably.

The neosome consists of plagioclase (mainly andesine), quartz, and potassic feldspar. Hypersthene and clinopyroxene are ubiquitous in small amounts, so that the rock is leucocratic. The texture is granoblastic, although a weak foliation is defined by slight flattening of the grains.

In the palaeosome, the plagioclase, quartz and potassic feldspar are accompanied by a greater proportion of mafic minerals, particularly hypersthene, hornblende, clinopyroxene and biotite. Nebulous banding in the palaeosome is an early fabric defined by layers of biotite and hornblende now largely recrystallized by later metamorphism. The overall texture is lepidoblastic. Besides granodiorite blocks, other older phases within the migmatite include amphibolite, mafic granulite and quartz diorite gneiss, and relationships indicate more than one period of migmatization. The banding and foliation in all older phases are cut by the granodiorite neosome. Chemical analyses of granulite at Point Irby are given by Clarke and others (1954) and Wilson (1959).

Zone 5: This zone has been distinguished from zone 4 because it seems to be of lower metamorphic grade. Hypersthene is even lacking in rocks of granodioritic composition, although only a few samples have been examined. The presence of zone 5 restricts the granulite-facies gneiss (zone 4) to a linear zone.

The symbol *Ægn* includes foliated, banded and unbanded gneiss which, in contrast to the same rock unit in zone 4, has numerous mesoscopic folds. At Cape Riche, gneiss containing abundant garnet and some sillimanite may be of sedimentary origin (Clarke and others, 1954; Hodgson and others, 1962). At the same locality, gneiss with a granoblastic texture and granodioritic composition is banded by the segregation of biotite into zones and by the alternation of this type of gneiss with layers of amphibolite. Around Cape Riche, abundant southwesterly plunging folds change in vergence in a sense consistent with the change in orientation of banding from a southerly to a northwesterly dip, indicating the presence of a southwesterly plunging synform. Early intrafolial isoclines have been noted in this gneiss.

Augen gneiss *Æhp* is abundant along the coast west of Cape Riche. The augen are either deformed single crystals of microcline with some metamorphic recrystallization or aggregates of quartz and microcline. Most of the augen gneiss is adamellite and has a granoblastic, seriate, and interlobate texture. Mafic minerals include biotite and hornblende and are accompanied by some opaques and secondary epidote. This augen gneiss differs from augen gneiss in the Pallinup River in the greater degree of deformation: the Cape Riche augen gneiss commonly exhibits two or three generations of minor folding, and recrystallized augen are common. Hypersthene has not been identified in the augen gneiss on the coast.

Post-tectonic adamellite and migmatite

Porphyritic adamellite (*Ɇgl*) occurs only on the coast near the western boundary of BREMER BAY, in the vicinity of Warriup Hill. It consists of abundant microcline phenocrysts set in a matrix of medium- to coarse-grained quartz, plagioclase, microcline, biotite, hornblende, and some opaques, apatite and zircon. The adamellite is slightly recrystallized and locally has a tectonic foliation, but the amount of deformation is relatively minor. The adamellite cuts across folds in the banding of the gneiss and evidently has a much less complex structural history than the gneiss. Stephenson and others (1977) have grouped this porphyritic adamellite with the Albany Adamellite, which has an age of about 1 100 m.y. (Turek and Stephenson, 1966). Although not extensive on BREMER BAY, these intrusions of porphyritic adamellite are part of a zone of post-tectonic and late-tectonic Proterozoic granitoid which extends at least from Baladonia (Doepel, 1975) to west of Albany and which, in common with the other zones described above, is an integral part of the Albany-Fraser Province.

In the Warriup Hill area, which is in the contact zone between abundant porphyritic adamellite on MOUNT BARKER and extensive gneiss on BREMER BAY, porphyritic adamellite has invaded the gneiss, either along layering in a lit-par-lit relationship, or, more commonly, with transgressive contacts. Where both adamellite (*Ɇgl*) and gneiss (*Æga*, *Ægn*) are present in significant proportions, the rock is regarded as migmatite (*Ɇgm*).

Proterozoic sediments—The Mount Barren Group

Proterozoic sediments are restricted to the eastern portion of BREMER BAY, within the Fitzgerald River National Park. They have been known by a variety of informal names. Schist and quartzite in the vicinity of Mid Mount Barren were referred to in a geological context by Roe (1852) as the "Middle Mount Barren Ranges", and by Blatchford (1919b) as the Mount Barren Series. The slightly metamorphosed sediments from Kundip on RAVENSTHORPE were named the Kundip Series by Woodward (1909). The equivalence of the Mount Barren Series (as they came to be known) and the Kundip Series was recognized by Sofoulis (1955, 1958) who combined these and the Stirling Range succession as the Stirling-Barren Series. More recently the succession has been informally referred to as the Mount Barren Beds (Cockbain and van de Graaff, 1973). These terms are here replaced by the formal name, Mount Barren Group.

The Mount Barren Group consists of three formations:

(i) the Steere Formation, which unconformably overlies the Archaean basement;
(ii) the Kundip Quartzite; and
(iii) the Kybulup Schist.

The type section of the Steere Formation is in the Western Steere River (lat. 33°41′36″S, long. 120°09′40″E); the type section of the Kundip Quartzite is at Kundip (lat. 33°41′05″S, long. 120°11′17″E); and the type locality of the Kybulup Schist is in the Phillips River (lat. 33°51′13″S, long. 120°04′41″E). All of these are on RAVENSTHORPE and are not described here, but some features of the rock units at these localities are described by Thom (1977). Only the Kybulup Schist (*ⱣBp*) and the Kundip Quartzite (*ⱣBk*) are present on BREMER BAY, together with part of the Cowerdup Sill (*Ᵽg*) and conglomerate and breccia (*Ᵽc*) derived mainly from the Kundip Quartzite. The Steere Formation occurs further north on NEWDEGATE (Thom and others, 1981) and on RAVENSTHORPE.

On BREMER BAY much of the Kybulup Schist (*ⱣBp*) is obscured by allochthonous quartzite or by the Plantagenet Group, but good exposures occur in river cuttings, on the coast, and around Woolbernup Hill. It consists mainly of fine- to medium-grained fissile rocks of pelitic and psammopelitic character, now metamorphosed to chlorite-quartz schist, muscovite-chlorite-quartz schist, and muscovite-biotite-quartz schist. Clarke and others (1954) suggested that some of the schist derives from greywacke. The unit also contains thin intercalations of sandstone and quartz arenite. Banded iron-formation at Naendip may result from iron enrichment of schist and finely layered quartz arenite, a process perhaps concomitant with manganese deposition in the same unit at this locality. Although kyanite has been reported in schist from West Mount Barren (Clarke and others, 1954), there is a lack of the index minerals that define a distinct metamorphic gradient within the Mount Barren Group farther east (Sofoulis, 1955; Thom, 1977). The Kybulup Schist is the thickest unit of the Mount Barren Group, but because of complex folding on all scales its thickness is indeterminate.

The Kundip Quartzite (*ⱣBk*) consists mainly of variably recrystallized orthoquartzite, but includes some micaceous and chloritic quartzite. Most quartzite contains some tourmaline and zircon in well-rounded grains. The morphology of the constituent quartz grains varies according to metamorphic grade, degree of mylonitization and the proportion of phyllosilicates. Quartz microstructural (textural) zones delineated for the eastern half of the Mount Barren Group (Thom, 1977) are incompletely represented on BREMER BAY, where most quartzite has interlobate, amoeboid or polygonal grains in a granoblastic (or lepidoblastic, where micaceous) texture. Quartzite is inequigranular where recrystallization is partial, and grains may be markedly elongate due to plastic deformation. Cross-bedding is ubiquitous in the Kundip Quartzite, and has been preserved in some completely recrystallized strata.

Clarke and others (1954) described metaconglomerate between Point Ann and Point Charles and at Dempster Inlet in which strongly deformed quartzite pebbles are contained in a schistose matrix. Similar rocks near Woolbernup Hill and at Mid Mount Barren are interpreted as tectonic breccia formed mainly from Kundip Quartzite during thrusting, and deformed during subsequent metamorphic events. In view of the difficulty of distinguishing deformed tectonic breccia from deformed sedimentary conglomerate, rocks of this type have been grouped on the map as *Ᵽc*. The best development of these conglomerates is at Mid Mount Barren, where the upper portion of the hill consists of angular quartzite fragments, both laminated and massive, in an arenaceous matrix. Cross-bedding can be recognized in some of the clasts.

An altered dolerite sill (*Ᵽg*), about 300 m thick, has been emplaced within or adjacent to the Kundip Quartzite. This intrusion, now named the Cowerdup Sill, was first recognized by Blatchford (1919b). On NEWDEGATE, the sill exhibits strong gravity differentiation, from ultramafic cumulate at the base to granophyre at the top (Thom, 1977), but on BREMER BAY, exposure is poor and differentiated fractions have not been recognized. Typically the Cowerdup Sill is strongly altered, with breakdown of the feldspar and pyroxene to saussurite, sericite, chlorite and amphibole.

Structure of the Mount Barren Group

The major fold structure of the Mount Barren Group is the Fitzgerald Syncline (Fig. 2), deduced mainly from facings defined by cross-bedding in thrust sheets of Kundip Quartzite to the north and northeast of BREMER BAY. It is a southwesterly plunging, overturned syncline with an axial plane dipping steeply southeast. The complementary anticline to the southeast has apparently been thrust over the Fitzgerald Syncline, so that the Mount Barren Group on BREMER BAY includes at least two thrust sheets of orthoquartzite and gabbro. On Figure 2 these thrust sheets are shown as allochthonous schist and quartzite and are distinguished from the autochthonous schist and quartzite that have not been displaced by low-angle thrusting.

Thrust planes can be recognized by the presence of breccia derived by disruption of the overthrust sheet, as at Mid Mount Barren, West Mount Barren, and between Point Charles and Point Ann. In addition, thrusts are loci of geological misfits, as evident at Naendip.

Several generations of folding have been recognized, but are not separately represented on the map. Some are shown diagrammatically on Figure 2. The latest folds, which plunge consistently southwest, are abundant within the Kybulup Schist. An earlier group of folds and associated lineations plunge at low angles to the east and southeast, and earlier isoclinal folds have a wide range of orientations due to overprinting.

Clastic dykes—evidence for post-Mount Barren Group sediments

A clastic dyke was reported at Dillon Bay by Clarke and others (1954), and several at Albany on MOUNT BARKER have been described by Kay (1974). During the mapping of BREMER BAY, clastic dykes were discovered on the coast near Warriup Hill and on the coast east of Cape Riche (Thom, 1980).

The dykes are composed of feldspathic wacke and contain rounded pebbles of jasper, chert, quartz, feldspar and banded iron-formation. Angular clasts of gneiss within the dykes have been plucked from the country-rock walls. The dykes occupy complex fissures that resemble fault zones rather than joints. Evidence of flowage in these fissures includes the presence of flow banding, the tendency for pebbles to be concentrated near the middle of dykes, and the presence in some dykes of a dimensional preferred orientation of elongate quartz grains parallel to dyke margins. It is suggested that the dykes were formed by the downward injection of water-saturated sediment into fissures opened during seismic activity. This mechanism, which has been proposed for comparable clastic dykes elsewhere (Potter and Pettijohn, 1963; Logan, 1958), implies the former existence of overlying sedimentary rocks at least as extensive as the present distribution of clastic dykes.

Field relationships near Warriup Hill indicate that the clastic dykes are younger than both the gneiss (*Ægn*) and the porphyritic granite (*Ᵽgd*), and a maximum age of about 1 000 m.y. is suggested. This age is consistent with the lack of deformation and metamorphism in the dykes themselves. The presence within the dykes of rounded clasts of quartzite similar to quartzite in the Mount Barren Group indicates that the sediment within the fissures (and originally also overlying them) was partially derived by erosion of the Mount Barren Group.

It is tentatively concluded that stratified feldspathic wacke once covered an area at least as extensive as the present distribution of clastic dykes, that it was considerably younger than the Mount Barren Group, and that it was virtually unmetamorphosed.

Summary of Proterozoic Metamorphism

Gneiss and mafic dykes in the Pallinup River section show a progressive southwards development of an east-northeasterly trending foliation, a progressive southwards re-orientation of the foliation to a consistent east-northeasterly trend, and a progressive southwards increase in metamorphic grade to upper amphibolite facies. Farther south in zone 4, the gneiss has attained granulite-facies metamorphism and has undergone multiple folding. In zone 5, mineral assemblages diagnostic of granulite-facies metamorphism have not been recognized and the metamorphic grade of these gneisses may be lower than in zone 4.

In the Mount Barren Group, a southeastwards increase in metamorphic grade was noted by Sofoulis (1955) and described by Thom (1977). Phyllite and quartz arenite in the northern exposures increase in grade to give kyanite and garnet schist and metamorphic quartzite on the coast. This metamorphic gradient is roughly parallel to the metamorphic gradient of the dykes and gneisses in zones 3 and 4. A prominent foliation developed in the Mount Barren Group has the east-northeasterly strike and steep southeasterly dip of the overprinting foliation in the Pallinup River gneisses and mafic dykes. In the Mount Barren Group, early tight folds with prominent axial-planar foliation have been overprinted by southwesterly plunging minor folds, and early tight folds in gneiss in zones 4 and 5 have also been overprinted by southwesterly plunging minor folds. Easterly to southeasterly plunging folds and associated lineations in the Mount Barren Group may be equivalent to folds and lineations with the same orientation in zone 3 in the Pallinup River.

Correspondence between metamorphic and structural events preserved in the Mount Barren Group and in gneisses of the Albany-Fraser Province points to simultaneous metamorphism in the Proterozoic. This, the last main tectonothermal event recorded by these rocks, is tentatively equated with the last major tectonothermal event recorded by existing geochronology at about 1 100-1 400 m.y. ago.

FAULTING

The Bremer Fault, proposed by Wilson (1952, 1958) and featuring on maps published by the Geological Society of Australia (1971) and the Australian Bureau of Mineral Resources (1976), has been poorly documented. No details are known of the field evidence which led Wilson to believe that the Doubtful Island Bay gneiss has been "thrust over the highly sheared southern flank of the Mount Barren Group" (Wilson, 1952). In the vicinity of the fault line, exposures of Proterozoic gneiss and Mount Barren Group are no less than 15 km apart, and evidence on BREMER BAY indicates that the Mount Barren Group has been thrust over the gneiss. A map of total magnetic intensity on BREMER BAY, produced by the Australian Bureau of Mineral Resources in 1979, indicates a marked change in magnetic characteristics at about the line of the proposed Bremer Fault, and may mark the northern limit of granulite gneiss. The name Bremer Fault should be reserved for a fault in this position, and as explained below should not be applied to the southwesterly extension of the Jerdacuttup Fault, despite Wilson's suggestion (1952) that the one is a continuation of the other.

The total magnetic intensity map does indicate a southwesterly extension of the Jerdacuttup Fault, which on RAVENSTHORPE truncates the Mount Barren Group and marks the northwestern limit of exposure of the Albany-Fraser Province gneiss in that area (Thom and others, 1977). Similarly on BREMER BAY the Jerdacuttup Fault seems to mark the southeasterly limit of the Mount Barren Group, but the actual contact of Mount Barren Group with Albany-Fraser gneiss is concealed beneath a 15 km-wide belt of Cainozoic cover. The Jerdacuttup Fault on BREMER BAY is oblique to the proposed Bremer Fault and to the northern boundary of the granulite gneiss.

Clarke and others (1954) noted brecciation of gneiss at several places on the south coast, particularly at Cape Riche; near the mouth of Wilyunup Creek (Willyun Creek of Clarke and others); and both east and west of Cape Knob. Near the mouth of Wilyunup Creek they observed a fault breccia netted with pseudotachylyte, and near the Cape Knob breccia they noted a sandstone dyke. During mapping, pseudotachylyte was observed at other localities between the western boundary of BREMER BAY and Cape Riche, and clastic dykes have been discovered on the coast near Warriup Hill and west of Cape Riche (Thom, 1980). If the clastic dykes were formed in brittle fracture zones resulting from seismic shock (*see* section on clastic dykes), then the connection between pseudotachylyte, brecciated gneiss and sandstone dykes that Clarke and others (1954) seem to imply, may be valid. Their presence seems to indicate an episode of brittle fracture in the area between Cape Riche and the western boundary of BREMER BAY after the cessation of ductile deformation and metamorphism in the Albany-Fraser Province.

ECONOMIC GEOLOGY

Only manganese and heavy minerals are considered to have any economic potential. Lignite (with montan wax), iron, and copper have been investigated but have been considered uneconomic.

The manganese deposit at Copper Mine Creek was first inspected by Blatchford (1926), who thought it warranted further investigation. Gray and Gleeson (1951) considered, on the basis of partial analyses, that the manganese is unsuitable for chemical or metallurgical manganese. Townley (1953) estimated that the deposit contains 30 000-40 000 t of 40% Mn, about 150 000 t of 35% Mn, and considered that, because of the low grade of the ore and the long road haul, the deposit was uneconomic. The manganese deposit 3 km northeast of Naendip was inspected by Sofoulis (1956), who estimated 21 000 t of "indicated" and 58 000 t of "inferred" ore. The ore is low in manganese and high in iron and silica. De la Hunty (1963), who summarizes previous investigations, thought that the reserves might prove to be larger on further investigation. Recent mapping has demonstrated that the manganese occurs in Phillips River Schist (*ЕBp*) and not in Archaean Schist as previously thought.

Heavy-mineral deposits have been investigated by Baxter (1977), who describes prospects at Cheyne Bay and Gordon Inlet. About 160 t of concentrate were produced from the Cheyne Bay prospect between 1949 and 1950. McMath (1949a, 1949b, 1950) estimated 305 000 t of heavy minerals in this deposit. The concentrates are ilmenite and zircon with minor garnet, rutile and monazite. McMath and de la Hunty (1951) estimated that the Gordon Inlet prospect contains 372 000 t of heavy minerals, which are mainly ilmenite, with zircon and leucoxene (Baxter, 1977).

Lignite in the Fitzgerald River was first reported by Roe (1852), and the many subsequent investigations are summarized by Cockbain and van de Graaff (1973). The lignite occurs as a single bed or lens within the Werillup Formation of the late Eocene Plantagenet Group. Drilling has indicated 1.1 million t of lignite, which has a calorific value of 5.6 to 10.6 MJ/t, an extractable crude oil content of 0.3 barrels/t, and 2.3 per cent extractable montan wax.

Near the lignite deposits in the Fitzgerald River an exploratory well for petroleum was sunk in 1921 to a depth of 108 m, but the well was dry. Named Jonacoonack 1 by Cockbain and van de Graaff (1973), the hole penetrated Proterozoic quartzite and phyllite of the Mount Barren Group. Some of the drill core was described by Maitland (1922). As the rocks have undergone multiple deformation and considerable metamorphism, they are unlikely to contain petroleum.

Copper mineralization has been reported from around Naendip (Blatchford, 1926), but has not been relocated. The nearby Copper Mine Creek has a misleading name, for no mine or copper production is known from this locality.

A limonite occurrence with Plantagenet Group sediments on the coast six miles from Cape Riche was examined in 1961 by an exploration company as an iron prospect, but the tonnage was considered too small for the deposit to be of economic interest.

Spongolite in the Pallinup Siltstone has been quarried near Twertup Creek, 4 km northwest of Red Park, for building stone for local use. This quarry has accounted for 873 t of the State's total spongolite production of 4 193 t (to 1979).

Graphite occurs in veins and lenses within gneiss in the lower reaches of the Pallinup River (Maitland, 1924, 1925; Simpson, 1951). The occurrence is apparently small.

Minor occurrences of silver-lead minerals have been reported, including lead ore (cerussite, anglesite) at a locality eight kilometres north of Bremer Bay; galena in association with minor chalcopyrite in the Hamersley River area; and galena at Naendip (Blockley, 1971; Sofoulis, 1958).

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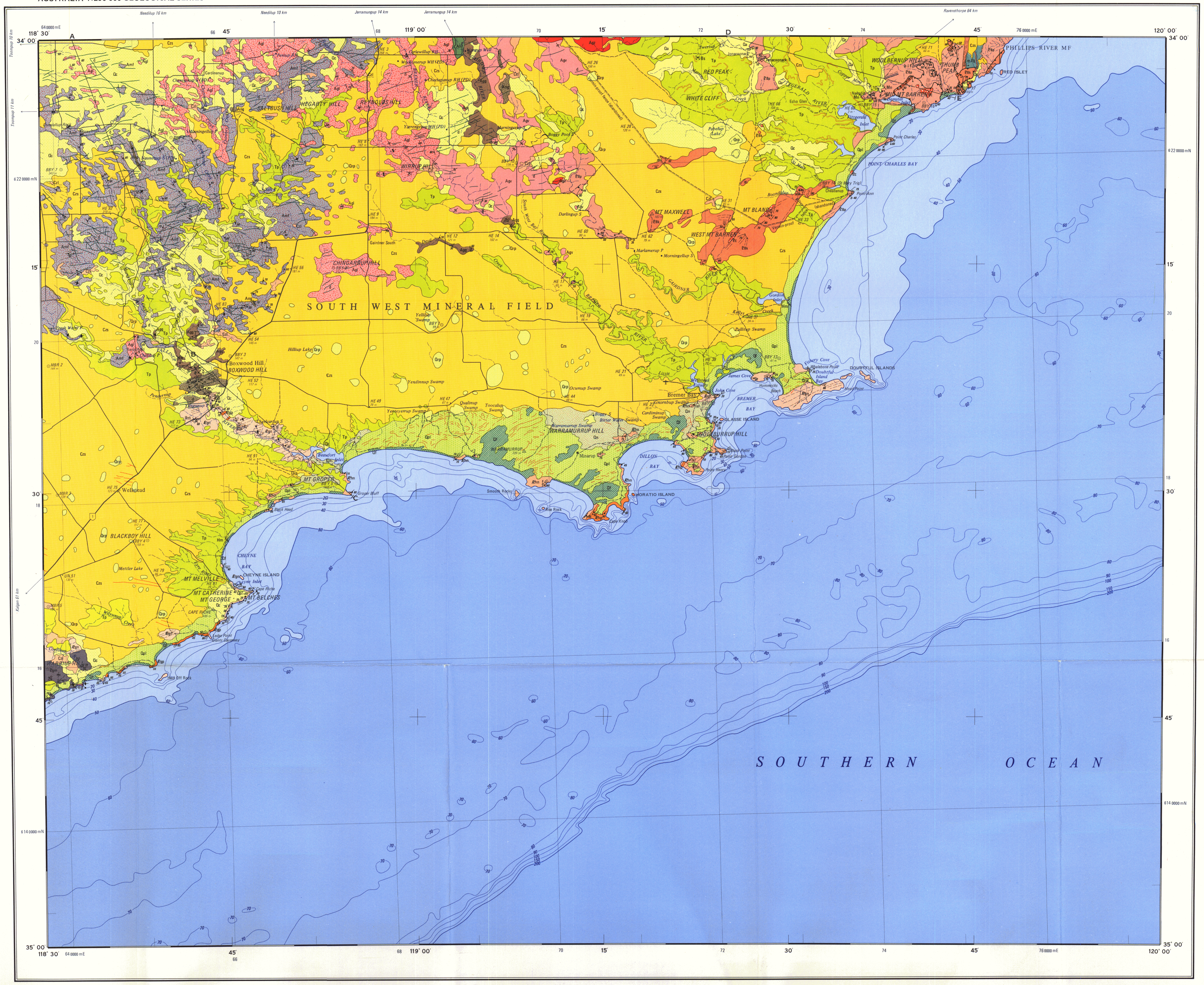
AUSTRALIA 1:250 000 GEOLOGICAL SERIES

BREMER BAY

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SI 50-12



SYMBOLS

Geological boundary
Fold
- minor
- minor with vergence

Low angle thrust; folded
Shear zone
Strike and dip of strata (facing not inferred)
- inclined
- vertical

Facing indicated by cross bedding
Trend line visible on air photo
Cleavage, foliation in metamorphosed sedimentary rocks and fracture cleavage in gneiss
- inclined
- vertical

Lineation
Metamorphic foliation in crystalline rocks
- Archaean
  - inclined
  - vertical
  - dip undetermined
- Proterozoic
  - inclined
  - vertical

Compositional layering in gneisses, augen gneissosity
- inclined
- vertical
- dip undetermined

Alignment of phenocrysts in porphyritic granitoid
- inclined
- vertical
- dip undetermined

Petroleum exploration well, dry, abandoned

Mineral field boundary
Highway with national route marker
Formed road
Track
Townsite, gazetted, population less than 1000 — Bremer Bay
Homestead — Minarup
Locality — Naendip
Landing ground
Horizontal control; major, minor
Benchmark, height accurate — HE 9 184 m
Breakaway
Sand dunes

Watercourse, intermittent
Bathymetric contour, depth in metres — 70
Pool — P
Waterhole — WH
Rockhole — RH
Spring — S
Position doubtful — (PD)

Quarry, abandoned
Prospect
Mineral occurrence
- Building stone — Bs
- Copper (reputed) — ?Cu
- Heavy mineral beach sand — Hm
- Lignite (with montan wax) — Cwl
- Manganese — Mn
- Road material — Rm

REFERENCE

CAINOZOIC

QUATERNARY

- Qf — Mobile sand in unvegetated dunes and beach deposits
- Qn — Eolian sand in vegetated dunes
- Qpl — Calcareous shelly sandstone and grit in coastal dunes, sheets and foreshore reefs – may be equivalent to TAMALA LIMESTONE; commonly with thin sand cover
- Qrp — Clay and silt deposits in brackish claypans and swamps
- Qa — Sheetwash and alluvium – derived mainly from Tp
- Qc — Colluvium and minor alluvium – derived mainly from Czs and bedrock
- Czs — Sandplain – yellow to white sand and clay; contains scattered limonite nodules derived from underlying gravel and laterite
- Czl — Duricrust and weathered rock – includes laterite, lateritic gravel, silcrete and kaolinized rock

TERTIARY — EOCENE

- Tp — **PLANTAGENET GROUP:** yellow to grey siltstone, silty sandstone and spongolite of the PALLINUP SILTSTONE, with minor sandstone and conglomerate of the WERILLUP FORMATION

PROTEROZOIC

PROTEROZOIC METAMORPHISM

- c — Clastic dyke – poorly-sorted feldspathic wacke; contains pebbles of quartz, jasper, feldspar and banded iron-formation
- Ꝑgl — Porphyritic granite – medium to coarse-grained; foliated and partially recrystallized in places
- Ꝑgm — Migmatite – Ꞓgn and Ꞓgp extensively invaded by Ꝑgl

(Post-date main Tectono-thermal event)

- Ꝑc — Deformed quartzitic breccia and conglomerate – mainly derived from ꝐBk
- Ꝑg — **Cowerdup Sill:** altered dolerite

Mount Barren Group

- ꝐBk — **KUNDIP QUARTZITE:** partially to completely recrystallized quartz arenite and micaceous sandstone
- ꝐBp — **KYBULUP SCHIST:** shale, sandstone, phyllite and schist
- bif — Banded iron-formation – alternating layers of iron oxides and granoblastic quartz

(Metamorphic gradient: greenschist facies (north) to amphibolite facies (south))

Ꞓ Denotes Archaean metamorphic and igneous rocks with superimposed Proterozoic metamorphism and strong Proterozoic structural elements

ARCHAEAN

Amphibolite facies

- Ꞓgn — Compositionally layered gneiss and strongly foliated granoblastic gneiss – adamellitic and granodioritic in composition
- Ꞓgp — Gneiss – mainly granitic augen gneiss
- Ꞓgs — Metamorphosed conglomerate

Granulite facies

- Ꞓhn — Compositionally layered gneiss, mafic granulite and migmatitic granulite – polyphase deformation
- Ꞓhp — Augen gneiss – polyphase deformation

- d — Dolerite and diorite dykes

ARCHAEAN TECTONISM

Post-tectonic granitoids

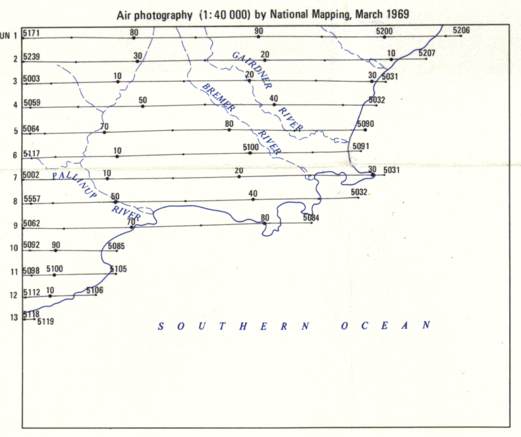
- Agv — Adamellite – medium to coarse-grained, variably textured; commonly seriate due to continuous variation in grain size; locally porphyritic
- Agl — Granite and adamellite – medium to coarse-grained, with abundant large phenocrysts; commonly seriate in texture and gradational into Agv
- Agz — Hornblende granodiorite – medium to coarse-grained

Pre-and syn-tectonic granitoids

- Agg — Adamellite and granodiorite – foliated, granoblastic texture and sparse garnet; foliation defined by entrainment and alignment of clusters and grains of biotite (less commonly hornblende)
- Ang — Quartz, feldspar and biotite (or hornblende) orthogneiss and paragneiss – compositional layering
- Ana — Granitic and adamellitic augen gneiss
- Amf — Metamorphosed agmatite – granoblastic or gneissic older phase consisting of Agg, minor paragneiss and amphibolite; enclosed by granoblastic leucocratic granite and adamellite
- Ah — Schist and paragneiss – includes cordierite schist, calc-silicate gneiss and basic granulite gneiss

FLIGHT DIAGRAM

Air photography (1:40 000) by National Mapping, March 1969



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.

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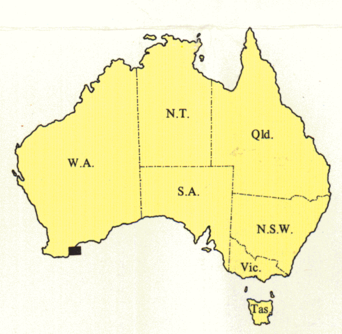
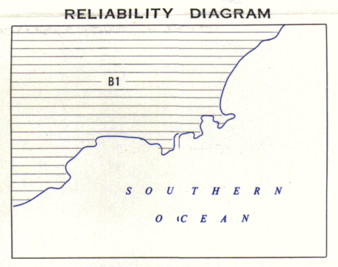


RELIABILITY DIAGRAM



B1 Numerous traverses with air photo interpretation

HON. DAVID PARKER, M.L.A.
MINISTER FOR MINERALS AND ENERGY
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SCALE 1:250 000

TRANSVERSE MERCATOR PROJECTION
ZONE 50 AUSTRALIAN MAP GRID

Geology by R. Thom and R.J. Chin 1977-78

INDEX TO ADJOINING SHEETS

DUMBLEYUNG SI 50-7	NEWDEGATE SI 50-8	RAVENSTHORPE SI 51-5
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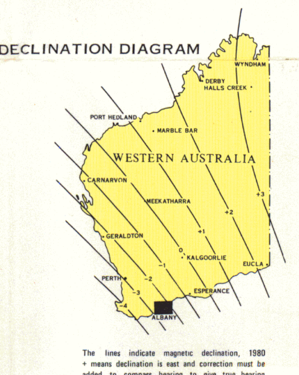
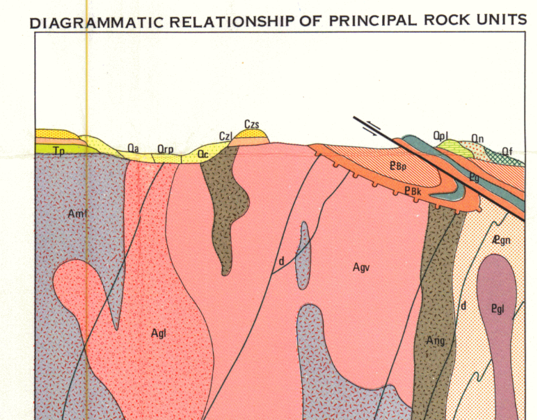
DECLINATION DIAGRAM



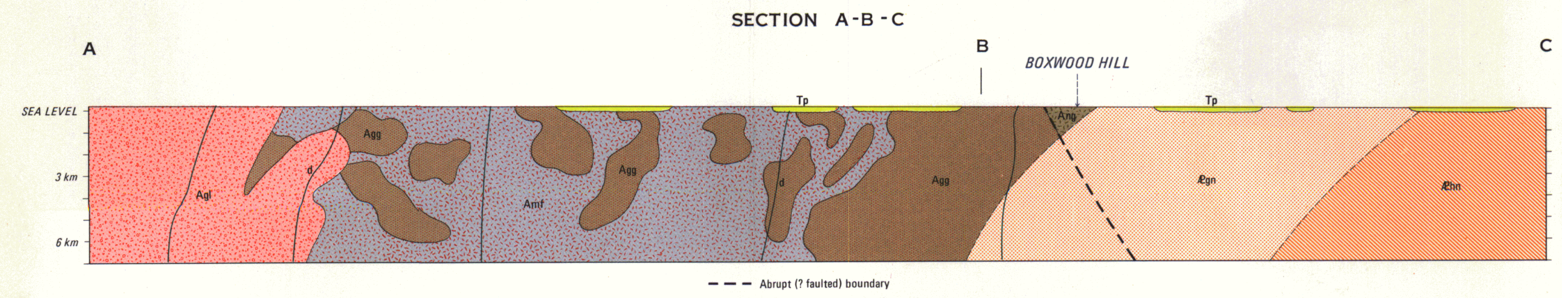
DIAGRAMMATIC RELATIONSHIP OF PRINCIPAL ROCK UNITS



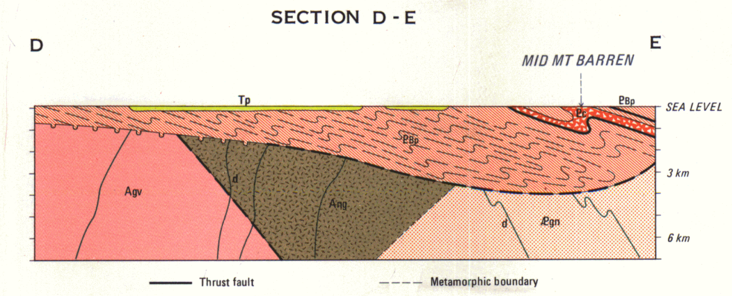
DIAGRAMMATIC SECTIONS

NATURAL SCALE

SECTION A-B-C



SECTION D-E



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