IMAGE CLASSIFICATION FROM LANDSAT TM, AIRBORNE MAGNETICS AND DEM DATA FOR MAPPING PALEOPROTEROZOIC BEDROCK UNITS, BAFFIN ISLAND, NUNAVUT, CANADA

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ABSTRACT

A novel approach in image classification to bedrock mapping is applied to a 1:100 000 scale map area of the Meta Incognita Peninsula Baffin Island, Nunavut, Canada to support mapping of the Paleoproterozoic basement and cover boundary. The classification algorithm was trained by input from ground traversed bedrock geology, and applied to 7 TM bands, airborne magnetics and digital elevation data (CDED). We report the results of this investigation, with an emphasis on the comparison of interpretive bedrock mapping of the off-traverse areas. Focusing the training and the classification on the most exposed areas, by masking out overburden, vegetation and hydrographic features allows more specific targeting of bedrock exposures in the field. This approach supports remote geological mapping in similar geologic terrains were expense, access and inclement weather place severe constraints on the efficiency of traditional surveying. This research is a development contribution to enhance the ongoing natural resources management of Nunavut through partnership with the Geological Survey of Canada and its various geological mapping programs.

1 INTRODUCTION

A pilot study was undertaken to asses the usefulness of applying remotely sensed data from standard sensor platforms, such as airborne total field magnetic data and satellite based multispectral data (TM), as an aid in regional bedrock mapping in arctic terrains. The approach used was similar to previous work (An and Chung, 1994; Schetselaar et. al. 2000), which employs actual ground truth data of the bedrock geology from traverses across the study area to define the training set. The classification was conducted on areas dominated by bedrock exposures masked out from densely vegetated areas on the basis of a green vegetation index. The main objective of this preliminary investigation was to determine if regionally significant bedrock features such as 'basement ' and 'cover' could be predicted by combining various data types that individually would be less successful. The approach, if successful, could be employed before, during and after a detailed geological ground survey, as a tool to target specific tectonostratigraphic domains or areas of conflicting predictability, which require detailed analysis. Typically bedrock classification research has employed random spatial sampling of existing geological maps to act as the training set. As off-traverse areas are interpreted by geologists, and depending on methods used to extend lithologic units, the final geological map can have variable confidence. We assume that the highest confidence samples to be used for training are on the traverse lines. Provided the traverses reflect a reasonable sampling of the range and abundance of lithologies they should provide the most reliable data set to control the image classification.

2   GEOLOGICAL CONTEXT

The study area is located near the southeastern coastal region of Baffin Island, Nunavut on the Meta Ingognitia Peninsula (figure 1). The area has been recently surveyed at 1:100,000 scale by Quaternary (Hodgson 1997) and bedrock (St-onge et al. 1996a, 1996b) geologic mapping by the Geological Survey of Canada. Extensive well exposed (> 80% of total area) bedrock zones are characteristic of this area. Vegetation is confined to low lying shrubs, arctic grasses, moss and lichen cover. These more vegetated zones are typically located along river valleys, adjacent to lakes and coastlines. Quaternary studies suggest that the area has been extensively glaciated with many localized ice flow domains resulting in deposition of minor till cover in the study area.

Figure–1: Study area, roughly 60 x 60 km, in the arctic of Nunavut, Canada. Stippled pattern on detailed map indicates unconsolidated quaternary cover, white indicates lakes, coloured (Blues, Reds and greens) areas underlain by supracrustals of Level-3 Lake Harbour Group Markham Bay sequence (Hanging wall cover rocks). Grays indicate regions underlain by Level-2 Orthogneisses.
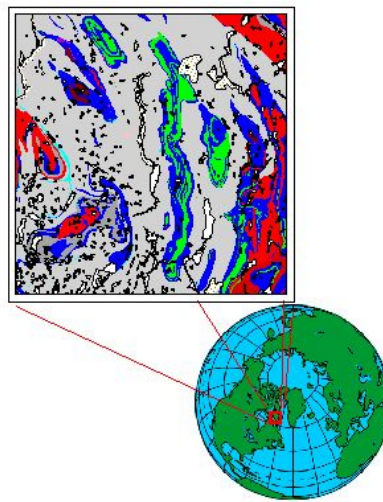

Topographic variation is from near sea level in the south to 800 meters in the central study area. A network of incised drainage valleys cut the area in roughly north-south direction (Figure 2). Much of the structural fabric in the region is characterized by northeast dipping gneissosities in orthogneisses and foliation/bedding fabric in supracrustal rocks. This contributes to the regional northwest-southeast grain to the landscape with numerous northeast dip slopes.

Figure-2: Digital Elevation Model of the study area. Elevation ranges from < 200 meters (Browns and tans) to 800 meters (Light to dark greens). Note northeast dip-slopes in top right of image.
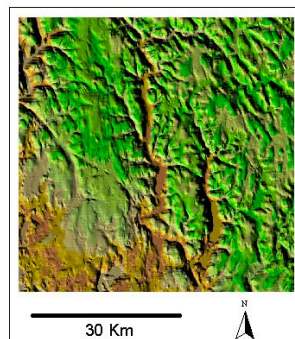
Paleoproterozoic metamorphic rocks in the study area display a range in lithologies from granulite facies mafic and quartzofeldspathic gneisses, granitoids, and mid to upper amphibolite supracrustal assemblages of Paleoproterozoic age (1857 - 1827 Ma; Wodicka and Scott 1997). Regional tectonostratigraphic subdivisions in the study area include two major subdivisions. A footwall othogneiss complex referred to as structural Level-2 and a hanging wall supracrustal assemblage of psamites, pellites and quartzites with minor marbles and peridotite, which constitutes structural Level-3. The supracrustal suite in this area is an outlier of the Markham Bay assemblage. This cover unit is also variably intruded by monzogranites from the Cumberland batholith suite. The boundary between these two regional classes is likely to be a regional scale découlment or thrust which has juxtaposed the supracrustal Level-3 rocks against Level-2 orthogneisses and tonalites (St-Onge et. al. 1996a, 1996b). For this study the Level-2 package is referred to as 'basement' and the Level-3 rocks as 'cover' (Figure-3).

Figure-3: General tectonostratigraphic subdivision of bedrock map units. Blue areas underlain by structural Level-3: supracrustal rocks of the Markham Bay assemblage (garnetiferous psammite, semipelite and quartzite) intruded by 1.85 Ga Cumberland Batholith monzogranites. Pink areas represent structural Level-2: orthogneisses (orthopyroxene – biotite tonalite, diorite and monzogranites). The boundary between Level-2 and Level-3 rocks is a Paleoproterozoic thrust. The thrust, and local associated imbricates, was subsequently polydeformed through two ductile folding events that result in dome and basin structures (central study area) and complex mushroom shaped interference patterns (southwest quadrant of the study area). Dips of the Level-2/Level-3 boundary thrust are generally steeper than topography. Average range of dips is 45° to 75°.


30 Km
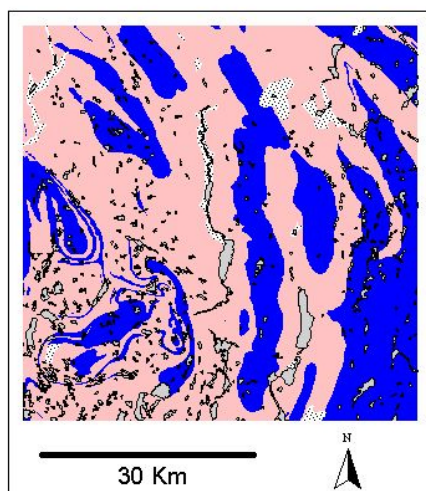
3 DESCRIPTION OF THE DATA AND PREPROCESSING

The study employed five main datasets (Figure-4). I) Digital topographic data in the form of CDED (Canadian Digital Elevation Data) gridded at 60-70 meters per pixel. This data was derived form 1:250 000 scale topographic contours. II) Geological map data in GIS format at 1:100 000 scale compiled from recent mapping. III) Digitized bedrock traverse lines used for the training locations, IV) 7 bands Landsat 5 Thematic Mapper (TM) imagery from August 15, 1995 and V) Total Field Magnetic data flown at 800 meter flight line spacing and gridded to 200 meters cells.

Vertices from traverse lines were used to sample the 'basement' and 'cover' classes from the geological map. These points were saved with coordinate and class information in a sequential ASCII file that could be used during the training phase. All data sets were gridded to a common pixel size (25.853 meters) and clipped to a common image dimension (2243 rows x 2173 columns). In addition a data mask was created from the addition of lakes, quaternary overburden and vegetated areas. The mask is represented as black areas on the TM colour composite image (Figure-4C) and as white areas on the classified images (figure-5). The vegetation component of the mask was developed using a GVI

(Green Vegetation Index) (B4 – B3) / (B4+B3). All values greater than zero, i.e. high GVI were included in the mask. The traverse lines represented 62,263 training pixels. The unmasked regions totaled 3,732,893 pixels. Using these values the training set accounted for less then 1.7 % of the training area. The total field magnetic data were processed to generate an apparent susceptibility map. This procedure essentially converts the total field measurements in a map representation of magnetization, provided that the magnetic anomalies arise from vertical prisms with the same depth to their tops and the same depth extent (Milligan and Gunn, 1997). Although these conditions are obviously violated in the area of study, the reduction to the pole and downward continuation filters involved in generating such a representation more likely yield patterns that match with surface geology patterns in comparison to the total magnetic field representation.

Figure-4 Summary of data sets used in the classification. A) Traverse lines, B) 1:100 000 geological map data. Detailed geology is displayed with shaded DEM. C) Landsat 5 – TM represented as linearly stretched colour composite using RGB bands 751. D) Total Field Magnetic data. Blues represent potential field lows and reds delineate highs.
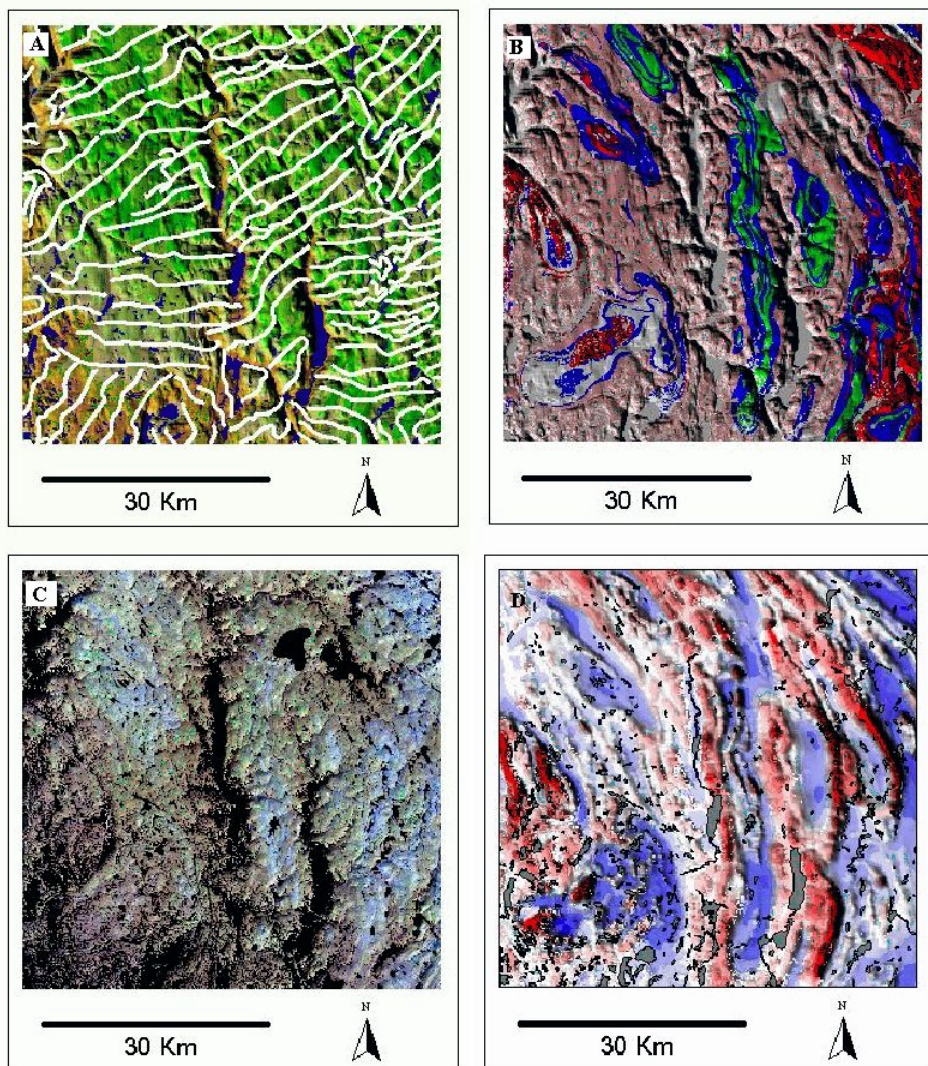
4   CLASSIFICATION OF LEVEL 2-3 AREAS

Three classification experiments to predict level 2-3 areas were conducted: one employing the TM bands, one employing the magnetic susceptibility channel and a classification on the magnetic and TM channels combined. All the image channels were augmented with their average filtered derivatives to exploit the spatial autocorrelation between pixels (Switzer, 1980). This method is applicable to the purpose of this study, because the units to be classified occur on a larger scale than a single pixel. Experiments with different classification methods revealed that the classification was not sensitive to a particular algorithm. The best results, however, were obtained with the Maximum Likelihood Classifier in which prior probabilities were set in proportion to the distribution of training samples over the two classes.
No unclassified pixels were allowed to map the patterns with the greatest structural continuity possible.

Attempts were made to utilize the DEM alone or in combination with TM and Magnetic channels. The resultant classification map patterns did not readily match any of the general geology and degraded the overall classification accuracy. The DEM was thus used only as a backdrop image to display the data for interpretive purposes. Future investigations aim at analyzing relationships between topography and the major classes. For example it may be possible that topographic highs could be used to isolate cover unit klippens, as is commonly observed in other fold and thrust terrains. Unfortunately this preliminary investigation did not reveal consistent relationships between the basement-cover contact and topography throughout the study area. Figure 5 shows the resulting map patterns of our classification experiments. Table 1 provides the confusion matrices obtained from the experiments.

Table-1: Classification Results Incognita Peninsula, Nunavut

Landsat TM (14 channels)

	Basement	Cover
Basement	86.2 %	49.0 %
Cover	13.8 %	51.0 %

Overall accuracy: 71.3 %

Magnetic susceptibility (2 channels)

	Basement	Cover
Basement	75.5 %	27.4 %
Cover	24.5 %	72.6 %

Overall accuracy: 74.3 %

Magnetic susceptibility and TM bands (16 channels)

	Basement	Cover
Basement	79.0 %	27.8 %
Cover	21.0 %	72.2 %

Overall accuracy: 76.2 %

Note: Classification results of Maximum Likelihood supervised technique applied in various band combinations. A combined quaternary, vegetation and hydrography mask was used to exclude areas from the classification. Total accuracy calculated by summing all correctly classified pixels and dividing by the total unmasked pixels. Masked pixels are excluded from the calculation.

Figure-5: Classification results by data set. A) The generalized geology map used to test the accuracy of the classification. Blue areas represent 'cover' and pink areas reflect 'basement'. B) Classification using 7 bands TM Bands, achieving 71% total accuracy. C) Classification using magnetic susceptibility as derived from downward continued magnetic data. 74% accuracy achieved. D) Combined magnetic and TM data results in 76% overall accuracy.
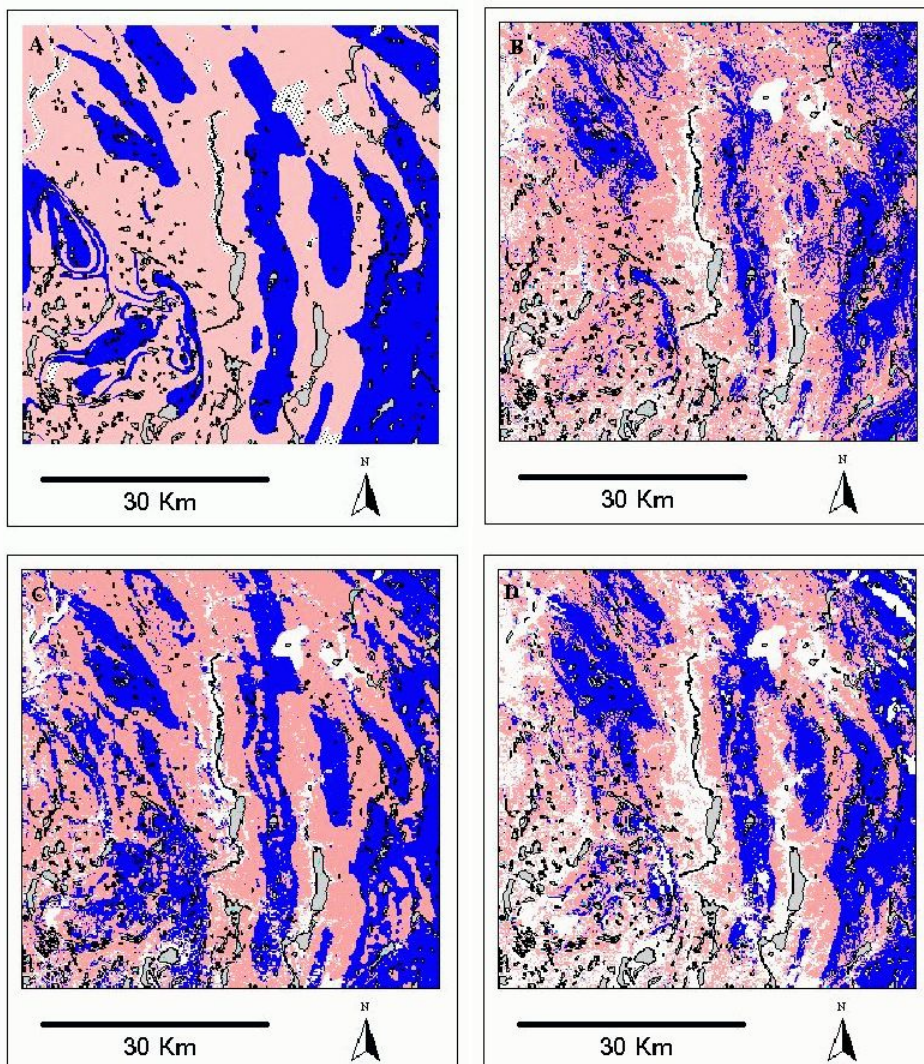
4   DISCUSSION

The classification on the basis of the TM channels shows a disproportionate performance in the prediction of basement and cover (85 % versus 52 %). This is largely the result of internal lithological variations in the cover that are misclassified as basement. These misclassified pixels are clearly reflected in the structural patterns that show-up in the classified patterns within cover (Figure 5 B). The classification of the magnetic data suggest a greater continuity of units in comparison to the TM classification and the geological map, possibly suggesting rapid transitions from unit to another in the near-subsurface.

The TM classification fails to identify the mushroom interference patterns on the SW quadrant of the area, only showing thin slivers of cover. This could be a result of a widening of internal class spectral signatures. This would result in spectral overlap of basement and cover rocks, which could cause either class to be misrepresented. A geological facies change in the supracrustal suite or more paragneiss components in basement rocks could account for this discrepancy.

An interesting observation that can be made form the results is that the classifications on the basis of magnetic data and TM data yielded similar coincidence percentages with the geological map, whereas their combined use only slightly improved the coincidence percentage. It essentially demonstrates that both data sets complement one another to only limited extent. This result would favour a classification approach where both data sets are used independently. Discrepancies with the geology map can than be tested against classification from independent remote sensing methods, reinforcing the significance of conflicting patterns. If, for example, both suggest a conflict with the geology map in an area between traverse lines, such an area would warrant attention in follow-up field studies. An additional advantage of this approach is that the magnetic data can be used to predict the basement-cover relationships underneath overburden.

5   CONCLUSIONS

• Combined data from Potential Fields Magnetic data from standard regional airborne surveys and TM multispectral satellite sensors can be used to give reasonable predictions of general bedrock classes. In this area 76 % accuracy can be expected for supracrustal verses othogneiss terrain classification.

• The TM data shows spectral contrast related to compositional variations between lithologies within the two structural levels that can be used to predict the basement and cover relationships. Misclassification of basement and cover in the TM data is likely due to spectral contrast both within the cover stratigraphic sequence, as well as lateral variations within individual units.

• The apparent magnetic susceptibility map provides a representation of surface and near subsurface geological patterns. Discrepant patterns with the geological map over several flight line intervals may be interpreted as areas where the basement-cover relationships occur at shallow depth. Although such an hypothesis requires further testing, such areas are potentially targets for magnetic inversion. In combination with structural observations from the surface this may prove useful to extend the mapping of the basement-cover relationships in the subsurface.

• Classification on the basis of seven TM band and a single magnetic susceptibility channel yield about similar performance. This result support classification approaches for the region where the data sets are separately classified. Areas where discrepancies with geological map patterns appear in both classifications, provide interesting target areas for map refinement.

• Pre-field, concurrent and post-field classification studies of this nature could be helpful during the planning stages of major field investigations, as an aid in targeting domains for detailed analysis and in extending well mapped areas beyond the training set.

• Further studies are required to determine the minimal ground truth training set that will be able to give useful predications.

• Further study is required to determine which additional discriminatory data layers, such as from advanced sensor technologies, will be able to enhance the predictive capacity of this method in the Arctic.

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