Processing LANDSAT Thematic Mapper imagery for mapping surficial geology, District Keewatin, Northwest Territories

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Abstract

The classification results from a Landsat TM image and a surficial geology map produced from air photo interpretation at a scale of 1:125 000 were digitally compared. The digital nature of the maps facilitated the evaluation, particularly with respect to areal comparisons. We conclude that the classification results were similar and that the data should have a wide application to mapping surficial geology in other areas of the Arctic. The discrepancies were due to human interpretation on the conventional map or overlap in the spectral signatures on the TM map. The TM map has the added advantage of facilitating the integration of other geological data sets.

Résumé

Les résultats de classification obtenus grâce aux images prises par un satellite Landsat muni d’un appareil de cartographie thématique ont été comparés numériquement à une carte au 1/125 000 de la géologie des formations en surface obtenue par interprétation de photos aériennes. Le fait que ces cartes étaient numériques a simplifié cette évaluation, particulièrement en ce qui a trait aux comparaisons de superficies. Ces deux méthodes ont donné des résultats similaires et, en outre, ce type de données pourrait s’avérer très utile pour cartographier la géologie des formations en surface dans d’autres régions de l’Arctique. Les résultats non concordants étaient attribuables à l’interprétation dans le cas de la carte classique ou à un recouvrement des signatures spectrales dans le cas de la carte obtenue avec l’appareil de cartographie thématique. Cette dernière carte est d’autant plus pratique qu’elle permet également d’intégrer plus facilement d’autres ensembles de données géologiques.

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INTRODUCTION

Satellite imagery has been used to map surficial sediments with varying degrees of success. Several studies have commented on useful results (Rencz and Shilts, 1981; Hornsby, 1983); whereas other studies have noted limitations (Belanger and Rencz, 1984; M.D. Clarke, pers. comm., 1989). In general, the results are dependent upon several factors: type of imagery, scale of output map, and the nature of the environment.

The successful application of digital TM data to mapping would have several benefits: 1) TM imagery would greatly reduce field costs and production times; 2) The production of digital map products would be facilitated; 3) The digital map base would facilitate map revisions and 4) The digital map base would promote integration of surficial data with other forms of geological and topographic data sets.

The evaluation of LANDSAT capabilities to produce a map is difficult to undertake if a purely objective appraisal is required. Generally this is accomplished by overlaying a point grid on two maps- a LANDSAT derived map and a ‘truth’ map- and comparing the classification results at a number of points. A more effective method may be to digitize the conventional map and to register this product with a map generated from TM imagery. This could permit a comparison of the two maps by looking at the overlap between them on an areal basis rather than at sample points only.

In the current study, the objective was to determine whether TM images can be used to map surficial geology. This was assessed for a low arctic tundra location in the District of Keewatin, by comparing a TM derived map with a 1:125 000 scale map of surficial geology (Aylsworth et al., 1979).

STUDY AREA

Surficial Geology

The study area lies on the eastern flank of the Keewatin Ice Divide (KID) which was the position to which the last great ice sheet shrank west of Hudson Bay (Fig. 1). The KID was also a major centre of glacial outflow during the Wisconsinan stage. Ice flow across the region was generally southeastward and eastward from the KID as it migrated tens of kilometres eastward during the final phases of the last glaciation. Deglaciation of the area was by means of downwasting on what was by then a very thin, relatively stagnant ice mass. As the low gently rolling landscapes became ice free, the postglacial Tyrell Sea inundated the area which had been isostatically depressed, to an altitude of approximately 155m. Following deglaciation and marine recession, the land has been exposed to periglacial processes and minor alluvial action.

The surficial geology of the study area is typical of much of the region underlying or lying close to the KID-
The processing of the conventional map was carried out on a micro-computer using a commercially produced geographic information system (TYDAC, 1989). An area of 30 x 30 km was outlined on the map. The boundries of all the surficial units on the conventional map were digitized manually. An area of 30 x 30 km was outlined on the map and all the units in this area were traced.

The units on the conventional surficial geology map of the study area can be summarized as follows. Rock (R) designates areas of greater than 80% bedrock outcrop; in this region mainly layered Archean gneiss. Rock/till (R/T) is a generalized unit designating areas of discontinuous till plain with 20 to 80% bedrock outcrop or bedrock very close to the surface. Till plain (Tp) consists of a blanket of pinkish or red, sandy silty till. Striped till (Ts) is a sub-unit of Tp and refers to the prominent striped pattern consisting of alternating stripes of light and dark-toned vegetation that runs parallel to slope direction. In some cases the light tone represents mineral soil. The striping probably results from solifluction processes on particularly fine grained substrates. There are minor areas of ice-contact stratified drift (Gk). These are mainly small esker segments but also include small hummocky gravel deposits with a probable ice-contact origin. A few beaches occur, formed during marine recession, and are difficult to distinguish from small areas of Gk. As both Mn and Gk are unvegetated gravel deposits, they will have very similar spectral signatures, and for the purpose of this paper they are treated as one unit, beach/esker (Ag). Al is an undifferentiated unit of modern alluvium and marine mud, commonly peat covered and characterized by frost polygons and marshy areas; it also includes some areas of unvegetated alluvium.

**DATA SETS**

The LANDSAT TM image we have used for this study was acquired on 15 July, 1986. The thermal band (band 6) was not used in the classification. The map of surficial geology (1:125 000) was compiled from air photo interpretation with some ground verification (Aylsworth et al., 1981). The two maps will be referred to as the TM map and the conventional map.

**DATA PROCESSING**

**Digitizing Conventional Map**

The processing of the conventional map was carried out on a micro-computer using a commercially produced geographic information system (TYDAC, 1989). The boundaries of all the surficial units on the conventional map were digitized manually. An area of 30 x 30 km was outlined on the 1:125 000 map and all the units in this area were traced.

Each separate polygon on the map was given a unique identifying number and these were later grouped into their representative surficial geology classes using a look up table. The seven units as discussed above were: rock, rock/till, till plain, alluvium, beach/esker and water. The digitized map was 'imported' into the computer system using 5 geographic reference points. These points were used to ensure that the image of surficial data would be registered to a topographic map.

**Classifying LANDSAT TM Data**

The processing of the LANDSAT data was carried out on a micro-computer using the commercially produced image analysis system EASI/PACE (PCI, 1989). The initial step in processing the TM data was to classify the image into groups based on spectral information, in an attempt to match the classes on the surficial geology map. To accomplish this a 30 x 30 km area was designated as the study area and 6 bands of TM data were transferred to a micro-computer. A supervised maximum likelihood classification was used to group the data into seven surficial geology units. This was done by identifying 'training sites' that were known to represent a given surficial material, and by gathering statistics (mean and standard deviation of each band) for each of the units. The unclassified pixels were then allocated to the spectrally closest surficial unit based on their reflectance levels. The classification was facilitated by first enhancing the image on the image analysis screen (Fig. 2). The classified TM image (Fig. 3) and the digitized conventional map (Fig. 4) were brought into geometric alignment by registering the TM map onto the surficial map. This was accomplished by locating 17 matching ground control points on the two maps. This association between locations on the two maps was used for resampling the TM map. In this study a nearest neighbour resampling was used to preserve the integrity of the classified data.

The colour images (Fig. 2, 3 and 4) were made by downloading images to a VAX mainframe where digital plot files were generated using a UNIRAS program. Colour separation into cyan, magenta, yellow and black were made and four separate transparencies produced on an Optronics 4040 at Environment Canada.

**RESULTS**

There is an obvious visual difference between the two maps. The conventional map has relatively large polygons; whereas the TM derived map has more of a 'salt and pepper' appearance. This is a result of the pixel by pixel (30m x 30m) classification of literally hundreds of thousands of pixels which provides a level of discrimination far more detailed than humanly possible. Conversely, the conventional mapping method relies on generalizations for quite large areas because of the limitations of the human eye and patience.

Table 1 shows that the two maps provide similar areal estimates for each of the units. The biggest discrepancies were in the significantly higher levels of till plain (Tp) and...
Figure 2. Enhanced LANDSAT TM image displaying bands 4, 5 and 7 as varying intensities of red, green and blue, respectively.

Figure 3. Classified LANDSAT TM image showing 7 surficial geology units for the Ferguson Lake area, N.W.T.
lower estimates of rock (R) on the TM derived map. This result was not unexpected, developing, in part, from an overlap of spectral signatures.

A ‘confusion matrix’ was created to illustrate the comparison between these transitional closely related map units which are more arbitrarily differentiated than other, more distinctive units on the conventional map. Table 2 was calculated by superimposing the TM results for each unit on top of the conventional map. For example, of the area mapped as rock/till on the conventional map, 72% was similarly mapped on the TM image. Of the remaining 28% on the conventional map 2% was classified as rock, 11% as till plain, 5% as striped till, 3% as alluvium, 0% as beach, and 7% as water.

Generally, we feel that there is a good correlation between the classification results on the two maps. The most obvious problems occur in those units that are mapped by hand, more on the basis of a conceptual unit or because they represent small scale patterns discernable to the eye, such as the rock and striped till classes. The low classification accuracy in the rock class is due to the significantly lower estimate of rock on the TM map, whereas the low accuracy on the striped till class appears to be its confusion with the similar till plain and rock/till class. It should be appreciated that in most cases the errors in classification were confusions with classes to which a unit was generically very similar, for example till plain and the rock/till plain class. The relatively poor results for till plain are related to the larger class size on the TM map (as the conventional map has only 62% as much till plain as the TM map, the highest accuracy would be 62%) and the similarity between till plain and rock/till classes.

Table 1. Area composition of surficial geology units based on LANDSAT TM imagery and conventional methods for an area at Ferguson Lake, N.W.T.

<table>
<thead>
<tr>
<th>Unit Type</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>R/T</td>
</tr>
<tr>
<td>Conventional</td>
<td></td>
</tr>
<tr>
<td>TM</td>
<td>1.2</td>
</tr>
<tr>
<td>CONVENTIONAL</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Table 2. Confusion matrix illustrating the comparison between the conventional map and the LANDSAT TM derived map. The figures show, for each of the units mapped on the conventional map, how much of that unit was similarly mapped on the TM image and the area mapped as other units (confusion classes). Values in the diagonal represent the percentage of agreement between the two maps.

<table>
<thead>
<tr>
<th>LANDSAT TM Image</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>R/T</td>
</tr>
<tr>
<td>Conventional</td>
<td></td>
</tr>
<tr>
<td>TM</td>
<td>6</td>
</tr>
<tr>
<td>R/T</td>
<td>2</td>
</tr>
<tr>
<td>Tp</td>
<td>0</td>
</tr>
<tr>
<td>Ts</td>
<td>0</td>
</tr>
<tr>
<td>Ag</td>
<td>10</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 4. Surficial map of the Ferguson Lake area. Original from Aylsworth et al. (1981).
The spectral signature of the units is displayed for bands 1, 4 and 7 in Figure 5. The figure illustrates that although the spectral signatures grade into each other, each of the classes had a relatively unique signature at least on one channel. For example, the R and Ag classes were similar in bands 4 and 7, but showed no overlap of reflectance values on band 1. These results suggest that each of the surficial units probably has a specific spectral signature, and it would be difficult to make the TM classification more compatible with the conventional map. In other words, the major discrepancies between the maps cannot be eliminated by a better classification.

Comparison of the data sets was facilitated by their digital nature. There were, however, problems with the registration of the data sets and this adversely affected the map-to-map comparisons. Accurate registration was hampered by geometric inaccuracies in the original maps, hand tracing of lines, and the inability of any regular transform to register the maps perfectly. These misregistration problems undoubtedly affected the results, but it is not possible to determine the magnitude of this error.

CONCLUSION

Comparison of the maps illustrated several points that underlie the differences in the methods used in their production. Interpretation by the conventional mapping methods is naturally more subjective than interpretation based on mathematical algorithms. This permits the airphoto interpreter to integrate directly observed information about the region in the classification. However, this method produces a map that inevitably suffers from greater or lesser degrees of human inconsistency. A second factor that significantly affects the comparison of the two images is the scale at which discrete units can be represented. The TM image operates on a pixel by pixel basis, whereas in the conventional method, the interpreter uses a much broader generalization. The end result is that the TM map has significantly more polygons than the conventional map.

Notwithstanding the discrepancies between the two maps, TM and conventional surficial deposit maps showed what we consider to be a high degree of correlation. In general the maps were very similar, and differences were usually related to human interpretation of units on the conventional map. At the map scale chosen (1:125 000) the conventional method effectively yields classes that are sometimes mixtures of several units. The TM image is better able to represent detail of units because it is differentiated at a pixel size of 30 x 30m. The results suggest that LANDSAT TM imagery can be used effectively to map surficial sediments in tundra landscapes.

Furthermore, TM surficial deposit maps, because of their digital nature can be integrated easily with diverse sets of geophysical, geochemical, and other geological information that is also stored and collected in digital form. With conventional maps to provide the interpretive (subjective) context on which to base supervised classifications, the TM maps in areas of limited vegetation cover can provide a powerful base for evaluating mineral exploration and environmentally significant data.

REFERENCES

Cover Illustration

The colour image shows an area of eastern shore Nova Scotia underlain by rocks of the Meguma terrane. The image was made using a FIRE system at the Canada Centre for Remote Sensing (CCRS) by Jeff Harris (Intera Technologies and the Radarsat office of CCRS). The picture combines two image channels by means of an intensity, hue and saturation transform. Airborne side-looking radar values were used for intensity, estimated gold potential values (see Bonham-Carter et al., this volume were used for hue and saturation values were set to a constant.

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