DEPARTMENT MINES AND ENERGY
SOUTH AUSTRALIA

RPT BK NO. 88/72
DME NO. 142/83
DISK NO. E00087

Coastal Palaeogeography and Heavy Mineral Sand Exploration Targets in the Western Murray Basin, South Australia

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Running Title: Heavy mineral sands, Murray Basin

ABSTRACT

The Murray Basin is known to contain major deposits of heavy mineral sands and intensive exploration for new deposits is being conducted in Victoria, South Australia and New South Wales. The western Basin was well served in the Pliocene and Early Pleistocene by a variety of appropriate sediment sources, and potential coastal traps. Immature, fluvially-sourced sediments forming the Pliocene coastal complex of the Marmon-Jabuk Range in South Australia are part of a marginal marine assemblage containing a suite of economically important heavy minerals that include ilmenite, zircon, rutile and tourmaline. From a consideration of Pliocene palaeogeography and coastal dynamics, specific targets where concentrating processes are likely to have operated are identified in the South Australian portion of the Murray Basin. Such palaeo-environments include the down-drift, littoral zone of discrete foredunes or coastal barriers, the source area for transgressive dune complexes, tombolo facies, and intertidal shoals and sandbanks. Similar coastal processes are recognised for a preserved Early Pleistocene barrier complex.

Keywords: Heavy minerals, exploration models, coastal sediments, Murray Basin, Cainozoic.

INTRODUCTION

Australia is one of the world's largest producers of heavy mineral sands, particularly rutile, zircon, ilmenite and monazite. With increasing restrictions on mining of near-coastal deposits, exploration interest has turned to the Cainozoic of the Murray Basin. Earlier investigations by Colwell (1976, 1977, 1979) found localised heavy mineral contents of up to 20% in Pliocene beach ridges and exploration has focussed on this strand plain (Brown, 1985). In western Victoria, a potentially economic resource of heavy minerals has been delineated by CRA Exploration Pty Ltd at the WIM 150 prospect, and an Aberfoyle Exploration Pty Ltd Sandhurst Mining N.L. joint venture has reported potentially economic heavy mineral grades from its Tyrrel Ridge prospects.

In this paper, we interpret the palaeogeography and coastal dynamics of Pliocene and Early Pleistocene depositional systems in the western Murray Basin in South Australia. Specific targets where heavy mineral sands may have accumulated are defined.

EXPLORATION MODELS

The littoral zone is the most efficient environment for producing economic concentrations of heavy minerals from a background supply (Cronan, 1980). Hydraulic separation and selective transport of light and heavy fractions occur through a variety of coastal processes including wave shoaling, and longshore drift on beaches, flow separation and decelleration over tidal flats, and wind deflation and selective transport above water level. Coastal relief, particularly that produced by shoals and headlands, provides obstacles to longshore transport and enhances selective depositional processes associated with wave diffraction and flow separation. Most major heavy mineral sand deposits can be interpreted in the context of such coastal processes and examples of major Australian deposits are:

* the WIM 150 deposit, located southeast of Horsham in Victoria and being explored by CRA, is contained in Pliocene marine sands of the Murray Basin. The deposit has a measured resource of 1000 million tonnes grading in excess of 3% total heavy minerals (rutile, anatase, leucoxene, ilmenite, zircon, monazite and xenotime) in fine-grained, laminar bedded, silty sands overlain by coarser-grained cross-bedded sands and non-marine clay. During deposition, primary wave direction was from the southwest, and the sands would have accumulated under the influence of easterly longshore drift. An analysis of the morphology of the prospect area suggests the heavy mineral sand deposit formed as part of a composite tombolo and intertidal sand flat marginal to the basin and attached to offshore basement shoals (Bluck, 1988b).

* At Eneabba in Western Australia, Late Tertiary or Early Pleistocene heavy mineral sands were derived from local streams and concentrated and deposited in a northwest facing embayment exposed to prevailing southwesterly winds and waves (Lissiman and Oxenford, 1975). The deposits occur downdrift of, and partly behind, a major headland in a series of palaeostrandlines occurring over a vertical interval of approximately 50 metres. The headland caused wave refraction and shoaling into the embayment, and interrupted a northerly coastal current, resulting in flow separation and deposition within the embayment.

* The Quaternary heavy mineral sands of eastern Australia were deposited in coastal environments dominated by southeasterly swell and northerly longshore drift. Marine drowning of the shelf in the Late Pleistocene and again in the Holocene resulted in formation of sandy barrier complexes between bedrock headlands, and refraction-controlled shoreface alignment (Roy and Thom 1981; Thom, 1983). Heavy minerals were concentrated in embayment beaches, often at their northern (downdrift) ends, and in associated tombolos, foredunes and transgressive dune sheets. This is demonstrated by the heavy mineral sands at Crowdy Bay and Diamond Head (Winward, 1974). Here, swash-aligned foredunes were constructed with tombolo accumulation behind islands and shoals. Continued sedimentation attached the barrier complex and tombolo system to the islands which then acted as headlands to embayment beaches. Economic grades of heavy minerals are located along the downdrift swash zone of beach sediments, and on the updrift side of tombolo attachment systems.

* At Geographe Bay, Western Australia, the mixed quartz-carbonate Holocene coastal barrier contains economic heavy mineral sand deposits. Cape Naturaliste causes refraction of the dominant westerly swell and a consequent northerly longshore current within the arcuate embayment. Concentration of heavy minerals has occurred in upper shoreface and dune sands through swash-backwash separation, littoral transport and deflation lag (Collins and Hamilton, 1988). The resultant beach placers are of high grade (c.40% heavies) and low tonnage, whereas dune sands are of lower grade (c.5% heavies) and high tonnage.

GEOLOGICAL FRAMEWORK - HEAVY MINERAL SOURCES

The western Murray Basin is well served by heavy mineral source areas (Fig. 1). The fault-bounded Mt. Lofty Ranges comprise Middle and Late Proterozoic sediments and metamorphics, together with an eastern flank of high grade Cambrian metasediments (Kanmantoo Group). Felsic and mafic igneous rocks outcrop discontinuously through the Cainozoic cover of the Murray Basin, and occur at relatively shallow depths in the subsurface.

The ability of Proterozoic strata to supply an adequate mineral suite is amply demonstrated by the Golden Grove heavy mineral sand deposit on the western flanks of the Mt. Lofty Ranges (McCallum 1981). Ilmenite, rutile and zircon, with lesser amounts of monazite, tourmaline, staurolite, sillimanite and kyanite, occur in lacustrine shoreline sediments of Middle Eocene age, comprising a resource of at least 98,000 tonnes. The heavy minerals were derived from schists, pegmatites and quartzites of andalusite-staurolite and sillimanite metamorphic zones of the central Mt. Lofty Ranges (McCallum and Morris, 1978). Smaller deposits of contemporary mineralised sand similarly sourced from Proterozoic strata, are known from several localities along the eastern shore of Gulf St Vincent (Morris, 1978).

Kanmantoo Group metasediments of the eastern Mt. Lofty Ranges and Kangaroo Island are also an excellent source for a metamorphic and multicyclic sedimentary suite of heavy minerals. These include garnet, sillimanite, kyanite, zircon, tourmaline, ilmenite, magnetite, rutile, sphene, epidote and actinolite (e.g. Flint, 1976). Kanmantoo Group metasediments have been the source of the Morrison Beach rutile and zircon deposit on Kangaroo Island, and smaller beach sand deposits around Kangaroo Island and on southern Fleurieu Peninsula (Hillwood, 1960; Johns, 1968; Morris, 1978, 1986). Along the modern Coorong beach, high rank metamorphic minerals derived from southern Fleurieu Peninsula indicate southward littoral transport of at least 30 kilometres (Colwell, 1976). Mineralised sands, derived from contemporary drainage systems of the Finniss, Angas and Bremer Rivers draining the eastern Fleurieu Peninsula, are also forming at present along the western shore of Lake Alexandrina. Although dominated by garnet, the heavy mineral fraction includes ilmenite, zircon, rutile, leucoxene and tourmaline (Bluck, 1988a).

Syn- and post-tectonic granites and acid volcanics of Cambro-Ordovician age occur in a belt from Naracoorte to Tailem Bend (Padthaway Ridge) and north through Mannum (Fig. 1). Present-day outcrops are relicts of larger granitoid complexes that would have formed extensive islands or shoals during Cainozoic marine incursions, providing local siliciclastic sources. These granites, adamellites and rhyolites are variously characterised by accessory hornblende, epidote, sphene, apatite, magnetite, ilmenite, fluorite, monazite, zircon and tourmaline (Colwell 1976, 1979; Webb, 1976). Monazite is particularly common in some of the granitoids (Hillwood, 1960).

Largely concealed beneath overlying sediments are various ?Cambro-Ordovician mafic volcanics, basic and ultrabasic intrusives, and highly magnetic amphibolites (Fig. 1). These contain abundant magnetite and maghemite, and accessory zircon, apatite, sphene and leucoxene. Ultrabasic peridotites and pyroxenites also record kimberlitic-indicating chromite, ilmenite and garnet (CRA Exploration 1985a,b). A major felsic norite and gabbro complex between Mannum and Blanchetown contains abundant ilmenite, magnetite and accessory sulphides (North Broken Hill 1977). In places these mafic complexes are shallowly buried (e.g. Morris and Nichol, 1974) and would have locally provided sediments for redistribution by Cainozoic fluvial, marine and coastal processes.

Probably the most important source of heavy minerals was the proto-Murray River with its extensive drainage network extending east and northeast into Victoria, New South Wales and Queensland. With wetter and more humid climates experienced during the Tertiary (Bowler, 1982), a more dynamic river system supplied large quantities of siliciclastics to the Murray Basin. With increasing aridity during the Pleistocene, the capacity of the ancestral Murray to transport coarse siliciclastics, including heavy minerals, progressively decreased. Quaternary coastal barriers are therefore characterised by decreasing silicate and increasing carbonate compositions.

It is clear that the western Murray Basin has received sediment from a variety of sources of appropriate heavy minerals. Other requirements for producing mineralised deposits are firstly suitable concentrating mechanisms, and secondly their preservation. The former is believed to have been provided by coastal processes associated with Pliocene, and, to a limited extent, Pleistocene shorelines. The latter has been provided by regional upwarp of the Murray Basin through the Quaternary and by subsequent aridity.

PLIOCENE PALAEOGEOGRAPHY

The Pliocene of the Murray Basin is characterised by a composite onlap-offlap sequence that is clearly reflected in the preserved sedimentary strata. Rising sea level resulted in deposition of shallow marine marls (Bookpurnong Beds) and marginal marine and fluviatile sands (Loxton Sand) in the Early Pliocene (Rogers, 1980). Fluvio-lacustrine deposition predominated in the eastern sector of the Murray Basin, and an estuarine system (Norwest Bend Formation) was established along the course of the ancestral Murray River in the western extremity of the Basin (Brown, 1985). Depositional shoreline progradation concommitant with slow marine regression resulted in the formation of a major regressive beach ridge plain (Loxton Sand-Parilla Sand, collectively referred to as Pliocene Sands) in western Victoria and South Australia (Firman, 1965, 1966, 1972; Rogers, 1980; Brown, 1985).

Throughout much of the Basin, remnant Pliocene shoreline structures are visible on satellite imagery or are mappable features on the ground (Brown and Stephenson, 1984). The Marmon-Jabuk scarp and range is a prominant linear topographic feature Fig. 2) that has been variously interpreted as a fault scarp (Firman, 1965) or as a coastal erosional structure (Rogers, 1980). Although mineralogically immature and pedogenically altered, the poorly sorted sands contain a preserved marine fauna (Lindsay, 1977), and retain a sub-parallel ridge and swale topography (Fig. 3). The Marmon-Jabuk structure is thus part of the degraded strand plain recognised elsewhere in the basin and represents the southwestern limit of the regressive Pliocene coastal sands. These sediments are now variously altered by post-depositional pedogenesis and aeolian reworking.

In the Bordertown and Naracoorte area, the Parilla Sand contains a mature heavy mineral assemblage dominated by moderately- or well-rounded opaques, zircon and tourmaline (Colwell, 1976). Up to 1.2% total heavy minerals are recorded in calcareous Pliocene sediments (? Bookpurnong Beds) beneath Quaternary cover west of Bordertown. Aberfoyle (1987) recorded a goethite, ilmenite, leucoxene, and zircon assemblage grading up to 2.5% total heavy minerals north of Coonalpyn. In western Victoria, localised concentrations of up to 20% heavy minerals are recorded in littoral sediments (Parilla Sand). Here the suite is also mineralogically mature and comprises predominantly ilmenite plus leucoxene, rutile and zircon (Colwell, 1977). Rutile, zircon and ilmenite are also the main constituents of the recent discoveries in Victoria.

The Pliocene palaeogeography, reconstructed largely from existing 1:250 000 scale geological maps and drillhole data thereon, is summarised in Fig. 2. A geological section across the Marmon-Jabuk range is shown in Fig. 3. The ancestral River Murray was confined to a corridor defined by estuarine Norwest Bend Formation sediments, and constrained between the evolving strand plain and the Mt. Lofty Ranges. A regressive strand plain was created by coalescing foredunes and coastal barriers some 40-60 m high. Palaeo sea level is inferred at between +30 m and +50 m relative to present sea level. A large fluvial sediment supply promoted coastal progradation, resulting in limited maturity of coastal sands. Orientation of coastal barriers and remnant transgressive dune complexes indicate a dominant westerly wind, southwesterly swell, a clockwise coastal current and longshore transport to the southeast. Granitoid complexes near Tailem Bend, west of Coonalpyn and south of Keith formed offshore islands and shoals. These refracted incoming swell, causing flow separation in their lee, and tombolo-style accumulation that ultimately linked them with the mainland. Coastal barriers thus changed progressively from linear forms to headland-attached structures with well-defined embayments.

Potential areas of heavy mineral sand accumulation in such environments are considered to be (Fig. 2):

(A) the downdrift, swash zone of linear or arcuate foredunes and coastal barriers,
(B) the swash and upper beach face zones at the source points of transgressive dune complexes,
(C) the accumulating tombolo facies (updrift side) behind islands, and
(D) intertidal shoals and sandbanks.

Surficial sampling and shallow rotary drilling by Aberfoyle (1987) indicates preferential concentration of heavy minerals (to 2.5%) towards the southern end of the Marmon-Jabuk Range (predicted Zones A and B in Fig. 2). In the central and northern portions of the Range, recorded concentrations were low, although drilling was of insufficient depth to sample the palaeo-swash zone (+30 to +50 m) beneath the prospective coastal barriers (Fig. 3).

EARLY PLEISTOCENE PALAEOGEOGRAPHY

Unlike the prograding strand plain deposited by the regressing Pliocene sea, Quaternary sea level fluctuations, concomittant with continuing uplift, resulted in the formation of successive, distinctly separate coastal barriers. The ancestral Murray was largely entrenched into its present position throughout the Quaternary. Its coarse siliciclastic load decreased with increasing aridity, and Quaternary barriers are characterised by an increasing carbonate component with decreasing age. Barrier evolution also resulted in damming of the river mouth to form the large inland Lake Bungunnia (Bowler 1982) and back-barrier marine lagoons.

Pedogenic calcrete has developed on these coastal complexes, clearly preserving gross morphological features (Fig. 4). In general, the Quaternary sequences (Bridgewater Formation) host low concentrations of heavy minerals, with recorded contents west of Naracoorte rarely exceeding 0.5% by weight (Colwell 1979). Despite these low primary grades, the earliest Pleistocene coastal complex is considered prospective for the following reasons:

- carbonate sedimentation was not fully developed at this time;
- erosional cutback and reworking of parts of the Pliocene strand plain and shallow marine sediments resulted in recycling of heavy minerals (Colwell, 1976);
- granitoid shoals and headlands west of Coonalpyn and south of Keith provided favourable areas for heavy mineral concentration and accumulation; and
- the Early Pleistocene barrier sediments contain a significant background population of ilmenite, zircon, tourmaline, rutile and garnet (Bluck, 1988a).

The inferred Early Pleistocene palaeogeography is shown in Fig. 4. Transgressive dune complexes (blowouts) again indicate a dominant westerly wind and the orientation of the coastal barriers indicate a dominant southwesterly swell and clockwise coastal current. Attachment of coastal barriers to granitoid shoals and headlands indicates that processes of flow separation, longshore drift and tombolo accumulation were active.

Reconnaissance sampling of the Pleistocene coastal complex indicates a major contribution from the eastern Mount Lofty Ranges in the Lake Alexandrina area. Here, garnet dominates the heavy mineral fraction, together with low concentrations of ilmenite, zircon and rutile. Near Coonalpyn, this contribution is no longer evident, and the suite is dominated by ilmenite with lesser amounts of tourmaline, rutile, zircon and leucoxene.

Drilling by BMR west of Bordertown (Colwell, 1976) indicated a heavy mineral suite similar to that found in the Pliocene Parilla Sand, characterised by multicyclic zircon and leucoxene.

In the dynamic Early Pleistocene coastal system, with its background population of heavy minerals, potential areas of heavy mineral sand concentration and accummulation are considered to be (Fig.4):

(A) the downdrift, swash zone of arcuate coastal barriers,

(B) the swash zone at the source points of transgressive dune complexes, and

(C) the accumulating tombolo facies (updrift side) behind islands and headlands.

CONCLUSIONS

The western Murray Basin was served by a variety of sources of economically important heavy minerals throughout the Cainozoic. Emergent shoals and islands of the Padthaway Ridge provided sufficient topographic contrast and variation in coastal morphology to have created numerous potential traps for the accumulation of heavy minerals in the Pliocene and Early Pleistocene. Within the littoral zone of the prograding Pliocene strand plain, preferential accumulation is predicted for downdrift beach, tombolo and intertidal shoal environments. Concentration by deflation lag is expected in the source areas for transgressive dune sheets. A marine transgression in the Early Pleistocene constructed a large coastal barrier complex. Concentration of heavy minerals within this structure is similarly predicted in selected intertidal environments. Exploration strategies for heavy mineral sands should be based upon dynamic and palaeogeographically-inferred depositional models. The data collected from drilling will in turn provide additional palaeogeographic information for refinement of coastal depositional models.

ACKNOWLEDGEMENTS

This paper is published with permission of the Director-General of the South Australian Department of Mines and Energy.

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Figure Captions

Figure 1.	Bedrock geology, western Murray Basin and Fleurieu Peninsula. Drillhole information from Barnett (1983), CRA Exploration (1985a, b), North Broken Hill (1977), Theiss (1980) and Theiss - CSR (1986).
Figure 2.	Pliocene palaeogeography, western Murray Basin, showing potential zones of heavy mineral sand accumulation as discussed in the text. For line of section, see Figure 3.
Figure 3.	South to North geological section across the Marmon-Jabuk Range, showing drillholes of Aberfoyle (1987) and inferred zones of heavy mineral concentration in palaeo-shoreline environments.
Figure 4.	Early Pleistocene palaeogeography, western Murray Basin, showing potential zones of heavy mineral sand accumulation as discussed in the text.

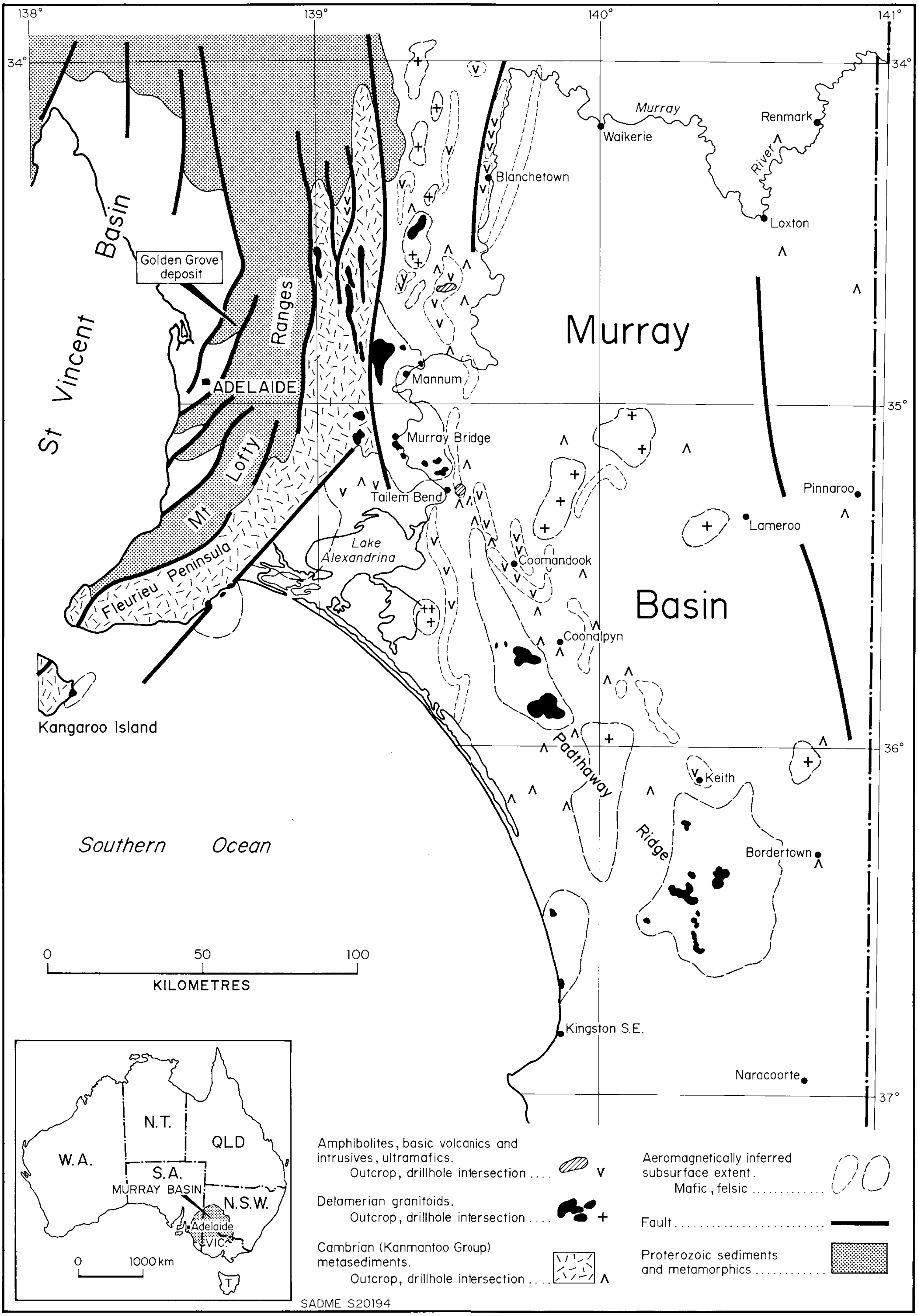

Figure 1. Bedrock geology, western Murray Basin and Fleurieu Peninsula.

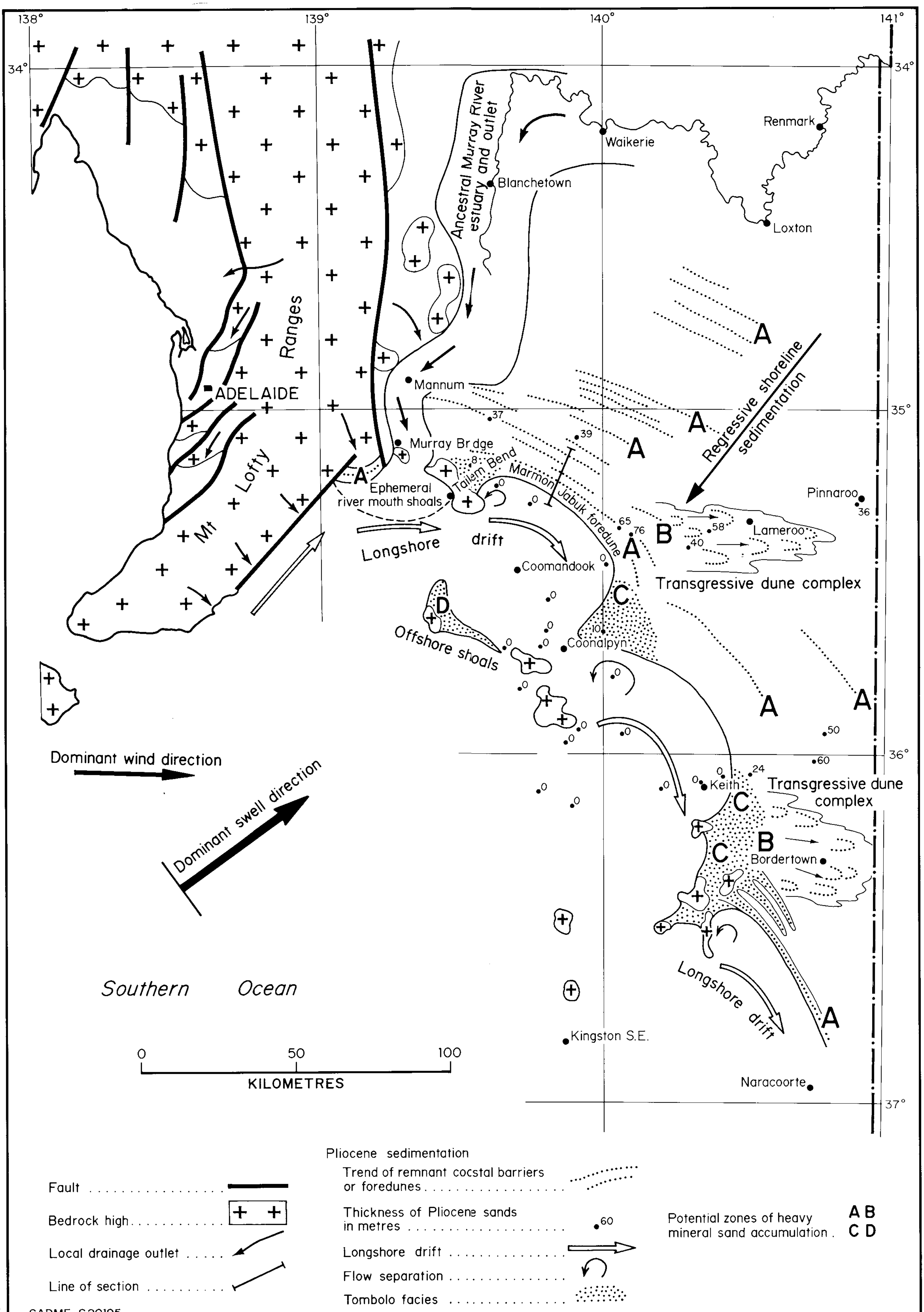

Figure 2. Pliocene palaeogeography, western Murray Basin.

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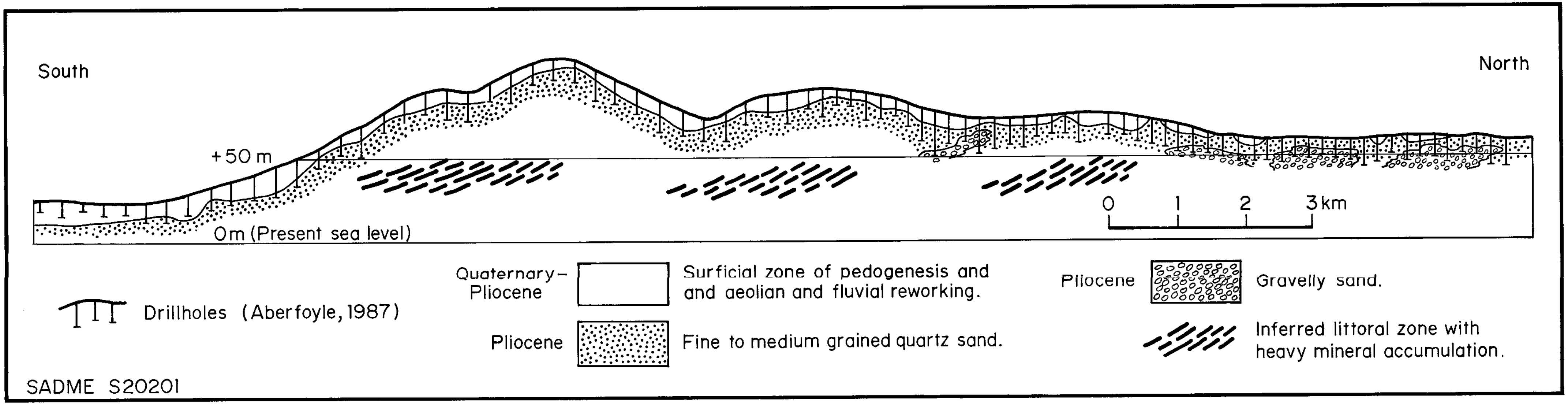

Figure 3. N - S section, Marmon-Jabuk Range.

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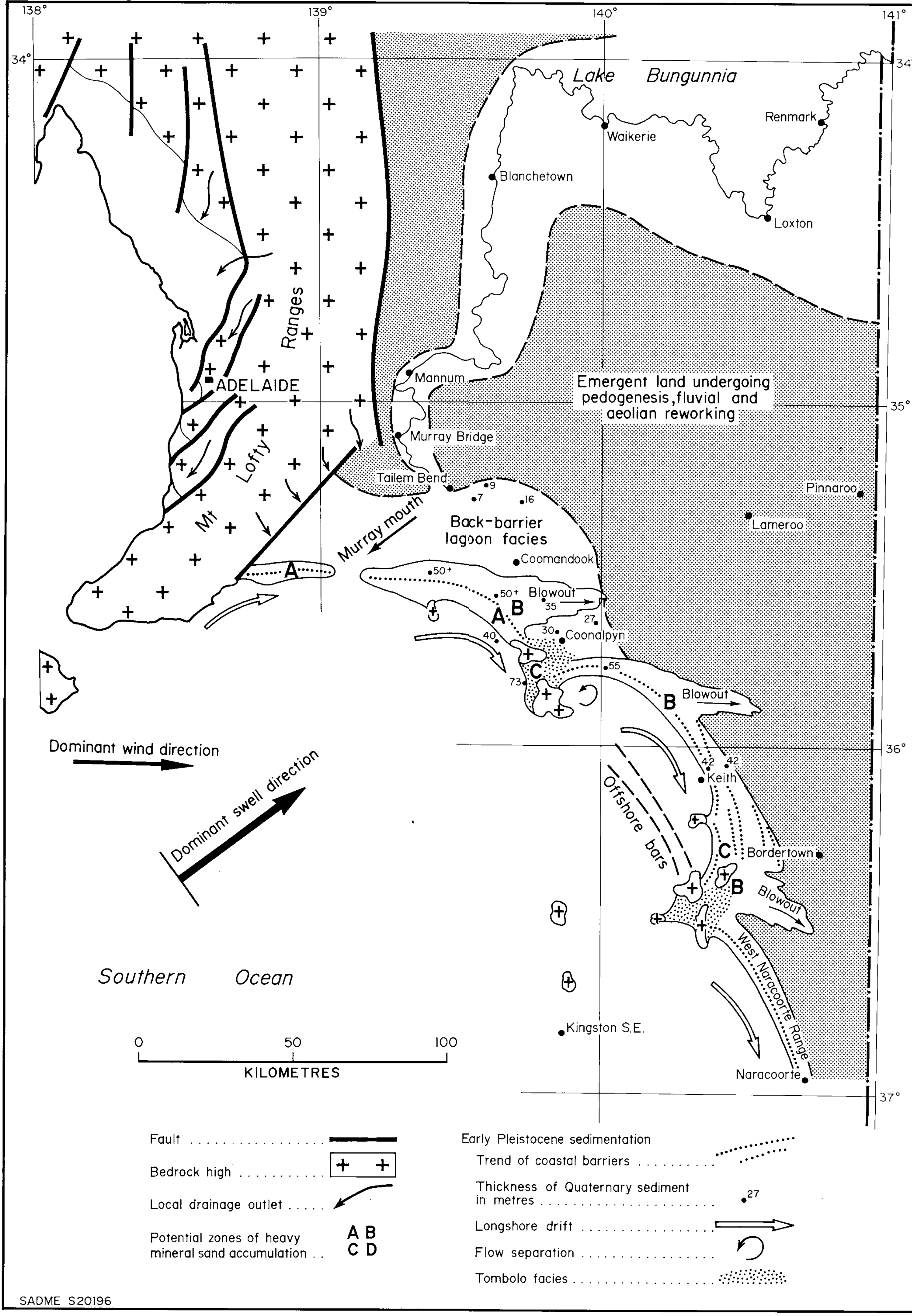

Figure 4. Early Pleistocene palaeogeography, western Murray Basin.