XPLANATORY NOTES

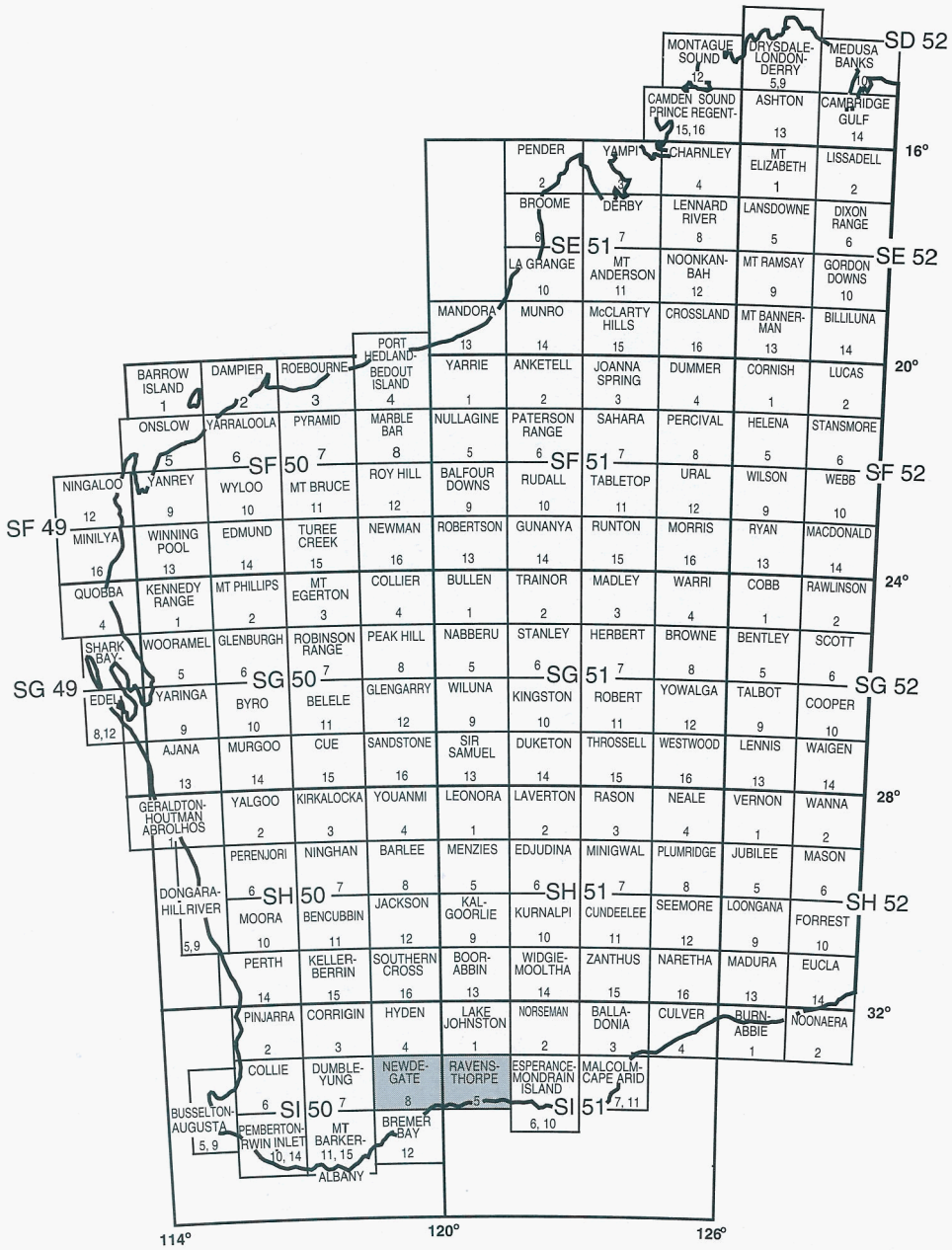
GOVERNMENT OF WESTERN AUSTRALIA

GEOLOGY OF THE RAVENSTHORPE AND COCANARUP 1:100 000 SHEETS

by W. K. WITT

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY



NEWDEGATE 2731	KING 2831	MOOLYALL 2931	NORTHOVER 3031
NEWDEGATE SI50–8		RAVENSTHORPE SI51–5	
JACUP 2730	COCANARUP 2830	RAVENS-THORPE 2930	OLDFIELD 3030

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by
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Perth 1997

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Copy editor: J. F. Johnston

The recommended reference for this publication is:

WITT, W. K., 1997, Geology of the Ravensthorpe and Cocanarup 1:100 000 sheets: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 26p.

National Library of Australia Card Number and ISBN 0 7309 6558 9

ISSN 1321–229X

Cover photograph:

Kyanite-bearing pelites (Kybulup Schist) in foreground; prominent bluff in background is formed by Kundip Quartzite. View looking across West Beach from Cave Point (COCANARUP).
The rocks were accreted to the southern Yilgarn Craton during the Mesoproterozoic Albany–Fraser Orogeny. Similar processes are interpreted to have occurred during accretion of terranes in the Archaean Ravensthorpe greenstone belt.

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Geology of the Ravensthorpe and Cocanarup 1:100 000 sheets

by

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Abstract

The Archaean Ravensthorpe greenstone belt contains two distinct tectonostratigraphic terranes and a third unit of uncertain affinity. In the east, the Carlingup Terrane (2958 ± 4 Ma) contains metamorphosed komatiite, basalt, sedimentary rocks (including banded iron-formation) and minor acid volcanic rocks. The Ravensthorpe Terrane (c. 2970 to 2980 Ma) occupies the central part of the greenstone belt and consists of tonalite and a volcanic association dominated by andesitic pyroclastic rocks. A third tectonic unit called the Cocanarup greenstones encompasses a strongly deformed belt of predominantly metasedimentary rocks, with fewer ultramafic and mafic rocks, along the western margin of the greenstone belt.

Metamorphic assemblages were attained during tectonic emplacement of the Ravensthorpe Terrane and the Cocanarup greenstones eastward over the Carlingup Terrane, and the thermal gradients responsible for metamorphism were controlled largely by contemporaneous emplacement of granitoid sheets below the greenstones. Metamorphic assemblages formed during terrane amalgamation indicate conditions that range from <400°C to >600°C, at about 2.5 kb.

The Archaean basement is structurally (and ?unconformably) overlain by the mid-Proterozoic Mount Barren Group. The metasedimentary Mount Barren Group was deformed by several phases of folding and faulting during the Albany–Fraser Orogeny. The metamorphic grade of the Mount Barren Group increases southward from the contact with Archaean rocks. Kyanite-bearing metapelitic schists exposed on the coast, west of Hopetoun, equilibrated at P>4.8 kb and T = 540–560°C. These high-pressure metamorphic rocks were uplifted south of secondary splays related to the Jerdacuttup Fault. High-grade Archaean (Munglinup) orthogneiss south of the Jerdacuttup Fault was deformed during the Albany–Fraser Orogeny, and subsequently uplifted.

KEYWORDS: Carlingup Terrane, Ravensthorpe Terrane, Cocanarup greenstones, Yilgarn Craton, Mount Barren Group, Albany–Fraser Orogeny, regional geology

Introduction

Location and physiography

The RAVENSTHORPE* and COCANARUP 1:100 000 sheets are located on the south coast of Western Australia, in the southwest corner of the RAVENSTHORPE 1:250 000 sheet, and in the southeast corner of the NEWDEGATE 1:250 000 sheet, respectively. The town of Ravensthorpe, on the South Coast Highway approximately midway between Albany and Esperance, lies on RAVENSTHORPE, near the map boundary with COCANARUP. Hopetoun, on the coast, is connected to Ravensthorpe by sealed road and has a small fishing harbour.

RAVENSTHORPE and COCANARUP lie south of the Jarrahwood Axis (Cope, 1975) that separates northward-directed drainage toward inland (mostly saline) lakes from southward-directed drainage systems such as the Jerdacuttup and Phillips Rivers. The highest peaks are in the Ravensthorpe Range, north of Ravensthorpe, which rise to 448 m. The Fitzgerald River National Park includes peaks of around 300 m that rise abruptly from sea level.

Regional geological setting

RAVENSTHORPE and COCANARUP contain three major Precambrian tectonic units. The northern parts of the map sheets cover the southern margin of the Archaean Yilgarn Craton, including the Ravensthorpe greenstone belt (Griffin, 1990). The Ravensthorpe granite–greenstone association has traditionally been regarded as forming part of the Southern Cross Province (Gee et al., 1981). It lies within the Southern Cross Superterrane of Myers' (in press) more recent subdivision of the Yilgarn Craton.

The Archaean granite–greenstone association is overlain by metasedimentary rocks of the Mount Barren

* Names of 1:100 000 and 1:250 000-scale map sheets are printed in capital letters.

Group to the south. The Mount Barren Group was deformed during the Albany–Fraser Orogeny, at about 1300 Ma (Nelson et al.,1995; Myers,1995).

Munglinup Gneiss, which underlies much of southeast RAVENSTHORPE, is part of the Biranup Complex. It is separated from the Mount Barren Group and Archaean granite–greenstones by the northeast-trending Jerdacuttup Fault.

Previous studies

The first detailed description of the geology and mineral deposits in the Ravensthorpe–Hopetoun area was published by Sofoulis (1958). The geology of RAVENSTHORPE and COCANARUP is shown on the RAVENSTHORPE and NEWDEGATE 1:250 000 geological map sheets, respectively, and is described in the relevant Explanatory Notes (Thom et al., 1977, 1984). Davy and Leonard (1989) carried out an orientation geochemical survey of the Fitzgerald National Park and adjoining areas to assist in determining the economic potential of areas within the park. Several recent research projects, most of which are incomplete at the time of writing (February, 1996), have been carried out in support of university degrees.

Archaean geology

Archaean greenstones of the Ravensthorpe greenstone belt on RAVENSTHORPE and COCANARUP have been subdivided into several fault-bound tectonic units — the Carlingup Terrane; the Ravensthorpe Terrane; and the Cocanarup greenstones (Fig. 1).

The Carlingup Terrane was previously called the Jerdacuttup Terrane (Witt, 1995), and has been renamed to avoid confusion with the younger Jerdacuttup Fault. The Carlingup Terrane comprises metamorphosed mafic and ultramafic rocks together with metasedimentary rocks, including banded iron-formation, and minor felsic metavolcanic (dacitic to rhyolitic) rocks. This rock package is folded to form the Maydon Syncline. The least-deformed portion of the Carlingup Terrane is in the Maydon farm area on the southwest limb of the Maydon Syncline. A provisional stratigraphy (see below) is proposed for this area. The Carlingup Terrane is in fault contact with the Ravensthorpe Terrane, which contains abundant metamorphosed tonalite and calc-alkaline volcanic rocks (basalt, andesite and dacite, minor rhyolite). Ravensthorpe Terrane rocks have not been folded around the Maydon Syncline. It is uncertain to which terrane, if either, the Cocanarup greenstones belong, but the rock types and associations are sufficiently distinct to warrant description as a separate tectonic unit.

In the following sections, descriptions of rock units appearing on the two 1:100 000 maps are arranged under their respective tectonic units. For the most part, these are stratigraphic units (defined in Appendix 1) but the Carlingup Terrane also contains some unassigned lithological units. It was not possible to recognize any coherent stratigraphic sequence within the strongly deformed Cocanarup greenstones, and rock types in the Cocanarup greenstones are therefore described as lithological units. Gneissic granitoid and biotite monzogranite are described separately as intrusive rocks.

Carlingup Terrane

The low-strain southwest limb of the Maydon Syncline contains four stratigraphic units (Fig. 2) that are the main components of the Carlingup Terrane. The Bandalup Ultramafics, Maydon Basalt and the Hatfield Formation are folded about the Maydon Syncline although, on the northeast limb of the syncline, Maydon Basalt and Bandalup Ultramafics have been cut out progressively to the northwest by simple shear along the gneissic granitoid–greenstone contact. Metapelitic to meta-psammitic rocks do not underlie Bandalup Ultramafics on the northeastern limb of the Maydon Syncline, but the Chester Formation may have been completely cut out against the gneissic granitoid–greenstone contact, at the present level of erosion.

Other rock types that form part of the Carlingup Terrane but cannot be placed in stratigraphic context with confidence are felsic volcanic rocks, namely dacite and rhyolite (*Afv*), polymictic conglomerate (*Asc*) and its strongly deformed counterpart (*Ascn*) and (if Archaean) an oligomictic conglomerate–quartzite association (*Aso*). These rock types are interleaved with the above-named units, mainly along the northeastern limb of the Maydon Syncline. The oligomictic conglomerate and quartzite west of Bandalup magnesite quarry may form part of an isolated relict of a tectonically emplaced Proterozoic thrust sheet (klippe), in which case they do not form part of the Carlingup Terrane. SHRIMP* dating of zircon in rhyolite from the Carlingup Terrane has yielded an age of 2958 ± 4 Ma (Nelson, 1995).

Chester Formation

Metamorphosed shale, siltstone and fine-grained greywacke (Acp) with porphyroblasts (Acpb)

Grey, green or brown, metamorphosed shale, siltstone and greywacke (*Acp*), interbedded with metamorphosed chemical sedimentary rocks, are exposed in the Ravensthorpe Range, from near Kundip to north of Ravensthorpe. Most of these fine-grained metasedimentary rocks are finely and evenly bedded with little evidence of cross-bedding or graded bedding. They are widely associated with similar porphyroblast-bearing rocks (*Acpb*). Porphyroblasts of chloritoid, garnet and andalusite, and less commonly biotite, are locally abundant (up to 50%) and largely bedding controlled. Anhedral, subequant porphyroblasts of cordierite, and quartz–muscovite (–chlorite) pseudomorphs after cordierite, have been identified in some samples. Porphyroblasts occur within a fine-grained matrix of quartz–muscovite(–chlorite–biotite–hematite) and accessory magnetite and rutile. Plagioclase feldspar is an important component of the matrix in some samples.

* Sensitive High-Resolution Ion Microprobe

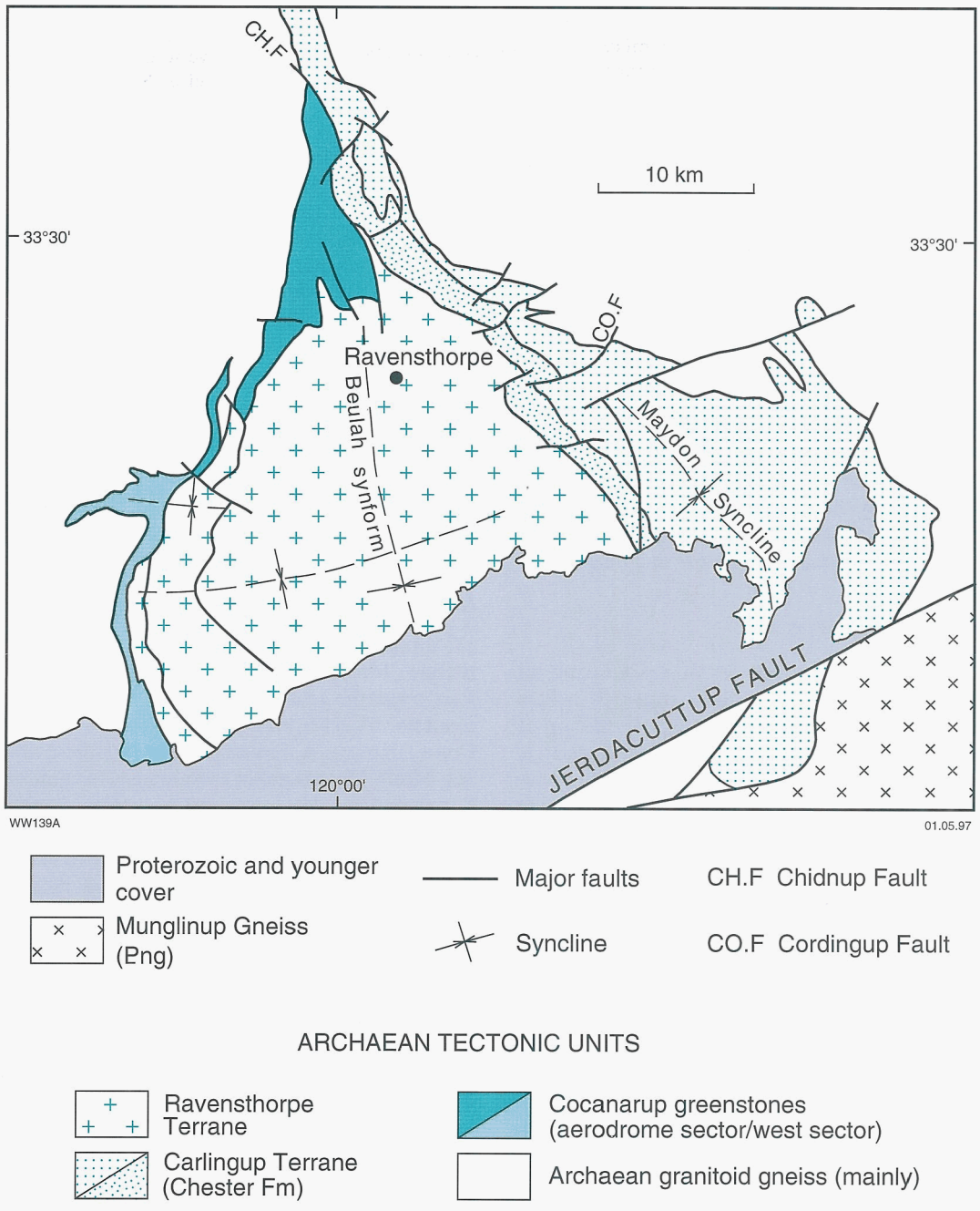


Figure 1. Geological map showing main tectonostratigraphic subdivisions and some of the main structures of the Archaean Ravensthorpe greenstone belt. Note that the area of the figure does not correspond exactly with the 1:100 000 sheets

Metamorphosed sandstone, siltstone and grit (Acs, Acg)

Thinly bedded, metamorphosed sandstone and siltstone (*Acs*) are associated with metapelitic rocks along the Ravensthorpe Range. Quartz-rich layers are interbedded with relatively silty and pelitic layers containing various amounts of sericite, biotite and opaque minerals, possibly including organic material. Locally (e.g. east of Kundip, around RAVENSTHORPE AMG 418705), coarser grained sandstone and grit (*Acg*) contain clasts of subangular to subrounded quartz and chert.

Metamorphosed chemical sedimentary rocks (Acc, Aci, Acl)

Metamorphosed chert (*Acc*), banded iron-formation (*Aci*) and massive to bedded limonite (*Acl*) are interbedded with pelitic rocks, forming prominent ridges that constitute the main topographic highs of the Ravensthorpe Range. Many of the chert units correspond with strong, linear magnetic highs and are probably underlain by banded iron-formation at depth. However, chert units have been intersected by diamond drilling in the Mount Chester area. Along strike, the chert units pass into massive to bedded limonite that is gossanous after pyrite. Millimetre-scale banding in banded iron-formation is defined by alternating layers of fine- to medium-grained quartz, grunerite and magnetite.

Heterogeneous unit (Acf)

Units designated (*Acf*) comprise an association of metamorphosed banded iron-formation, iron-rich pelites and probable volcaniclastic rocks. The largest outcrop of these units is north of Mount McMahon, where it is associated with a thick porphyroblast-bearing pelitic unit. Metamorphosed banded iron-formation is similar to that described above but tends to be dominated by quartz and grunerite with less opaque material.

Weakly deformed to schistose, volcanic to volcaniclastic rocks consist mainly of fine- to medium-grained quartz, plagioclase and calcic amphibole with variable amounts of colourless amphibole (cummingtonite–grunerite), biotite and garnet. Although the rocks have a predominantly granular to decussate metamorphic fabric, a clastic origin is indicated by angular clasts of quartz (≤3 mm), chert and dacite (≤1 cm). The modal composition of the samples suggests an andesitic to dacitic provenance but with dacitic compositions dominant. Opaque oxides, including ilmenite and hematite after magnetite, are relatively abundant (up to 5%), and some samples contain up to about 3% pyrite.

Bandalup Ultramafics

Ultramafic rocks covered by a surficial, silica-rich unit or 'caprock' (*Czu*) occur extensively in a north-northwesterly trending zone through Bandalup Hill, and also north of the South Coast Highway, between Boaiup Creek and Bandalup Creek. Relict adcumulate texture, and pseudomorphs after bladed metamorphic olivine (RAVENSTHORPE AMG 410817) have been recognized in this silica caprock, near Baoiup Creek and north of Bandalup. Exploration drilling has shown that the 'caprock' is underlain by serpentinized adcumulate dunite at Bandalup Hill. Between Boaiup Creek and Bandalup Creek, it is underlain by serpentinized dunite and peridotite, tremolite-rich rock, talc–forsterite (metamorphic forsterite) rock and talc–carbonate schist. Anthophyllite has been recorded in places (Marston, 1984).

Metamorphosed peridotite (ABp)

Metamorphosed peridotite, locally associated with minor magnesite and talc–carbonate rock, forms a 500 m-thick unit within komatiite, west of Maydon Road (RAVENSTHORPE AMG 395765). The peridotite is an olivine orthocumulate to mesocumulate. Serpentine pseudomorphs after rounded, cumulus olivine (up to about 4 mm) are dominant, accompanied by smaller amounts of talc, tremolite, chlorite, opaques and carbonate. Hopper-shaped olivine and harrisitic texture have been recognized locally but are a minor component of *ABp* units. An increase in the proportion and size of post-cumulus pyroxene, and the presence of thin metapyroxenite and high-Mg basalt layers, consistent with upward fractionation of the komatiite flow sequence, indicate younging toward the northeast. Smaller units of olivine orthocumulate also occur within dominantly komatiitic units (*ABk*, below).

Metamorphosed komatiite (ABk)

Metamorphosed komatiite, locally with olivine spinifex texture, forms a major unit between the Ravensthorpe Range and the Jerdacuttup River. Smaller komatiite units trend northwest from Bandalup Creek, south of the South Coast Highway. A minor component of these units is high-Mg basalt. Metamorphic assemblages in spinifex-textured komatiites are dominated by tremolitic amphibole after skeletal olivine. Tremolitic amphibole after fine-grained, acicular to skeletal pyroxene is found with minor chlorite, plagioclase and opaque minerals in interstitial domains between coarser grained skeletal olivine forms. More magnesian rocks consist mainly of talc and serpentine with minor but various amounts of chlorite, carbonate and opaque minerals (mainly magnetite and chromite).

Talc–carbonate schist (ABt)

Talc–carbonate schist after ultramafic rock is interleaved with komatiite and high-Mg basalt south of Maydon farmhouse. It also occurs as thin slices within the strongly deformed northeastern margin of the Ravensthorpe greenstone belt. The schist is generally deeply weathered but supports a distinctive, light-coloured soil that on air photos is readily distinguished from adjacent, less carbonated rocks.

Tremolite-rich rock and schist (ABr)

Tremolite-rich ultramafic rock lies along the northeastern margin of the Ravensthorpe greenstone belt. A narrow slice of tremolite-rich ultramafic rock also occurs near the greenstone – gneissic granitoid contact, east of Bandalup Hill. They are medium- to coarse-grained, massive to

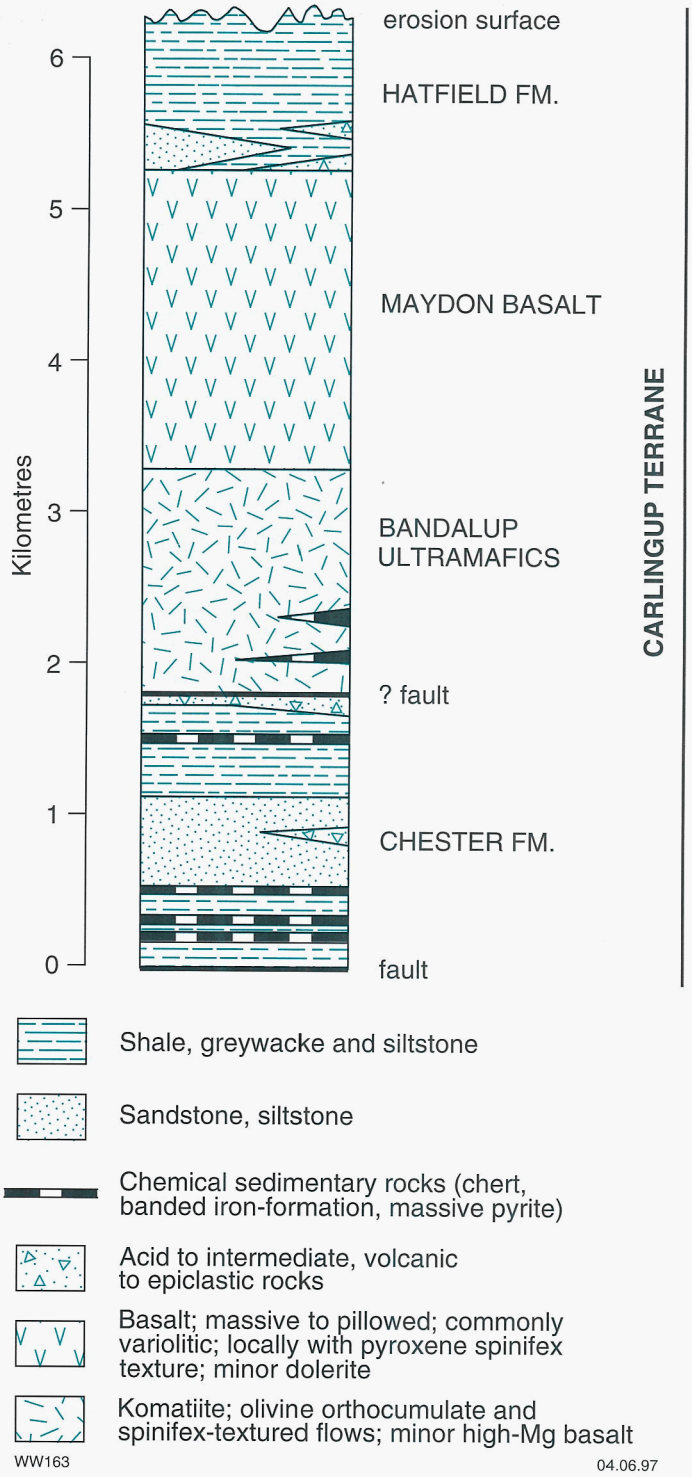


Figure 2. Stratigraphy of the Carlingup Terrane

schistose rocks. Tremolitic amphibole may be oriented parallel to the dominant foliation in schistose rocks, or randomly oriented (where metamorphic recrystallization has outlasted deformation). Up to 40% chlorite, and less commonly talc, occurs as fine-grained, felted masses, interstitial to prismatic amphiboles. Accessory opaques (?magnetite) and rutile complete the metamorphic assemblage.

Tremolite-rich rock, in a zone close to the greenstone – gneissic granitoid contact, northwest from Boaiup Creek (on RAVENSTHORPE), contains up to 30% pseudomorphs after porphyroblasts of blotchy to bladed metamorphic olivine, up to 6mm across. The olivine has been replaced by fine-grained aggregates of serpentine, chlorite, tremolite, opaques and bowlingite.

Tremolite-rich rock, interpreted as metamorphically recrystallized talc–carbonate schist, is also identified at several localities on contact zones between ultramafic rocks and adjacent units. These occurrences are associated with talc–(chlorite)–carbonate schist.

Along the northeastern margin of the Ravensthorpe Range, the Bandalup Ultramafics contain numerous thin banded iron-formation units (*Abi*). Banded iron-formation is less commonly associated with ultramafic rocks north of the South Coast Highway, between Jerdacuttup River and Bandalup Creek.

Maydon Basalt

Metamorphosed basalt (Amb)

Metamorphosed basalt dominates the central part of the Carlingup Terrane, and is also present as smaller units interleaved with ultramafic and other rocks along the northeast margin of the greenstone belt. The metabasalt is commonly pillowed, with variolitic texture, and acicular amphibole pseudomorphs after skeletal pyroxene. The metamorphic assemblage is dominantly tremolite–actinolite and plagioclase, with accessory opaque minerals. Although generally aphyric, tabular phenocrysts (<2 cm) of plagioclase have been observed west of Bandalup (RAVENSTHORPE AMG 532768) and near Bandalup Creek (RAVENSTHORPE AMG 505778).

Metamorphosed dolerite (Amd)

Metamorphosed dolerite is much less abundant than in Archaean greenstone sequences in the Eastern Goldfields Province of the Yilgarn Craton (Swager et al., 1990; Witt et al., 1991). However, thin metadoleritic units are identified within metabasalt southwest of Bandalup and within ultramafic rocks in the Mosaic mine area, east of Kundip. Dolerite is generally a non-porphyritic rock containing mainly amphibole and plagioclase with accessory ilmenite or leucoxene.

Amphibolite (Ama)

Fine- to medium-grained amphibolite is widespread at or near the contact of the greenstones with gneissic granitoid. Amphibole and plagioclase are accompanied in some samples by up to 10% biotite and quartz. Accessory minerals are ilmenite(–titanite–apatite–zircon).

Hatfield Formation

Metamorphosed shale, siltstone and greywacke (*Ahp*), locally with porphyroblasts (*Ahpb*), are interbedded with massive to bedded limonite, possibly after sulfide-rich sedimentary rocks (*Ahl*), in a belt that trends southeast from Maydon farmhouse. These rocks are similar to sedimentary rocks in the Chester Formation. However, although andalusite, garnet and chloritoid porphyroblasts have been observed in the unit *Ahpb*, cordierite has not been identified. Metamorphosed shale near Bandalup Pools contains minor intervals of coarser metasedimentary rocks with angular clasts of metamorphosed chert, shale and felsic volcanic rocks. Thinly bedded, metamorphosed siltstone and sandstone (*Ahs*) forms a prominent unit in the core of the Maydon Syncline. Near Bandalup Pools (RAVENSTHORPE AMG 490699) low-angle cross-bedding is found in this unit. The metasedimentary units are associated with minor dacitic volcanic and volcaniclastic sedimentary rocks (*Ahv*) and felsic schist (*Ahf*). Dacitic volcanic rocks are porphyritic, with phenocrysts of quartz and feldspar. The presence of chessboard albite in sample 110265 (RAVENSTHORPE AMG 441757) suggests the former presence of alkali feldspar phenocrysts. Other components are mainly calcic amphibole, chlorite and muscovite. Volcaniclastic rocks contain rounded to subangular clasts (up to 30 cm across) of volcanic material. Garnet and chloritoid porphyroblasts are locally abundant.

Unassigned units

Metamorphosed dacite, rhyolite (Afv)

Metamorphosed acid volcanic rocks form a minor component of the Carlingup Terrane. In addition to dacitic rocks in the Chester and Hatfield Formations, there are several occurrences of felsic metavolcanic rocks that are not readily assigned to any of the defined stratigraphic units. The main localities are southeast of Bandalup and east of Kundip where the volcanic rocks are dacitic to rhyolitic. They differ from volcanogenic rocks assigned to the Annabelle Volcanics in the Ravensthorpe Terrane in that they lack metabasalt and have a relative paucity of andesitic rocks.

Felsic volcanic rocks southeast of Bandalup are probably fine-grained pyroclastic rocks. Although the rocks are moderately deformed, igneous structure and texture are commonly well preserved. Rhyolitic rocks contain phenocrysts of blue-grey β-quartz (≤4 mm) and alkali feldspar in a fine-grained to aphanitic quartzo-feldspathic matrix. Thin, elongate biotite aggregates may be flattened lithic fragments or fiamme. Minor quartz-poor amphibole–plagioclase rock (metamorphosed ?andesite) is also present.

Weakly to moderately deformed felsic volcanic rocks east of Kundip are poorly sorted and hydrothermally altered fragmental rocks containing angular to subangular lithic clasts up to about 10 cm in diameter.

Fine-grained felsic gneiss (Afvn)

Fine-grained, leucocratic to mesocratic, quartzofeldspathic gneiss, locally with small (≤3 mm) quartz and feldspar porphyroclasts (*Afvn*), is exposed along the South Coast Highway, east of Bandalup Creek. Relict igneous texture in low-strain domains indicates this unit is a more highly deformed equivalent of the felsic metavolcanic unit (*Afv*) described above. The present mineralogy is quartz, plagioclase, K-feldspar, biotite(–chlorite–muscovite) with accessory titanite and opaque minerals. Calcic amphibole forms up to about 15% of some samples. Small magnetite porphyroblasts are present locally.

Metamorphosed sandstone (Ass) and oligomictic conglomerate (Aso)

Poorly bedded, quartz-rich metamorphosed sandstone (*Ass*) and oligomictic conglomerate (*Aso*) are found between Bandalup Creek and the Bandalup magnesite pits. Although the conglomerate is poorly exposed, float of rounded pebbles of chert or quartzite is widespread. Whilst these occurrences are shown as Archaean deposits on RAVENSTHORPE, the quartz-rich conglomerates and relatively pure orthoquartzites contrast with the finely bedded, opaque-rich, muddy sandstone and siltstone of the Chester and Hatfield Formations. Similar quartzites have not been observed elsewhere in the Archaean greenstones. It is possible that the Bandalup quartzite and oligomictic conglomerate are part of an originally more extensive, tectonically emplaced slice of the Proterozoic Mount Barren Group.

Metamorphosed polymictic conglomerate and greywacke (Asc) and quartz–feldspar–hornblende(–biotite) gneiss and schist (Ascn)

Metamorphosed, poorly sorted, clast- to matrix-supported, polymictic conglomerate and greywacke (*Asc*) exist as two lenses within mafic and ultramafic volcanic rocks in the Bandalup Creek area. A third polymictic conglomerate unit occurs in the Jerdacuttup River area, east of Kundip. There are excellent exposures of polymictic conglomerate in Bandalup Creek (RAVENSTHORPE AMG 516759). Rounded to subrounded clasts, up to a metre across, of tonalite and basaltic to dacitic volcanic rocks are set within a medium- to coarse-grained greywacke sand and grit matrix. Clasts of banded iron-formation and komatiite are rare. Conglomerate is interleaved with thinly bedded grit and lithic and feldspathic sandstone. The sandstone and grit display low-angle cross-bedding and contain quartz, feldspar, chlorite and calcic amphibole, and accessory opaque minerals hematite and sericite. Biotite is present in some samples. Ferromagnesian minerals typically comprise 30 to 50% of the rock.

Medium- to coarse-grained quartz–plagioclase–amphibole(–biotite) schist and gneiss (*Ascn*) occur as discontinuous lenses along strike from polymictic conglomerate and greywacke (*Asc*), near the northeastern margin of the Ravensthorpe greenstone belt. Although compositionally similar to them, this unit is coarser grained than deformed intermediate volcaniclastic rocks in the Ravensthorpe Terrane (*Aav*). It is also characterised, in relatively low-strain domains, by the presence of stretched and flattened clasts equivalent to those found in polymictic conglomerate. The unit is exposed along the South Coast Highway, near RAVENSTHORPE AMG 448784.

Ravensthorpe Terrane

The Ravensthorpe Terrane contains the Annabelle Volcanics and the Manyutup Tonalite. The intimate spatial association of tonalite, tonalite porphyry dykes and calc-alkaline volcanic rocks suggests a co-magmatic relationship between all three. Such a relationship is supported by preliminary chemical data that indicate porphyry dykes could have formed by fractional crystallization from tonalite (Savage, 1992; Witt, in prep.). Coarse-grained tonalite, tonalite porphyry and calc-alkaline volcanic rocks from the Ravensthorpe Terrane have given U–Pb in zircon (SHRIMP) dates of c. 2970–2980 Ma (Savage et al., 1995).

Annabelle Volcanics

Metamorphosed agglomerate, tuff and related epiclastic rocks (Aav)

Massive to coarsely bedded, metamorphosed andesitic and dacitic agglomerate and tuff are exposed in a broad arc adjacent to the Manyutup Tonalite, from south of Cocanarup Spring (COCANARUP AMG 682742) to the Kundip mining centre. The same rock types form abundant xenoliths within the margins of the tonalite. This unit was shown as basalt or basalt and dacite on the RAVENSTHORPE and NEWDEGATE 1:250 000 sheets. Reassessment during the current mapping program suggests that the proportion of rock types (based on field estimations) is approximately 10–20% metabasalt, 50–70% meta-andesite and 20–30% metadacite. Quartz-phyric rocks are scarce but rhyolite has been tentatively identified northeast of Elstree Farm (COCANARUP AMG 737794). The proportion of metadacite increases away from the Ravensthorpe area toward Kundip in the southeast and West River in the southwest. Metadolerite is a minor component, comprising some 5% of the unit.

Although primary depositional structures are well preserved, the small-scale rock fabrics and the mineralogy are metamorphic. Metabasalt and meta-andesite consist predominantly of fine- to medium-grained, granoblastic plagioclase and granular to decussate, blue-green calcic amphibole with varying amounts of quartz, biotite and chlorite. Small plagioclase phenocrysts, and amphibole and/or biotite pseudomorphs after hornblende or pyroxene are common. Minor colourless amphibole (?cummingtonite) has been identified in some andesitic rocks north of Ravensthorpe, becoming more abundant southwest of the town. Blue-green amphibole is commonly poikilitic. Metadacite is mainly fine-grained, granoblastic

quartz and plagioclase with up to about 30% amphibole, biotite and chlorite. Blue-green calcic amphibole is present near Ravensthorpe and Kundip, but cummingtonite becomes increasingly common toward Cocanarup. Subhedral plagioclase phenocrysts (≤2 mm) are commonly preserved in metadacitic rocks. Amphibole phenocrysts are less common and quartz phenocrysts are relatively rare. Accessory phases include opaque minerals, titanite and apatite. Leucoxene is present in some metabasalt and metaandesite samples. Zircon and rutile have been recognized in metadacite.

Small (≤2 mm) garnet porphyroblasts are locally common in clasts and matrix, north and northeast of Ravensthorpe. Minor amounts of quartz–plagioclase–biotite–garnet(–calcic amphibole–cordierite–andalusite) schist with up to 35% quartz have been identified at several localities, and probably represent metamorphosed sedimentary rocks derived from the associated volcanics.

Intermediate to acid gneiss (Aavn)

Fine- to medium-grained quartz–plagioclase–amphibole (–biotite) gneiss, interpreted to be a strongly deformed and recrystallized equivalent of the volcanic unit (*Aav*) occurs within and around the southwest margin of the Manyutup Tonalite. Stretched clasts, indicative of an original fragmental structure, can be recognized in relatively low-strain domains. Reasonable exposures of this rock type can be seen in the Phillips River and Twertatup Creek, around Cocanarup AMG 685738. Near Cocanarup, lenses of metadacitic rock are found within metamorphosed andesite, and one of the larger lenses (*Aavd*) has been shown separately on Cocanarup. The proportion of metadacitic rocks increases to the south to become subequal or slightly dominant in the area of the Last Venture and Copper King mines. Amphiboles include prismatic to poikiloblastic, blue-green calcic amphibole and prismatic to acicular, colourless cummingtonite. The latter is dominant in metadacitic rocks. Clinopyroxene, accompanied by brown-green calcic amphibole, is an essential component of GSWA sample 118840, collected south of Cocanarup (Cocanarup AMG 679735), but has not been identified elsewhere.

A small unit shown as *Aavn*, west of the Copper King and Last Venture mines, comprises a relatively diverse assemblage of rock types including fine- to medium-grained intermediate gneiss, metapelitic schist and ultramafic schist.

Cordierite–orthoamphibole rock (Aava)

A 2.5 × 0.5 km lens of massive to banded, medium- to coarse-grained quartz–plagioclase–biotite–orthoamphibole–cordierite(–andalusite–garnet) rock (*Aava*) lies within quartz–plagioclase–amphibole(–biotite) gneiss (*Aavn*) west of Kybulup Pool (Cocanarup AMG 663595). Several smaller lenses of this unit are also present in the area, mainly within the mixed gneiss and schist unit (*Aavn*), but most are too small to be shown at map scale. The rock is characterized by coarse, radiating sheaves and fans of orthoamphibole (anthophyllite–gedrite series) up to about 2 cm long, and rounded to ovoid poikiloblasts of andalusite and cordierite.

Manyutup Tonalite

Tonalite (Ayt, Aytm)

A large tonalite body (referred to as granodiorite by Sofoulis (1958) and by Thom et al. (1977) as quartz diorite) is named here the Manyutup Tonalite. There is some modal, and considerable textural, variation within the Manyutup Tonalite but the most widespread phase of the tonalite is a coarse-grained, equigranular biotite–hornblende tonalite. Ferromagnesian minerals comprise 5–15% of the rock, K-feldspar is absent or a very minor component, and accessory minerals are magnetite, ilmenite, apatite and zircon, and rarely allanite. Cummingtonite is present with calcic amphibole in samples collected from the southwestern part of the intrusive complex.

Sharp but very irregular intrusive contacts between coarse-grained tonalite and volcanic country rocks (Annabelle Volcanics) are exposed in Cattlin Creek on Ravensthorpe. Similar intrusive contacts between medium-grained tonalite and volcanic rocks are exposed in Stevenson Creek on Cocanarup. The northwest margin of the coarse-grained tonalite, from southeast of Cocanarup, contains abundant volcanic xenoliths and extensive textural and modal variation for up to about 100 m from the contact. Xenolith-rich marginal zones are also present, though less extensive, between Kundip and Elverdton. Only xenoliths of rock types included within the basalt–andesite–dacite volcanic unit (*Aav*) have been observed, even south of Mount McMahon where the volcanic unit is very thin or absent.

There are numerous dykes of relatively fine-grained tonalite and tonalite porphyry in tonalite and volcanic country rocks along the northwest and eastern contact zones. The dykes are less abundant in the interior of the pluton. Contacts between coarse-grained, equigranular tonalite and dykes and other compositional or textural variants are sharp and irregular, or sharply transitional (over one or two centimetres).

Small plutons of medium-grained tonalite (*Aytm*) lie within the coarse-grained tonalite and adjacent volcanics, particularly along the northwest margin of the intrusion. Contact relations between these plutons and the coarse-grained tonalite have not been observed but, based on rock-float distribution, are probably sharp to gradational over tens of metres. As with the coarse-grained tonalite, widespread textural and modal variation (including mm-scale magmatic banding), and abundant xenoliths of volcanic country rocks, are found in marginal zones of the plutons (e.g. Manyutup Creek, Cocanarup AMG 724732).

Medium-grained tonalite is also a marginal phase (up to several kilometres wide) to coarse-grained tonalite along the west and southwest contacts of the unit. Contacts between medium-grained and coarse-grained phases are broadly gradational (over several hundred metres). The inner medium-grained tonalite (*Aytm*) zone contains abundant greenstone xenoliths but the outer zone lacks xenoliths and is moderately to strongly recrystallized. In particular, there is extensive subgrain development in quartz. Some samples display a distinct tectonic foliation,

defined by closely spaced, anastomosing zones of intense recrystallization and granoblastic fabric. The foliation is generally oriented subparallel to lithological contacts.

A unit shown as dolerite (*Ard*), on the contact between Manyutup Tonalite and Annabelle Volcanics east of Cocanarup, may be a marginal phase of the tonalite complex.

Unassigned units

Feldspar(–quartz) porphyry dykes (Apf)

Between Manyutup Creek and the Phillips River on COCANARUP, the Manyutup Tonalite is cut by a swarm of northwest-trending, fine-grained leucocratic feldspar porphyry dykes. The age of these dykes is unknown but their occurrence is restricted to the Ravensthorpe Terrane and they are provisionally related to the Archaean tonalite. This unit contains 5–10% phenocrysts, mainly plagioclase, but accompanied by minor biotite and quartz in some samples. Subhedral to euhedral plagioclase phenocrysts are up to about 2 mm across, and locally glomeroporphyritic. They are set within a very fine-grained, quartzofeldspathic groundmass containing minor muscovite, biotite and opaque minerals. The dykes are difficult to distinguish from the dacitic component of the Annabelle Volcanics but have been observed within volcanic rocks near Stevenson Creek (COCANARUP AMG 735758).

Cocanarup greenstones

The Cocanarup greenstones are mainly metasedimentary rocks but also contain metamorphosed mafic and ultramafic rocks. They are separated from the Chester Formation (Carlingup Terrane) by the Chidnup Fault and also have deformed contacts with the Ravensthorpe Terrane. Correlation between metasedimentary rocks of the Cocanarup greenstones and the Chester Formation is uncertain, as described below. The Cocanarup greenstones are subdivided into the Aerodrome sector in the north and the West sector in the west and south (Fig. 1), reflecting changes in the nature of the metasedimentary rocks and associated units across a northwest-trending fault near Cocanarup.

Aerodrome sector: The Aerodrome sector comprises mainly metasedimentary rocks (*Alqm* and *Ald*) interleaved with metamorphosed ultramafic rocks (*Aur*), and minor amphibolite (*Aba*) and mafic gneiss (*Anb*). Units designated *Al* are deeply weathered and presumed to be quartz–muscovite schist (*Alqm*) and biotite schist (*Ald*). Although this interleaved association is similar to that east of the Chidnup Fault, a major difference is the abrupt decrease in the amount of banded iron-formation. Banded iron-formation has been identified, but is extremely rare, in the Aerodrome sector. Furthermore, where they are well exposed, metasedimentary rocks of the Aerodrome sector differ from the mainly metapelitic rocks and quartz-rich metasedimentary rocks of the Chester Formation in that they are predominantly quartzofeldspathic and commonly contain several percent tourmaline.

West sector: The West sector differs from the Aerodrome sector in its relatively minor ultramafic component and different metasedimentary association. Metasedimentary rocks in the West sector are mainly metapelite (*Alg*) and para-amphibolite (*Anp*). Para-amphibolite has not been identified outside the West sector on either RAVENSTHORPE or COCANARUP. Metapelitic rocks contrast with the coarse-grained, feldspathic, micaceous quartzites of the Aerodrome sector. However, quartz–feldspar–biotite(–garnet–aluminosilicate) schist (*Ald*) north and south of the fault separating the two sectors may represent a transitional sedimentary facies between quartzo-feldspathic metasedimentary rocks of the Aerodrome sector and metapelites of the West sector. Detailed exploration mapping in the area of the Copper King and Last Venture mines indicates the presence of several poorly exposed banded iron-formation units, mainly near the top (eastern contact) of the para-amphibolite (Perring, 1991).

Ultramafic rocks (Au, Auk, Aur)

Ultramafic rocks are found as rare slices in the West sector of the Cocanarup greenstones. The largest of these slices (at COCANARUP AMG 640663) is massive, fine-grained talc serpentinite with minor chlorite. Talc and chlorite occur interstitially to serpentinized, bladed (metamorphic) olivine up to 10 × 2 mm. Banded talc–tourmaline rock and massive, coarse-grained (2–6 mm) tourmalinite occur on the contact with the metasedimentary unit to the east. Tremolite-rich ultramafic rock with pseudomorphs after metamorphic olivine (*Aur*) is common in the Aerodrome sector of the Cocanarup greenstones. Undeformed komatiite with spinifex texture (*Auk*) is less common.

Amphibolite (Aba)

Fine- to medium-grained amphibolite is common at or near the contact of the greenstones with gneissic granitoid. Hornblende is the dominant amphibole (based on weak pleochroic brown-green colours), but subordinate cummingtonite (a colourless amphibole) is present in some samples.

Mafic gneiss (Anb)

Thin slices and lenses of medium-grained mafic gneiss lie along the contact between greenstones and gneissic granitoid, and within gneissic granitoid around Cocanarup. A relatively large, isolated body of mafic gneiss within gneissic granitoid is exposed in the West River, southwest of Cocanarup Spring. Mafic gneiss has a better developed gneissic banding than amphibolite, and commonly contains clinopyroxene in addition to hornblende and plagioclase. Up to 10% quartz and biotite are present in some samples. Accessory minerals are titanite, apatite, opaque oxides and possibly zircon.

Undivided metsedimentary rock (Al)

Deeply weathered, quartzose metasedimentary rocks are commonly exposed north of South Coast Highway on COCANARUP. Relict sedimentary structures are locally preserved. They are interpreted to be weathered versions

of mainly psammitic metasedimentary rocks, equivalent to the unit *Alqm*, described below.

Banded iron-formation (Aci)

Banded quartz–amphibole–garnet rock, containing about 10% garnet, occurs south of Elstree farm (COCANARUP AMG 715765). Colourless amphibole (?grunerite) and green calcic amphibole coexist with quartz, garnet, clinopyroxene and magnetite in this rock, which is interpreted to be a metamorphosed, muddy (silicate facies of James, 1954) banded iron-formation. The banded rock occurs with metapelitic rocks as a thin unit within metamorphosed intermediate volcaniclastic rocks (*Aavn*). Other banded iron-formation units in the West sector are poorly exposed.

Micaceous quartzite and quartz–muscovite schist (Alqm)

Quartz–muscovite(–plagioclase–microcline–sillimanite) schist with rare andalusite and garnet and micaceous quartzite are exposed in thin units north of the South Coast Highway, on COCANARUP. This unit is more quartz- and feldspar-rich than the quartz–plagioclase–mica–garnet schist (*Alg*) and the dominant mica is muscovite rather than biotite. Small (≤1 mm) porphyroblasts of garnet and andalusite are present locally. Some samples are quartz rich, others are plagioclase rich. Tourmaline is relatively abundant, forming up to 5% of the rock.

Quartz–plagioclase–mica–garnet schist (Alg) and quartz–feldspar–biotite–andalusite schist (Ald)

Medium- to coarse-grained quartz–plagioclase–biotite schist (*Alg*) with abundant garnet porphyroblasts (up to about 7 mm) is a thin, discontinuous unit along the southwestern margin of the Cocanarup greenstones and within gneissic granitoid near the West River. Cordierite, fibrolitic sillimanite, andalusite and muscovite are also present locally. Accessory opaque oxides, rutile and tourmaline have been recognized and opaque oxide minerals form up to about 15% of some samples. Toward the southern end of the greenstone belt, the schist becomes finer grained and more like metapelitic rocks designated *Acpb* (Chester Formation) in the Carlingup Terrane. Northeast of Cocanarup Spring (COCANARUP AMG 703750), metapelitic schists (designated *Ald*) become less micaceous and more quartzofeldspathic, although retaining a similar overall mineralogy.

Quartz–K-feldspar–sillimanite gneiss (Anl)

A lens of medium- to coarse-grained granoblastic quartz–microcline–sillimanite rock and quartz–clinopyroxene–hornblende rock outcrops around COCANARUP AMG 638645. The quartz–microcline–sillimanite rock contains minor muscovite and biotite, and accessory opaque oxides, tourmaline, zircon and rutile. Some samples display a pink and white mottling. Petrographic examination shows the mottling corresponds to domains of quartz and prismatic sillimanite within a more continuous matrix of quartz–microcline–fibrolitic sillimanite. The quartz–clinopyroxene–hornblende rock contains minor microcline and accessory titanite but no plagioclase. The precursor for this unusual assemblage may have been a siliceous carbonate rock with a minor clay component.

Banded quartz–amphibole–plagioclase rock (Anp)

A relatively thin but continuous unit of medium-grained amphibolite and quartz–amphibole–plagioclase gneiss, interpreted as paragneiss (*Anp*), extends southward from Cocanarup. Green to brown-green calcic amphiboles are generally dominant. Cummingtonite is abundant in some samples, and clinopyroxene has been identified at COCANARUP AMGs 635647 and 650600. Although the unit is heterogeneous, many samples have some to numerous quartz bands up to about 1 cm thick. Biotite and minor microcline and garnet are present locally, and plagioclase is anorthite rich ($An_{>90}$) in one of two samples analyzed. These features suggest a metasedimentary origin. Plagioclase-rich pebbles containing minor calcic amphibole (?metadacite) occur within an amphibolitic matrix at COCANARUP AMG 662741.

Intrusive rocks

Gneissic granitoid (*Agn, Agni*)

Gneissic granitoid (*Agn*) outcrops extensively northwest and northeast of the Archaean greenstone belt. Large areas northeast of the Carlingup Terrane, portrayed as intrusive granite by Thom et al. (1977), have been reclassified as gneissic granitoid. Gneissic granitoid is medium- to coarse-grained, equigranular to seriate, and locally contains porphyroclasts of feldspar. Although compositions range from trondhjemite and tonalite to syenogranite, the dominant rocks are monzogranite and granodiorite. Gneissic banding is well developed in samples with more than about 10% ferromagnesian minerals, but is weak in more leucocratic samples. The gneiss is predominantly granoblastic but relict igneous textures are widespread. Where gneissic banding is not well developed, a prominent foliation is defined by oriented aggregates of biotite and elongated quartz aggregates.

Relatively melanocratic, tonalitic to dioritic gneiss (*Agni*) forms elongate bands within the gneissic granitoid (*Agn*), north of Cocanarup. Contacts between the units *Agn* and *Agni*, observed in the Phillips River north of Cocanarup, are gradational over 50–100 m. The tonalitic gneiss bands are parallel to the gneiss–greenstone contacts. The tonalitic gneiss is commonly associated with bands of mafic gneiss and, in some cases, appears to lie along strike from mafic gneiss units at the base of the greenstones. Tonalitic gneiss contains >20% ferromagnesian minerals (normally biotite and amphibole). It is intruded by veinlets and lenses of relatively undeformed tonalite and monzogranite.

Biotite monzogranite and granodiorite (*Agm*)

A number of small plutons of undeformed, equigranular biotite monzogranite and biotite granodiorite (*Agm*) have

been emplaced near the northern and eastern contacts of the Ravensthorpe greenstones with gneissic granitoid. A larger body of potash feldspar-phyric monzogranite has been identified northwest of Cocanarup. Good exposures of this pluton can be seen in Hicks Creek (around COCANARUP AMG 595775) where pegmatitic segregations, biotite schlieren and xenolithic blocks of gneissic granitoid are common.

Reworked Archaean rocks — Munglinup Gneiss (*Png*)

Granitoid gneiss southeast of the Jerdacuttup Fault has been named Munglinup Gneiss (Myers, 1995). Although shown as Proterozoic gneiss by Thom et al. (1977), recent geochronological data (Nelson et al., 1995) indicate that the granitic protolith was Archaean (*Agn*) — c. 2 630 Ma. The Munglinup Gneiss is petrographically similar to the gneissic granitoid exposed along the West River but has been overprinted by Proterozoic deformation related to the mid-Proterozoic Albany–Fraser Orogeny (Myers, 1995). Contorted bands of amphibolite in the Munglinup Gneiss are probably deformed early Proterozoic dolerite dykes.

Structure of the Archaean granitoid gneiss and greenstones

The margins of the Ravensthorpe greenstone belt dip inward at angles of 40–70°, defining a structure here termed the Beulah synform (Fig. 1). However, the synform is not a simple fold, and structural relationships within the synform are complex. The Archaean structural history of the Ravensthorpe greenstone belt is summarized in Table 1, which describes and correlates deformation events in each of the three tectonic units: the Carlingup Terrane, the Ravensthorpe Terrane and the Cocanarup greenstones.

The structure of the Carlingup Terrane is dominated by the F_2 Maydon Syncline. This is an asymmetric, southeast-plunging fold, the northeast limb of which has been disrupted and attenuated by deformation against the adjacent gneissic granitoid unit. An early fabric (S_1) is locally preserved in porphyroblasts and low-strain domains and is generally parallel or subparallel to primary layering (bedding), suggesting D_1 involved low-angle thrusting. There are also some tight, mesoscopic and macroscopic fold closures on the limbs of the Maydon Syncline that can be attributed to early recumbent folding. The contact between Chester Formation and Bandalup Ultramafics is strongly deformed and could be interpreted as a low-angle thrust fault across which the upper part of the greenstone sequence (Bandalup Ultramafics, Maydon Basalt and Hatfield Formation) was tectonically emplaced over the Chester Formation (Fig. 2). Such an interpretation would view the Chester and Hatfield Formations as depositional equivalents. Precise geochronological data are required to confirm this hypothesis.

The Ravensthorpe Terrane displays gross discordance with structures in the Carlingup Terrane. Evidence for this discordance is: 1) gross outcrop relationships show that the Annabelle Volcanics have not been folded around the Maydon Syncline; 2) xenoliths of Annabelle Volcanics are locally abundant in Manyutup Tonalite, but xenoliths of metasedimentary rocks and other rock types that occur in the Carlingup Terrane have not been observed, even where they are in contact with the tonalite; 3) there is a broad zone of deformation and alteration in the Ravensthorpe Terrane adjacent to the boundary with the Carlingup Terrane; 4) thin slices of ultramafic schist have been recognized on and adjacent to the terrane boundary. In addition to the broad zone of deformation and alteration adjacent to the terrane boundary, the Ravensthorpe Terrane contains several shear zones that are subparallel to the terrane boundary, and separated from one another by relatively low-strain domains.

The Annabelle Volcanics are also grossly discordant to tight folds in metasedimentary and ultramafic rocks of the Aerodrome sector of the Cocanarup greenstones. The Cocanarup greenstones are strongly deformed and display an intense and near-pervasive foliation that is parallel to the contact with the Ravensthorpe Terrane to the east and the margins of the greenstone belt to the west. A stretching lineation is well developed on the contact with gneissic granitoids and locally within the Cocanarup greenstones. This linear fabric plunges steeply within the foliation planes. Up to two earlier foliations are locally preserved in porphyroblasts so that the near-pervasive foliation is assigned to D_3 in the Cocanarup greenstones.

The deformation history of the gneissic granitoid is generally consistent with that of the adjacent greenstone terranes.

When the effects of the Beulah synform are discounted, and contacts between greenstone units and gneissic granitoid are restored to their original subhorizontal attitudes, the Maydon Syncline is revealed as having formed as an overturned fold with eastward vergence (Fig. 3). The Ravensthorpe Terrane then structurally overlies the Carlingup Terrane, and contact-parallel shears in the Ravensthorpe Terrane are gently inclined structures, parallel to the tectonic contact between the two terranes. The pervasive foliation in the Cocanarup greenstones has a subhorizontal orientation and the linear fabric has an easterly orientation within the foliation.

Formation of the Maydon Syncline is correlated with contact-parallel deformation in the Ravensthorpe Terrane and the Cocanarup greenstones (Table 1). Formation of all these structures is attributed to tectonic accretion of the terranes in which the Ravensthorpe Terrane and the Cocanarup greenstones were thrust eastward over the Carlingup Terrane. Detritus eroded from the advancing upper thrust plate (Ravensthorpe Terrane plus Cocanarup greenstones) was deposited in alluvial basins to form the polymictic conglomerate units that are now interleaved within the Carlingup Terrane (Fig. 3).

Later Archaean events that post-date accretion of the tectonic terranes include east–west compression to form the Beulah synform and north–south compression.

Table 1. Correlation of deformation events in Archaean tectonostratigraphic units

Cocanarup greenstones	*Ravensthorpe Terrane*	*Carlingup Terrane*
D_1, D_2 (north–south and northeast–southwest compression) * Poorly understood but indicated by subhorizontal lineations and moderately south-plunging boudins on granitoid gneiss–greenstone contact * ?Tight to isoclinal folds	D_1 * Poorly understood but indicated by steep bedding attitudes in Ravensthorpe–Elstree Farm area	D_1 (subhorizontal, ?south to north movement) * Tight to isoclinal folds, especially in metasedimentary units including banded iron-formation * Irregular interleaving of units and low-angle thrust faults * Early fabric preserved in porphyroblasts and low-strain domains in Chester Formation metasedimentary rocks
D_3 (east to west transport) * Down-dip lineations on granitoid gneiss–greenstone contact * ?Tight to isoclinal folds	D_2 * Zones of deformation on contacts with adjoining tectonic units, and contact-parallel deformation within the Ravensthorpe Terrane rocks	D_2 (west to east transport) * Maydon Syncline and related structures; asymmetric, overturned (to ?recumbent), vergence to east, sheared out anticlines * Mesoscopic, reclined folds in Chester Formation * Dominant northwest-trending foliation
	Amalgamation of Ravensthorpe and Carlingup Terranes	
D_4 (east–west compression) * Beulah synform and north–south antiformal axis, near Cocanarup	D_3 (east–west compression) * Beulah synform	D_3 (east–west compression) * Rotation of all structures and gneissic granitoid–greenstone contact to form Beulah synform
D_5 (north–south compression) * Easterly trending folds in Cocanarup area	D_4 (north–south compression) * Basinal structure of Ravensthorpe Terrane; uplift of tonalite in southern part of Beulah synform	D_4 (north–south compression) * Reverse movement on Bonnymidgup Shear Zone * Small-scale, open folds with steep easterly trending axial planes

The latter event produced east-trending folds in the Cocanarup greenstones and adjacent Ravensthorpe Terrane and reverse movement along the the Bonnymidgup shear zone (mainly coincident with the northeast contact of the Carlingup Terrane against the adjacent gneissic granitoid unit).

Archaean metamorphism

The widespread metapelitic assemblage quartz–plagioclase –biotite–garnet–andalusite suggests metamorphism occurred mainly in bathozone 2 of Carmichael (1978). This bathozone corresponds to pressures of approximately 2.2 to 3.3 kb. Metamorphic assemblages, especially those in metapelitic rocks, indicate peak temperatures that range from <400°C east of Kundip to >600°C in the central part of the West sector of the Cocanarup greenstones. Peak metamorphic temperatures decrease from west to east and from north to south across the Ravensthorpe greenstone belt. Highest grade metamorphism generally occurs at the margins of the greenstone belt and cannot therefore be attributed to intrusion of the Manyutup Tonalite, as proposed by Sofoulis (1958). Instead, the thermal impetus for metamorphism is attributed to granitic sheets that were intruded into flat-lying structures and deformed during accretion of the terranes. These intrusive rocks are now exposed as gneissic granitoid to the northeast and west of the greenstone belt.

Fabric relationships indicate that porphyroblasts in all three tectonic units formed syn- to post-accretion. However, earlier metamorphic assemblages are locally preserved in the Chester Formation and the Cocanarup greenstones. Such assemblages indicate complex but contrasting metamorphic histories in the different tectonic terranes that are described more fully in a forthcoming report (Witt, in prep.).

Proterozoic geology

Proterozoic dolerite dykes (*Pd*)

The Archaean basement is intruded by abundant Proterozoic doleritic dykes (*Pd*) up to several hundred metres thick. Orientations are diverse but most fall broadly into easterly, east-northeasterly, or northwest-trending groups. Some east-trending dykes may be members of the Widgiemooltha dyke swarm (Myers, 1990b) that occurs throughout the Yilgarn Craton. Myers (1993) assigned northwest-trending dykes and east-northeasterly dykes, respectively, to the Boyagin dyke swarm and the Gnowangerup dyke swarm. The dykes become deformed close to the contact with the Mount Barren Group but do not intrude the Proterozoic rocks.

Savage (1992) noted that, in the Kundip area, easterly trending dykes contain olivine and orthopyroxene, but northeast- and northwest-trending dykes are quartz dolerite. Although primary igneous textures (cumulate to subophitic and granophyric) are well preserved, original igneous mineralogy is substantially modified by deuteric alteration or metamorphism.

Thom et al. (1984) showed northwest-trending Archaean amphibolite dykes intruding the Ravensthorpe Tonalite, between Manyutup Creek and the Phillips River. A sample from one of these dykes is plagioclase-phyric and metamorphosed. These dykes could not be routinely distinguished from Proterozoic dykes in the field. It is not known whether they are feeders to Archaean greenstones or post-cratonisation Proterozoic dykes.

Mount Barren Group

Proterozoic metasedimentary units on RAVENSTHORPE and COCANARUP were assigned to the Mount Barren Group by Thom and Chin (1984). The age of these rocks is uncertain but is probably somewhere in the range 1550 to 1300 Ma (Myers, 1995). Thom and Chin (1984) defined three stratigraphic units within the Mount Barren Group and the type localities for these units are on RAVENSTHORPE. The three units are, from oldest to youngest — Steere Formation: conglomerate, grit and dolomite (type locality at RAVENSTHORPE AMG 366680); Kundip Quartzite: quartzite (type locality at RAVENSTHORPE AMG 393692); Kybulup Schist: metapelitic schist and phyllite (type locality at RAVENSTHORPE AMG 296502).

A stratigraphic section through the lower part of the Mount Barren Group is shown in Figure 4. Dolerite and quartz dolerite, referred to as the Cowerdup Sill by Thom and Chin (1984), intrude the Mount Barren Group.

There are, as yet, no U–Pb zircon geochronological data for the Mount Barren Group. Type localities for all three formations are in the lowermost part of the Mount Barren Group, adjacent to the contact with Archaean rocks. Gross stratigraphic relationships in overlying parts of the Mount Barren Group are ambiguous. Several quartzite units, separated by thick metapelitic sequences, are exposed between the type locality of Kundip Quartzite and the coast to the south. Further complications are introduced by the presence of interbeds of quartzite within schist, and vice versa. Although contacts between quartzite and metapelitic rocks are mostly clear at map scale, micaceous quartzites (containing >10% muscovite) are common, and are finely interbedded with orthoquartzite at some localities (e.g. west side of Cave Point, COCANARUP AMG 754387). These notes and the accompanying maps follow the original interpretation of Thom et al. (1984) and Thom and Chin (1984) and interpret the quartzites south of the type locality as thrust repetitions of Kundip Quartzite. However, the interpretation is largely model-driven and it is possible that there was more than one depositional unit of sandstone prior to metamorphism.

Steere Formation (*PBS*)

The Steere Formation consists of a basal conglomerate (*PBSC*) and overlying dolomite (*PBSD*). At the type locality, the conglomerate unit is about 5 m thick. It is overlain by several metres of bedded grit and 4 m of dolomite (Fig. 4, and Thom et al., 1984). The conglomerate and dolomite are exposed beneath Kundip Quartzite, in the side of a steep escarpment that marks the contact between the Mount Barren Group and the Archaean basement, and are

therefore more widespread than shown on RAVENSTHORPE. The Steere Formation is not laterally continuous, which suggests restricted near-shore deposition. The dolomite unit lenses out to the east and west of the type locality. Further west, the conglomerate also pinches out leaving Kundip Quartzite directly overlying Archaean rocks. These lateral variations in the rock sequence are tentatively assigned to facies variations within the Steere Formation but alternatively may have been influenced by low-angle thrust faulting (see below). Although minor conglomerate and rare dolomite have been identified along the coast, the association of conglomerate and dolomite, which characterizes the Steere Formation, is restricted to the zone of contact with Archacan rocks.

Metamorphosed conglomerate (PBsc)

Massive to weakly deformed, well-sorted to moderately well-sorted conglomerate outcrops near the contact with Archaean rocks near Kundip. Rounded to well rounded clasts of quartzite, chert, jaspilite (?banded iron-formation), quartz and felsic volcanic rocks, up to about 10 cm across, are supported by a metamorphically recrystallized quartz-rich matrix. Thom (1977) recorded the local presence of altered basalt clasts where the conglomerate overlies Archaean metabasalt. However, this observation could not be confirmed and it is possible that the conglomerate with basalt clasts observed by Thom (1977) is actually Archaean (see *Asc*). Clasts of granitoid and gneissic granitoid are notably absent, although to the west of Kundip the conglomerate overlies tonalite. Sofoulis (1958) noted that the conglomerate near Kundip is locally strongly deformed.

Metamorphosed dolomite (PBsd)

Massive to thinly bedded, brown dolomite and dolomitic breccia lie near the contact with the Archaean, mainly between Kundip and the Phillips River. Outcrops in the Phillips River (COCANARUP AMG 735576) and west of Kundip (RAVENSTHORPE AMG 366680) have been described as stromatolitic. However, the presence of stromatolites has not been confirmed by palaeontologists and it is possible that these are ripple marks.

Kundip Quartzite (*PBk*)

Massive to coarsely bedded orthoquartzite occurs more or less continuously on or just above the contact between Archaean and Proterozoic rocks on RAVENSTHORPE and COCANARUP. Beds are a few centimetres to about 1 m thick, and dip at 10 to 30°S. Low-angle, planar cross-bedding and ripple marks are common. Thom et al. (1984) noted that the Kundip Quartzite is only 7 m thick at the type locality. East of Kundip, near Bandalup Pool, the Kundip Quartzite lenses out and Kybulup Schist directly overlies Archaean rocks. Much thicker units of strongly contorted orthoquartzite and micaceous quartzite are exposed south of the type locality, between the Proterozoic/Archaean boundary and the present-day coastline, forming prominent topographic features such as the Eyre Range, Whoogarup Range and East Mount Barren. The degree of metamorphic recrystallization increases southward from the contact with Archaean rocks, and the quartzite is typically a white to grey to blue-green, fine- to medium-grained equigranular rock with granoblastic fabric. Some quartzite samples contain small (<1 mm) quartz porphyroclasts. Tourmaline, zircon and opaque oxide minerals are accessory phases in most samples. Rare kyanite has been observed in thin, muscovite-rich bands within quartzite in the Barrens Beach area.

Thin lenses and interbeds of conglomerate (*PBkc*) are found at several localities between the Archaean contact and the coast. Quartzite clasts are dominant in these units. Good exposures can be seen at Barrens Beach on RAVENSTHORPE, and at East Mylies Beach on COCANARUP. Spectacular exposures of poorly sorted oligomictic conglomerate containing subrounded to subangular quartzite clasts up to 2 m across can be observed on the north face of the Whoogarup Range. These were mapped as breccia by Thom et al. (1984).

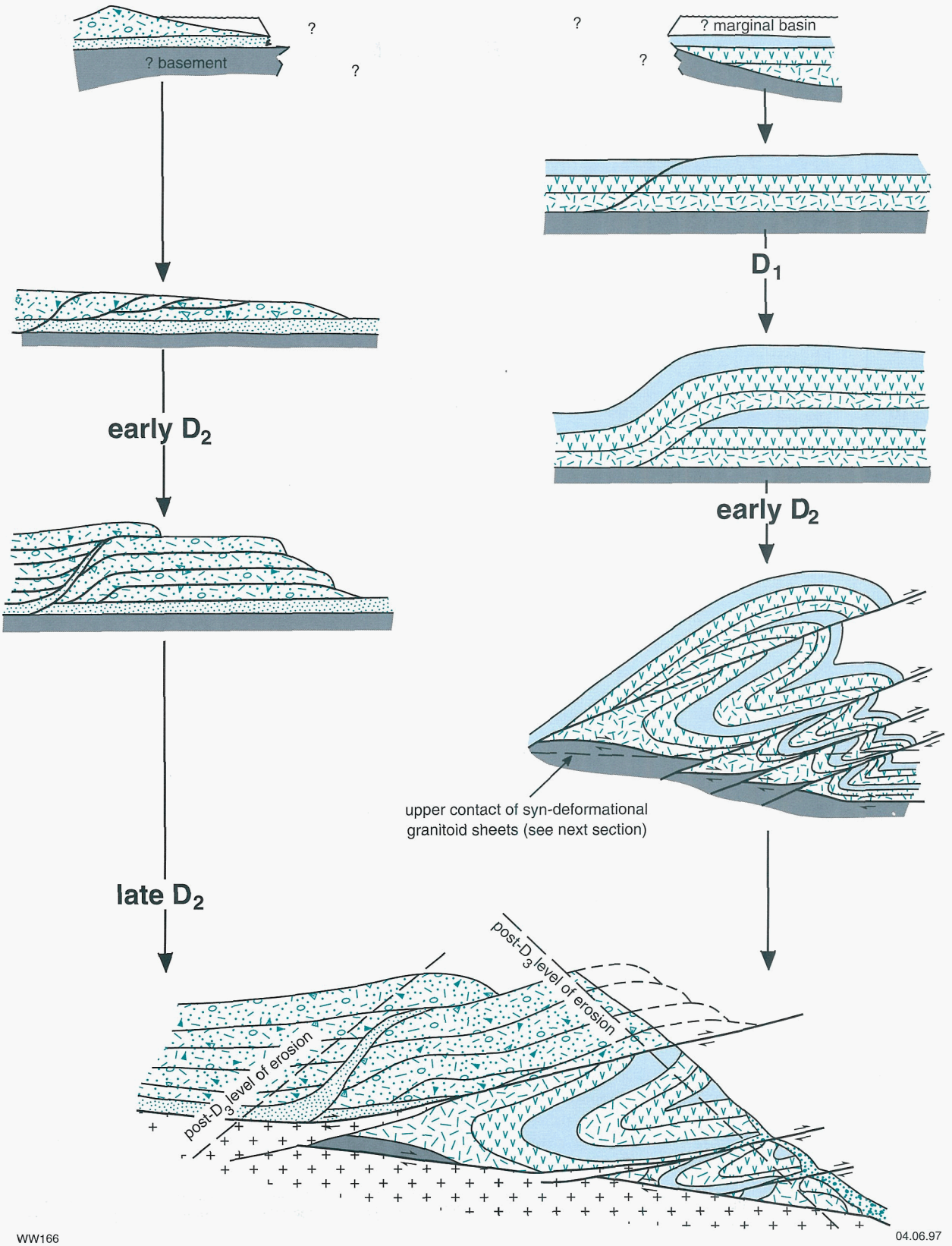
Figure 3. Schematic cross sections illustrating interpreted structural evolution of the Carlingup Terrane, Ravensthorpe Terrane and Cocanarup greenstones, up to the time of amalgamation (prior to formation of Beulah synform). This interpretation presumes depositional equivalence of the Chester and Hatfield Formations

RAVENSTHORPE TERRANE

Emergent island-arc volcanoes on shallow, marine sediments

CARLINGUP TERRANE

Deep to moderately shallow mafic to ultramafic volcanic sequence overlain by metasedimentary units, including banded iron-formation



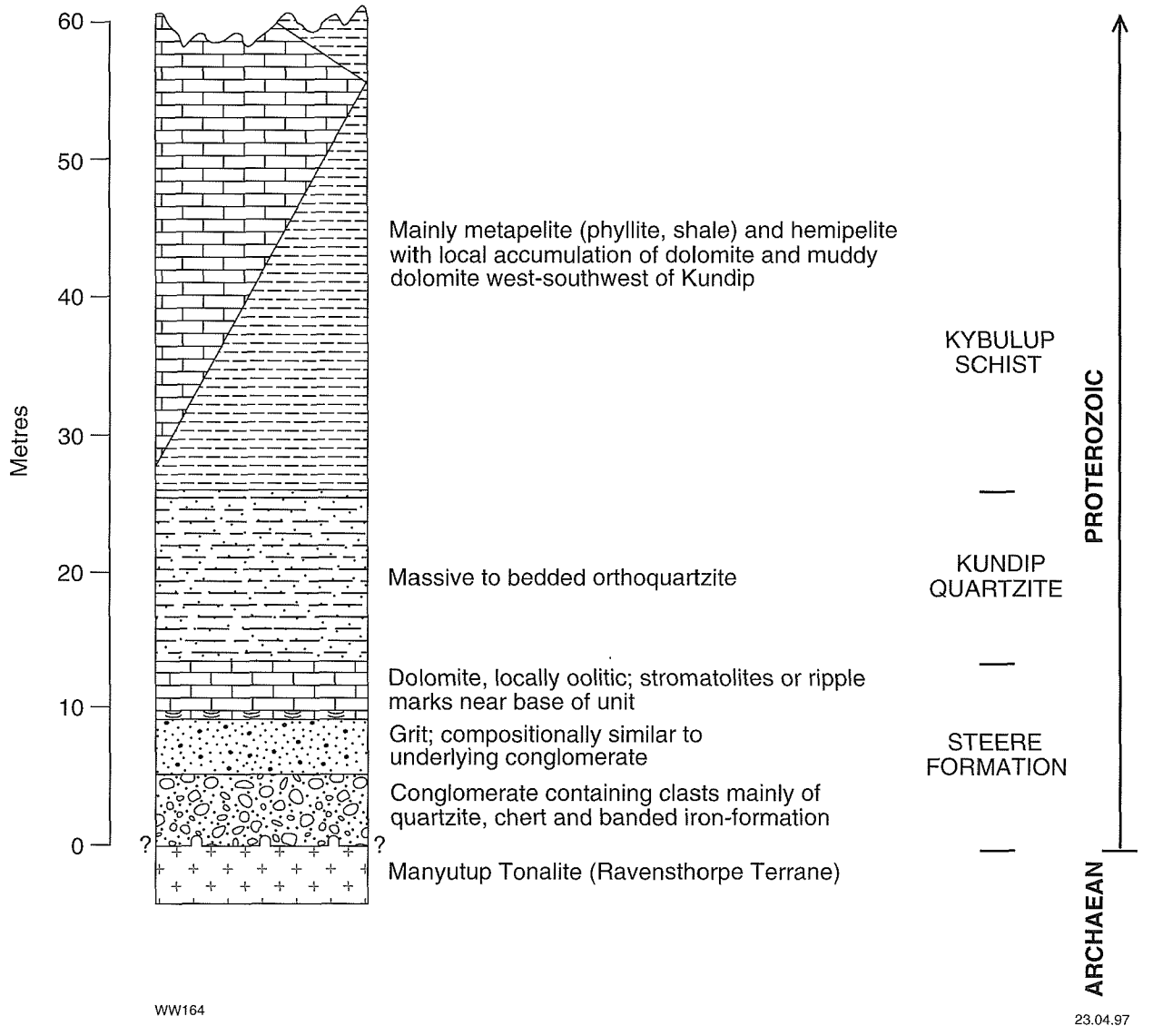


Figure 4. Stratigraphic section through the lower part of the Mount Barren Group, west of Kundip

Kybulup Schist (*Pby*)

The Kybulup Schist is the uppermost unit of the Mount Barren Group recognized by Thom and Chin (1984). The type section is in the Phillips River at RAVENSTHORPE AMG 296502. Structural complexity renders the thickness of the schist indeterminable. The unit ranges from phyllite near the contact with Archaean rocks to kyanite-bearing quartz–mica schist near East Mount Barren. Interbeds of micaceous quartzite are present in some areas.

Near the contact with the Archaean, weathered phyllite is poorly exposed in topographic lows, with abundant scree and float derived from quartz veins. The weathered rocks were probably derived from quartz–sericite–chlorite schist and phyllite. Grainsize and crystallinity increase southward from medium- to coarse-grained quartz–muscovite(–chlorite–biotite) schist. Chlorite, where present, is normally a minor component but may form up to 20% of some samples. Many samples contain up to 10% fine-grained opaque material, including hematite and possibly graphite. Small (≤2 mm) magnetite porphyroblasts are evident over a wide area, extending from near the coast right up to the contact with the Archaean (e.g. RAVENSTHORPE AMG 470627). Tourmaline is a common accessory mineral.

Quartz–mica schist in the East Mount Barren area (including Barrens Beach and West Beach) contains biotite and muscovite; the latter is dominant in most samples. The proportion of biotite decreases westward and northward, and most schist located more than a few kilometres from the coast contains only muscovite and local chlorite. Kyanite (≤3 cm long), and garnet, staurolite and biotite (about ≤3 mm long) form prominent porphyroblasts in schists of the East Mount Barren area. Abundant quartz veins in the schists have quartz-poor selvages containing coarse-grained biotite, garnet, staurolite, kyanite and chlorite.

Table 2. Partial analyses of dolomitic metasedimentary rocks, Mount Barren Group

	113947	*113951*	*SARM–40 (Lab)*	*SARM–40 (CV)*
Fe_2O_3	4.01	1.27	2.67	2.75
MnO	0.25	0.71	0.18	0.18
MgO	17.7	18.0	1.74	1.97
CaO	11.8	27.1	50.3	49.77
CO_2	29.4	41.4	38.5	38.3
Total	**63.16**	**88.48**		

Notes: 113947 — Dolomitic micrite (COCANARUP AMG 328670);
113951 — Sandy oosparite (COCANARUP AMG 288638);
SARM–40 is a reference sample;
Lab — Laboratory analysis, CV — Certified value;
Lithological terminology is after Folk (1968)

West of Kundip, the Kundip Quartzite is overlain by a substantial thickness of dolomite and calc-silicate schist (*PByd*). The calc-silicate schist consists mainly of biotite, chlorite and carbonate. This calcareous unit appears to be a facies variation of the more typical metapelitic component of Kybulup Schist and is interpreted to record the presence of carbonate banks surrounded by deeper water depositional environments. Two partial chemical analyses of dolomite collected from west of Kundip are given in Table 2. The low totals reflect the significant quartz sand component of both samples. Excess magnesium in GSWA sample 113947 suggests the presence of magnesite in addition to dolomite. The magnesite is probably a product of Tertiary weathering (Abeysinghe, 1996). A thin, limonitic unit within the dolomite and calc-silicate schist (*PByl*) may be gossanous.

A small dolomite outcrop has also been recognized on the beach west of Hamersley Inlet (COCANARUP AMG 676373). This dolomite has a well-developed granoblastic fabric.

Cowerdup Sill (*PBc* and *Pc*)

A metamorphosed dolerite unit, known as the Cowerdup Sill, intrudes the Mount Barren Group within or adjacent to Kundip Quartzite. The Cowerdup Sill, typically about 300 m thick, is exposed as rubble and sporadic outcrop on many low hills between Quoin Head (on COCONARUP) and Fortification Hill (on RAVENSTHORPE). Although broadly conformable with the metasedimentary rocks within fault-bound blocks, the unit cuts across the stratigraphy on a regional scale. Contacts, although rarely observed, are strongly deformed. Thom (1977) documented petrographic and chemical zoning within the Cowerdup Sill but this zoning was difficult to recognize in the field and the intrusion provided unambiguous evidence of way-up at only a few localities.

The Cowerdup Sill is largely mafic granophyre with abundant quartz, and local K-feldspar. The typical assemblage is quartz–plagioclase–calcic amphibole–chlorite(–K-feldspar–relict clinopyroxene). The calcic amphibole appears to be tremolite or actinolite. Subophitic to granophyric texture is preserved where deformation has not been intense, and in strongly deformed samples biotite and muscovite are common components. Pyroxenitic rocks have been observed near the base of the sill at some localities. Mafic (chlorite–amphibole) schist with relict quartz granophyre, presumably derived from tectonic slices of the sill, is present at Pichi Rich (RAVENSTHORPE AMG 295523), and north of East Mount Barren (around RAVENSTHORPE AMG 240440). A thin unit of ultramafic (quartz–talc–tremolite) schist has been identified at west Whalebone Beach (COCANARUP AMG 633373).

Structure of the Proterozoic Mount Barren Group

The Archaean–Proterozoic contact is marked by a scarp, up to about 30 m high, formed by the gently south-dipping Kundip Quartzite. The contact is poorly exposed and, at most locations, can only be constrained to within a few metres. The best exposure is 3 km west of Kundip, at RAVENSTHORPE AMG 366680, where, however, the basal conglomerate does not contain clasts of the tonalite that it overlies. Moderate to strong deformation of the lowermost Mount Barren Group, and low-angle discordance between Proterozoic units and the Archaean basement, suggest a tectonised contact. There is thus no unequivocal evidence for an unconformable contact between the Archaean and the Proterozoic.

The structure of the Mount Barren Group is essentially that of a fold-and-thrust belt with north to northwest vergence. Proterozoic metasedimentary rocks of the Mount Barren Group have undergone several phases of folding (Table 3) during the Albany–Fraser Orogeny and have been cut up by numerous faults. Most of the major faults are probably splays off the Jerdacuttup Fault. This fault is a regional-scale reverse fault across which Archaean Munglinup Gneiss to the south has been uplifted and juxtaposed against the younger Proterozoic metasedimentary rocks. The faults, which occur within the Mount Barren Group, may however have had an earlier history related to folding (especially F_{B2} and F_{B3}, annotated with squares on the accompanying maps).

Amphibolite, polymictic conglomerate and ultramafic rock (beneath Tertiary magnesite) south of the Jerdacuttup Fault are interpreted to be a fault-bound fragment of the Carlingup Terrane.

Late movement across east-northeasterly trending structures in all Archaean tectonostratigraphic units probably occurred at the same time as movements on the Jerdacuttup Fault.

Proterozoic metamorphism

Within the Mount Barren Group, the distribution of porphyroblast minerals in metapelites clearly indicates an increase in metamorphic grade southward and eastward toward the Jerdacuttup Fault. The highest grade

Table 3. Descriptions of folding events in the Mount Barren Group

Folding	*Average orientation of axial plane*	*Plunge of fold axes*	*Fold shape, vergence*	*Timing criteria*
F_{B1}	Diverse, ?recumbent, poorly constrained	Diverse, poorly constrained	Isoclinal, vergence unknown	Fold closures in limbs of F_{B2} and F_{B3}
F_{B2}	Easterly	Shallow to moderate (<40°)	Moderately tight to tight, overturned, vergence to north	Minor F_{B3} buckling of F_{B2} fold limbs in Whoogarup Ranges and west of Fortification Hill
F_{B3}	West-southwesterly	Moderate (35–60°) southwest and northeast (shallow in areas of plunge reversal)	Moderately tight to tight, overturned, vergence to northwest	Mesoscopic F_{B2} folds refolded by F_{B3} near Laurina Road
F_{B4}	southwest to southeast	35–75°S, locally steeply to north	Open to moderately tight, small-scale, upright to steeply inclined	Small-scale buckling and warping of F_{B2} and F_{B3} folds

Note: F_{B1} to F_{B4} correspond to fold structures produced during deformation events D_{B1}–D_{B4} respectively. Folding in the Mount Barren Group is annotated with squares on the accompanying maps

rocks are exposed along the coast between Barrens Beach and West Beach, and immediately north and west of East Mount Barren. Pelites in this area contain the equilibrium assemblage quartz–muscovite–biotite–garnet–staurolite–kyanite, constraining metamorphic temperatures to about 540 to 560°C and pressure to ≥4.8 kb. Fabric relationships in coastal pelites indicate an extended period of prograde metamorphism coincident with the Albany–Fraser Orogeny. Uplift of deeply buried metasedimentary rocks in the West and Barrens Beaches area probably took place across faults such as the Whoogarup Fault, after peak metamorphism and toward the end of the Albany–Fraser Orogeny. Progressively deeper crustal sections have been uplifted across these faults, southward from the Archaean–Proterozoic contact.

The Jerdacuttup Fault is the largest of the late faults associated with uplift. This structure has brought the Munglinup Gneiss to the surface south of the fault. Myers (1990a) interpreted the Munglinup Gneiss as Archaean granitoids that were deformed and metamorphosed at the granulite facies during the Albany–Fraser Orogeny.

Phanerozoic geology

Figure 5 schematically summarizes interpreted relationships between Phanerozoic units and the Precambrian basement.

Tertiary rocks

The Pallinup Siltstone (*Tpp*) forms the upper part of the Plantagenet Group (Cockbain, 1968). Hocking (1990) reported a maximum thickness of 61 m for the Pallinup Siltstone, but on RAVENSTHORPE and COCANARUP it generally forms a thin veneer unconformably overlying Archaean and Proterozoic rocks. There are extensive exposures on southwest COCANARUP, but isolated outliers also occur in Archaean rocks on RAVENSTHORPE, particularly south of Bandalup. On southwest COCANARUP, Pallinup Siltstone forms a plateau that has been dissected by drainage forming steep canyons and isolated, flat-topped hills. The unconformity is marked by a breakaway, up to about 10 m high.

The Pallinup Siltstone consists of siltstone and spongolite, generally fine grained, porous and friable. The siltstone contains angular quartz grains and abundant sponge spicules and other fossils, including foraminifera and molluscs. This faunal assemblage constrains the age of the Pallinup Siltstone to the Late Eocene (Hocking, 1990). Hocking (1990) concluded that the Pallinup Siltstone was deposited in a sediment-starved marine basin. The rocks are undeformed and unmetamorphosed.

A bryozoan-rich, foraminiferal limestone occurs as an isolated remnant on top of a hill near the Jerdacuttup River (RAVENSTHORPE AMG 476624). This may be the upper part of the Werillup Formation (Hocking, 1990) that underlies the Pallinup Siltstone. However, the Werillup Siltstone has not been recognized elsewhere on RAVENSTHORPE or COCANARUP.

Cretaceous to early Tertiary weathering of ultrabasic rocks produced surficial layers of magnesite (*Czm*) and chalcedonic silica that includes a brown, siliceous 'caprock' in which original igneous or metamorphic textures may be preserved (*Czu*). Grey silcrete consisting of small, angular quartz grains in a siliceous cement (*Czz*) is developed mainly over granitic rocks, although, southwest of Bandalup Rockhole, rotary air-blast drill chips indicate ultramafic rocks at depth below the silcrete. A similar rock consisting of angular quartz grains in a ferruginous cement (*Czf*) is locally developed over Archaean mafic and metasedimentary rocks on RAVENSTHORPE. The latter unit grades upward into laterite (*Czl*) and it is likely that the magnesite and caprock units (*Czm* and *Czu*) developed before or during laterite formation in the Cretaceous and early Tertiary.

Colluvium (*Czc*) has accumulated locally along major drainages where laterite and related deposits have been stripped away from Archaean rocks. Calcrete (*Czk*) is

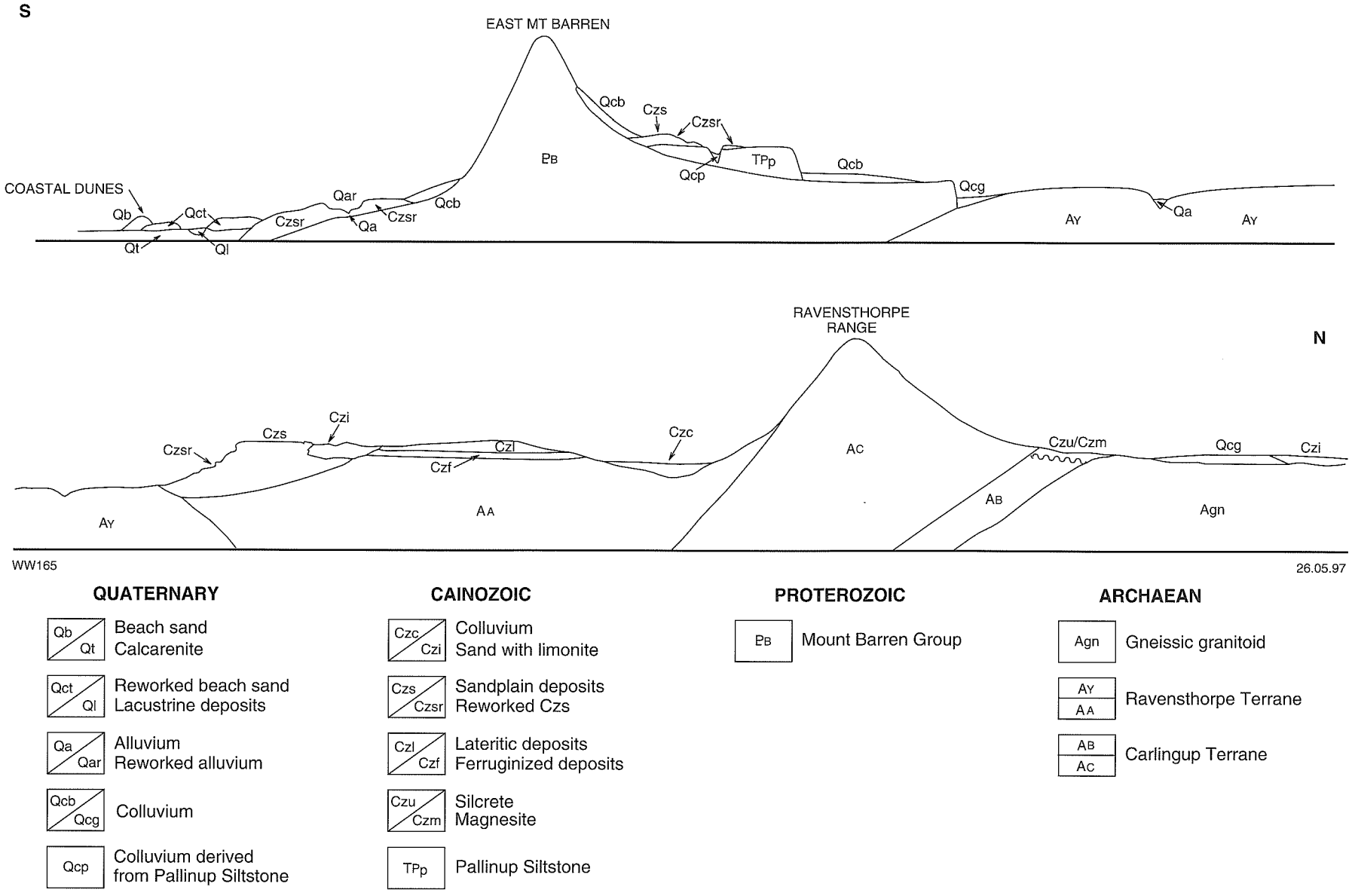


Figure 5. **Schematic cross section from coastline to northern boundary of RAVENSTHORPE emphasizing relationships among Cainozoic units. Note that the lower section is contiguous with the upper section**

locally developed over Archaean rocks, especially east of Cocanarup Pool (COCANARUP AMG 718740). Remnants of an extensive quartz sandplain (*Czs*) overlie Archaean and Proterozoic rocks as far north as Kundip. The unit overlies laterite, and Thom et al. (1984) reported that this unit overlies Pallinup Siltstone on NEWDEGATE. The depositional age of the sand is unknown, although it must be younger than late Eocene (the age of the Pallinup Siltstone). The sandplain has mostly been reworked by erosion to form gently undulating areas of sand (*Czsr*). Large tracts of unconsolidated sand that contains limonitic pisoliths derived from underlying laterite is designated *Czi*. Relations between the units *Czs* and *Czi* are uncertain.

Quaternary rocks

Widespread residual erosional surfaces evidenced by rock fragments, sand and grit (named *Qcb* and *Qcg*) developed respectively over the Mount Barren Group, and Archaean granitoid rock and gneissic granitoid. These units post-date erosion of the quartz sandplain and are probably largely of Quaternary age. Scree slopes and colluvium derived from the erosion of Pallinup Siltstone (*Qcp*) is widespread on southwest COCANARUP. Reworked Tertiary deposits (*Qar*) form broad floodplains adjacent to contemporary, mature drainage systems (e.g. along the Steere River, around RAVENSTHORPE AMG 330494). These floodplains are readily distinguished from younger alluvial deposits (*Qa*), which are more closely restricted to the present drainage channels.

Calcarenite (*Qt*), locally with shell fragments, forms consolidated dunes and foreshore reefs along the coast. This unit is probably equivalent to Tamala Limestone in the Perth and Canarvon Basins. Unconsolidated material (*Qct*) derived by reworking of, and probably underlain by, the calcarenite forms undulating hills for up to several kilometres inland. Several active depositional environments occur along the coast. Unconsolidated calcareous sand dunes and beach deposits (*Qb*) overlie calcarenite. Alluvium, clay and silt deposits (*Ql*) are forming in brackish swamps and lakes immediately behind the beach deposits and up to about 20 km inland. Eolian sand sheets and dunes (*Qs*) are found on southeast RAVENSTHORPE, inland from calcarenite (*Qt*).

Economic geology

The Ravensthorpe area has had a long history of mining and has produced a wide variety of mineral commodities. Resource figures quoted below are from the Department's MINEDEX* database unless otherwise indicated.

Epigenetic copper, gold and silver

Descriptions of epigenetic copper–gold(–silver) mineralization in the Ravensthorpe area have been compiled by Sofoulis (1958) and Marston (1979). The main copper- and gold-producing mines are shown in Table 4. There are two current hypotheses for the origin of the copper–gold (–silver) mineralization in the Ravensthorpe area. Sofoulis (1958) and Savage (1992) proposed a magmatic–hydrothermal origin in which mineralization was related to the Manyutup Tonalite. Marston (1979) suggested that ore components may have been remobilised from originally stratiform sulfide mineralization in the Annabelle Volcanics during regional deformation and metamorphism. A third genetic model for the copper–gold mineralization, proposed by Witt (1995), is that the deposits are synmetamorphic and formed in a similar manner to the more widely recognized gold-only Archaean lode deposits (Groves, 1993; Witt, 1993).

Table 4. Gold production from the Ravensthorpe area

Mining centre	*Mine*	*Gold produced (kg)*
Ravensthorpe	Floater	349.90
	Mount Cattlin	187.64
	Maori Queen	133.50
Kundip	Flag	306.69
	Two Boys	273.73
	Gem	253.66
	Gem Consolidated	202.76
	Harbour View	184.27
	Beryl	80.71
Mount Desmond	Elverdton	99.62

Stratabound sulfides and base metals

Metamorphosed volcanogenic base metal sulfide deposits in the West River area are hosted by Annabelle Volcanics. Three strata-bound copper–zinc sulfide deposits occur within a larger area of cordierite–orthoamphibole rock. The largest of these mines (Last Venture) has produced 43 t of copper, and exploration drilling in the mine area has intersected Cu–Zn mineralization up to several metres wide (summarized in Marston, 1979).

Nickel

Exploration for nickel during the 1960s and 1970s revealed the presence of nickel sulfide mineralization at several localities east of Ravensthorpe. The Number 8 deposit contains an indicated resource of 249 900 t averaging 1.95% Ni (Marston, 1984). This, and several other prospects described by Marston (1984), occurs along the deformed northeastern limb of the Maydon Syncline.

Lithium, tantalum

Descriptions of the pegmatite at Cattlin Creek can be found in Sofoulis (1958), Blockley (1980) and Witt (1992). The pegmatite contains lithium in the form of lepidolite and

* The Department of Minerals and Energy's MINEDEX database provides rapid access to information on mineral deposits and current mines. The mainframe database may be accessed through terminals in Perth and regional offices. See Townsend et al. (1996) for more information.

spodumene. Production of spodumene from Cattlin Creek has accounted for 6 670 kg Li_2O, and Hill (1976) reported resources of 1.3 Mt of spodumene. This pegmatite has also yielded a small amount of tantalite and contains a further 120 000 t at 0.09% tantalum (Louthean, 1993).

Manganese

Stratiform deposits of massive to bedded manganese oxide ore are found in both Archaean and Proterozoic metasedimentary rocks in the Ravensthorpe area. The larger deposits are identified in Kybulup Schist near the Hamersley River gorge (COCANARUP AMG 679441) where there are some shallow workings. The deposits have been described by Gray and Gleeson (1949), and Sofoulis (1958), and are generally regarded as being too small and low grade (approximately 33% Mn) to be economic.

Magnesite

Several occurrences of magnesite in the Ravensthorpe area have been described by Abeysinghe (1996). High-quality magnesite is found at the base of the Pallinup Siltstone where this unit overlies Archaean ultramafic rocks. The most significant deposit is at Bandalup where production of coarse, nodular magnesite has been intermittent. Between 1959 and 1984 the deposit yielded 67 945 t of magnesite. Reserves are estimated at 1.252 Mt containing 18.2% $MgCO_3$.

Talc

Recent exploration southwest of Kundip has targeted altered Proterozoic dolomite and has identified small quantities of talc in the Proterozoic Mount Barren Group. The talc is a high-grade bedded product suitable for use in the cosmetics industry (Abeysinghe, 1996).

Spongolite

Spongolite is extensive within Pallinup Siltstone in the southern parts of RAVENSTHORPE and COCANARUP. Spongolite has been used as a building stone in Hopetoun and Ravensthorpe, but could also find application as an insulating or abrasive material.

Acknowledgements

Outokumpu Australia Pty Ltd provided regional geological maps and aeromagnetic maps of the Archaean portions of RAVENSTHORPE and COCANARUP. The author has benefited from discussions with Simon Wetherly and Mark Savage.

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Appendix 1

Definitions of some stratigraphic units in the Carlingup and Ravensthorpe Terranes

Bandalup Ultramafics

Derivation of name: This unit is named after Bandalup Hill, a prominent topographic feature on eastern RAVENSTHORPE (AMG 566742), which is underlain by ultramafic rocks.

Lithology and chemistry: Bandalup Ultramafics comprise mainly metamorphosed komatiite and serpentinite after olivine cumulates. Minor high-Mg basalt and gabbro are also present. Bandalup Ultramafics contain several thin (?tectonically emplaced) banded iron-formation units that are most abundant on the southwest limb of the Maydon Syncline. Sun and Nesbitt (1978) published major-element and rare-earth element data for a komatiite sample from the Jerdacuttup River. The high CaO/Al_2O_3 ratio of sample 331/347 is part of the original definition of komatiites (Viljoen and Viljoen, 1969) but subsequent investigations have shown that most komatiites worldwide have ratios close to 1 (Nesbitt and Sun, 1976).

Thickness and lateral extent: The Bandalup Ultramafics are approximately 1500 m thick. They extend along the eastern side of the Ravensthorpe Range, from several kilometres north of the map area southward to near Kundip. North of the map area and on the northeastern limb of the Maydon Syncline, the Bandalup Ultramafics are strongly deformed and structurally interleaved with other units.

Relationships with other units: The Bandalup Ultramafics are in fault contact with the Chester Formation to the west. The upper (eastern) contact with Maydon Basalt is not exposed. The unit is (?unconformably) overlain by the Proterozoic Mount Barren Group east of Kundip.

Type area: The best exposures of Bandalup Ultramafics are in the Jerdacuttup River and tributaries, around RAVENSTHORPE AMG 427729.

Maydon Basalt

Derivation of name: This unit underlies much of Maydon farm from which the name is derived. It has previously been referred to as Ravensthorpe basalt by Thom et al (1977) and Redman and Keayes (1985) but that name is oversubscribed and is used elsewhere in this publication to denote a geological terrane.

Lithology and chemistry: The Maydon Basalt comprises metamorphosed, massive to pillowed basalt. Variolitic texture is widespread and pyroxene spinifex texture locally developed, suggesting a high-Mg basalt composition. Minor dolerite occurs within Maydon Basalt on the northeast limb of the Maydon Syncline but interflow sedimentary rocks are rare. Redman and Keayes (1985) analysed two samples of Maydon Basalt and classified them as siliceous high-Mg basalt.

Thickness and lateral extent: The Maydon Basalt is about 2 km thick. It occurs extensively within the core of the Maydon Syncline between the Cordingup Fault and Jerdacuttup Fault. Amphibolite along the margins of the greenstone belt, especially north of the Cordingup Fault, probably represents deformed and metamorphosed Maydon Basalt.

Relationships with other units: Contacts between Maydon Basalt and overlying (Hatfield Formation) and underlying (Bandalup Ultramafics) units are not exposed. The Maydon Basalt is (?unconformably) overlain by the Proterozoic Mount Barren Group and the Tertiary Pallinup Siltstone, east and southeast of Kundip.

Type area: The type area for Maydon Basalt is in the Jerdacuttup River, south of Maydon farm, around RAVENSTHORPE AMG 422743.

Hatfield Formation

Derivation of name: This unit is named after Hatfield Road, which provides access from the South Coast Highway to the type area.

Lithology: The Hatfield Formation comprises mainly metapelitic rocks with minor felsic volcanic and volcaniclastic rocks (mainly dacite). Coarser grained metasedimentary rocks (psammites) become more abundant, but are poorly exposed, toward the south.

Thickness and lateral extent: The Hatfield Formation is exposed from near Maydon farmhouse southeastward almost to Jerdacuttup North Road. It is at least 1 km thick north of Bandalup Pools but may thicken southward. However, the unit lies in the core of the Maydon Syncline and the upper contact is not exposed.

Relationships with other units: The Hatfield Formation is the uppermost unit of the Carlingup Terrane. The contact with underlying Maydon Basalt is not exposed. It is possible that the Hatfield Formation is a thrust repetition of the Chester Formation and Figure 3 reflects this interpretation. The Hatfield Formation is unconformably overlain by Pallinup Siltstone near Jerdacuttup North Road.

Type area: The type area for the Hatfield Formation is where a firebreak crosses a low range of hills, southeast of Maydon farmhouse, around RAVENSTHORPE AMG 455740.

Chester Formation

Derivation of name: This unit is named after Mount Chester, one of the highest points along the Ravensthorpe Range, which is underlain by Chester Formation metasedimentary rocks.

Lithology: The Chester Formation comprises mainly metapelitic rocks with subordinate psammites. Pelitic rocks are interbedded with several horizons of chemical metasedimentary rocks, including chert, banded iron-formation and massive sulfide deposits.

Thickness and lateral extent: Structural ambiguity precludes confident interpretation of internal stratigraphic relations within the Chester Formation. Either 1) predominantly metapelitic rocks overlie a mainly psammitic unit, or 2) the psammitic unit occurs as a discontinuous horizon, or as lenses, within metapelitic rocks. With the first interpretation, the unit is isoclinally folded and the Chester Formation is 0.75 to 1 km thick. If the second alternative is true, apparent fold closures are simply lateral facies changes and the thickness is 1.5 to 2 km. The Chester Formation underlies much of the Ravensthorpe Range between Kundip and Mount Short (3.75 km north of the map area).

Relationships with other units: The Chester Formation is in fault contact with the adjacent Bandalup Ultramafics (to the east) and Annabelle Volcanics (to the west). It is thought to be (?para-)autocthonous, whereas the overlying units are allocthonous.

Type area: The type area for the Chester Formation is along a tributary of the Jerdacuttup River, around RAVENSTHORPE AMG 403743.

Annabelle Volcanics

Derivation of name: Good exposures of this unit can be found in the area around Cattlin Creek and Annabelle Creek, from which the name is derived.

Lithology: Annabelle Volcanics are mainly metamorphosed andesitic volcanic and volcaniclastic rocks with subordinate basalt, dacite and dolerite. The more strongly deformed and recrystallized equivalent of this unit can be traced southward from Cocanarup as quartz–plagioclase–amphibole gneiss.

Thickness and lateral extent: The thickness of Annabelle Volcanics in low-strain domains is not known since bedding is poorly developed. Therefore, the attitude of bedding and the amount of internal folding is not known. It is mainly exposed north and west of Ravensthorpe, but extends along the western side of the Ravensthorpe Range to Kundip in the south, and along the Cocanarup greenstone belt to West River.

Relationships with other units: The Annabelle Volcanics are in fault contact with the Chester Formation to the east, and contacts with mainly metasedimentary rocks of the Cocanarup greenstones are strongly deformed. The unit is intruded by Manyutup Tonalite. It is (?unconformably) overlain by the Proterozoic Mount Barren Group.

Type area: The type area for the Annabelle Volcanics is in a creek near the Maori Queen mine, around RAVENSTHORPE AMG 263843. Other good exposures are in Annabelle Creek (COCANARUP AMG 777785) and Stevenson Creek (COCANARUP AMG 746788).

Manyutup Tonalite

Derivation of name: The name is derived from Manyutup Creek, which lies near the northwestern margin of this intrusive complex.

Lithology: The dominant rock type is medium- to coarse-grained tonalite; textures are variable though mostly equigranular. The unit includes small dykes, stocks and plutons that intrude the Annabelle Volcanics. Minor rock types are quartz diorite and hornblendite.

Thickness and lateral extent: The thickness of the intrusive complex is not known. However, together with the Annabelle Volcanics, it is believed to be a structurally emplaced (allocthonous) unit. It occupies much of the area between the Carlingup Terrane and Cocanarup greenstones.

Relationships with other units: Manyutup Tonalite is intrusive into Annabelle Volcanics but there is no evidence of it having intruded any other Archaean unit. The close spatial association with Annabelle Volcanics and the compositional similarities suggest a cogenetic relationship between the two units. Irregular intrusive contacts, and the presence of numerous tonalite porphyry dykes and small plutons of medium-grained tonalite in the Annabelle Volcanics near Ravensthorpe suggest the latter overlie Manyutup Tonalite. The Manyutup Tonalite is (?unconformably) overlain by the Proterozoic Mount Barren Group.

Type area: The type locality is in a quarry located on RAVENSTHORPE at AMG 315769. There are also good exposures along tracks that cross the complex westward from Moir track near Manyutup Creek, and near Norndup Spring (on COCANARUP).

Appendix 2

Locations of places referred to in text

Locality	*AMG co-ordinates*	
	Easting	*Northing*
Bandalup Creek	251000	6276800
Bandalup Hill	256600	6274200
Bandalup magnesite pits	255200	6277900
Bandalup Pools	248800	6270000
Bandalup Rockhole	249900	6280300
Barrens Beach	225300	6241700
Boaiup Creek	242400	6282700
Carracarrup Creek	222400	6266700
Cattlin Creek mine	224700	6282000
Cocanarup Pool	768900	6274100
Cocanarup Spring	768200	6274200
Copper King mine	766700	6258900
East Mount Barren	224700	6242400
Eyre Range	776000	6250500
Fortification Hill	222600	6251000
Hamersley Gorge mine	767800	6244800
Hamersley Range gorge	767900	6244700
Hatfield Road	249600	6276500
Hicks Creek	759500	6277500
Jerdacuttup	266000	6267000
Jerdacuttup River	249100	6267200
Kundip	239200	6268100
Kybulup Pool	773400	6256800
Last Venture mine	766700	6257400
Manyutup Creek	776900	6274400
Maydon Road	243500	6277500
Mount Benson	228300	6286100
Mount Desmond	235600	6276900
Mount Drummond	741300	6244500
Mount McMahon	231100	6283800
Mylies Beach	776500	6241800
Phillips River	773000	6260700
Quoin Head	759900	6235400
Ravensthorpe	224400	6277600
Steere River	233000	6249400
Twetatup Creek	761500	6272500
West Beach	775000	6238800
Whalebone Beach	764500	6237200
Whoogarup Range	763000	6241000

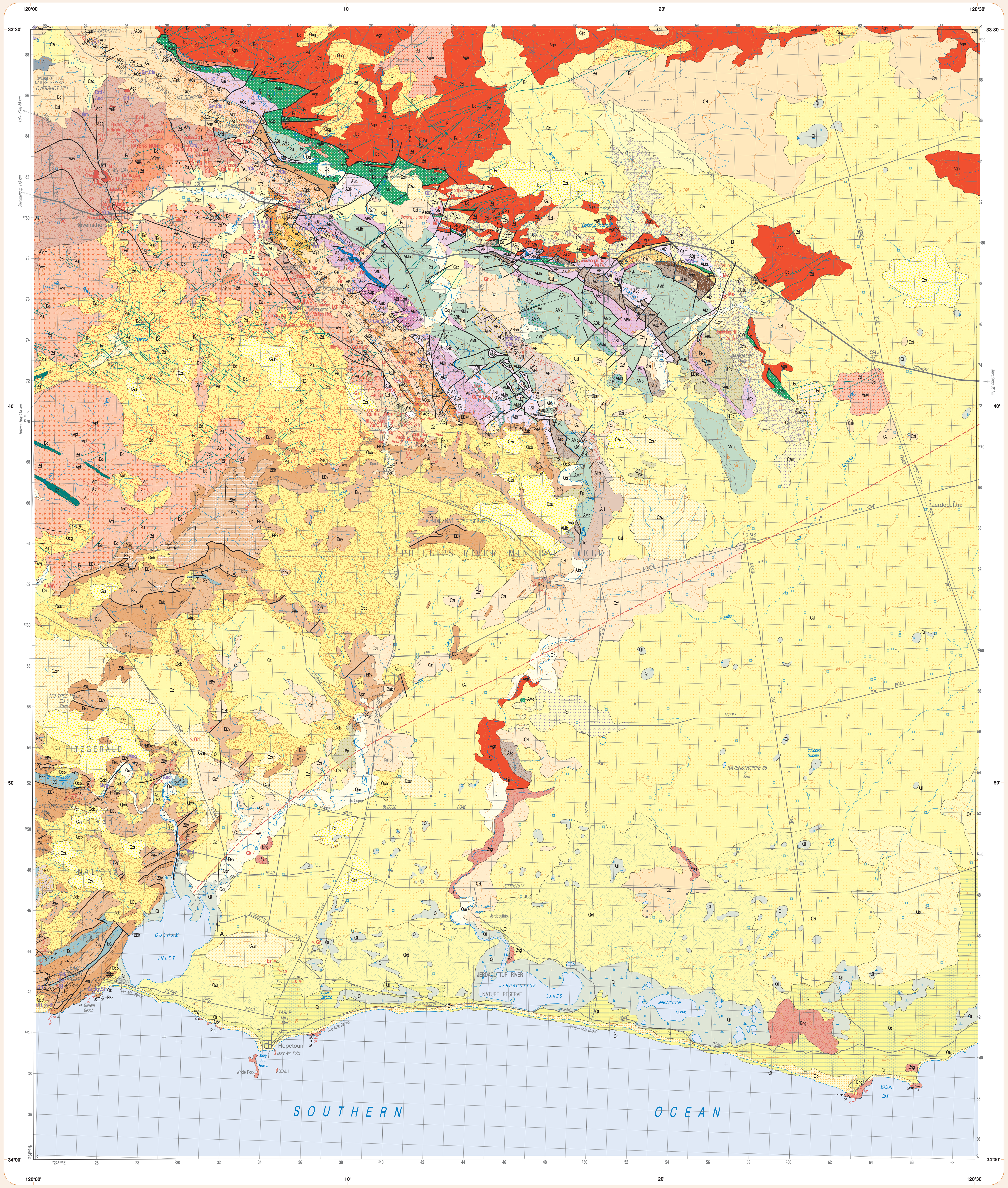
NOTE: Localities in bold are on RAVENSTHORPE, the remainder are on COCANARUP

AUSTRALIA 1:100 000 GEOLOGICAL SERIES

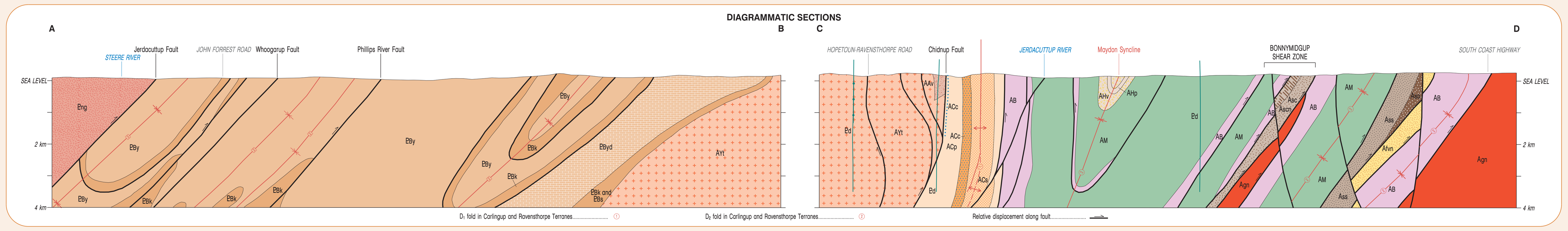
RAVENSTHORPE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 2930



DIAGRAMMATIC SECTIONS



Legend

PHANEROZOIC — CAINOZOIC — QUATERNARY

Coastal deposits

Qb — Beach sand—quartz and calcareous sand on beaches and in unstable dunes
Qct — Coastal dune sand, derived by reworking of Qt
Qt — Consolidated coastal deposits—calcarenite, locally shelly; forms consolidated dunes and foreshore reefs; equivalent to TAMALA LIMESTONE

Inland deposits

Qa — Alluvium—clay, silt, and gravel in channels
Qar — Reworked Cainozoic deposits—clay, silt, and sand in broad floodplains of mature drainage
Ql — Lacustrine deposits—clay and silt in claypans and swamps
Qs — Eolian deposits—sand in sheets and dunes
Qcb — Colluvium—rubble of boulders and sand derived from MOUNT BARREN GROUP; minor outcrops of MOUNT BARREN GROUP
Qcg — Colluvium—rubble of boulders and sand derived from granitoid rock and granitoid gneiss; minor outcrops of grantoid rock

Czc — Colluvium—clay, silt, and rock fragments
Czs — Sandplain deposits—unconsolidated sand; remnants of peneplain
Czsr — Sandplain, undulating; reworked Czs
Czi — Sand with limonitic pisoliths and gravel
Czl — Lateritic deposits—laterite, ferruginous duricrust, and ferricrete; massive
Czf — Ferruginous deposits—undifferentiated; mainly ferruginous quartz sand and granules, and angular rock fragments with ferruginous cement
Czu — Silcrete—brown silica caprock over ultramafic rock
Czm — Magnesite—massive to nodular; mainly developed over ultramafic rock

TERTIARY — Plantagenet Group (BREMER BASIN)

TPp — **PALLINUP SILTSTONE:** white to yellow to brown siltstone, silty sandstone, and spongolite; mainly deeply weathered

PROTEROZOIC (ALBANY—FRASER OROGEN)

ЕC — **COWERDUP SILL:** dolerite and quartz dolerite, metamorphosed, and mafic to ultramafic schist

Mount Barren Group

ЕBy — **KYBULUP SCHIST:** pelitic schist and phyllite with minor psammitic layers
ЕByd — Dolomite; metamorphosed; massive to finely bedded; locally ?stromatolitic; with calc-silicate rock and calcareous schist
ЕByl — Limonitic unit (possibly gossanous after sulfides)
ЕBk — **KUNDIP QUARTZITE:** quartzite, massive to coarsely bedded; minor pelitic beds
ЕBkc — Oligomictic conglomerate; metamorphosed; quartzite clasts in psammitic matrix; massive to coarsely bedded
ЕBs — **STEERE FORMATION:** conglomerate and dolomite; metamorphosed
ЕBsd — Dolomite; metamorphosed; massive to finely bedded; locally ?stromatolitic
ЕBsc — Conglomerate; metamorphosed; quartzite clasts in psammitic matrix; massive to coarsely bedded

Еd — Dolerite dyke, partly interpreted from aerial photography; interpreted from aeromagnetic data where dashed

Biranup Complex

Еng — **MUNGLINUP GNEISS:** granitoid gneiss, heterogeneous; mainly derived from Archaean granite, granodiorite, tonalite, and pegmatite

ARCHAEAN (YILGARN CRATON)

q — Quartz vein
Apf — Feldspar(-quartz) porphyry dyke
Agm — Biotite monzogranite and granodiorite; massive to weakly recrystallized
Agp — Pegmatite, granitic to tonalitic

Agn — Gneissic granitoid rock; compositions include trondhjemite, tonalite, granodiorite, and syenogranite
Agnb — Interleaved gneissic granitoid rock and greenstones

Cocanarup greenstones

Al — Metasedimentary rocks, undivided; deeply weathered
Aur — Tremolite-rich rock and schist; locally with pseudomorphs after metamorphic olivine

Ravensthorpe Terrane

AY — **MANYUTUP TONALITE:** tonalitic complex; metamorphosed (Simplified Geology map only)
AYt — Tonalite and quartz diorite; massive, coarse-grained, and equigranular; metamorphosed
AYtm — Tonalite, diorite, and tonalite porphyry; massive, medium-grained, and equigranular to porphyritic; metamorphosed
AYd — Dolerite; metamorphosed

AA — **ANNABELLE VOLCANICS:** calc-alkaline volcanic association; metamorphosed (Simplified Geology map and section only)
AAv — Mafic to intermediate tuff and agglomerate, and related epiclastic rocks (mainly andesite); subordinate dacite; metamorphosed

Carlingup Terrane

Ass — Orthoquartzite
Aso — Oligomictic conglomerate; orthoquartzite clasts in psammitic matrix
Asc — Polymictic conglomerate and greywacke; metamorphosed
Ascn — Quartz-feldspar-biotite-hornblende gneiss and schist; deformed Asc
Ac — Chert; metamorphosed

Afv — Felsic volcanic rock; dacite and rhyolite; metamorphosed
Afvn — Felsic gneiss, fine-grained; deformed Afv

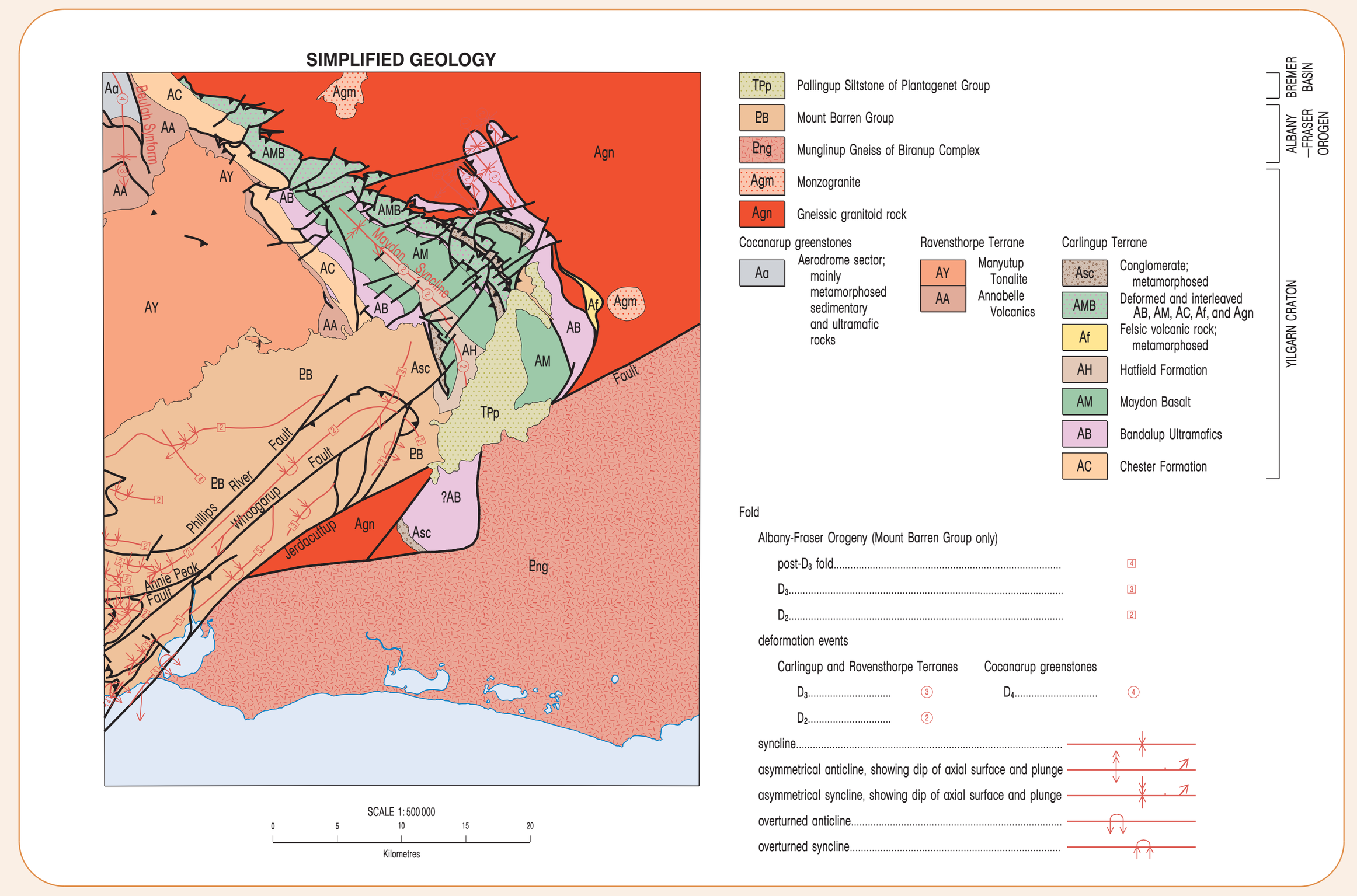
AH — **HATFIELD FORMATION:** pelite, psammite, and metamorphosed chemical sedimentary and felsic volcanic rocks
AHf — Epiclastic sedimentary rock (metamorphosed) and felsic schist
AHl — Limonitic unit (?after metamorphosed sulfides); massive to bedded
AHp — Shale, siltstone, and greywacke; metamorphosed
AHpb — Pelitic schist and slate with porphyroblasts of andalusite, garnet, and chloritoid
AHs — Sandstone and siltstone, metamorphosed, with thin chert and pelitic interbeds
AHv — Felsic volcanic rock; mainly dacite; metamorphosed

AM — **MAYDON BASALT:** undivided mafic rocks; metamorphosed (Simplified Geology map and section only)
AMa — Amphibolite
AMb — Basalt, variolitic and vesicular; metamorphosed
AMd — Dolerite; metamorphosed

AB — **BANDALUP ULTRAMAFICS:** undivided ultramafic rocks (Simplified Geology map and section only)
ABi — Banded iron-formation; metamorphosed
ABk — Komatiite, metamorphosed; chlorite-tremolite rock and schist
ABp — Peridotite, olivine orthocumulate and mesocumulate; metamorphosed
ABr — Tremolite-rich rock and schist; local pseudomorphs after metamorphic olivine
ABt — Talc(-chlorite-tremolite-carbonate) schist

AC — **CHESTER FORMATION:** pelite, psammite, and metamorphosed chemical sedimentary rocks (Simplified Geology map only)
ACc — Chert; metamorphosed
ACf — Quartz-feldspar-hornblende rock (metamorphosed) and schist; includes ACi and ACpb at some localities
ACg — Grit; chert and quartz fragments in a ferruginous, sandy matrix; metamorphosed
ACi — Banded iron-formation; metamorphosed
ACl — Limonitic unit (?after metamorphosed sulfides); massive to bedded
ACp — Shale, siltstone, and greywacke; metamorphosed
ACpb — Pelitic schist and slate with porphyroblasts of andalusite, garnet, chloritoid, staurolite, and cordierite
ACs — Sandstone and siltstone with thin chert and pelitic beds; metamorphosed

SIMPLIFIED GEOLOGY



Symbols

Geological boundary
- exposed

Fault
- exposed
- thrust, triangles placed on the upper plate
- concealed
- concealed, position uncertain
- concealed, interpreted from aeromagnetic data

Minor fold, showing trend, direction of plunge, and dip of axial plane
- Albany—Fraser Orogeny (Mount Barren Group only)
  - post-D_3 fold
  - D_3 fold
  - D_2 fold
- anticline, commonly isoclinal; plunge unknown
- syncline, commonly isoclinal
- minor isoclinal fold with vergence to left; plunge unknown
- anticline, open to tight, showing vergence to right where known
- syncline, open to tight, showing vergence to right where known
- reclined fold
- overturned fold

Bedding, showing strike and dip
- inclined
- vertical

Igneous layering/lamination, showing strike and dip
- vertical
- dip indeterminate

Way-up indicator
- igneous layering or differentiation trend
- pillow structure
- sedimentary structure

Metamorphic foliation, showing strike and dip
- inclined
- vertical
- dip indeterminate

Cleavage, showing strike and dip
- inclined
- vertical

Mineral lineation, showing trend and plunge direction
- on foliation plane
- on bedding plane

Airphoto lineament
- foliation, bedding, or layering trend

Sample locality for age determination with GSWA sample number — 112163

Highway with national route marker
Formed road
Track
Railway, abandoned
Townsite, population less than 1000 — Ravensthorpe
Building
Locality — Elverdton
National park boundary
Reserve boundary
Horizontal control, minor
Breakaway
Sand dune
Contour line, 20 metre interval — 100

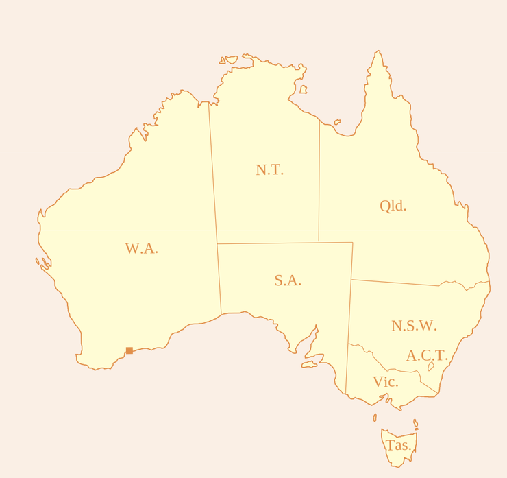
Lake; perennial, intermittent
Watercourse, ephemeral; pool
Swamp
Dam, earth
Rock, exposed

Mining centre — RAVENSTHORPE
Mine (gold, unless otherwise indicated) — Ironclad
Opencut
Quarry or pit
Prospect
Battery or treatment plant, abandoned
Mining area
- opencut

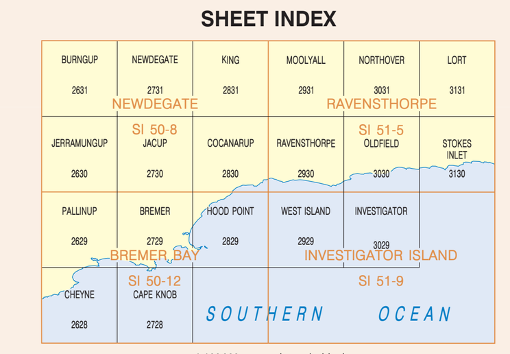
Mineral exploration hole or costean, showing subsurface data — AMb

Mineral occurrence
- Copper — Cu
- Gold — Au
- Gravel — Gr
- Kaolin — Ck
- Limestone — Ls
- Lithium — Li
- Magnesite — Ms
- Manganese — Mn
- Nickel — Ni
- Pyrite — Py
- Road materials — Rm
- Silver — Ag
- Talc — T
- Tungsten — W

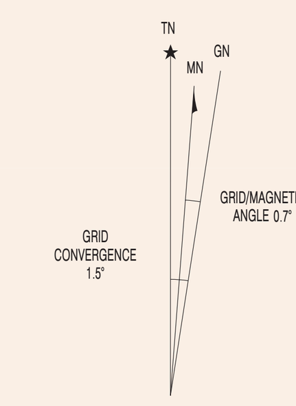
Metamorphic mineral occurrence
- Andalusite — And
- Chloritoid — Cld
- Cordierite — Crd
- Garnet — Grt
- Graphite — Gr
- Kyanite — Ky
- Magnetite — Mag
- Olivine — Ol
- Staurolite — St



SHEET INDEX



1:100 000 maps shown in black
1:250 000 maps shown in brown



True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 1995 and moves easterly by about 0.1° in three years.

DEPARTMENT OF MINERALS AND ENERGY
K.R. PERRY, DIRECTOR GENERAL

GOVERNMENT OF WESTERN AUSTRALIA
HON. KEVIN MINSON, M.L.A.
MINISTER FOR MINES

PIETRO GUJ
DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SCALE 1:100 000

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

Grid lines indicate 1000 metre interval of the Map Grid Australia Zone 51

The Map Grid Australia (MGA) is based on the Geocentric Datum of Australia 1994 (GDA94)
GDA94 positions are compatible within one metre of the datum WGS84 positions

Reference points to align maps based on the previous datum, AGD84, have been placed near the map corners

Geology by W.K. Witt 1995

Edited by S. Willis, D. Ferdinando, C. Strong, and G. Loan

Cartography by S. Collopy, and B. Williams

Topography from the Department of Land Administration Sheet SI 51-5, 2930, with modifications from geological field survey

Published by the Geological Survey of Western Australia. Copies available from the Mining Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, WA, 6004. Phone (09) 222 3459, Fax (09) 222 3444

This map is also available in digital form

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The recommended reference for this map is: WITT, W.K., 1996, Ravensthorpe, W.A. Sheet 2930: Western Australia Geological Survey, 1:100 000 Geological Series

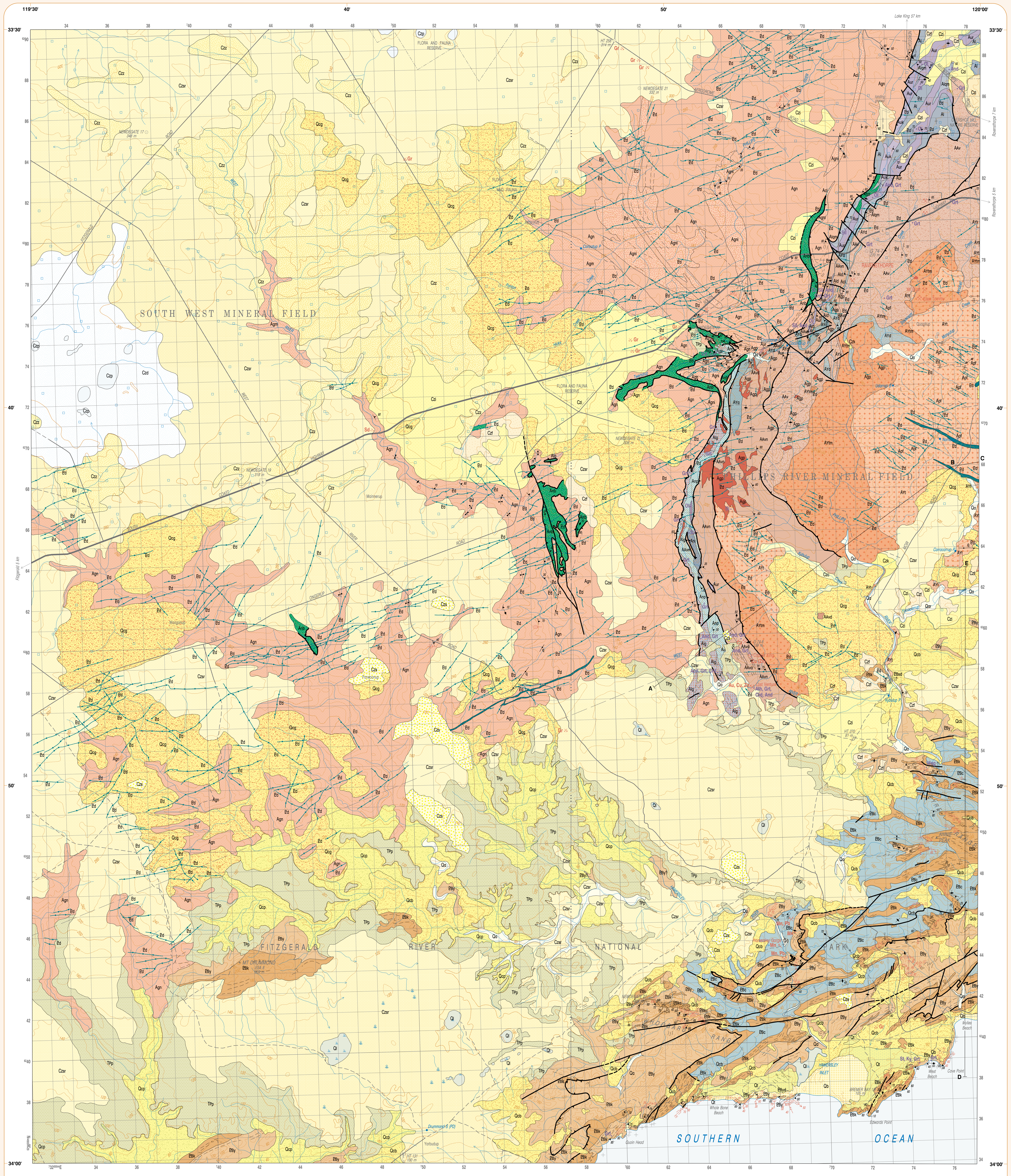
RAVENSTHORPE

SHEET 2930 FIRST EDITION 1996
Version 1.1 — December 2004

COCANARUP

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 2830



PHANEROZOIC — CAINOZOIC — QUATERNARY

Coastal deposits

Qb | Qt

- Qb — Beach sand—quartz and calcareous sand on beaches and in unstable dunes
- Qt — Consolidated coastal deposits—calcarenite, locally shelly; forms consolidated dunes and foreshore reefs; equivalent to TAMALA LIMESTONE

Inland deposits

Qa | Qar | Ql | Qcb | Qcg | Qcp

- Qa — Alluvium—clay, silt, sand, and gravel in channels
- Qar — Reworked Cainozoic deposits—clay, silt, and sand in broad floodplains of mature drainage
- Ql — Lacustrine deposits—clay and silt in claypans and swamps
- Qcb — Colluvium—rubble of boulders and sand derived from MOUNT BARREN GROUP; minor outcrops of MOUNT BARREN GROUP
- Qcg — Colluvium—rubble of boulders and sand derived from granitoid rock and granitoid gneiss; minor outcrops of granitoid rock
- Qcp — Colluvium—scree and sand derived from PALLINUP SILTSTONE

Czd | Czp

- Czd — Dune deposits—quartz sand and gypsum in stabilized dunes adjacent to playa lakes
- Czp — Playa deposits—saline and gypsiferous evaporites interbedded with clay, silt, and sand in playa lakes

Czc | Czs | Czsr | Czi | Czl | Czf | Czk | Czz

- Czc — Colluvium—clay, silt, and rock fragments derived from greenstones
- Czs — Sandplain deposits—unconsolidated sand; remnants of peneplain
- Czsr — Sandplain, undulating; reworked Czs
- Czi — Sand with limonitic pisoliths and gravel
- Czl — Lateritic deposits—laterite, ferruginous duricrust, and ferricrete
- Czf — Ferruginous deposits—undifferentiated; mainly ferruginous quartz sand and granules, and angular rock fragments with ferruginous cement
- Czk — Calcrete
- Czz — Silcrete—angular quartz grains in siliceous cement; mainly developed over granitoid rock

TERTIARY — Plantagenet Group — BREMER BASIN

- TPp — **PALLINUP SILTSTONE:** white to yellow to brown siltstone, silty sandstone, and spongolite; mainly deeply weathered

PROTEROZOIC — ALBANY—FRASER OROGEN

- ÐBc — **COWERDUP SILL:** dolerite and quartz dolerite, metamorphosed, and mafic to ultramafic schist

Mount Barren Group

- ÐBy — **KYBULUP SCHIST:** pelitic schist and phyllite with minor psammitic layers
- ÐByd — Dolomite; metamorphosed; massive to finely bedded; locally ?stromatolitic; with calc-silicate rock and calcareous schist
- ÐBk — **KUNDIP QUARTZITE:** quartzite, massive to coarsely bedded; minor pelitic beds
- ÐBkc — Oligomictic conglomerate; metamorphosed; quartzite clasts in psammitic matrix; massive to coarsely bedded
- ÐBsd — **STEERE FORMATION:** Dolomite; metamorphosed; massive to finely bedded; locally ?stromatolitic
- Ðd — Dolerite dyke, partly interpreted from aerial photography; interpreted from aeromagnetic data where dashed

ARCHAEAN — YILGARN CRATON

- q — Quartz vein
- Apf — Feldspar(-quartz) porphyry dyke
- Agm — Biotite monzogranite and granodiorite; massive and weakly recrystallized
- Agp — Pegmatite, granitic to tonalitic

Agn | Agni

- Agn — Gneissic granitoid rock; includes trondhjemite, tonalite, granodiorite, and syenogranite
- Agni — Gneissic granitoid rock, mesocratic to leucocratic with some mafic bands

Cocanarup greenstones

- Acl — Limonitic unit (?after metamorphosed sulfides); massive to bedded

Al | Ald | Alg | Alqm | Anl | Anp

- Al — Metasedimentary rock, undivided; deeply weathered
- Ald — Quartz-feldspar-biotite-sillimanite schist with andalusite porphyroblasts
- Alg — Garnetiferous quartz-plagioclase-biotite schist; local cordierite, andalusite, and sillimanite
- Alqm — Micaceous quartzite and quartz-mica schist; local sillimanite, andalusite, and garnet
- Anl — Quartz-K-feldspar-sillimanite gneiss and granoblastic quartz-clinopyroxene-amphibole-(K-feldspar) rock
- Anp — Banded quartz-amphibole-plagioclase rock; local garnet; para-amphibolite

Anb | Aba

- Anb — Mafic gneiss; fine- to medium-grained, banded plagioclase-hornblende(-quartz) rock
- Aba — Amphibolite; fine- to medium-grained

Au | Auk | Aur

- Au — Ultramafic rock, undivided; includes metamorphic talc-forsterite rock
- Auk — Komatiite; metamorphosed; chlorite-tremolite rock and schist
- Aur — Tremolite-rich rock and schist; local pseudomorphs after metamorphic olivine

Ravensthorpe Terrane

AY | AYt | AYtm | AYa | AYd | AYx

- AY — **MANYUTUP TONALITE:** tonalitic complex; metamorphosed (Simplified Geology map and section only)
- AYt — Tonalite and quartz diorite; massive, coarse-grained and equigranular; metamorphosed
- AYtm — Tonalite, diorite, and tonalite porphyry; massive, medium-grained, and equigranular to porphyritic; metamorphosed
- AYa — Amphibolite; metamorphosed dolerite
- AYd — Dolerite; metamorphosed
- AYx — Pyroxenite; metamorphosed

AA | AAv | AAva | AAvd | AAvn

- AA — **ANNABELLE VOLCANICS:** calc-alkaline volcanic association; metamorphosed (Simplified Geology map and section only)
- AAv — Mafic to intermediate tuff and agglomerate, and related epiclastic rocks (mainly andesite), subordinate dacite; metamorphosed
- AAva — Cordierite-gedrite rock; coarse-grained
- AAvd — Quartz-feldspar(-amphibole-biotite) gneiss; fine-grained; metamorphosed dacite
- AAvn — Quartz-plagioclase-amphibole gneiss; fine- to medium-grained; derived from AAv; local minor metasedimentary layer

Geological boundary
- exposed

Fault
- exposed
- thrust, triangles placed on upper plate
- concealed

Minor fold, showing trend, direction of plunge, and dip of axial plane
- Albany—Fraser Orogeny (Mount Barren Group only)
  - post-D_3 fold
  - D_3 fold
  - D_2 fold
- anticline, commonly isoclinal; plunge unknown
- syncline, commonly isoclinal
- minor isoclinal fold with vergence to left
- anticline, open to tight
- overturned anticline
- overturned syncline

Bedding, showing strike and dip
- inclined
- vertical

Igneous layering/lamination, showing strike and dip
- vertical
- dip indeterminate

Way-up indicator
- igneous layering or differentiation trend
- sedimentary structure

Metamorphic foliation, showing strike and dip
- inclined
- vertical
- dip indeterminate

Cleavage, showing strike and dip
- inclined
- vertical

Mineral lineation, showing trend and plunge direction
- horizontal
- on foliation plane
- on bedding plane
- on cleavage plane

Igneous lineation, horizontal

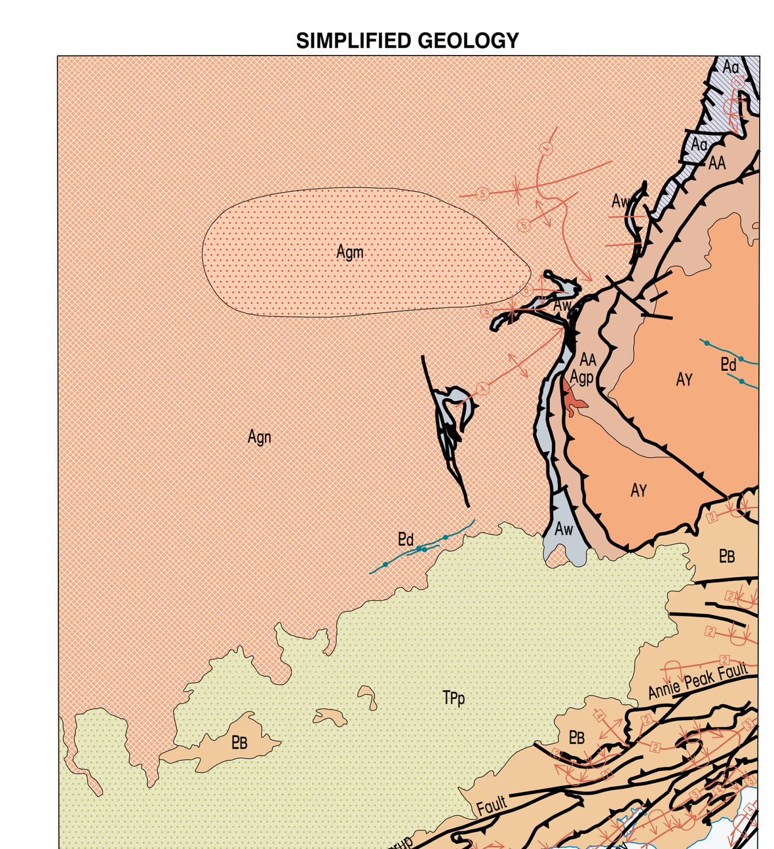
Intersection lineation, showing trend and plunge direction
- inclined

Airphoto lineament
- foliation, bedding, or layering trend

Stromatolite locality

- Highway with national route marker
- Formed road
- Track
- Building
- Locality — Cocanarup
- National park boundary
- Reserve boundary
- Horizontal control, minor
- Breakaway
- Contour line, 20 metre interval — 200
- Watercourse, ephemeral; pool
- Spring; swamp
- Dam
- Position doubtful — (PD)
- Rock, exposed
- Mineral field boundary
- Mining centre — RAVENSTHORPE
- Mine (gold, unless otherwise indicated) — Mt Eliza
- Opencut
- Quarry or pit
- Prospect
- Battery or treatment plant, abandoned
- Mineral occurrence
  - Copper — Cu
  - Gold — Au
  - Gravel — Gr
  - Lead — Pb
  - Manganese — Mn
  - Sand (building) — Sd
  - Zinc — Zn
- Metamorphic mineral occurrence
  - Andalusite — And
  - Anthophyllite — Ath
  - Cordierite — Crd
  - Diopside — Di
  - Garnet — Grt
  - Kyanite — Ky
  - Magnetite — Mag
  - Olivine — Ol
  - Sillimanite — Sil
  - Staurolite — St

SIMPLIFIED GEOLOGY



- TPp — Pallinup Siltstone of Plantagenet Group — BREMER BASIN
- ÐB — Mount Barren Group — ALBANY—FRASER OROGEN
- Agm — Monzogranite
- Agp — Pegmatite
- Agn — Gneissic granitoid rock

YILGARN CRATON

Cocanarup greenstones
- Aa — Aerodrome sector; mainly metasedimentary and ultramafic rocks
- Aw — West sector; mainly metasedimentary rocks

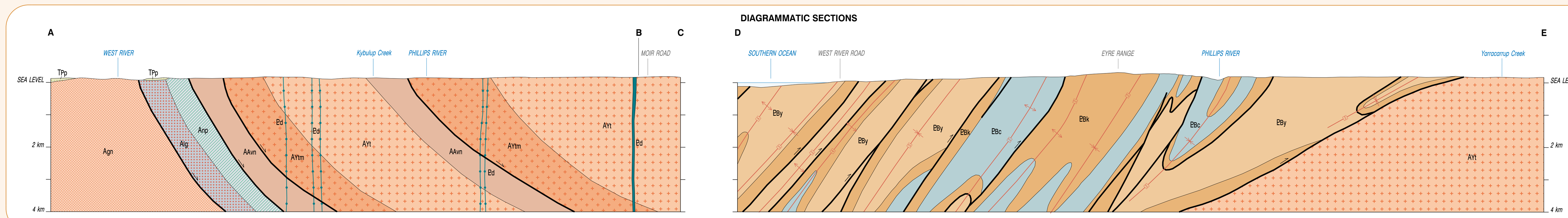
Ravensthorpe Terrane
- AY — Manyutup Tonalite
- AA — Annabelle Volcanics

Fault
- thrust

Fold
- Albany—Fraser Orogeny
  - post-D_3
  - D_3
  - D_2
- deformation events in the Cocanarup greenstones
  - D_5
  - D_4
  - D_3
- anticline
- syncline
- overturned anticline, showing dip of axial surface and plunge
- overturned syncline, showing dip of axial surface and plunge

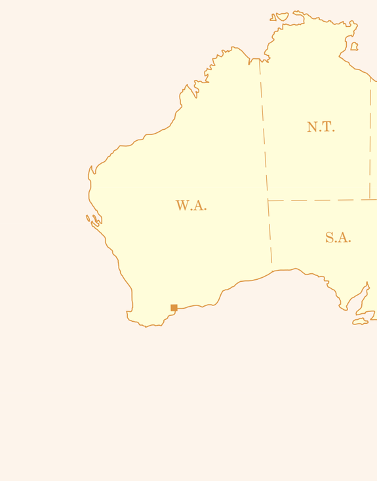
SCALE 1:500 000 — 0 5 10 15 20 Kilometres

DIAGRAMMATIC SECTIONS

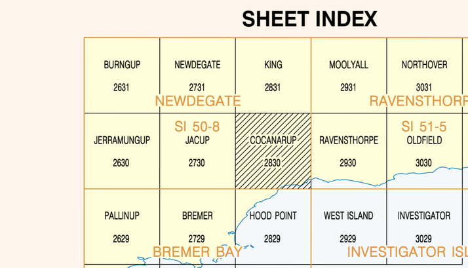


The original thrusts dipped to the west on section A—B—C

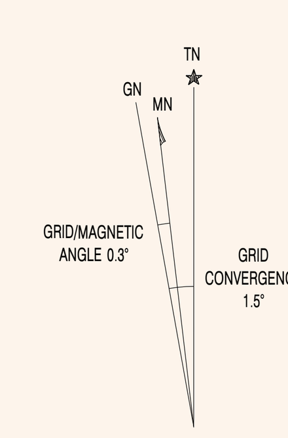
Relative displacement along fault



SHEET INDEX



1:100 000 maps shown in black
1:250 000 maps shown in brown



True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 1995 and moves easterly by about 0.1° in 3 years

Geology by W. K. Witt 1994

Edited by D. Ferdinando, J. Mikucki, C. Strong, S. Willis, and G. Loan

Cartography by K. Greenberg, S. Collopy, and M. Prause

Topography from the Department of Land Administration Sheet SI 50-8, 2830, with modifications from geological field survey

Published by the Geological Survey of Western Australia. Copies available from the Mining Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, WA, 6004. Phone (09) 222 3459, Fax (09) 222 3444

This map is also available in digital form

Printed by Allwest Print, Western Australia

The recommended reference for this map is: WITT, W. K., 1996, Cocanarup, W.A. Sheet 2830: Western Australia Geological Survey, 1:100 000 Geological Series

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DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SCALE 1:100 000

1000 0 1 2 3 4 5 6 7 8 9 10
Metres — Kilometres

TRANSVERSE MERCATOR PROJECTION
Grid lines indicate 1000 metre interval of the Australian Map Grid Zone 50

COCANARUP

SHEET 2830 FIRST EDITION 1996