LANDSAT THEMATIC MAPPER

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1. INTRODUCTION

The first Landsat satellite was launched in July 1972. Of the sensors carried, the Multispectral Scanner (MSS) with 80 metre pixels and four spectral bands was found to provide information of unforeseen value. In July 1982, the launch of Landsat 4 saw the inclusion of the Thematic Mapper (TM) sensor with a 30 metre resolution and 7 spectral bands. Both sensors are on Landsat 5.

The newest in this series of remote sensing satellites is Landsat 7. Launched on 15 April 1999, Landsat 7 has the new Enhanced Thematic Mapper Plus (ETM+) sensor. This sensor has the same 7 spectral bands as its predecessor, TM, but has an added panchromatic band with 15 metre resolution and a higher resolution thermal band of 60 metres.

The radiance measured by the Landsat sensor is a measure of the integration of soil, rock and vegetation characteristics. A processed Landsat TM image should, therefore, show a high degree of correspondence to a regolith-landform map and show that spectrally homogeneous units can be equated with terrain units and therefore named and described.

The use of Landsat TM data for geological mapping is well known (Drury and Hunt, 1989, Drury, 1993, Podwysocki, et al., 1985). How it is used to help construct a regolith-landform map is generally less widely understood. The results of a study of Landsat TM data in the North-eastern Goldfields region of Western Australia by Tapley and Gozzard (1992) and Gozzard and Tapley (1992) indicated that most units interpreted on 1:25,000-scale air photos could be identified on enhancements of the TM data. In addition, the TM data revealed considerably more detail about the compositional variability within the terrain units, especially those within the erosional and depositional regimes. The effectiveness of the data can be attributed to the spectral resolution of the TM data, particularly the ability to detect features related to the absorption of Fe oxides (band 4) and the absorption of clay minerals in band 7.

Spectral characteristics of common surface materials including vegetation, bedrock and regolith materials that can be resolved in the visible and near infrared range of the electromagnetic spectrum when using Landsat TM data are shown in Figure 1 and Table 1.

In Papp, É. (Editor), 2002, *Geophysical and Remote Sensing Methods for Regolith Exploration*, CRCLEME Open File Report 144, pp 6-12.

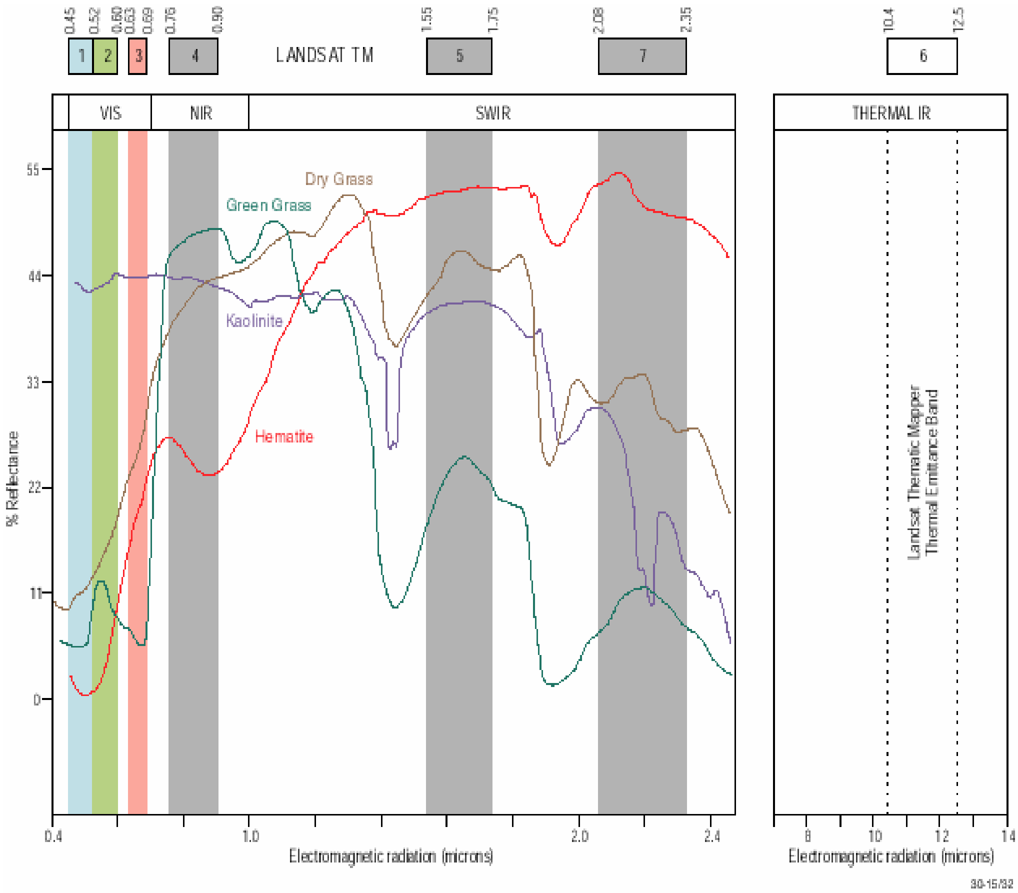

Figure 1. Spectra of selected surface materials and wavelength positions of LANDSAT TM band passes.

TM bands 1 to 4 are primarily useful to detect the spectral response of vegetation and Fe minerals including hematite and goethite. TM1 (0.45–0.52 µm) and TM3 (0.63–0 69 µm) correspond to the position of absorption bands of chlorophyll pigments. TM2 (0.52–0.60 µm) lies in the "green peak" caused by lower absorption of chlorophyll and carotenoids around 550nm. TM4 (0.76–0.90 µm) is related to NIR scattering due to internal leaf structure and the amount of leaf area. The positions of TM1 to 4 also coincide with several diagnostic Fe oxide features including the charge-transfer absorption feature in TM1, a reflectance ramp in TM2, a crystal-field absorption feature in TM3, and a strong crystal-field absorption feature in TM4. Because green biomass produces a reflection peak in TM4, the responses from green vegetation and iron oxide can be uncoupled. TM5, centred at 1.65 µm, is located where most soils and rocks have their maximum reflectance. TM7, centred at 2.22 µm, covers the absorption region of Al-OH- and Mg-OH-bearing minerals. These minerals include chlorite, clay, mica, and the amphibole and carbonate groups.

Table 1. General and specific regolith spectral responses associated with Landsat TM bands (excluding band 6) (modified from Podwyzocki, et al., 1985).

	General spectral responses	Regolith spectral responses
Band 1	Ferric and ferrous iron absorption.	Fe duricrusts, ferruginous saprolite low. Haematitic Fe very low. Kaolinite high.
Band 2	Ferric iron absorption and ferrous iron reflection. Chlorophyll reflection peak	Fe duricrusts, ferruginous saprolite low. Kaolinite high.
Band 3	Short-wavelength shoulder of ferric iron reflection. Ferrous iron absorption. Chlorophyll absorption	Moderate reflection for goethitic and haematitic iron. Kaolinite high.
Band 4	Short-wavelength shoulder of ferric iron and ferrous iron absorption. Vegetation reflection peak.	Moderate reflection for goethitic and haematitic iron. Kaolinite high.
Band 5	Highest reflection for most rock types. High reflection peak for hydrothermally altered rocks. Vegetation absorption.	Highly reflective for haematitic Fe duricrusts and ferruginous saprolite and clays
Band 7	Absorption band for Al-O-H, H-O-H, Mg-O-H and $C0_3$ (clays, micas, carbonates, sulphates. Vegetation water absorption. Dry grass high.	Absorption associated with hydroxyl bearing minerals and carbonates (Bleached or pallid zone, secondary carbonate-calcrete and travertine). Highly reflective for haematitic Fe duricrusts and ferruginous saprolite.

2. METHOD

When image data, such as LANDSAT TM, are recorded using satellite and aircraft systems, they can contain errors in geometry and in the measured brightness values of the pixels (Richards, 1986). The latter are referred to as radiometric errors and can result from the instrumentation used to record the data and atmospheric effects.

Geometric processing

In order to: (1) compare and contrast the information content of each dataset; and (2) integrate datasets, it is essential for the data to be geometrically correct and registered to a common map base, a process termed geo-referencing. The most common method is to relate image pixels to ground control points either from maps, GPS or other imagery and use a polynomial process to rectify the image to a datum and map projection (Richards, 1986). Geometrically corrected imagery can be purchased from approved distributors.

Radiometric processing

Atmospheric attenuation and backscatter modulates the upwelling spectral radiance field in a wavelength-dependent manner. The amount of backscattered radiant energy recorded is greatest in the shorter wavelength bands. Thus, it is essential, before performing any image processing and enhancement techniques, to improve the radiometric quality of the data by compensating for these effects and hence increase the information content of the data.

Ideally, atmospheric corrections are made either by obtaining atmospheric measurements simultaneously with the satellite overpass or from radiometric measurements over calibrated ground targets. Generally such measurements are not available. Estimates of the additive component of atmospheric backscatter can be made using the dark pixel subtraction method. This simply takes the values for all bands of a dark pixel in the image from which there is no reflected signal, or by calculating the minimum value for each band. The latter method needs to consider any data drop-out points or bad lines in the image.

3. DATA PROCESSING

False colour composite images

Combinations of Landsat TM bands can be used to provide overviews of landscape and regolith materials. Landsat TM bands 1,4,7 displayed as BGR can highlight clays, vegetation and iron oxides in a broad context. However topographic effects, high albedo that contributes to high correlation between the bands is generally the dominant effect in colour composite images. Single band images (eg. TM5) displayed in greyscale can be used for highlighting spatial details. Both colour composites and greyscale images are useful backdrops to other thematic layers. They can be appropriately integrated further with gamma ray spectroscopy data and draped over DEM to enhance terrain visualisations.

Ratios

Ratios of Landsat TM bands are useful for separating and mapping different weathered materials. Ratios of bands remove brightness variations and highlight spectral differences between the bands. Hence ratios images are generally saturated and show no topographic information. Examples of ratio combinations include: 1) 3/1 and 5/4 for mapping ferruginous saprolite and lags; 2) 5/7 for identifying residual and transported clays; and 3) 4/2 for separating ferruginous from non-ferruginous regolith. These ratio combinations can be displayed individually or as various three band false-colour combinations.

Directed Principal Component Analysis

One of the most effective enhancements for discriminating a range of different regolith materials is a technique called Directed Principal Component Analysis (DPCA) developed by Fraser and Green (1987). The DPCA is used to separate clays in the imagery by deriving principal components from ratios of bands 4/3 and 5/7. Ratio 4/3 enhances green vegetation and ratio 5/7 enhances a mixed response of vegetation and clay. The DPCA operating on these band ratios is able to separate the vegetation from the clay response. The 'clay' band (derived from the second principal component) is then combined with a ratio of bands 5/4 and bands 7 + 1 in a colour composite image. Ratio 5/4 highlights ferruginous materials and bands 7 + 1 highlights silica-rich materials. The final image is displayed as a three-band composite image with clay in red, iron oxides in green and silica in blue.

4. DATA INTERPRETATION

An example of the application of Landsat TM data for surficial mapping is taken from regolith and landscape studies over part of the Gawler Craton near Half Moon Lake, in South Australia (Wilford, et al., 1998). The area has a semi arid with low relief and poor bedrock exposure. Regolith materials dominate the landscape consisting of aeolian sand, ferruginous lags, calcrete and silcrete. The enhanced Landsat TM image in Figure 2, once field-checked, was the main mapping surrogate for extrapolating regolith units to the surrounding region (Figure 3). The patterns derived from the image responses were used to either define regolith units or to describe the variability of surface materials within units defined by other mapping surrogates such as aerial photos and gamma-ray spectrometry imagery. Superimposed regolith polygons over the enhanced Landsat imagery enabled further assessment of the type and variability of surface materials within each regolith unit.

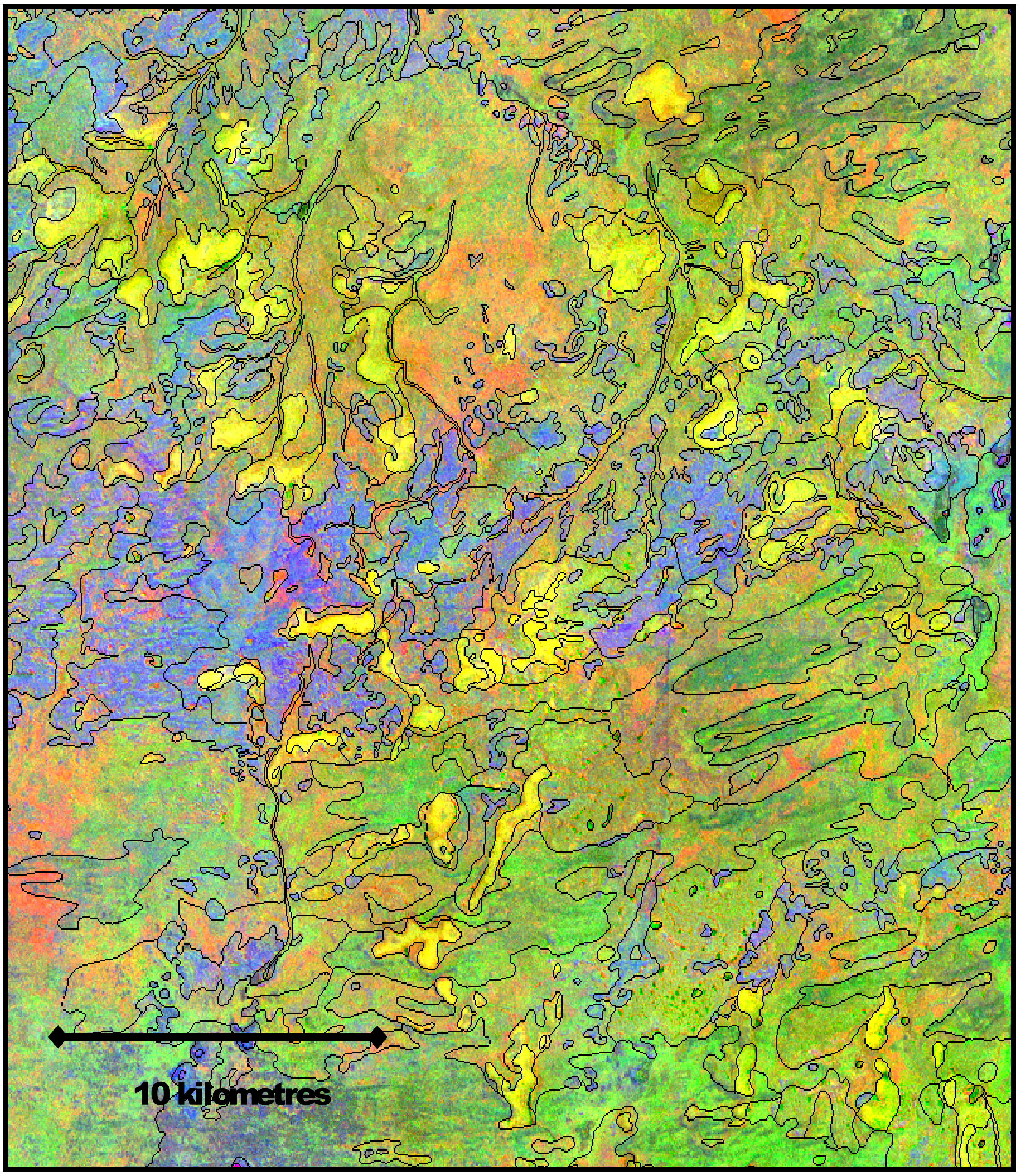

Figure 2. Three-band Landsat TM image of second principal component of ratios 4/3 and 5/7 in red, ratio 5/4 in green and the addition of bands 7 + 1 in blue, overlain with regolith and landform vectors. Ferruginous saprolite, Fe duricrust and ferruginous gravel lags appear in bright yellow hues. Silcrete, silicified saprolite appear in mottled green and yellow, ferruginous dune sands and sandplains appear in olive green to apple green hues. Orange to yellowish orange hues correspond to ferruginous sands and clays over depositional plains. Floodplain sediments and lacustrine sediments appear in red hues. Highly calcareous soils containing calcrete lags and granules appear in blue/magenta. See Figure 3 for descriptions of regolith and landform types.

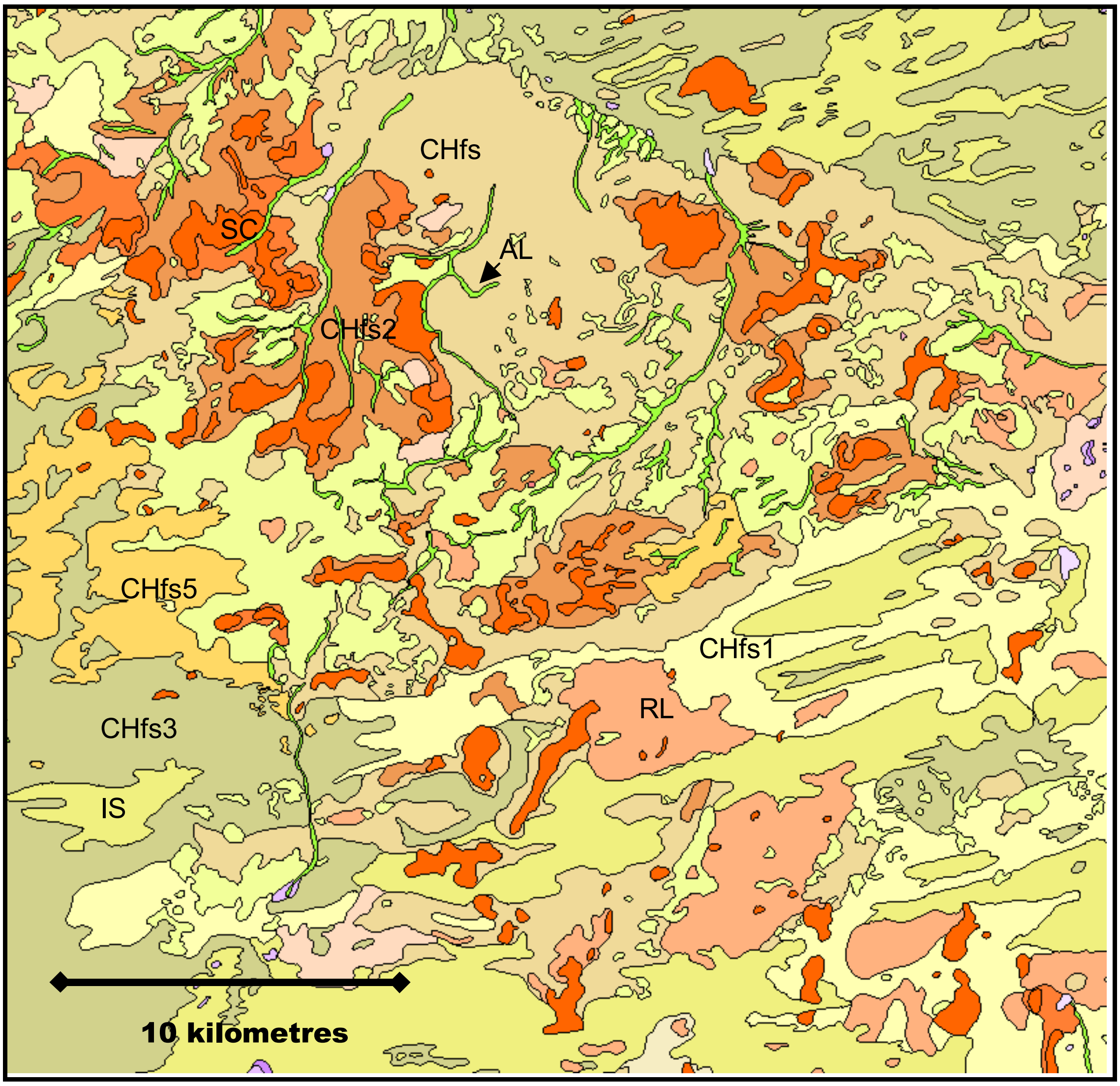

Figure 3. Regolith and landforms from part of the Jumbuck map, Half Moon Lake region, Gawler Craton, South Australia (Wilford, et al., 1998).

AL	Alluvial sediments within poorly defined drainage lines
IS	Aeolian sediments comprising undulating sandplains with occasional parabolic dunes
CHfs	Colluvium - sheet-flow sands with occasional erosional rises mantled by lag gravels
CHfs2	Colluvium - sheet-flow plains comprising lag of ferruginous saprolite and silcrete gravels and ironstone nodules over clayey sands. Occasional indurated pavements of silcrete.
CHfs3	Colluvium - sheet-flow modified sandplains and minor erosional sandplains
CHfs5	Colluvium - extensive sheet-flow sandplains and minor residual plains - calcareous nodules common
Lpp	Lacustrine sediments
SC	Erosional plain comprising abundant ferruginous buckshot gravels, ironstone granules and minor silcrete over granitic saprolite, occasional calcrete nodules
RL	Lag of ferruginous and silcrete gravels and calcrete nodules over silcrete and calcareous sands

5. PROBLEMS, LIMITATIONS

Landsat TM imagery has a scale limitation for interpretation of around 1:50,000. However the additional panchromatic 15 metre band in LANDSAT ETM7+ imagery can be used to enhance the spatial resolution of the other bands and enable larger scales to be used. Scene dependent features such as fireburns and other cultural effects such as variably-grazed paddocks can also make interpretation difficult. Field checking can resolve interpretation issues but should take into account the ground resolution of the data.

6. DATA ACQUISITION AND COST

The Australian Centre for Remote Sensing (ACRES) receives and processes data from the Landsat series of satellites. Imagery can be purchased direct from ACRES or from a network of distributors (http://www.auslig.gov.au/acres). Landsat TM digital imagery is available in a range of forms as shown in Table 2 (in $AUD as of April 2002):

Table 2. Prices for full and partial scenes for Landsat 5 and ETM7+.

LANDSAT 5 & ETM7+

	Raw	Map oriented	Orthorectified
Small scene (25x25km)		535	
Full scene (220x180km)	1400	1730	2160
Super scene (240x250km)		2590	3240

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