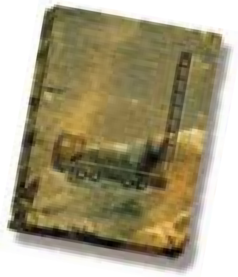

Northwestern Murray Basin — stratigraphy, sedimentology and geomorphology

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Introduction

Heavy mineral sands (HMS) in the Murray Basin have become a major exploration focus, with numerous discoveries across the basin in the last few years. Regionally prominent subparallel ridges which occur throughout the basin are believed to be remnant strandlines of the former Murravian Gulf (Roy et al., 2000). These palaeo-coastal features are the targets for HMS exploration in the basin. Stratigraphic drilling, as part of the Targeted Exploration Initiative South Australia (TEISA), was undertaken in the South Australian portion of the northern Murray Basin to investigate stratigraphy and sedimentology of the Cainozoic sequences as well as HMS potential of the area. This reconnaissance drilling program aimed to investigate these regional strandlines and, at the same time, look in detail at host sediments to the heavy mineral accumulations. A second objective of the program was to aid in analysis of the basement underlying this portion of the Murray Basin. Results of the drilling are provided in Fabris (in prep. a).

This article summarises concepts of the sedimentological history of the northwestern Murray Basin and its implications for HMS exploration resulting from the 2001 PIRSA drilling program, together with previous drilling and research.

Geological setting

The intracratonic basin Murray Basin, containing mostly Tertiary fluvial to shallow marine sediments, covers an area of ~330 000 km^2 (Stephenson, 1986). The South Australian portion of the basin is flanked to the west by Neoproterozoic to Cambrian rocks of the Adelaide Geosyncline and Kanmantoo Trough, and to the north by Palaeo- and Mesoproterozoic rocks of the Willyama Inliers. Basement geology has been interpreted using regional gravity, aeromagnetics, and basement-intersecting drillholes where available.

The Tertiary sequence consists of fluvial, marginal marine and marine sediments up to 600 m thick in the west-central Renmark Trough area, but generally 200–300 m elsewhere in the basin. Tertiary sediments are covered by a thin blanket of Quaternary aeolian and fluvio–lacustrine sediments.

Generalised stratigraphy

The Tertiary succession accumulated over three major depositional events as described by Rogers et al. (1995) and Brown and Stephenson (1991), and generalised below.

Paleocene – Early Oligocene (Renmark Group)

Floodplain and swamp environments dominated this interval, resulting in the deposition of carbonaceous sand, clay and silt (Warina Sand and Olney Formation). A minor marine incursion in the Late Eocene was marked by deposition of fossiliferous clay and marl (Buccleuch Formation; Fig. 1a).

Late Early Oligocene – Middle Miocene (Murray Group)

Major marine incursions in the Late Oligocene to Mid-Miocene resulted in fluvial environments being replaced by lagoonal and marginal marine muddy facies (Geera Clay) and, in deeper water areas, marl (Ettrick and Winnambool Formations) and limestone (Mannum Limestone). A eustatic sea-level fall in the Late Miocene brought an end to this depositional cycle and led to local erosion and weathering (Fig. 1b).

Latest Miocene – Pleistocene

A rapid marine transgression in the latest Miocene led to drowning of fluvial tracts and development of shallow marine depositional environments. This is represented by clay with occasional sandy, silty, carbonaceous and calcareous beds (Bookpurnong Formation). As rising sea levels steadied, a move towards highstand deposition saw a change to prograding beach strandplains and barrier islands (Loxton–Parilla Sands). Occasional transgressive phases saw the formation of elevated stacked barrier islands. Between these barriers, variegated silty clay was deposited in fluvio-lacustrine environments (Blanchetown Clay; Fig. 1c).

Tectonic damming related to uplift of the Pinnaroo Block at ~2.4 Ma, and predicted rainfall of at least 500 mm/year, is believed to have led to the formation of a large freshwater lake known as Lake Bungunnia (Brown and Stephenson, 1991). The Blanchetown Clay was deposited within this shallow lake, and later shallowing led to deposition of variably dolomitic limestone (Bungunnia Limestone; Fig. 1d).

Loxton–Parilla Sands

The Murray Basin was strongly influenced throughout the Pliocene by coastal processes that resulted in the formation of numerous arcuate strandlines (Roy et al., 2000). These features, which in the western part of the basin are orientated roughly northwest–southeast, constitute the majority of the targets for HMS exploration.

Sediments of the Loxton–Parilla Sands in the area of the 2001 PIRSA drilling program were studied using analysis of geophysical logs and sedimentological studies of grainsize, rounding, sorting, skewness, kurtosis and colour. Using a combination of these parameters allow the identification of a number of zones associated with varying depositional environments within the Loxton–Parilla Sands. These include:

1. Lower shoreface — grey, very fine to medium-grained, clayey quartz sand.

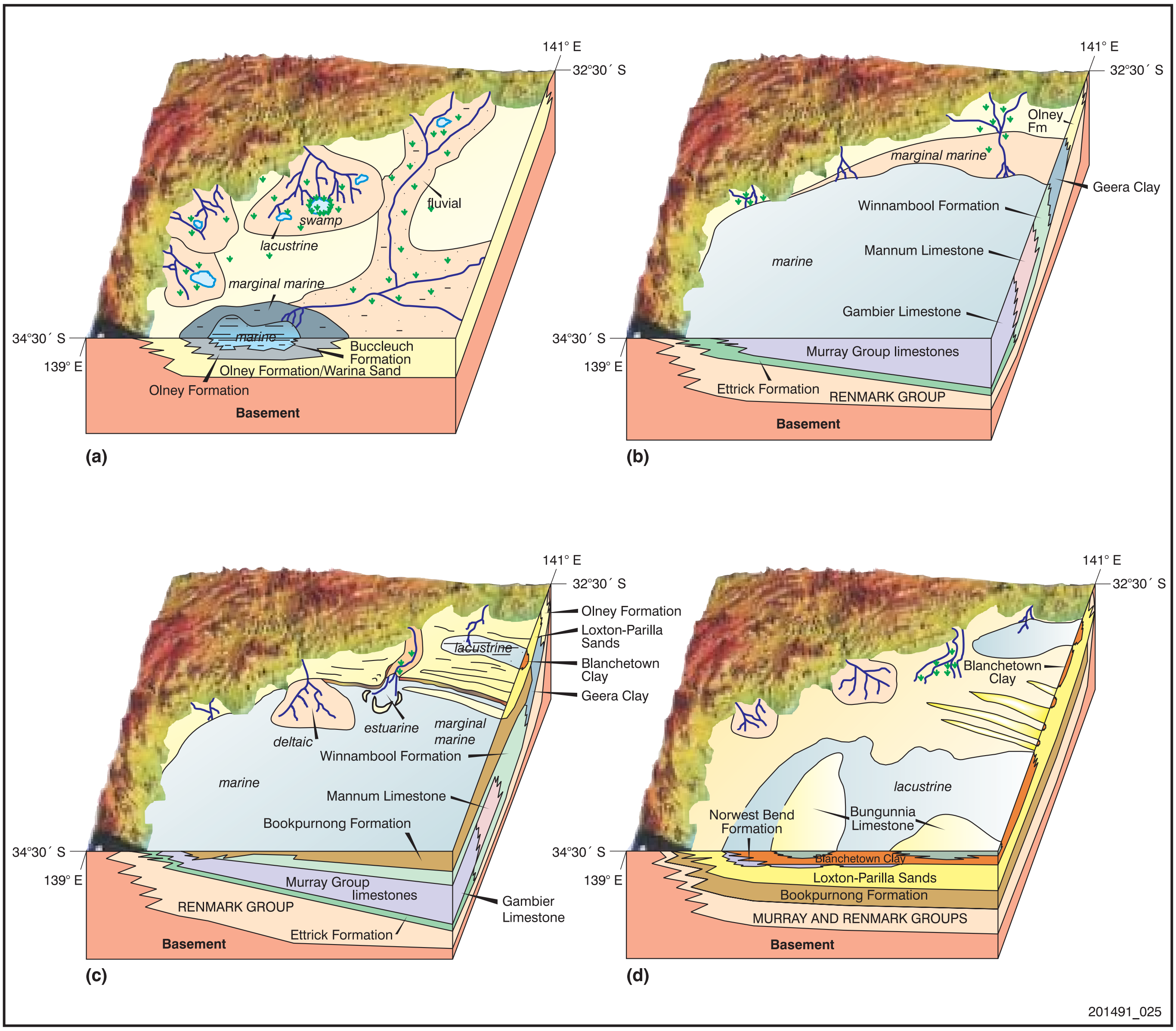

***Fig. 1** Northern Murray Basin through the Cainozoic. The stratigraphy is based on 1376 drillholes throughout the northern Murray Basin in South Australia. **(a)** Floodplain and swamp environments (Renmark Group) dominated until the Early Oligocene; a minor marine incursion resulted in limited marine deposition (Buccleuch Formation) which extended just north of the present Murray River. **(b)** The peak of the marine incursion in Mid-Miocene resulted in deposition of thick packages of marine clay and limestone (Murray Group). **(c)** A rapid marine transgression at the end of the Miocene led to highstand deposition in the Pliocene and resulted in the shallow marine Bookpurnong Formation and progradation of the littoral Loxton–Parilla Sands. **(d)** Pleistocene deposition was dominated by lacustrine clay and variably dolomitic limestone within the ancient Lake Bungunnia.*

This is typically moderately well sorted, sub-angular to rounded, with positive skewness. The positive skew indicates that the facies represents the combination of a dominantly sandy unit and the underlying clayey unit. It is the transition zone into the underlying clayey, shallow water marine Bookpurnong Formation.

2. Upper shoreface — mustard coloured, fine to fine-medium-grained quartz sand with <10% clay content. Variable sorting and rounding, with a slight negative skew which suggests mixing of the fine grain size with coarser material of the foreshore environment.

3. Foreshore to backshore (berm, beach, dunal and washover fan) — white, yellow, orange to red, fine-medium to very coarse-grained quartz sand with minor fossiliferous material. The unit is positively skewed, with variable sorting and roundness, and varies from a very clean quartz sand to yellow and red slightly clayey sand.

4. Backshore (dunal) — orange to red, frosted, medium-grained, subrounded, moderately well-sorted sand. These sediments occur in the upper sections of the Loxton–Parilla Sands but were not seen to occur at the top of the unit as might be expected for a prograding shoreline. Kotsonis (1995) noted the apparent lack of aeolian deposition at the top of the Loxton–Parilla Sands in

a large number of sections examined. It is most likely that these sediments have been reworked into Quaternary sandy units.

5. Backbarrier lagoonal — mustard coloured, fine to fine-medium-grained, variably micaceous clayey quartz sand.
6. Fluvial — white, coarse-grained sand to gravel, subrounded to well rounded and poorly sorted.

Based on interpretation of the depositional environments, the Loxton–Parilla Sands are a combination of backshore to lower shoreface facies. These environments include the offshore, beach, berm, dune, washover fan, fluvial and back barrier lagoonal environments. Recognition of these littoral depositional environments within the Loxton–Parilla Sands gives meaning to anomalous intersections of HMS and aids targeting of future drilling.

Formation of barrier island features

The strandline features within the Murray Basin have previously been recognised as prograding barrier complexes of the Loxton–Parilla Sands (Roy et al., 2000). Recent drilling by PIRSA has shown that the largest of these are a result of transgressive to still-stand deposition and the formation of stacked barrier island complexes (Fig. 2). Sedimentological analysis of the Loxton–Parilla Sands has been used to show that these features contain multiple, stacked beach deposits and back-barrier lagoonal sediments associated with barrier island complexes rather than strand-plain deposition. This implies that these features are prospective for HMS accumulations, not only in reworked foreshore sediments, but also in washover fans associated with storm-wave deposition. Analysis of the digital elevation model, radiometrics, aeromagnetics, ASTER, NOAA and Landsat day and night time satellite imagery has been used for the detailed identification of strandlines in the northwestern Murray Basin (Fabris, 2002, in prep. b)

Exploration models for HMS in the Murray Basin

The formation of a HMS deposit is fundamentally controlled by the ability of sedimentary processes to concentrate heavy minerals above that of background levels. Roy (1999) described two mechanisms thought to be responsible for their development:

- Transgressive barrier fractionation which involves erosional reworking during a transgression where there is a negative sediment budget.
- Littoral bypassing fractionation which involves repeated storm erosion and winnowing of beach sediments over hundreds to thousands of years to produce lag-style deposits. These lag deposits are commonly associated with the trapping of heavy minerals at headlands.

Whitehouse et al. (1999) speculated that growth faulting can be responsible for creating virtual headlands of upfaulted blocks. Many of the Murray Basin HMS deposits can be related to areas of growth faulting (Fig. 3).

Analysis of the digital elevation model in the western Murray Basin highlights an elevated block related to reactivation of the Hamley Fault, herein referred to as the 'Hamley Ridge' (Fig. 3). Work by Lindsay and Barnett (1989) involving the analysis of drillhole cross-sections and correlation of the Middle Miocene *Lepidocyclina* foraminiferal zone within the Mannum Limestone indicated thinned and anticlinally draped Tertiary units over a high of pre-Tertiary rocks centred over the Hamley Ridge. They suggested reactivation of the Hamley Fault throughout the Tertiary to create this upwarping. Current drillhole analysis suggests that the Hamley Ridge was gently elevated at the time of deposition of the Loxton–Parilla Sands. This implies that during deposition of the sands in the Pliocene, the Hamley Ridge would have acted as a potential mechanism for concentration of heavy minerals. Pleistocene reactivation of the fault meant that a similar mechanism was active during the development of Lake Bungunnia. Wave action within the lake may have been sufficient to winnow the underlying Loxton–Parilla Sands and further concentrate heavy minerals, increasing the prospectivity of the area (Rogers, 1999).

The Hamley Ridge had a significant effect on morphology of the Plio-Pleistocene Lake Bungunnia. White (2000) attributed the effect of the ridge to the formation of a divide to the lake, responsible for the segregation of the lake during its drying and greater occurrence of stromatolite and evaporite-type deposits in the western part of the lake.

Conclusions

The Loxton–Parilla Sands are prospective for HMS deposits throughout much of the Murray Basin. Sedimentological analysis of the unit has enabled specific littoral facies identification, facilitating the targeting of drilling programs in an otherwise uniform sedimentary package. The two main mechanisms identified for concentrating heavy minerals into potentially economic deposits were transgressive conditions producing barrier islands (strandlines), and by trapping related to structural and erosional features. The most prospective areas outlined by the project for HMS concentrations within the western Murray Basin are:

Table 1 *Summary of grain data for depositional environments characterised from the Loxton–Parilla Sands.*

Depositional environment	No. of samples	Range of mean grainsizes (mm)	Average mean grainsize (mm)	Skewness	Kurtosis	Sorting
Lower to upper shoreface	12	0.12–0.26 (vf–f)	0.19 (fine)	3.29	43.44	moderate
Shoreface to foreshore	11	0.15–0.34 (vf–m)	0.24 (fine)	2.22	24.64	moderate
Foreshore to backshore	46	0.23–0.88	0.37 (medium)	1.5	8.38	poor

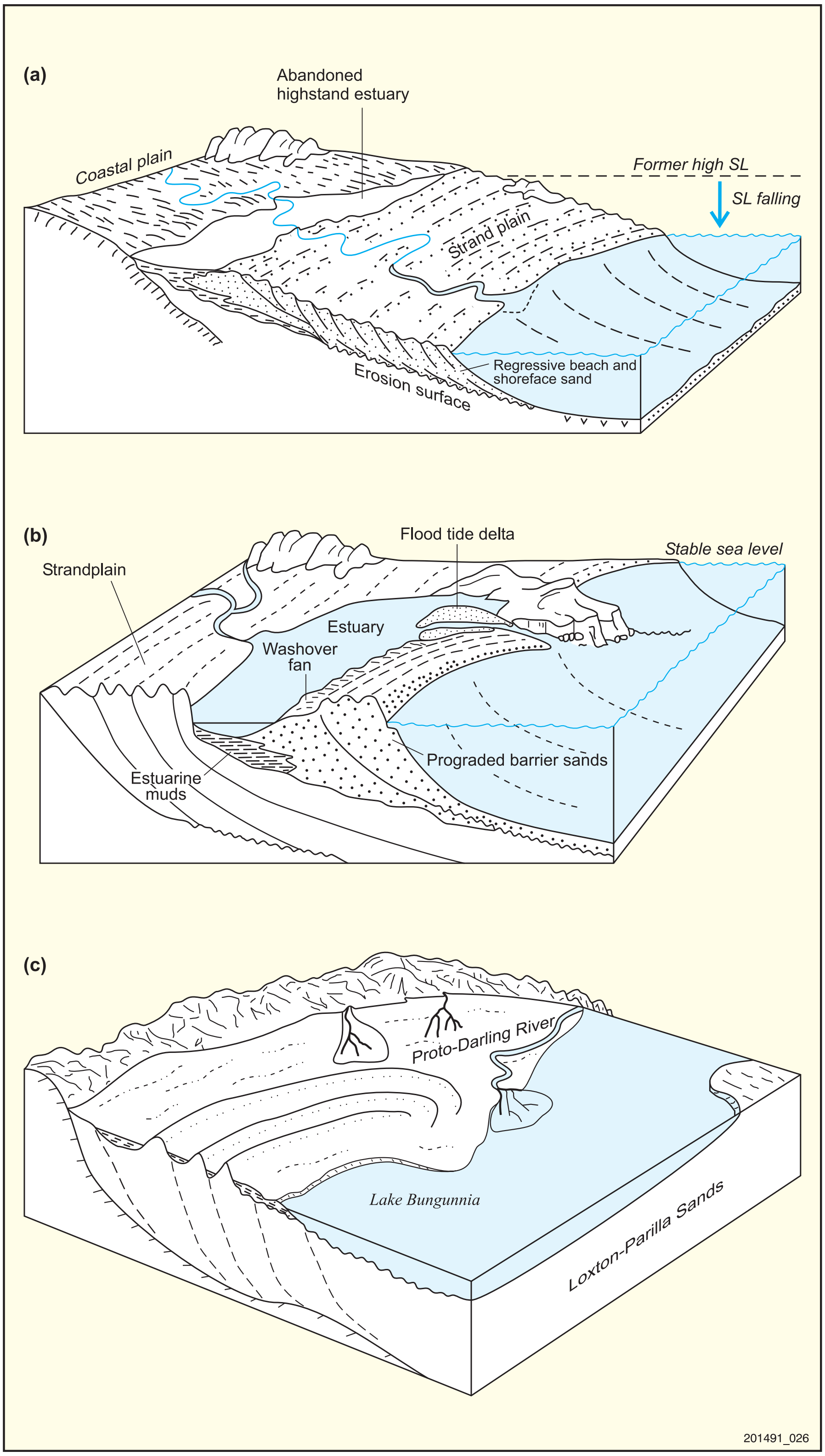

***Fig. 2(a)** Onset of highstand deposition and sea-level retreat in the Pliocene led to progradation of the Loxton–Parilla Sands and formation of strand plains. The majority of deposition was in shoreface, beach and dune environments (after Roy et al., 1994). **(b)** Stable or rising sea levels led to the formation of stacked barriers. Stacking caused the elevation of the barrier island to be greater than strand plain forming barriers. Deposition involved shoreface, beach and dune facies, as well as back barrier lagoon and washover fan deposits (after Roy et al., 1994). **(c)** The Loxton–Parilla Sands were deposited in strand plain as well as barrier island forming conditions due to fluctuations in sea level and sediment supply. This resulted in numerous arcuate features seen throughout the Murray Basin. Note: the topographic effects of strandline features are subdued where they were eroded and reworked by the Quaternary Lake Bungunnia.*

- numerous barrier island features interpreted from a combination of Landsat night time thermal imagery, digital elevation model and radiometrics
- the Hamley Ridge
- margins of Lake Bungunnia.

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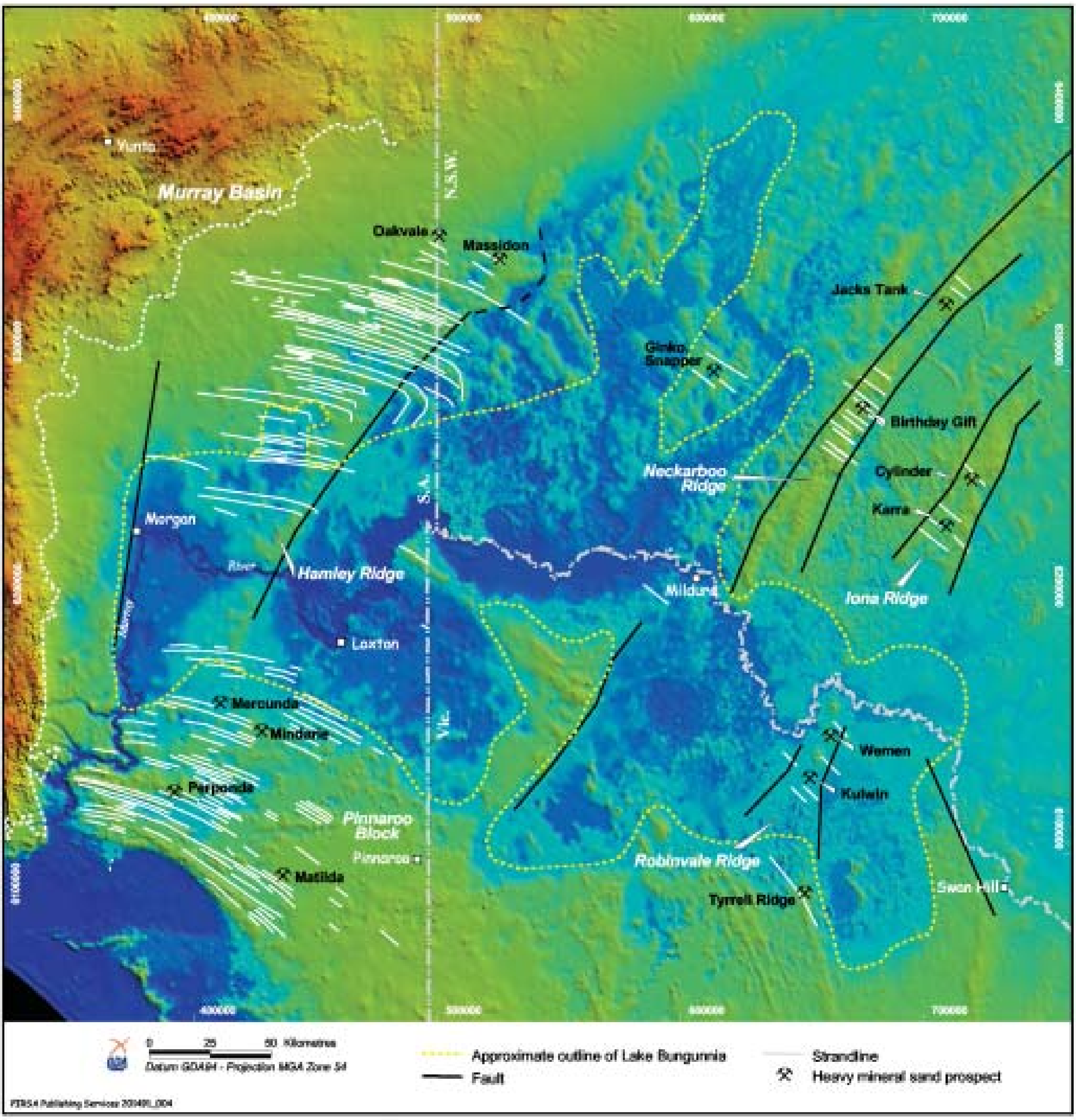

Fig. 3 *HMS deposits of the Murray Basin overlayed on a digital elevation model. Uplifted fault blocks are closely correlated to the location of HMS prospects. This can be attributed to the effect of growth faulting in most cases. Exploration for HMS in the Murray Basin can be focused towards these ridges.*

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