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Mapping granite outcrops in the Western Australian Wheatbelt using Landsat TM data

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Abstract

Granite outcrops are of considerable interest in terms of geomorphology, biodiversity, cultural heritage, recreation and as sources of fresh water in arid landscapes. In the south-west of Western Australia, which is unusually rich in granite outcrops, standard 1:100 000 maps often show granite rocks, as do the vegetation maps published by Beard (1974, 1975a,b, 1976, 1981). While these outcrop locations include many major granite outcrops, no assessment has been made of the completeness of the coverage, and no up-to-date inventory exists.

This paper gives details of an analysis of a sequence of calibrated Landsat TM images for the Kellerberrin scene to identify granite outcrops. The images contain prominent granite outcrops such as Mt Caroline and Mt Stirling. Granite outcrops are mapped by using canonical variate analysis to determine spectral indices (linear combinations of the Landsat TM bands) that best distinguish granite outcrops from other cover types. An interval is then determined for each spectral index that unambiguously identifies granite outcrop. The results are combined to form a 'granite likeness' score for each pixel, and a map of the granite score is produced. Visual agreement with the interpretation based on aerial photos suggests that there is the potential to produce an atlas of Western Australian granite outcrops based on remote sensing imagery.

Keywords: mapping, granite outcrops, Landsat TM, spectral indices

Introduction

Granite outcrops cover 15% of the earth's surface (Twidale 1982). Western Australia is unusually rich in outcrops, which are of considerable interest in terms of geomorphology, biodiversity, cultural heritage, recreation and as sources of fresh water in arid landscapes (Withers & Hopper 1997; Bayly 1999; Nikulinsky & Hopper 1999).

In the south-west of Western Australia, standard 1:100 000 maps often show granite rocks, as do the vegetation maps published by Beard (1974, 1975a,b, 1976, 1981). These outcrop locations, which have been identified visually from aerial photographs, include many major granite outcrops. However, no assessment has been made of the completeness of the coverage, and no up-to-date inventory exists.

The Remote Sensing and Monitoring group in CSIRO Mathematical and Information Sciences (Floreat Park) is using long-term sequences of carefully rectified and calibrated Landsat TM imagery to map and monitor land condition in the WA wheatbelt. Of special interest is the spread of salinity and the status of vegetation (see, for example, Wheaton *et al.* 1992; Wheaton *et al.* 1994; Evans *et al.* 1995).

This paper gives details of an analysis of a sequence of calibrated Landsat TM images for the Kellerberrin scene to identify granite outcrops. We investigated this area because it contains prominent granite outcrops such as Mt Caroline and Mt Stirling, and as a preliminary study to establish the feasibility of producing an atlas of south-western granite outcrops from remote sensing imagery.

We first provide brief details of the Landsat scenes, including image rectification, registration and calibration. Then, granite outcrops are mapped by determining spectral indices (combinations of the Landsat TM bands) which distinguish granite outcrops from other cover types. Finally, the indices are combined to form a 'granite likeness' score for each pixel, and a map of the granite score is produced.

Landsat TM and ground data

The area studied is the Landsat TM scene for Kellerberrin (path 111, row 082) in the WA wheatbelt. The following four scenes are analysed: 2 February 1990; 28 January 1994; 3 February 1996; and 7 January 1998.

The January 1994 scene was first rectified to the WA Main Roads Department Regional Roads database. The rectification approach adopted uses north-south and east-west road segments, and incorporates image overlap with adjacent scenes (see Campbell *et al.* 1999). This approach has produced a sixteen-scene 'mosaic' in which the roads on the Landsat images generally agree to within less than one pixel (<25 m) with the GPS-recorded road position.

The remaining (target) images in the sequence are then registered to the January 1994 (reference) image by selecting a sequence of high-contrast ground control points (GCPs) on the two images, and using cross-correlation matching (Campbell 2000) to find the best sub-pixel match in the target image for each GCP in the reference image. The images are resampled using cubic convolution (see, for example, Schowengerdt 1997, 350).

The third stage in the process is to calibrate the images so that the same condition on the ground has the same recorded value on the rectified satellite image. This is done by selecting pseudo-invariant targets, and using robust regression to relate the values on the target images to those on the reference image (Furby & Campbell 2000).

The Landsat TM satellite records values in 30 m x 30 m pixels over a 185 km x 185 km area in six spectral regions: blue, green, red, near infra-red (IR) and two mid-IR bands (see, for example, Richards 1986, 13). Various three-colour displays can be produced by assigning the spectral bands, or combinations of them, to the three colour guns on the image display (Richards 1986, Section 3.2). After image calibration, it is expected that the granite rocks will not change in 'colour' over time for the various colour displays, whereas surrounding bush and farm areas will.

Identifying granite outcrops

The next stage in the analysis is to determine linear combinations of the Landsat spectral bands (referred to here as spectral indices) which best distinguish bare granite outcrops from other cover types. The approach adopted is canonical variate analysis (see, for example, Richards 1986, Section 10.4.2; Campbell & Wallace 1989).

Briefly, training classes are defined for the various cover classes of interest, and linear combinations of the spectral bands are determined to minimise the between-class variation for the resulting canonical variate scores relative to the within-class variation. Subsequent linear combinations are chosen to be uncorrelated between- and within-classes with previously determined sets of scores. As noted above, the approach requires training classes to be located for granite outcrops and other cover types.

There are several large granite outcrops in the study scene, and these are used to define training classes. The bare granite areas are clearly identifiable in aerial photos taken over the area in October 1994 (see, for example, Fig 1A, which shows an aerial photo for Mt Stirling 6478125N, 558325E). Fig 1B shows a three-colour display of bands 7, 5 and 4 (in red, green, blue respectively) for the January 1998 Landsat TM image. For each of the four scenes, twenty-seven training classes were extracted from regions of bare granite rock, which are identifiable in the three-colour display. Twenty classes were extracted from bush-covered areas of the outcrop, and fifteen classes were identified in adjacent areas (including areas from a chain of salt lakes). Fig 2A shows a plot of the class means for the first two canonical variates for the January 1994 data. A plot of simplified forms of the vectors in Figure 2B gives essentially the same configuration. The first canonical variate separates bare granite outcrop from bush-covered sites, while the second canonical variate separates granite outcrop from salt-lake sites. For these data, there is separation between the granite outcrop sites and the rest, though for other dates there is some confusion between the granite outcrop sites and the bush and salt-lake sites towards the top right of the cluster of granite outcrop sites. Examination of the aerial photos and various enhancements of the TM images suggest that the sites are correctly labelled, and that there is occasionally some spectral confusion between a few granite outcrop sites in the region of overlap.

The contributions that the various bands make to the identification of granite outcrop sites can be assessed by evaluating for all possible subsets the degree of separation between the granite sites and the remaining sites. For these data, bands 4 (near IR) and 6 (mid IR) provide much of the separation.

Calculating a granite index

Examination of the canonical variate (CV) plots in Fig 2 for the January 1994 data and similar plots for the other dates shows that for each date, there is a region in CV space which unambiguously identifies bare granite outcrop. There are also regions that clearly exclude bare granite outcrop. Finally, there are 'transition' zones where the identification is inconclusive.

One approach for identifying regions of bare granite outcrop is to determine an interval for each spectral index which unambiguously identifies granite outcrop; there are two indices for each of the four dates. If the index value falls within the granite interval for that index, then 1 is added to a granite score, and zero otherwise.

For the plot in Figure 2B, the first index is given by –3 x TM2 – TM3 – 9 x TM4 – TM5 + 17 x TM7. If the resulting index is greater than 375, then 1 would be added to the granite score. The second index is given by 5 x TM1 – 14 x TM2 + 14 x TM3 + 20 x TM4 + 2 x TM5 - 8 x TM7. If the resulting index is less than 1830, then 1 would be added to the granite score. The granite score can then be displayed as an image; the higher the score, the greater is the confidence that a pixel is bare granite outcrop. Fig 1C shows an image of the resulting score for the Mt Stirling region

There are several extensions to the approach which are being considered. The index-based approach can be modified to replace the 1-0 value for each index by a value which varies between 1 and 0. This can be done by adding a transition interval, in which the value changes smoothly from 1 to 0, to give a "probability" of granite. The resulting scores can then be combined using a rule-based system. Campbell & Woodgate (2000) have proposed a similar approach for estimating tree clearing for the Australian Greenhouse Office.

Another aspect that needs to be considered is the spatial pattern of the granite score. If the neighbouring pixels have a high score value (close to eight in our study), this should reinforce the value for the central pixel. If the neighbouring pixels have a low score, and the central pixel has a value, of say, six, then this should weaken the likelihood that the central pixel is granite outcrop. A simple approach would be to calculate a neighbourhood confidence factor, say using the sum of the neighbourhood granite score values divided by the maximum possible sum, and then multiply the granite score for the central pixel by this neighbourhood weighting. This can be done for several iterations to obtain a neighbour–modified granite score. More sophisticated forms of neighbour weighting can be

A

B

C

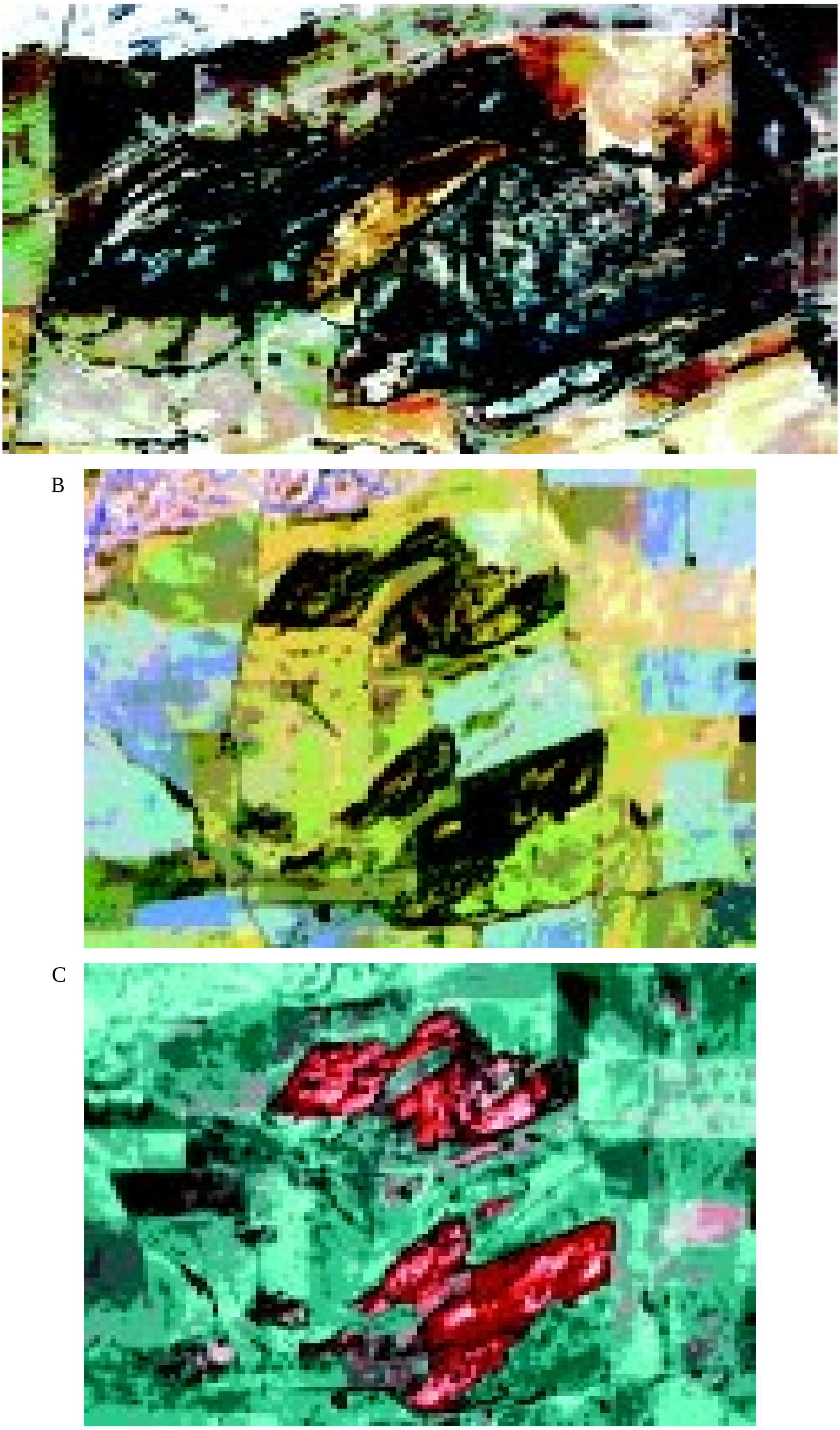

Figure 1. A: 1:25 000 aerial photo for Mt Stirling; 21-10-94. **B:** Three-colour image for Landsat TM data for January 1998 – band 3 assigned to blue gun, band 5 to the green gun and band 7 to the red gun. **C:** Image of granite score for Landsat TM data; brighter areas indicate higher granite score.

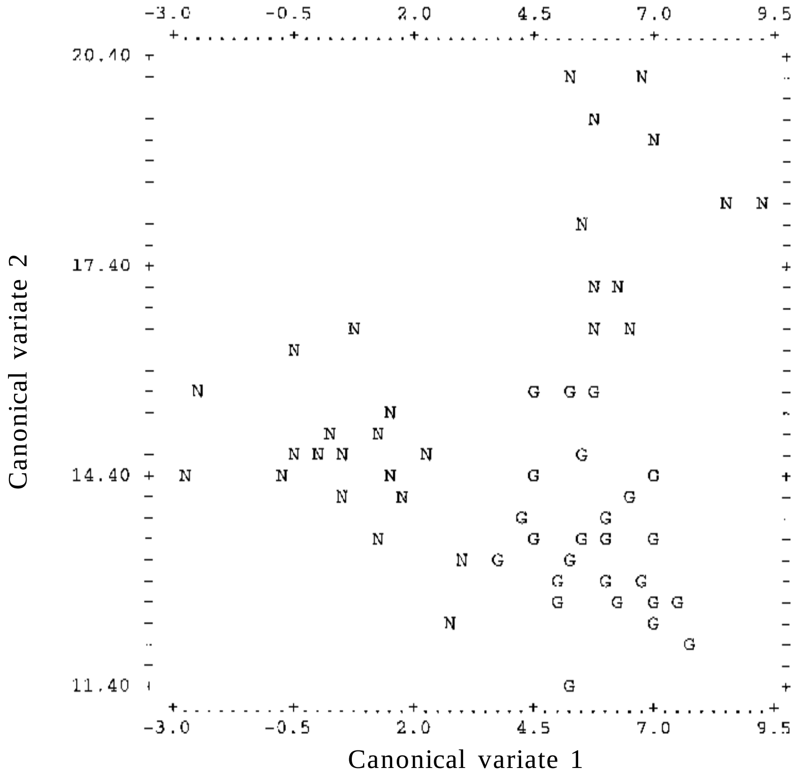

Figure 2. A: Plot of canonical variate class means for January 1994 TM data. G denotes granite outcrop, N denotes non-granite sites. The two canonical vectors are
(0.080 -0.051 0.103 -0.239 -0.027 0.141) and (0.103 -0.215 0.253 0.071 0.016 -0.118)

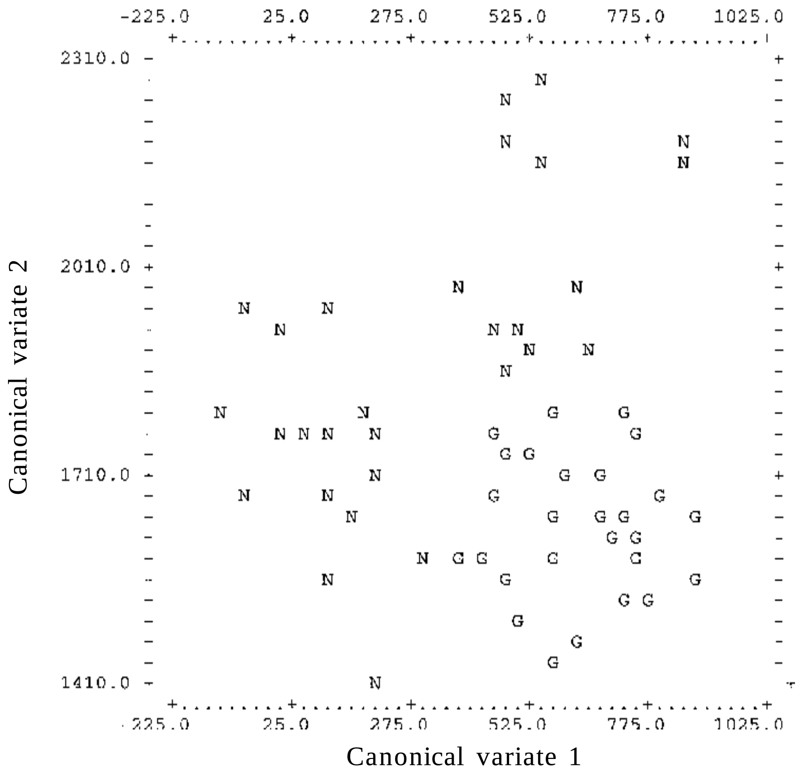

Figure 2. B: Smoothed canonical vectors and plot of canonical variate class means for January 1994 TM data. G denotes granite outcrop, N denotes non-granite sites. The two smoothed canonical vectors are
(0.00 -3.00 -1.00 -9.00 -1.00 17.00) and (5.00 -14.00 14.00 20.00 2.00 -8.00)

formulated, which take into account the actual distribution of the granite score values in the neighbourhood.

The result is again a granite score map. This can be displayed as a threshold map showing only those areas in which the spectral indices unambiguously identify bare granite outcrop. Alternatively, the varying degrees of confidence can be displayed in different colours, perhaps allowing better field validation of the accuracy of the mapping.

We see scope in pursuing these lines of investigation through a combination of ground-truthing and extending the geographical coverage across other landscapes in south-western Australia where granite outcrops are common. The potential to produce an atlas of Western Australian granite outcrops based on remote sensing imagery is encouraging, and merits further analysis.

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