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HEAVY-MINERAL DEPOSITS ALONG THE COASTS OF VICTORIA, TASMANIA, AND SOUTH AUSTRALIA

BY

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SUMMARY

Provenance, coastal geomorphology, climate and oceanographic features influence the nature of heavy-mineral sand accumulations. These features are diagramatically shown on 1:2,500,000 maps of Victoria, Tasmania, and South Australia together with the distribution, size, and mineralogy of the heavy-mineral deposits.

Bibliographic research and the maps show that: (1) the largest heavy-mineral accumulations are found at the junction of truncated beach ridge systems, (2) all the heavy-mineral deposits are found within Holocene sediments, unlike the eastern Australian coast where heavy-minerals are found within both Pleistocene and Holocene deposits, (3) no heavy-mineral deposits have been reported from within calcareous sediments and (4) the literature has suggested that a variety of rock types contribute to the heavy-mineral suites.

1. INTRODUCTION

This report is a synthesis of information from published and unpublished reports on heavy-mineral sand deposits found on the coastlines of Victoria, Tasmania and South Australia. It is similar to an earlier report on the heavy-mineral deposits of eastern Australia (Gardiner, 1976). The aim of the synthesis is to see if any factors are clearly more important than others in the accumulation of heavy-mineral sands. To help in this study a series of maps has been compiled at 1:2,500,000 scale; these show the location of known heavy- mineral deposits and geological provenance, climate and oceanography, and coastal geomorphology, - factors commonly held to be important in the genesis of these deposits.

Acknowledgements

Much of the unpublished information used in compiling this report and listed in the references has been gathered from the files of the Geological Surveys of Victoria, Tasmania and South Australia. Assistance given by the Surveys during this operation is gratefully acknowledged. In particular, I wish to thank Messrs S. Tan, Geological Survey of Victoria, A. Noldart and I. Jennings, Geological Survey of Tasmania and D. Watkins, Geological Survey of South Australia.

2. THE OCCURRENCE OF HEAVY MINERALS

2.1 Sources of Information

Both dry-mill production figures and company estimates of reserves have been used to show the distribution, size and types of heavy-mineral deposits on the southern coasts.

Dry-mill production figures cover the period from the time mining commenced, at particular locations, to December 1974 (Table 7). Problems associated with the use of these figures, particularly with regard to the loss of information when combining production figures, have been outlined by Gardiner (1976).

The estimated reserve figures have been taken from Open File Reports of the Geological Surveys of South Australia, Tasmania and Victoria (Table 2). Calculation of the ore reserves is generally based on a cut-off grade of about 0.5 percent heavy mineral or 0.15 percent rutile and zircon, with the average grade ranging from 0.3 percent to 0.47 percent rutile (Ward, 1972). However none of the Open File reports examined mentioned the methods used to calculate the ore reserves.

2.2 The distribution of heavy-mineral deposits

The location of heavy-mineral deposits in southeastern Australia is shown in Figure 1. Unlike the situation on the northern New South Wales and Queensland coasts, economic heavy-mineral deposits along the Victorian, Tasmanian and South Australian coastlines are uncommon. The heavy-mineral deposits along the South Australian coastline group into six areas: (1) between Mallacoota Inlet and Betka River, in the northeast of Victoria; (2) in the Port Phillip Bay area, Victoria; (3) along the southern Eyre Peninsula, South Australia; (4) on Kangaroo Island and the adjacent tip of the Fleurieu Peninsula, South Australia; (5) King Island, Tasmania; and (6) at various locations around the Tasmanian coast. The largest known deposits, and the only areas from which there is any production, are on King and Kangaroo Islands (Table 1).

TABLE 1. Production of heavy minerals from coastal sands.

Location	Company	Year	Heavy minerals mined (tonnes)						
			Ilmenite	Rutile	Zircon	Monazite	Cassiterite	Garnet	Others
King Island (Naracoopa)	Not known	1933	515						
	Naracoopa Rutile Ltd	1969	22 968	5323	6193				
		1970	25 605	7527	5172				
		1971	24 169	6930	3830			1012	
	Kibuka Mines	1973		2965	1238				
		1974		4322	5531				
		Total	73 257	27 067	21 964			1012	
									Total 123 289
Kangaroo Island (Nepean Bay)	Grasso Pty Ltd	1972		120					
		1972-3		858					
		1973		261	187				
		Total		1239	187				
									Total 1426

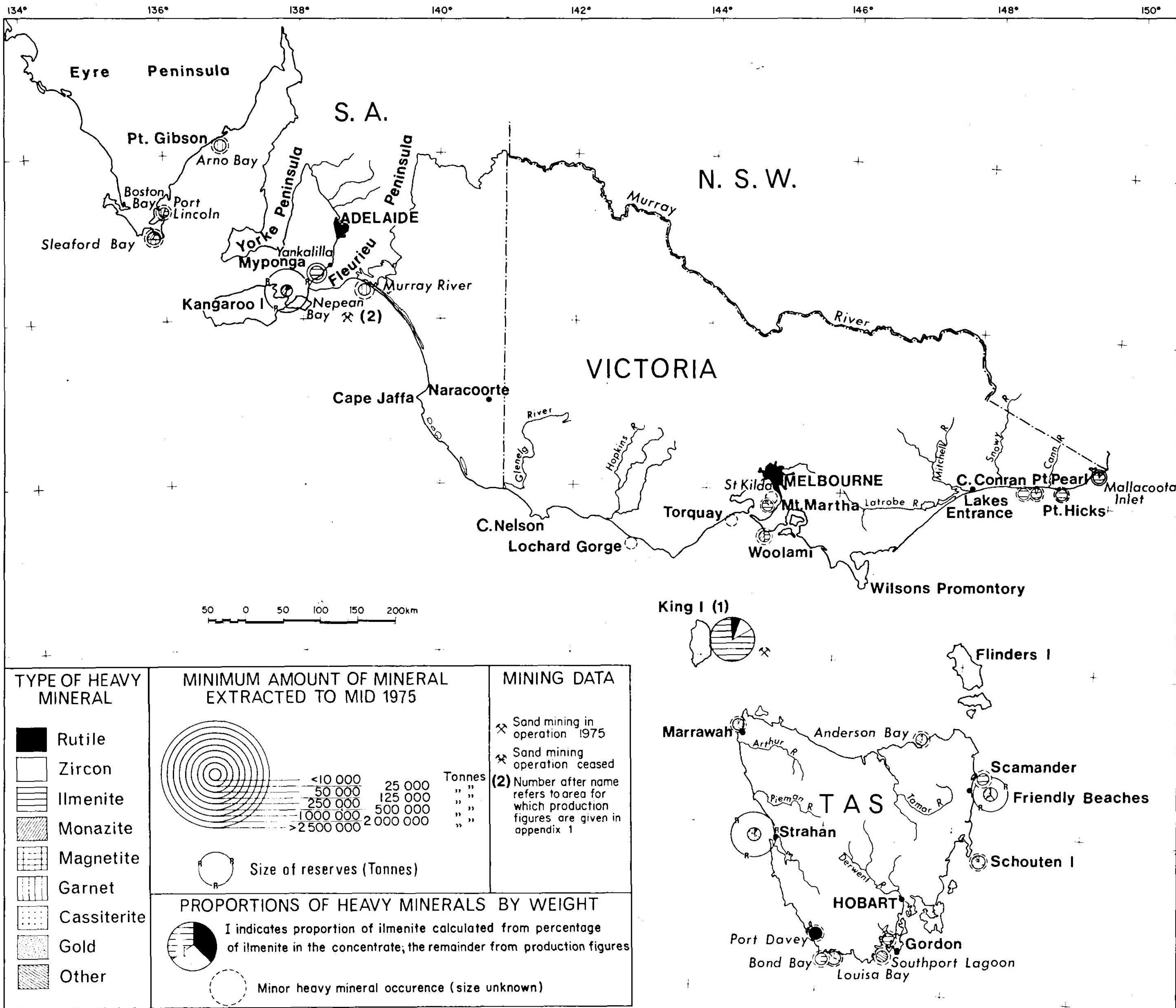

Fig. 1 Distribution of heavy-mineral deposits

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2.2.1 Northeastern Victoria

The largest deposits in Victoria have been recorded from the northeast coast (Table 2). Tan (1973), studying the coastline from Mallacoota Inlet to Marlo, concluded that the largest concentrations were at Point Hicks, Point Pearl, Cape Conran and Betka River. According to Fisher (1949), Bell (1953, 1955, 1956), Baker and Edwards (1956), and Tan (1973), these deposits consist essentially of low-grade ilmenite sands with minor amounts of rutile and zircon. The composition of the concentrate at each beach can be seen on Table 3. It has also been noted that ilmenite in these sands has a high Cr_2O_3 content.

2.2.2 Port Phillip Bay

Heavy-mineral deposits in Port Phillip Bay are found at St Kilda, Canada Bay, Aspendale, Rickets Point, Davey's Bay, and Mount Martha (Whincup, 1944; Baker, 1945; Baker & Edwards, 1956; Bell, 1956; Beasley, 1957). The heavy-mineral concentrates within the bay are composed predominantly of magnetite and ilmenite. Several patches of black sand are reported to have been bagged at Davey's Bay, for their titanium content, but the exact amount is not known.

2.2.3 Southern Eyre Peninsula

Garnetiferous sands dominate the heavy-mineral deposits on the southern Eyre Peninsula. They have been reported from Sleaford Bay (Giles, 1951; Mansfield, 1950; Johns, 1961), Point Gibbon (Whitten, 1961), and Port Lincoln (Mansfield, 1950). At Sleaford Bay, red garnet comprises 49-57 percent of the heavy-mineral fraction (Table 3). At Cunata Rocks, Porter Bay, Boston Bay, and Arno Bay, other heavy-mineral deposits have been found. In all these deposits, hematite and ilmenite are the principal heavy minerals, and zircon, rutile, monazite, and garnet occur as trace minerals (Johns, 1961). All the heavy-mineral deposits discussed are sub-economic and are often only surface washings along the beach (Table 2).

2.2.4 Kangaroo Island and the Fleurieu Peninsula

Heavy-mineral concentrations on Kangaroo Island are found along sections of Morrison beach and in several areas along the stranded shoreline at the base of fossil cliffs; zircon is the most common economic heavy-mineral, as can be seen in Table 3. These deposits have been examined by many authors (Bates & Penneshaw, 1953; McCahon, 1956; Grasso, 1964, 1968; Johns, 1965, 1966; Hiern, 1968; Miezitis, 1970), who have given various estimates of the reserves of heavy minerals (Table 2).

Surface concentrations of heavy minerals have been noted at Moana, Goolwa, and Myponga beaches, and Yankalilla Bay, on the Fleurieu Peninsula (Hillwood, 1960). The heavy-minerals present are mainly zircon, rutile, monazite and opaques (Farrell, 1968).

2.2.5 King Island

Heavy-mineral deposits are found in two raised beaches on the east coast near Naracoopa and at Cowper Point (Rowbotham, 1970). Rutile, zircon, and ilmenite are the dominant heavy minerals at Naracoopa, but cassiterite has been mined, and monazite and garnet have been recorded in the heavy-mineral fraction (Gardner, 1942; Keid, 1947; Rowbotham, 1970). Heavy-mineral grades vary from 20-90 percent in the recent beach deposits to 6-15 percent in the dunal deposits. As in northern New South Wales, there

TABLE 2. Estimated reserve figures.

Location	Company and/or Investigator	Heavy minerals (tonnes)							
		Rutile	Ilmenite	Zircon	Monazite	Cassiterite	Garnet	Tourmaline	Others
TASMANIA									
Bond Bay	Geotechnics (1970a)		——9204*——						
Louisa Bay	Geotechnics (1970a)		——7361*——						
Ocean Beach	Straham Sands Pty Ltd	12 000	11 500	38 000			30 000		11 500
	McDonald (1970)	28 000	11 500	6700					9130
Ann Bay - Marrawah Beach	McDonald (1970)		8600						
Friendly Beaches	Planet Metals Ltd (Tassel, 1970)	650		16 600			10 000		20 000
VICTORIA									
Betka River	Tan (1972)	260	1510	130					
Point Hicks	Tan (1972)		1980						
Point Pearl	Tan (1972)	135	1380	140					
Point Conran	Tan (1972)		200						
SOUTH AUSTRALIA									
Port Lincoln	Mansfield (1950)						730		

* - mixed concentrates

is a high percentage of Cr_2O_3 in the heavy-mineral sands of King Island. This has caused much of the ilmenite to be stockpiled and, therefore, not shown in the dry-mill production figures (Fig. 1). King Island has the largest heavy-mineral deposit on the southern coast, with a total of 123 289 tonnes of heavy mineral having been mined (Table 1), and estimated reserves as of 1974, of 4 million tonnes (Kibuka Mines Pty Ltd, pers. comm.).

2.2.6 Tasmania

Tasmanian heavy-mineral deposits differ in size and mineralogy at each location. In the southwest of the State, from Louisa Bay to Port Davey, small heavy-mineral deposits have been recorded. The most significant of these is at Louisa Bay (Table 2). The heavy-mineral content of the sand varies from 51 to 3.1 percent, and the heavy-mineral concentrate averages 38 percent ilmenite, 2 percent rutile, 2 percent zircon, 50 percent garnet, and 8.0 percent others (Geotechnics, 1970b). The chrome content of the heavy-mineral fraction is small, ranging from 324 ppm to 394 ppm (Geotechnics, 1970a). A deposit at Strahan, on the central west coast, is the largest deposit in Tasmania. However, most of it consists of uneconomic heavy minerals such as garnet and leucoxene. This is also the situation further north in the Ann Bay - Marrawah Beach area. Deposits there are estimated to contain 100 000 tonnes of heavy minerals, but only 8600 tonnes is composed of economic minerals (McDonald, 1970; Schmidt, 1968).

Along the north coast of Tasmania, small heavy-mineral deposits contain less than one percent heavy minerals. Again most of these deposits are composed of uneconomic minerals such as amphiboles, tourmaline, and iron oxide (McMahon & Partners, 1970). Of the economic heavy-minerals, ilmenite is the most abundant, ranging from 7 to 16.5 percent of the concentrate in the Bradger Head-Stoney Head area to 25.35 percent at Noland Bay (Lockhart, 1972) and 35 percent at Anderson Bay (Kociumbas, 1971).

There are several heavy-mineral concentrations along the east coast of Tasmania (Fig. 1), although these also are sub-economic. Near the Scamander River the deposits consist of ilmenite, (Denholm, 1968); at the Friendly Beaches zircon and garnet are predominent (Bruinsma, 1970; Tassel, 1970). A small deposit has also been noted on Schouten Island (Hughes, 1959). Further south, along the D'Entrecasteaux Channel, ilmenite and magnetite are the dominant heavy minerals (Hughes, 1947; Hale, 1953; Green, 1961).

3. GEOLOGICAL PROVENANCE

3.1 Introduction

Distribution of the major rock types in each drainage basin along the southeastern coast is shown in Figure 2. Geological information for these maps was taken from the Tectonic Map of Australia (G.S.A., 1960). Few basins consist wholly of one major rock type, and it is, therefore, difficult to deduce the influence of each drainage basin on the detrital heavy-mineral suites. A survey of the literature reveals that few studies have examined in detail the source rocks of the detrital heavy-mineral suites along the southeastern Australian Coast.

3.2 Origin of the heavy-mineral sands: previous investigations

3.2.1 Victoria

In Victoria no studies have been undertaken to correlate the heavy-mineral deposits of beaches with any particular source rocks. However, it has been suggested (Tan, 1973; Fisher, 1949; Bell, 1953) that the deposits along the coast from Mallacoota Inlet to Marlo were derived from the hinterland granitic and metamorphic rocks.

In Port Phillip Bay, granodiorites have been mentioned as the source rocks (Baker, 1945) of the few scattered deposits of heavy minerals in the bay. On Port Phillip Island (Western Port) the source of a storm-concentrated heavy-mineral deposit was thought to be Tertiary volcanics and Jurassic arkose (Beasley, 1957). The Tertiary volcanics are thought to be the primary source of opaques and olivine, and Devonian granites, the primary source of rutile and zircon which were then deposited in the Jurassic arkose, and finally eroded and deposited in Quaternary beach sands.

3.2.2 South Australia

In South Australia, studies on Kangaroo Island have resulted in different conclusions as to the source of the heavy-minerals. Hillwood (1960) named the flow basalts, of late Cainozoic age, as the source of the Kingscote heavy minerals, whereas other authors have suggested that the metamorphosed sediments of the Kanmantoo Group provided the heavy minerals (Johns, 1968). Farrell (1968), in a detailed study of the beach sand of the Fleurieu Peninsula, was able to correlate different heavy-mineral suites with particular source rocks (Fig. 3). For example, he correlated the heavy-mineral suite on the southern coast, dominated by garnet, tourmaline, and staurolite, with the Cambrian metamorphic terrain, and monazite, rutile, zircon, and opaques that dominate the western coast suites, with Cambrian inliers and Tertiary deposits (Farrell, 1968).

3.2.3 Tasmania

On King Island, where the largest heavy-mineral deposits on the southeastern coasts are found, Clarke (1966) and Rowbotham (1970) considered that the granites and gabbros in the area next to Sea Elephant River were the source of the heavy minerals. Elsewhere, a variety of source rocks have been cited as the source of small heavy-mineral deposits. At Louisa Bay, metamorphosed Precambrian schists are reported as the source of heavy-minerals in the Bay (Geotechnics, 1970b). Jurassic dolerite along the D'Entrecasteaux Channel (Hughes, 1947) and Devonian granites at Scamander (Denholm, 1968) have been cited as the source of heavy-minerals on the east coast of Tasmania.

3.3 Conclusions

Conclusions drawn from the survey of literature on the heavy-mineral deposits of Victoria, South Australia, and Tasmania are that (1) a variety of rock types contributes to the heavy-mineral suites; (2) granites tend to produce heavy-mineral suites dominated by monazite, rutile, zircon, and opaques; metamorphics, suites dominated by garnet, tourmaline, and ilmenite; and granodiorite suites rich in ilmenite and magnetite; (3) the deposit/provenance associations are different from those of the eastern coast of Australia, where Palaeozoic and Mesozoic arenaceous rocks are considered to be the source of the rutile, zircon and monazite, and Tertiary volcanics, the source of the ilmenite (Whitworth, 1956); (4) there are many areas with suitable source rocks for heavy minerals but where no concentrations of heavy minerals have been found. It has been suggested that this absence of heavy-mineral deposits is due to the abundance of calcareous sediments along much of the southern coastline (Hillwood, 1960).

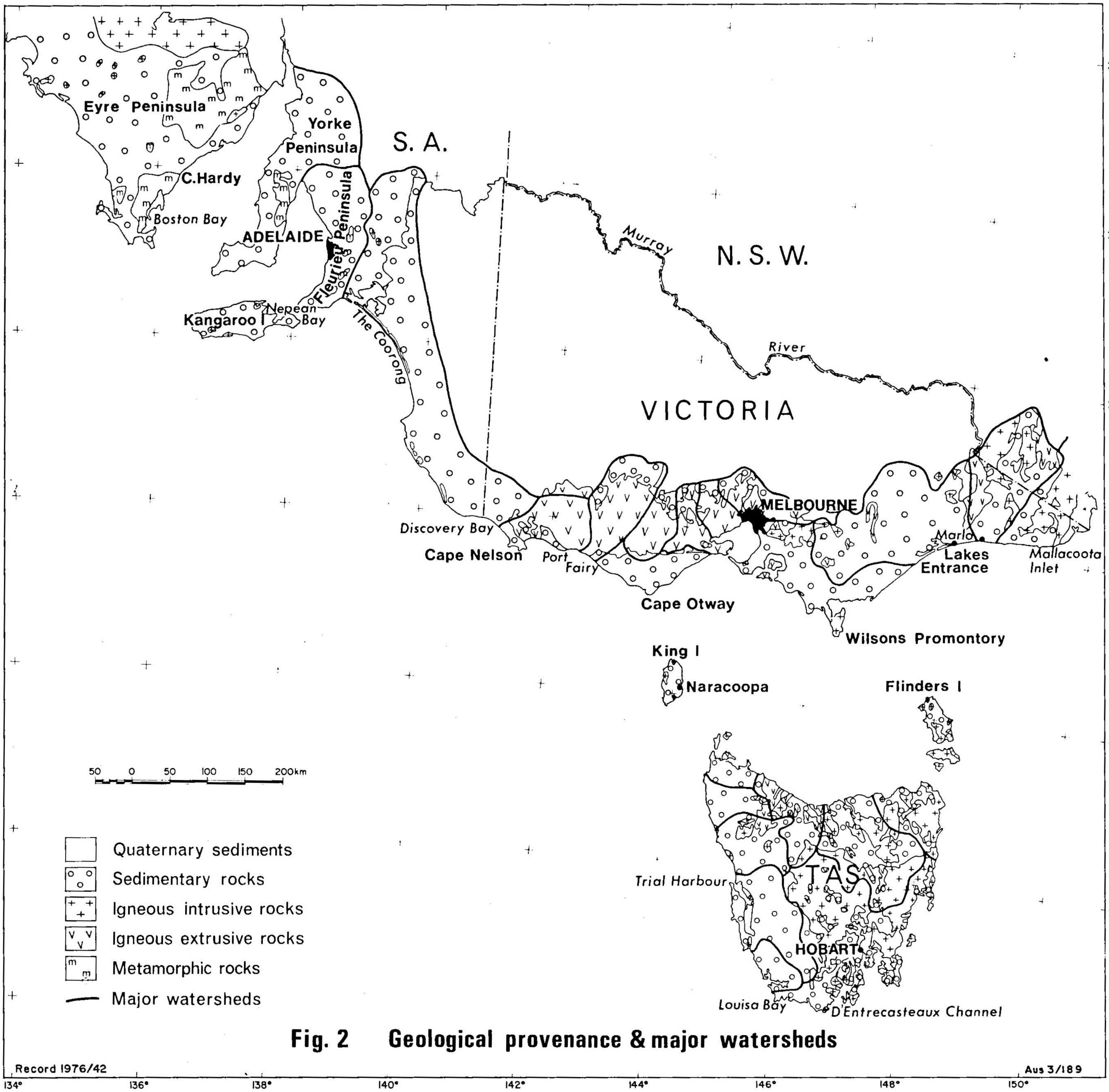

Fig. 2 Geological provenance & major watersheds

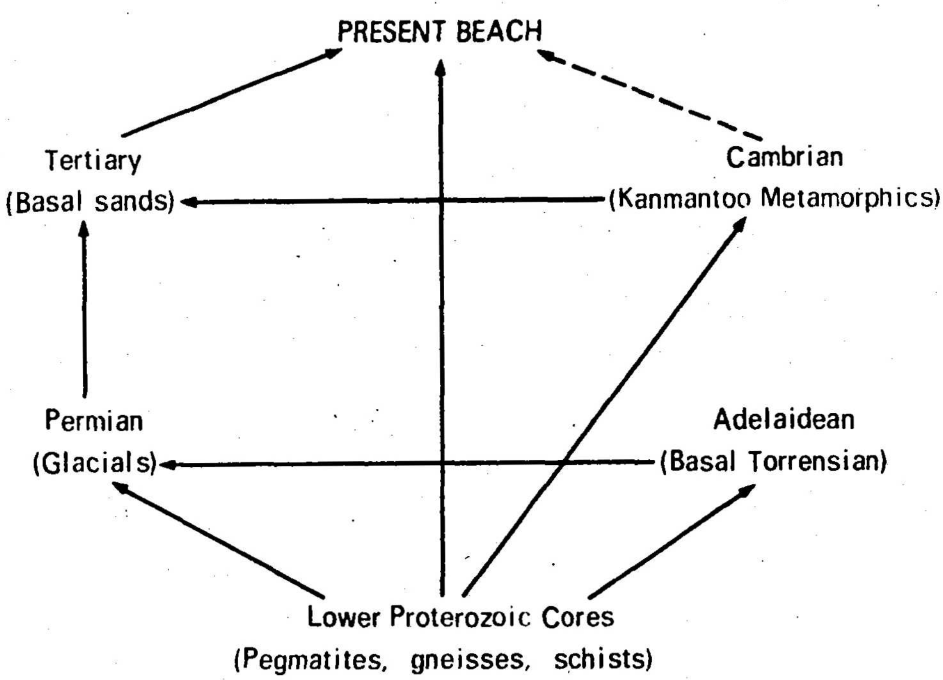

Fig 3. Heavy-mineral cycle, western Fleurieu Peninsula (from Farrell, 1968)

4. CLIMATIC AND OCEANOGRAPHIC DATA

4.1 Introduction

It has been noted (Gardner, 1955; Whitworth, 1956; Hillwood, 1960; Connah, 1961; Welch, 1964; Hails, 1964) that the concentrations of heavy minerals both along beaches and within dunes is influenced by climatic and oceanographic factors. Oceanographic and climatic data are shown on Figure 4. As the southern coasts of Australia are subject to a range of different climatic conditions, and changes are abrupt from one area to another, only climatic and oceanographic conditions in the areas of heavy-mineral deposits will be discussed.

Published articles provide the main source of information for the maps; climatic data (rainfall and wind activity) are from the Official Yearbook of the Commonwealth of Australia (Commonwealth Bureau of Census and Statistics, 1972). Tidal data were adopted from Easton (1970) and wave height analysis has been taken directly from a world-wide study by Meisburger (1962) and a study along the Victorian coastline by Fryer (1967). The bathymetry is from the Australian 1:2 500 000 Map Series.

4.2 Climatic and oceanographic conditions at specific locations along the southern coasts

4.2.1 Northeastern Victoria

This section of coast receives between 800-1600 mm of rain each year. Although the predominant airstream in Victoria is from the west, this area is influenced by southeasterly winds. Fryer (1967) working in the Gippsland area estimated that 32 percent of waves come from the southwest, 34 percent from the south, 26 percent from southeast and 8 percent from the east. Only 10-20 percent of all waves reaching this section of coast are greater than 2.75 m. The tidal range is less than 2 m. Bathymetric contours show that the continental shelf is wide and shallow adjacent to this section of coast.

Of these climatic and oceanographic conditions only the tidal and wind activity appear to have direct effect on the accumulation of the heavy-mineral deposits. Tidal conditions have concentrated the heavy minerals found in berms and along the beaches (Tan, 1973)*. On exposed coastal sections such as Point Hicks and Cape Conran the strong and continuous westerly winds (Fisher, 1949) have produced large dune systems which contain small disseminated heavy-mineral deposits.

* Normal conditions of changing tides result in the continual removal and washing of heavy minerals so that permanent deposits may be the products of storm waves and abnormal tides. (Hillwood, 1960).

4.2.2 Port Phillip Bay

In the Port Phillip Bay area the annual rainfall ranges between 400 and 800 mm. Wind roses for Melbourne show that the southerly wind is dominant (Fig. 4). Wave conditions and water level within the Bay are much affected by meteorological conditions. Prolonged southerly and westerly winds cause a rise in the level of the bay, whilst easterly and northeasterly winds cause the water level to fall (Division of Ports and Harbours, 1971). Tidal range is between 0.6 and 1 m. The bay is shallow and dredging is common (McKenzie, 1939). A combination of tidal, wave and wind conditions probably affects the location of heavy-mineral deposits within Port Phillip Bay. All deposits are found on the eastern side of the bay, which is the side most influenced by the dominant southerly and westerly winds. As along the northeastern coast of Victoria, the deposits are positioned by tidal activity.

4.2.3 Kangaroo Island and Fleurieu Peninsula

Annual rainfall in this area averages 500 mm, and ranges between 400 and 800 mm (Commonwealth Yearbook of Australia, 1972). At Adelaide southwesterly winds are dominant, but there is a high percentage of east and southeasterly winds. It has also been noted that the sea breeze is well defined along this coast from October to April/May (Commonwealth Bureau Meterology, 1961). Along the coast of northern Kangaroo Island and the western coast of the Fleurieu Peninsula few waves greater than 2.75 m are experienced, because of the shielding effect of Kangaroo Island. The swell is from the southwest and is most consistent in character and direction, being derived from sub-Antartic gales south of the Indian Ocean (Davies, 1965). Tidal range is small. The continental shelf, as along most of the southern coast, is wide and shallow.

As many heavy-mineral deposits along the Fleurieu Peninsula appear to be seasonal in nature (Hillwood, 1960), climatic and oceanographic factors, such as the number of storms throughout the year and abnormally high tides, are important in accounting for the position of the deposits within the beaches. On Kangaroo Island heavy-mineral deposits occur within ancient beach ridges and are only affected by current climatic and oceanographic factors such as storm wave activity along Morrison beach.

4.2.4 Southern Eyre Peninsula

The southern Eyre Peninsula has a similar annual rainfall to the Kangaroo Island and Fleurieu Peninsula area. Although Aduna is situated in the north of Eyre Peninsula, its wind rose reflects wind conditions in the south. Southwesterly and southerly winds are dominant. As can be seen in Figure 4 the western coast and southern coast, to Sleaford Bay, of the Eyre Peninsula are subjected a high percentage of waves greater than 2.75 m. Swell is from the southwest. Tidal range is 0-2 m. The shelf is wide and shallow. The influence of many of these climatic and oceanographic factors on the heavy-mineral deposits along the southern Eyre Peninsula is minimal. As deposits occur within the beachface as lenses averaging 100 m in length, and are not more than 1 m deep (Johns, 1961), tidal activity is the most important factor in their location and size.

4.2.5 Tasmania

The west coast of Tasmania experiences the highest rainfall in Australia, the Zeehan area receiving over 2400 mm each year. Along this coast the rainfall is reliable, falling predominantly in the winter months. On the east coast the rainfall is lower, 600-800 mm a year. Winds are important along the Tasmanian coasts, orientating the massive transgressive dune systems on the west coast, and foredune blowouts. On King and Flinders Islands the dunes are orientated east-west on the west coast and roughly north-south on the east coast. The prevailing winds in Tasmania are westerly, but it is noted that winds west of the ranges are predominantly from west to southwest, and in the eastern half of the state northwesterly winds prevail (Commonwealth Bureau Meterology, 1961). The continental shelf adjacent to the northern Tasmanian coast is wide, extending to the Victorian coast, and shallow, not exceeding 200 m in depth. The east and west coasts

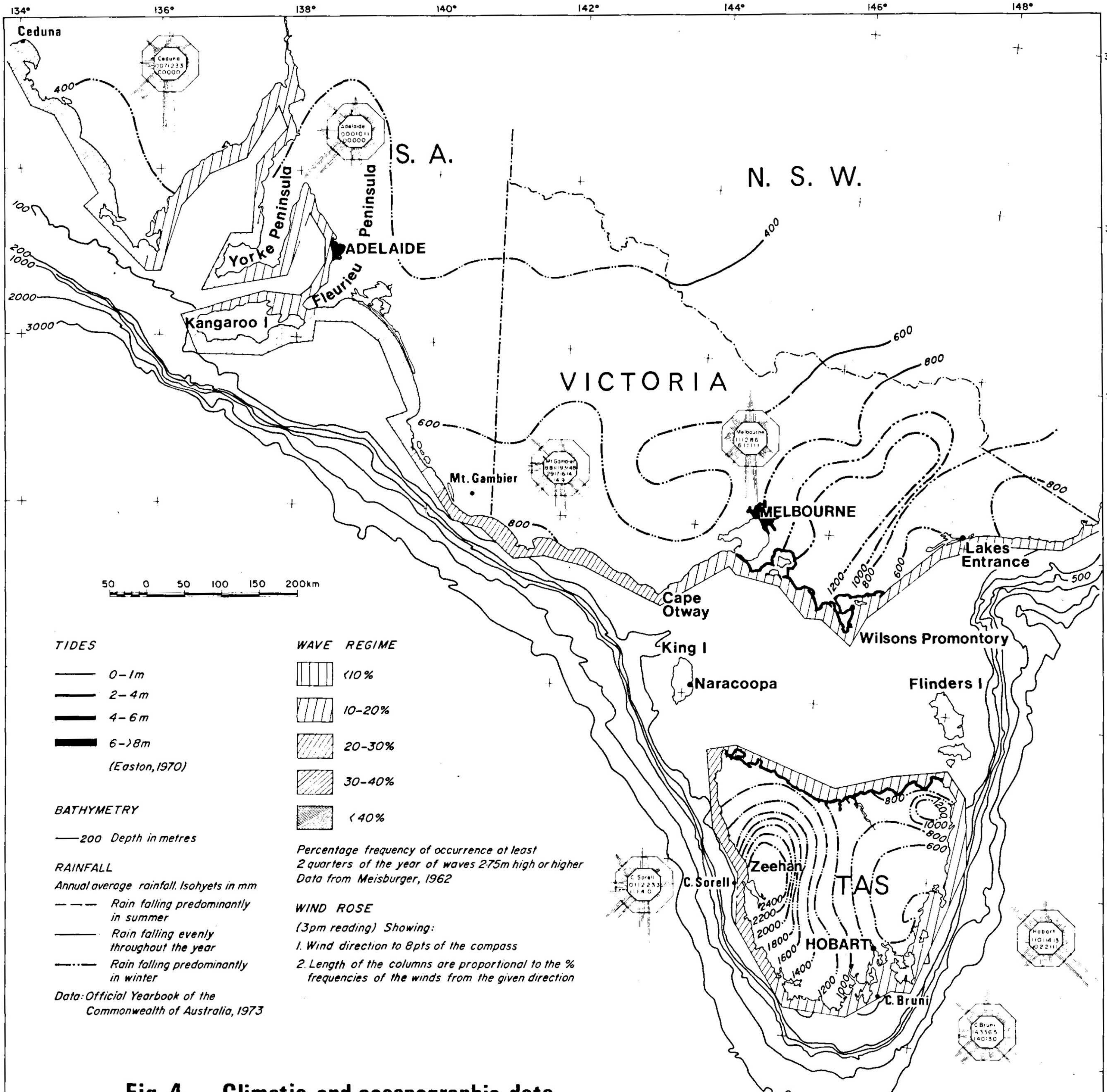

Fig. 4 Climatic and oceanographic data

are relatively narrow, not exceeding 40 km (to the 200 m contour). On the southeast coasts the shelf extends 70 km to the 200 m contour. Tidal range is small, mostly less than 2 m except for the Bass Strait Coast where it ranges from 2-4 m and produces double-ridged beaches (Davies, 1972). Tasmania is influenced by both east coast and west coast swell environments (Fig. 5). Along the west coast from Port Davey to Hunter Island, 20-30 percent of all waves are greater than 2.75 m, whereas along the east coast the swell produces a lower percentage of waves greater than 2.75 m.

The scattered nature of the Tasmanian heavy-mineral deposits suggests that different climatic and oceanographic factors are important at each location. For example, at Louisa Bay it has been noted (Geotechnics, 1970b) that the greatest concentrations of heavy minerals occur on the western side of the bay, which is exposed to the dominant westerly winds. Along the D'Entrecasteaux Channel increased exposure of sediments to wave action has resulted in a higher percentage of heavy minerals being found in exposed coastal beaches than within bays (Green, 1961).

4.3 Importance of certain climatic and oceanographic parameters along the Southern Coast

Climatic and oceanographic conditions along the southern coasts affect heavy-mineral accumulations on both a regional and local scale. On a regional scale the wave regime is important in accounting for the distribution of carbonate sediments and hence the distribution of heavy-mineral deposits.* According to Davies (1972), the relation between the swell and calcareous sediments is such that the larger the swell the greater will be the depth of bottom disturbance and hence the larger the amount of calcareous material brought in from offshore. The width and depth of the continental shelf also play a part in contributing carbonate sediments to the shore.

On a local scale, the degree of exposure of the coast to wave action affects the amount of heavy-mineral accumulation. Wind and tidal activity are also important, at a local scale, in accounting for the location and size of heavy-mineral deposits.

5. COASTAL GEOMORPHOLOGY

5.1 Introduction

As the largest concentrations of heavy-minerals along the southern coasts of Australia are found within Quaternary sediments, particularly beach ridges and foredunes, maps have been compiled to show the distribution of Quaternary coastal landforms (Fig. 6). Seven coastal landforms have been recognised from a study of aerial photographs (RC9; 1:80,000 scale), 1:250,000 scale maps (topographical and geological), and the literature. The seven landforms used to characterise the coastal geomorphology are described in detail in Gardiner (1976).

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* The abundance of carbonate sediments relative to the erosional products of granites (and other heavy-mineral bearing rocks) is thought to result in conditions unsuitable for the accumulation of heavy-minerals (Hillwood, 1960).

5.2 Coastal geomorphic history and the formation, concentration, and preservation of heavy-mineral deposits along the southern coasts

5.2.1 Introduction

Although Figures 1 and 6 show a relation between distribution of beach ridges, foredunes, and major heavy-mineral deposits, they do not show the close association that exists between Quaternary coastal depositional history and the formation, concentration, and preservation of heavy-mineral deposits. Thus a brief resume of the coastal depositional history at specific locations along southern Australia, noting associations with heavy-mineral deposits, is included.

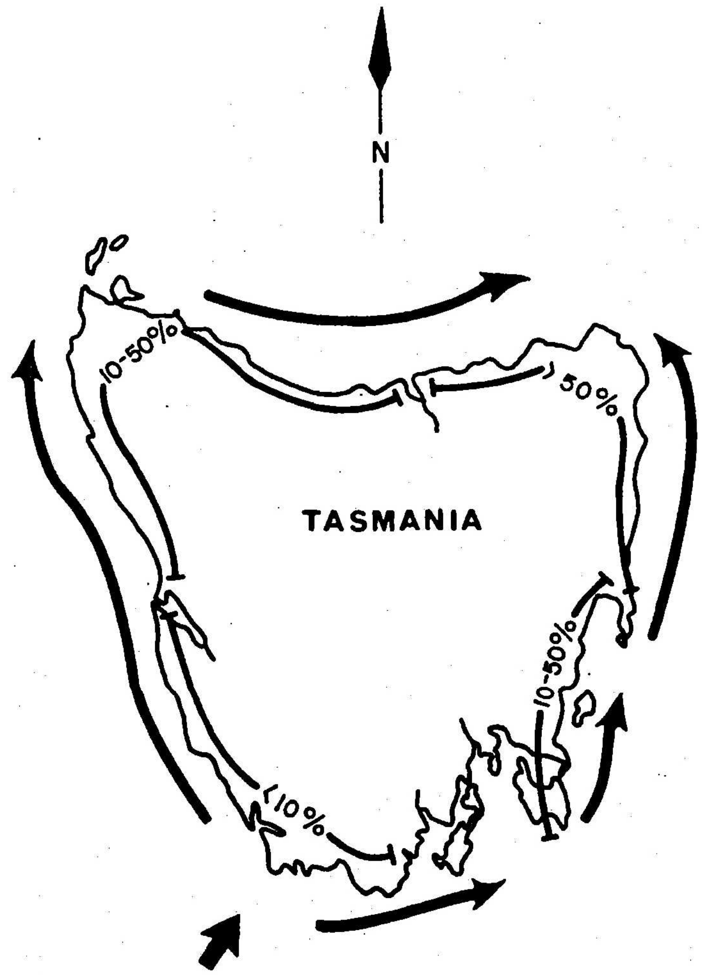
Preservation of heavy-mineral deposits requires that either the shoreline progrades or that sea level falls, removing the heavy-minerals from the influence of wave and tidal activity (Gardner, 1955; Winward, 1975). Sea level changes along the east Australian coast have been outlined by Gardiner (1975) and can be applied to these southern coasts. Probably the most notable aspects of coastal geomorphology along the southern coast is the similarity in coastal histories between the north coast of Tasmania, King Island (Jennings, 1959), Flinders Island (Sutherland & Kershaw, 1971), and the Gippsland Coast of Victoria (Bird, 1965; Jenkin, 1968).

5.2.2 Northeastern Victoria

The coastline is dominated by one of the largest barrier systems in the eastern part of Australia. From Lakes Entrance to Corner Inlet three barriers have been described by Bird (1961, 1965) and Jenkin (1968). Two of these barriers, the prior and inner, have been assigned to the Pleistocene and the third to the Holocene. The barriers are composed of parallel beach ridges and transgressive dunes. Along the New South Wales and Queensland coast these deposits are often associated with large highly concentrated heavy-mineral deposits, but none has been found within the accumulations in Victoria. Today, Holocene deposits along Ninety Mile Beach (Gippsland) are undergoing erosion (Bird, 1965) by the development of blowouts, which are disrupting and burying the parallel beach ridges, which had formed during the preceding phase of barrier progradation. East of Gippsland, along the Marlo to Mallacoota coastline, coastal deposits are of Holocene age. Beaches rarely exceed 30 m in width and are backed by two types of dunes, foredunes, situated immediately adjacent to beaches, and back dunes with well-developed soil profiles and dense vegetation cover (Tan, 1973). It is within these recent dunes and beaches that heavy-mineral deposits have been found. As in the Gippsland area, coastal erosion, including undercutting of the foredunes, is widely evident and has been observed west of Ram Head, at Petrol Point, west of Point Hicks, between the mouth of the Yeerung River and Dock Inlet, and at Cape Conran (Tan, 1973).

5.2.3 Port Phillip Bay

Both calcareous and siliceous sands were deposited during the Pleistocene in Port Phillip Bay. Probably the most important Pleistocene depositional feature was the spit extending from Sorento to Port Nepean, enclosing Port Phillip Bay (Jenkin, 1974). However, it is Holocene deposits within Port Phillip Bay which contain heavy-minerals.



The arrows suggest predominant long term directions of drift of beach materials

Proportions of the coast occupied by beaches are shown (Davies, 1965)

Fig 5 The influence of the south-westerly swell on Tasmania

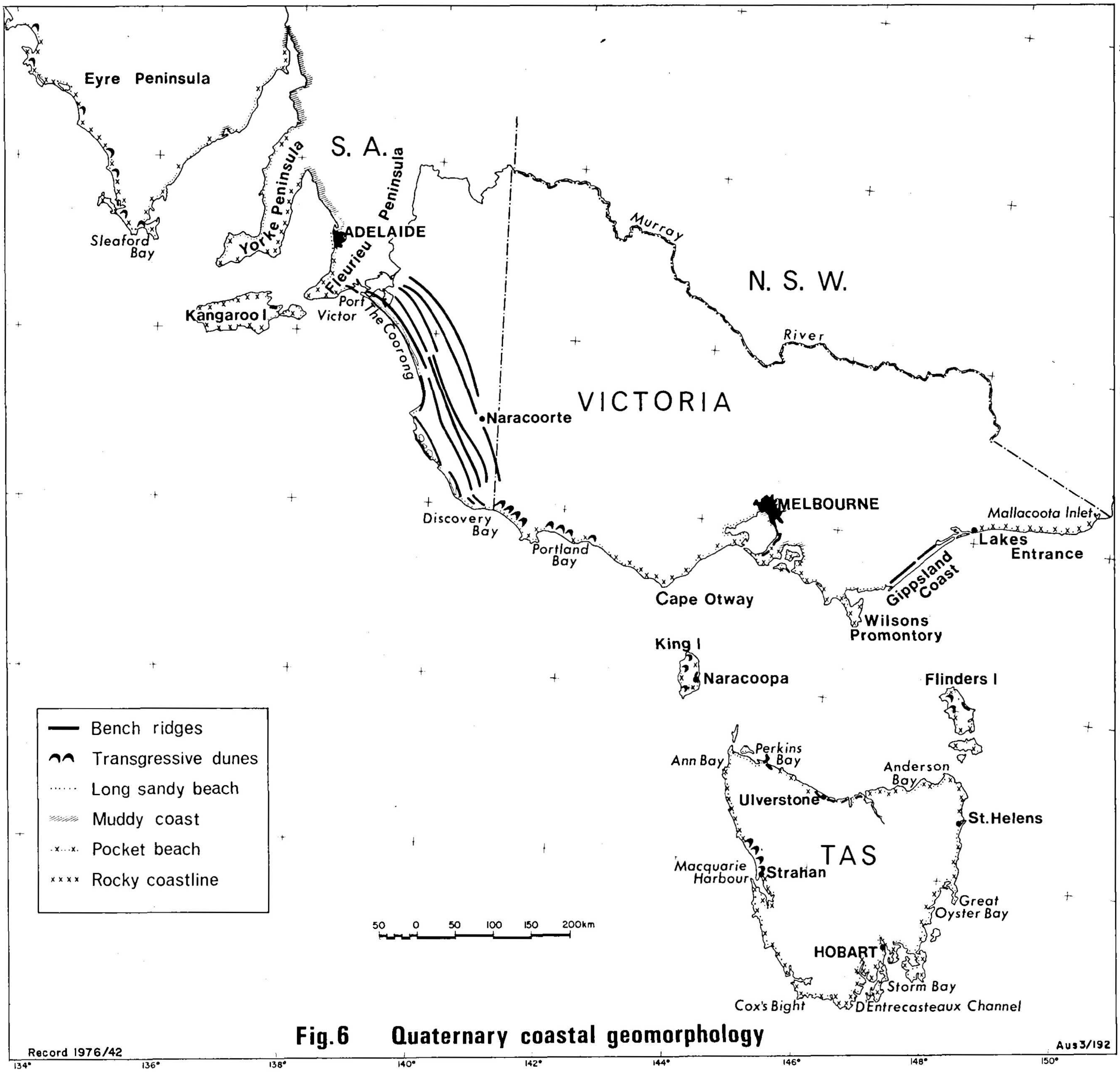


Fig. 6 Quaternary coastal geomorphology

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Holocene stranded beaches in the Mordialloc area (Whincup, 1944) contain heavy-minerals, but similar stranded beaches on the Yarra Delta (Neilson & Jenkin, 1967) do not. The Mud Islands, which also formed during the Holocene, like the stranded beaches on the Yarra Delta, do not contain significant amounts of heavy-mineral. The presence of heavy-minerals in some of the Holocene deposits and not others may be due to the fact that some parts of the Bay, i.e. Mordialloc area, are undergoing erosion (McKenzie, 1939) and during this erosion small heavy-mineral concentrations are being reconcentrated into notable mounts.

5.2.4 Kangaroo Island and Fleurieu Peninsula

The Holocene marine transgression which brought the sea approximately to its present level between 3000 and 6000 years B.P. age (Hails, 1965; Thom et al., 1969; and Bird, 1971) was followed by a period of coastal degradation. Beach ridges and foredunes, formed as a result of this progradation, are common on Kangaroo Island. The orientation of the beach ridges (Fig. 7) shows that they have been truncated and reformed several times during the Holocene (Johns, 1966). Within these beach ridges heavy-minerals are found particularly at the base of the fossil cliff at Nepean Bay and at Morrison beach, which is currently being eroded. The Fleurieu Peninsula is bounded mainly by calcareous cliffs and, in areas of little wave action, mangrove and tidal-flat swamps. There are a few narrow beaches at Waitpunga, Tunkalilla, Rapid Bay, and from Port Victor to the mouth of the Murray, but they are not backed by beach ridges and have only surficial deposits of heavy minerals (Hillwood, 1960; Farrell, 1968).

5.2.5 Southern Eyre Peninsula

Unconsolidated calcareous dune sands alternate with consolidated dune limestone cliffs along the west coast of the Eyre Peninsula. These dune sands have been derived from older systems of fixed-dune deposits, possibly of Pleistocene age, and shell fragments from the modern beaches (Johns, 1966). On the east coast of the Eyre Peninsula small pocket beaches of siliceous sediment predominate, and it is within these sands that small heavy-mineral deposits are found.

5.2.6 Tasmania

According to Davies (1965) the swell from the southwest, moving sediment to northeast Tasmania, and the draining of the coast between 12000 and 6000 years B.P. have dominated the coastal development of Tasmania. In Tasmania many coastal features are of Holocene age, except along parts of the northern and western coasts (Chick, 1970), and on King and Flinders Islands (Jennings, 1959; Sutherland & Kershaw, 1971).

Davies (1965) has noted that with distance north the percentage of beaches along the Tasmanian coastline increases (Fig. 5), and this is particularly noticable along the east coast. From Whale Head along the D'Entrecasteaux Channel to Great Oyster Bay, rocky outcrops and pocket beaches border the coast. Small heavy-mineral deposits arefound on these pocket beaches. From Cape Tourville to St Helen's Point there are four long narrow beaches with large foredunes which again contain small heavy-mineral deposits. Great Oyster Bay and Stormy Bay are both sediments traps as indicated by large numbers of constructional features such as Nine Mile Beach, the bay head barrier at Ralph's Bay, and the beach ridge systems at Hope Beach, Clifton Beach, Oppossum Bay, and Half Moon Bay (Green, 1961).

The coastal geomorphology of the southern coast is dominated by the strong southeast swell and hence less than 10 percent of the coastline is occupied by beaches (Davies, 1965). Where the coastline is protected by such features, as at Cox Bluff and Red Point, narrow beaches with high foredunes have developed. In some cases heavy minerals have been concentrated on these beaches.

South from Macquarie Harbour the west coast is similar to the southern coast, with a few large beaches and many rocky outcrops. To the north, the coastline is dominated by massive transgressive dune systems. There is evidence to suggest that the present cycle of transgressive dune development began in the 19th century as a result of burning and/or stocking of dune country (Davies, 1965). Heavy minerals are found at several places along this part of the coast, namely at Ocean Beach and Ann Bay, and like other Tasmanian heavy-mineral deposits they occur within the present beach.

Beach ridges are common along the northern coast of Tasmania, for example at Black River, Point Sorell, Green's Beach, and Ulverstone (Davies, 1961; 1965; Chick, 1970). They occur at various heights and indicate higher Pleistocene shorelines, however, none contains significant heavy-mineral deposits.

Phases of extensive dune building have characterised the coastal development of both King and Flinders Island from the Pleistocene to the present day (Jennings, 1959; Sutherland and Kershaw, 1970). Dunes on the west coast are calcareous while those on the east coast are siliceous. Holocene beach ridge systems occur mainly on the east coast of both islands. Some beach ridges on Flinder's Island have formed in recent times, as witnessed by discarded bottles and buried timber (Sutherland & Kershaw, 1970). On King Island two beach ridge systems have been truncated by a third ridge system called the Larherne dunes, at Naracoopa. It is this later ridge system that contains heavy-mineral deposits (Clarke, 1966). The most recent beach ridges on both islands are currently undergoing erosion, with minor blowouts forming along the foredunes (Clarke, 1966; Sutherland & Kershaw, 1970).

5.2.7 Southeastern South Australia

Numerous papers have been written on the beach ridges in this part of the State, for they are the most extensive in Australia, extending up to 100 km inland (Crocker & Cotton, 1946; Hossfeld, 1950; Sprigg, 1959; Ward & Jessup, 1965; Blackburn, et al., 1967). Despite the large number of studies on this area the maximum age of these ridges is not known nor have the effects of tectonism and eustatic sea level change been determined. Drilling of the ridges 60 km inland has indicated that they are underlain by about 10 m of Cainozoic beach and shallow marine sands (Cook, 1974), but to date no significant deposits of heavy minerals have been found. Calcareous sediments form the majority of the ridges, but the most inland are siliceous and are more likely to contain heavy minerals. The present coastline is backed by a lagoonal system, extending from Cape Jaffa to the Murray Mouth, commonly referred to as the Coorong. Long sandy beaches extend along this section of the coast, but the foredunes of these beaches are currently being eroded by the development of blowouts (Naracoote, 1:250,000 Sheet area).

6. CONCLUSIONS

Correlation of the distribution of heavy-mineral deposits with provenance, climatic and oceanographic factors, and coastal geomorphology has shown that:

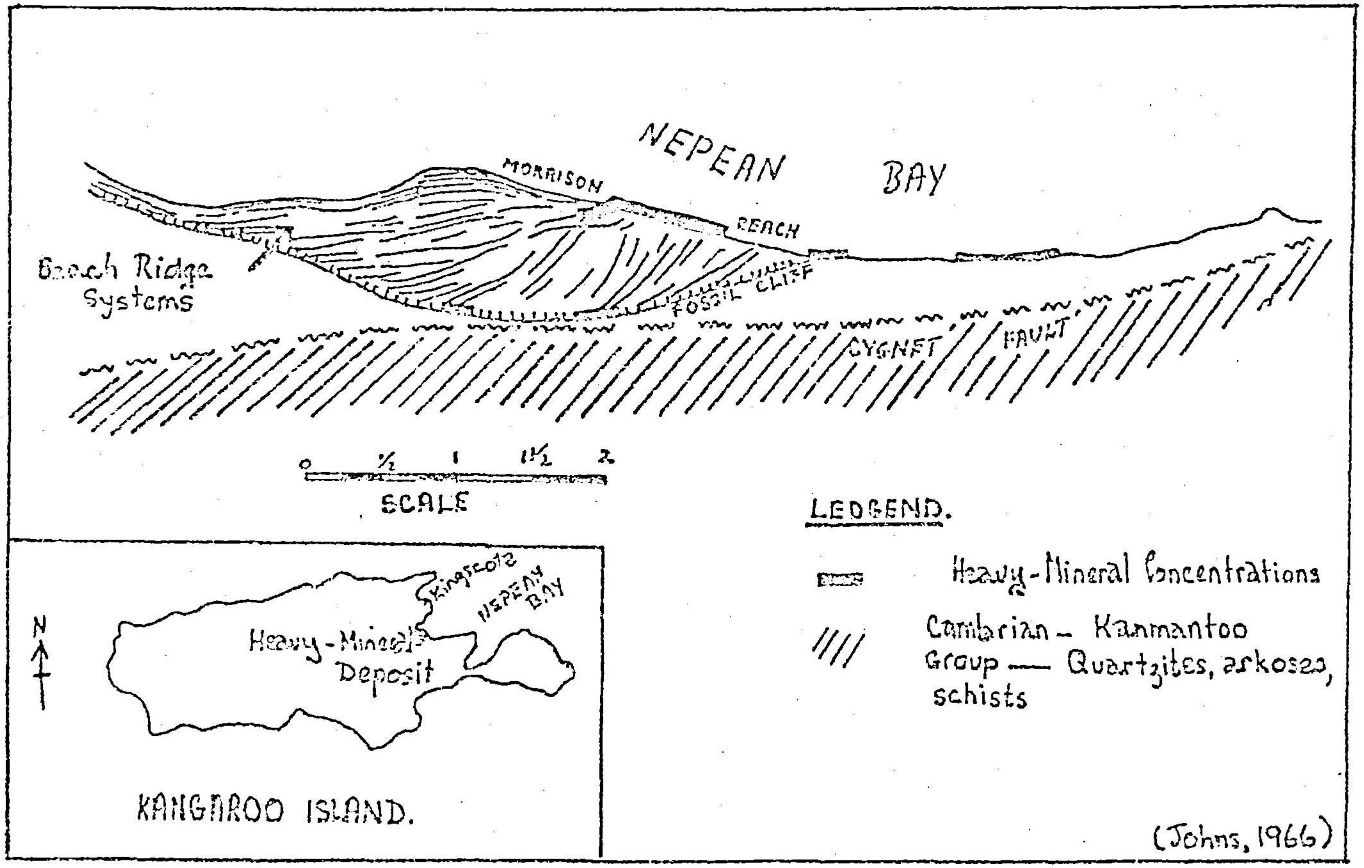

FIG. 7

HEAVY-MINERAL SANDS KANGAROO ISLAND

(1) all the heavy-mineral deposits are found in Holocene deposits. This differs markedly from the Australian east coast, where deposits are found both in Pleistocene and Holocene sediments;

(2) heavy-mineral deposits are mainly found on present-day beaches and within beach ridges;

(3) the largest heavy-mineral accumulations, on the southern coast, are found at the junction of truncated beach ridge systems;

(4) a variety of rock types appears to contribute to the heavy-mineral deposits along the southern coasts; the mineralogy of the deposits varies considerably along the coastline;

(5) heavy-mineral deposits do not seem to be present in the calcareous sediments along this coastline;

(6) local climatic and oceanographic factors are important in determining the location, size and type of small heavy-mineral deposits.

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TABLE 3. Percentage of heavy minerals in concentrates

Location	Reference	R	Zr	Im	M	Gt	Sn	Tourm	Other
SOUTH AUSTRALIA									
Cleaford Bay	Mansfield, 1950					57			43
Porter Bay	Johns, 1961	2	5	35	1	5			52
Moana	Cartwright, 1956	2		33		20			41
Normanville	Cartwright, 1956	2	2	15		20			61
Onkaparinga River	Cartwright, 1956	3	5			10			82
Kangaroo Is.	Johns, 1966	27.5	21.4	22.7	1.0				27.3
	Grasso, 1964	19	36						45
VICTORIA									
Betka River	Bell, 1953	0.6	0.6	46.9					51.9
Cape Everard	Fisher, 1949	7	17.6	61.9	2.1	1.8			9.0
	Tan, 1972	10.7	17.6	61.9	2.1				7.8
Clinton Rocks	Tan, 1972	5.7	8.4	79.6	1.1				5.1
Wingan Inlet	Tan, 1972	2	2	16					80.0
Point Pearl	Tan, 1972	4	6	59	1				31
Mornington District	Baker & Edwards, 1956	2.3	6.6	6.5	0.1				84.5
West Port	Bell, 1956	5.8	10.7	41.8	trace	0.6		1.3	39.8
Jindivick	Bell, 1956	trace	4.4	55.7	7.2			0.1	32.6
TASMANIA									
King Island	Carey, 1945		1	91.5		2.5			5.0
	Garnell, 1930	29.6	13.26	12.71					44.43
Friendly Beaches	Bruinsma, 1970	11.06		3.78		5.28			79.88
	Tassel, 1970	0.079	27.33			17.98		10.79	46.[illegible]
Schouten Is.	Hughes, 1959	trace	26.5	40.0		15.0	4	trace	14.5
Louisa Bay	Geotechnics, 1970b	2.6	2.4	38.0		49.0	0.02		8.0
Bridport	Kociumbas, 1971	6	9	35.0					50.0
Noland Bay	Lockhart, 1972	8.0	12.10	25.35					54.55

R - rutile; Zr - zircon; Im - ilmenite; M - monazite; Gt - garnet; Sn - cassiterite; Tourm - tourmaline; Other - epidote, amphibole etc.