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Application of Landsat Thematic Mapping to geology and salinity in the Murray Basin

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In hydrological and geological studies in the Murray Basin, composite images derived from Landsat Thematic Mapper (TM) digital data enable excellent delineation of both ancient and active groundwater discharge zones, including strong zoning within active salinas. Differentiation of aeolian deposits, including lunettes, is possible only where there are distinctive vegetation associations.

Introduction

One of the main objectives of a joint Commonwealth-States study of the regional hydrogeology of the Murray Basin is to define the regional groundwater processes, particularly those related to salinisation and surface water quality. Salinisation occurs today at sites that have experienced high salinity levels in the geologic past (Bowler & Teller, 1986). By inference, other sites which have experienced high salinisation within the landscape may represent those areas most at risk in the future. Techniques that can rapidly identify, map and monitor active and fossil discharge complexes in the landscape will be of great benefit in the management of these areas.

The results presented in this paper represent a preliminary evaluation of the applicability of Landsat Thematic Mapper (TM) raw data in identifying groundwater discharge features. In addition, an attempt has been made to identify various evaporite minerals within active salinas, in areas where field data were available to test the interpretations.

The study area

For this initial study, a number of saline lake complexes with active groundwater discharge zones were chosen in the Nulla and Scotia areas of the Mallee region north of Wentworth, western New South Wales (Fig. 1). Over a number of years immediately before this study, field investigations had been carried out in these areas by BMR geologists W.R. Evans, C.M. Brown and C.J. Simpson. In addition, 1:100 000 topographic maps, 1968 aerial photographs and a 1:1 000 000 geological map (Brown & Stephenson, 1985) were available for the area. The Landsat TM digital data used for this study were collected on September 25, 1986, from Landsat 5.

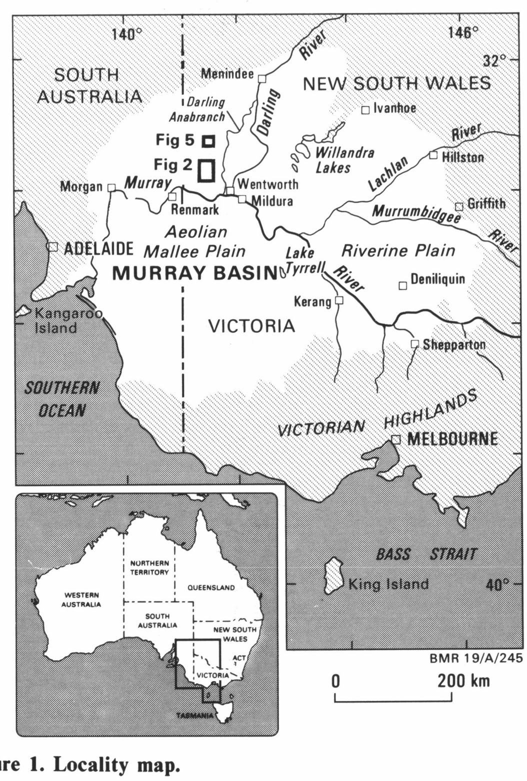

Figure 1. Locality map.

Vegetation consists mainly of stands of mallee and casuarina with widespread saltbush of various species. The dominant land use in the area is grazing, which has affected vegetation to various degrees.

Geomorphology and Quaternary geology

The geomorphology of the area is dominated by upper Pleistocene–Holocene saline lake complexes surrounded by aeolian dune fields and sand plains (Figs 2, 5, & Table 1).

The saline lake complexes represent groundwater discharge zones (Brown & Stephenson, 1986). Active salinas are now very small compared with their past maximum extent. There have been at least five maxima in the last 500 000 years, corresponding to periods of glaciation, the last of which occurred 18 000 B.P. (Bowler & Teller, 1986). The original extent of the lakes is delineated by dry playa floors, consisting of gypsum-rich clay deposits forming extensive flats covered by a thin gypsite layer. These are vegetated to various degrees by saltbush species. Active salinas occur in topographic lows entrenched within the former lake floor. These fossil and active saline lake deposits are known collectively as the Yamba Formation (Brown & Stephenson, 1986).

Playas are often bounded to the east by lunette dune systems, themselves concave to the west. These result from aeolian deflation of the lake floor, and consist of gypsum and clay pellet aggregates. The dunes may be quite extensive, and are vegetated by mallee and saltbush.

Between the lakes, the landscape is dominated by aeolian deposits. In the Nulla–Scotia area there are three main types — extensive dunefields of linear, east–west-trending low dunes with broad swales (Woorinen Formation); subparabolic, densely packed, locally mobile dunes; and flat to undulating sand plains. Aeolian deposits consist mainly of red-brown clay and silty sands, modified by pedogenesis and stabilised by vegetation, mainly mallee and saltbush. The Woorinen Formation typically has well-developed calcrete horizons, while the parabolic dunes show no development of calcrete, and result from reworking of the older Woorinen dune fields (Brown & Stephenson, 1985).

Salinas

Deposits within the active salinas typically consist of black anoxic muds underlying ephemeral salt crusts, which vary

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Table 1. Late Quaternary structural units (from Brown & Stephenson, 1986). Refer to Figures 2 and 5.

Qdu	
Lithology	Unconsolidated, locally mobile, red-brown, pale orange siliceous sand; consists of medium to fine quartz grains, admixed with humic debris, fragmented calcareous and gypseous filamental rhizoliths; only weakly modified by pedogenesis.
Depositional environment	Aeolian dune
Geomorphic	Forms sharp-crested, irregular to sub-parabolic, expression locally linear dunes with narrow interdune depressions; forms elongate, easterly-trending dunefields.
Qly	
Lithology	Yamba Formation and other saline lake deposits: friable, pale grey gypsite, gypsiferous clay with selenite crystals, grey pelletal gypsum-quartz sand aggregates; locally includes grey clay with crystalline gypsum mush, under black sulphide-rich mud with ephemeral salt crusts of gypsum, halite, bischofite, thenardite, and mirabilite; in places associated with mounds and sheets of ferricrete, calcrete dolomitic and silcrete cemented quartz sand.
Depositional environment	Lacustrine, evaporitic and aeolian environments of environment ephemerally active playas, maintained by groundwater discharge and by deflation of lake floors.
Geomorphic expression	Forms aeolian-modified gypsite flats; active salinas occur in topographic lows as irregularly shaped lake complexes entrenched within relict pedestals of former lake floors.
Qdl	
Lithology	Poorly consolidated, yellow, grey, brown, red, siliceous sand, silty clay, clay pellet aggregates, gypseous clay pellets, pale grey gypsite; older components increasingly modified by pedogenesis, includes intercalated red calcareous and gypseous palaeosols with calcrete glaebules and rhizoliths.
Depositional environment	Aeolian dune environment adjacent to deflated lake floors and shores.
Geomorphic expression	Forms single and multiple lunettes (crescentic, transverse dunes), concave to west, located on eastern side of lake basins; locally flanked by blowout dunes of mobile white sand.
Qdw	
Lithology	Woorinen Formation: unconsolidated, red-brown, siliceous, silty sand, red calcareous silty clay, sandy clay, clay pellet aggregates; sand component consists of medium to fine quartz grains with red clay cutans, admixed with humic debris and fragmented calcareous tap root and filamental rhizoliths; partly modified by pedogenesis, includes intercalated, red, calcareous palaeosols with gypsiferous and soft to resistant carbonate glaebules, grading to cemented calcrete hardpans which locally form massive brecciated sheets.
Depositional environment	Aeolian dune and swale.
Geomorphic expression	Forms extensive dunefields of discontinuous, expression east–west-oriented dunes with subdued crests and flanks, separated by broad swales and sand plains.
Qpc	
Lithology	Blanchetown Clay, poorly consolidated to friable, well laminated, greenish-grey, red-brown clay; locally mottled, silty, sandy, calcareous and gypsiferous; includes minor intercalated quartz sand, ostracod sand; contains calcareous, gypseous, siliceous nodules.
Depositional environment	Predominantly freshwater lacustrine; locally, saline lacustrine and fluvial environments.
Geomorphic expression	Mainly concealed; locally exposed in river cliffs and lake margins.

with season and rainfall. The lakes are distinctly zoned, both laterally and vertically. Variability is a function of depth to the water table and climatic conditions. Field observations verified by X-ray diffraction analysis indicate major zones characterised by:

1. quartz and clay with some areas of efflorescent salts (scattered samphyre may grow in this zone)

2a. small mounds of clay and gypsum sand pellets with some halite and quartz together forming characteristic 'fluffy' morphology

2b. complex associations of sulphate salts (gypsum, thenardite, epsomite, hexahydrite with some halite), often associated with desiccation features

3. predominately halite crust at the intersection of the water table and the ground surface.

These zones represent the present day sequence in the reactivation of a salina accompanying a rise in the water table. First, waterlogging results in the death of all vegetation, with samphyre (*Salicornia* sp.) last. Capillary rise of salts results in efflorescence and 'fluffy' clay structures; periodic wetting and drying result in desiccation features and leave a thin crust of the less soluble salts. As the water table nears the surface, concentration of salts through evaporative processes results in precipitation of more soluble salts. Halite crusts result when the water table reaches the ground surface. The ancient groundwater discharge complexes are thought to have developed as a consequence of progressive drying of lake systems and a lowering of the water table during a transition from relatively wet to arid climatic conditions (Bowler & Teller, 1986).

Landsat TM image evaluation

Landsat 5, launched in 1984, provides spectral data in 7 bands from an advanced multispectral scanner called the Thematic Mapper (TM). The range for each TM band, compared with the range for Landsat Multispectral Scanner (MSS) bands, is given in Table 2. Pixel size for TM data is 30 x 30 m for bands 1, 2, 3, 4, 5 and 7, and 60 x 60 m for band 6. TM data record reflected solar radiation received at the satellite, and are uncorrected for atmospheric attenuation and instrumentation differences, which may alter the signal received at ground stations.

As a first step in assessing the usefulness of TM data, the uncorrected raw digital data only were used. The results are discussed below. It was found that contrast-enhanced composite images of bands 1 (blue), 5 (green), and 4 (red) (1,5,4 = BGR) gave best definition of most features.

Comparison of TM images with mapped geology shows that TM data can be used to identify all major geomorphological features (compare Figs 2 & 3, and 5 & 6, respectively). Ancient playas, which are often poorly vegetated by predominantly halophytic species, show as white and light shades of grey and grey-blue (Figs 3, 4). Active salinas within the playas show zonation from white to magenta to deep blue (Fig. 4). On the basis of field observations made in April 1988, the following tentative correlations of colours in the 1,5,4 (BGR) composite image to zones in the salinas were made: blue — halite (which may be wet); magenta — complex sulphate associations; white — dominantly clay with quartz. Areas dominated by aeolian sands, characterised by mixed saltbush, grasses, and stands of mallee and casuarina, show in shades of yellow, green and brown (Fig. 6). The east–west-trending dunes of the Woorinen Formation are well defined because of the differences between the dunes (mallee) and swales (grasses and saltbush). Lunette dunes within the playas are easily distinguished by their vegetation cover (Fig. 4), but those

Table 2. Scanner band widths (in micrometres) of Landsat MSS (Multispectral Scanner) and TM (Thematic Mapper).

Landsat 1,2,3 MSS		*Landsat 4,5 TM*	
Band No.	*Band width (μm)*	*Band No.*	*Band width (μm)*
		1	0.45–0.52
4	0.5–0.6	2	0.52–0.60
5	0.6–0.7	3	0.63–0.69
6	0.7–0.8	4	0.76–0.90
7	0.8–1.1		
		5	1.55–1.75
		7	2.08–2.35
		6	10.40–12.50

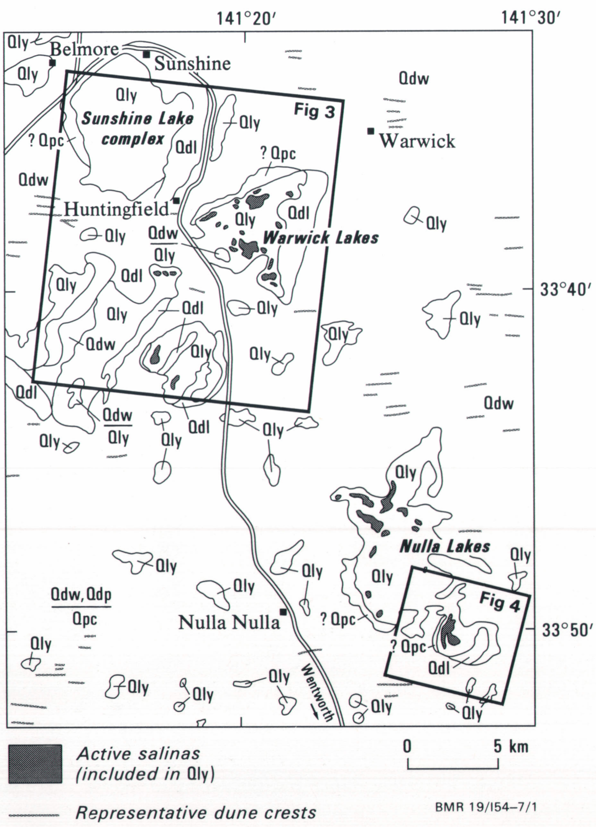

Figure 2. Surficial geology of the Nulla area, including Nulla Nulla, Belmore, Sunshine, Huntingfield & Warwick (after Brown & Stephenson, 1985).

The boxes indicate the lake complexes shown in the Landsat TM images of Figures 3 and 4. For structural units refer to Table 1.

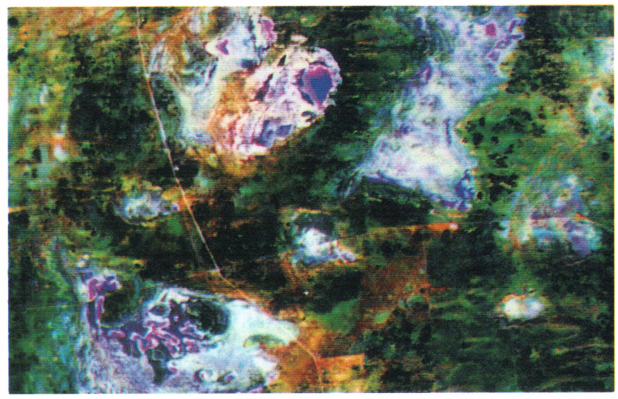

Figure 3. Landsat TM image (raw digital data 154 = BGR) of the lake complex of the Sunshine and Warwick discharge zone (see Fig. 2).

Ancient playas (Upper Pleistocene–Holocene) show as white to light grey and grey-blue; active salinas are zoned from white to magenta to deep blue; mixed saltbush, grasslands and mallee show as shades of yellow, green and brown.

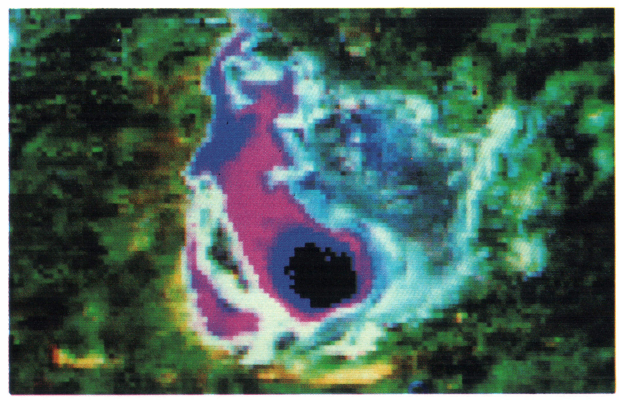

Figure 4. Enlarged section of a Landsat TM image (raw digital data 154 = BGR) of the southern Nulla lake complex (see Fig. 2).

This active salina shows distinct zonation of salts (blue: halite-rich, magenta: sulphate-rich). Standing water (black) was enhanced by further processing.

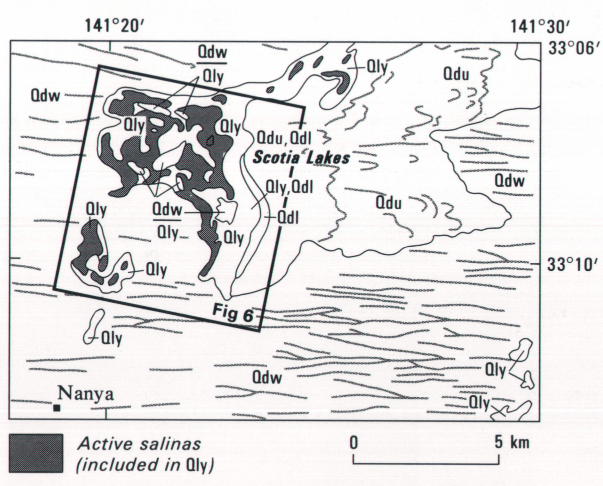

Figure 5. Surficial geology of the Scotia lakes area (after Brown & Stephenson, 1985).

The box shows the lake complex displayed in the Landsat TM image of Figure 6. For structural units refer to Table 1.

bordering the lakes are not as well defined, since their vegetation merges with that of the surrounding plains.

The blue, magenta and white zones of the images within the salinas were found to correlate reasonably with observed zonations in many of the lakes. An exception was that, at the time of field checking (at the end of the dry summer of 1988), there was no standing water in the lakes and halite was less widespread than indicated on the imagery.

A fall in groundwater levels during drought and seasonal dry periods is expected to remove many lakes from the zone of halite precipitation, and water stands in most lakes only after rain. Rain fell in this area on the days immediately before collection of the TM data (W.R. Evans, BMR, personal communication, March 1988). Virtually complete absorption in the near-infrared (NIR) region (bands 4 and 5) in the composite image suggests that water was present when the TM data were collected (see area enhanced in black by further processing in Fig. 4).

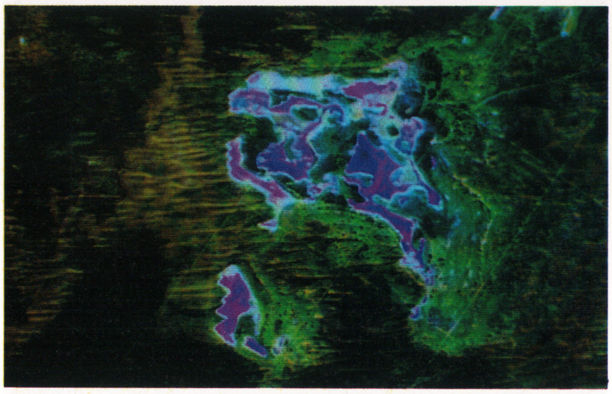

Figure 6. Enlarged section of a Landsat TM image (raw digital data 154 = BGR) of the Scotia lake complex (see Fig. 5).

The colour signatures are as for Figures 3 and 4. Note the east-west-trending linear sand dunes of the Woorinen Formation.

Comparisons between imagery and field observations highlight both the ephemeral nature of evaporative mineral assemblages and the dominating effect of standing water on reflected radiation. It is therefore important to note that, when using colour coding, firm correlations cannot be made unless ground observations are made at the same time as the TM data are acquired.

In using TM images, most geomorphological features are distinguished by geologically dependent changes in vegetation type and density. Karask & others (1986), in a study of the impact of scene component variables (such as type and density of vegetation, geology and soil characteristics) on Landsat TM spectral signatures, found that vegetation density was the dominant factor, usually swamping other factors. In general, in the Nulla and Scotia scenes there is a correlation between depth of colour and vegetation density. Contrast enhancement causes some ambiguity in areas of high reflectivity, since both sparse halophytic vegetation (in areas bounding the salinas) and completely bare areas (within the partly dry salinas) show as white. In the active salinas, which are not vegetated, mineral responses dominate, allowing delineation of mineral zones. Spectral responses of poorly vegetated ancient playas may also reflect the high gypsum content of the soils.

Conclusions

Uncorrected Landsat TM data provide a valuable tool for mapping active salinas and ancient playas in the Murray Basin. Geological features are distinguished primarily by variations in vegetation. Landsat TM images can also be used, in conjunction with field checking, to detect areas where saline seepage zones are developing.

Zonation within active salinas can be distinguished on the images. The uncorrected TM data can be used as a guide to the extent of salinisation and the evaporite mineral assemblages present within the salinas, providing the ephemeral nature of these is taken into consideration.

The technique is applicable over the entire Murray Basin, but caution must be exercised when comparing scenes from different areas, as colour differences between scenes recorded on different dates may result during processing of the data. This emphasises the need for field checking each scene, and comparison of pixel data for apparently similar areas in different scenes.

The investigation demonstrates that Landsat TM has potential for significant application to salinity studies in this environment, and more advanced processing techniques than those applied should be investigated.

Acknowledgments

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