Geological Survey
of Canada

# Current Research
# 2000-C4

# *Spectral characteristics of bedrock map units using LANDSAT TM and topographic data: application to bedrock mapping in Borden Peninsula, Nunavut*

*A. Rencz, J. Harris, D. Sangster, and P. Budkewitsch*

2000

Natural Resources Canada
Ressources naturelles Canada

Catalogue No. M44-2000/C4E-IN
ISBN 0-660-18023-5

Available in Canada from the
Geological Survey of Canada Bookstore website at:
http://www.nrcan.gc.ca/gsc/bookstore (Toll-free: 1-888-252-4301)

A copy of this publication is also available for reference by depository libraries across Canada through access to the Depository Services Program's website http://dsp-psd.pwgsc.gc.ca. A list of these libraries can be consulted at this site or obtained by calling the toll-free number above.

Price subject to change without notice



## Authors' addresses

***A. Rencz*** *(rencz@NRCan.gc.ca)*
***J. Harris*** *(jeff.harris@NRCan.gc.ca)*
***D. Sangster*** *(al.sangster@NRCan.gc.ca)*
*Mineral Resources Division*
*Geological Survey of Canada*
*601 Booth Street*
*Ottawa, Ontario K1A 0E8*

***P. Budkewitsch*** *(budkewit@NRCan.gc.ca)*
*Canada Centre for Remote Sensing*
*588 Booth Street*
*Ottawa, Ontario K1A 0Y7*

# Spectral characteristics of bedrock map units using LANDSAT TM and topographic data: application to bedrock mapping in Borden Peninsula, Nunavut[1]

A. Rencz, J. Harris, D. Sangster, and P. Budkewitsch

Mineral Resources Division, Ottawa

*Rencz, A., Harris, J., Sangster, D., and Budkewitsch, 2000: Spectral characteristics of bedrock map units using LANDSAT TM and topographic data: application to bedrock mapping in Borden Peninsula, Nunavut; Geological Survey of Canada, Current Research 2000-C4, 7 p. (online; http://www.nrcan.gc.ca/gsc/bookstore)*

**Abstract:** The ability to characterize rock types based on spectra from remotely sensed data is being evaluated for an area of Arctic Canada. Training sites from fourteen previously identified bedrock map units (scale of 1:250 000) were used to test the separability of each rock type based on LANDSAT TM bands 1–7 and topographic data. Box and whisker plots using one variable at a time versus 14 bedrock map units showed differences between the rock units. Discriminant analyses based on the training sites correctly classified 91% of all classes when LANDSAT and topographic data were integrated. An accuracy of 79.1% was found using the seven channels of LANDSAT TM data. It is postulated that the satellite data are responding to mineralogical and/or chemical differences between the map units.

**Résumé :** Dans une région de l'Arctique canadien, on évalue la possibilité de caractériser des types lithologiques d'après les spectres provenant de données de télédétection. On a utilisé des sites d'essai correspondant à 14 unités cartographiques du socle précédemment identifiées (cartographiées à l'échelle de 1/250 000) pour éprouver la possibilité de différencier chaque type lithologique d'après des données des bandes 1 à 7 du capteur TM du LANDSAT ainsi que d'après des données topographiques. Des tracés genre rectangle et moustaches pour une variable à la fois en fonction des 14 unités cartographiques du socle ont révélé des différences entre les unités lithostratigraphiques. Des analyses discriminantes basées sur les sites d'essai ont permis d'identifier correctement 91 % des classes lorsque les données LANDSAT et topographiques sont intégrées. On a obtenu une exactitude de 79,1 % en utilisant les données des sept canaux du capteur TM du LANDSAT. On formule l'hypothèse que les données de satellite reflètent des différences minéralogiques et/ou chimiques entre les unités cartographiques.

[1] Contribution to the 1998–99 Central Baffin Partnership Project

## INTRODUCTION

The remote detection of different rock types is dependent upon a consistent and predictable relationship between mineralogy and spectral reflectance. Within minerals, photons are absorbed by a variety of processes including vibrational and electronic (Clarke, 1999). The absorbance processes are wavelength dependent so that certain features become diagnostic of a specific mineralogical or chemical composition. The sum of these processes may be integrated into a spectral signature that can uniquely identify a specific mineral. As these processes may be recorded over the entire electromagnetic spectrum, from short-wave gamma radiation to long-wave microwaves, phenomena that are not visible to the human eye may be identified.

The capability to characterize and discriminate minerals is dependent upon several factors including the 'radiometric resolution' or the spectral bandwidth of the data. This refers to the wavelength range for an individual channel of recorded data. The narrower the channel (shorter wavelength interval), the higher the probability in detecting specific absorbance features. The summation of these absorbance features across the entire spectrum constitutes the spectral signature of a rock. There must be differences in these spectral signatures if rocks are to be discriminated. Hyperspectral sensors are able to provide the full spectral range of data. The satellite sensor, however, samples selective wavelength intervals of the spectrum. Consequently satellite data may be useful to provide generalized 'large scale' mapping features, whereas the identification of specific minerals or even chemistry is most effect using continuous spectra taken from airborne or ground spectrometers. It should be noted that there are plans over the next few years to launch commercial satellites capable of gathering hyperspectral data in regions of geoscientific interest.

In the past, studies in hot desert environments, where the identification of minerals is not impeded by vegetation or moisture, have been successful. Recent reviews by Kruse (1999) and Sabine (1999) provide case studies from a variety of spaceborne and airborne studies. There are only limited studies on bedrock identification in arctic environments. It is possible that these environments may provide a similar desert-like environment that is amenable to remote sensing studies. The arctic environment, although desert-like, is not vegetation free as plant cover may be significant, particularly in the low arctic and lichens tend to cover most rock surfaces. In addition moisture may prove to be a problem as evapotranspiration rates are relatively low and surfaces remain wet for long periods of time. Chung et al. (1992) successfully illustrated the capabilities of merging several data sets (LANDSAT, radar, and geophysical) in predicting bedrock geology on Melville Peninsula. Their study identified geophysical data (radiometric data) as the most significant variable in the predictive model.

The present study, including personnel from GSC and CCRS, was initiated to assess the ability of remote and ground-based spectrometer data to discriminate different rock types and alteration types in arctic environments. A variety of remotely sensed and ground data will be assessed: LANDSAT TM, RADARSAT, airborne hyperspectral data, ground spectra, and rock samples. This report will cover the current status of the assessment of LANDSAT TM data as it applies to bedrock mapping in an area of the Borden Peninsula, Nunavut.

## METHODS

### *Study area*

The area is located on the northern end of Baffin Island (Fig. 1). It comprises parts of map areas NTS 48 A, 48 B, and 48 D and lies within co-ordinates 85°35′W;73°15′N (northwest) and 80°20′W;72°15′N (southeast).

The geology has been mapped at a scale of 1:250 000 (Jackson and Sangster, 1987) and Scott and De Kemp (1998) have provided a regional compilation. The compilation by Scott and de Kemp (1998) was published at a scale of 1:500 000; however it is based in large part on the map of Jackson and Sangster and will be considered as a 1:250 000 scale map. Three major subdivisions of rocks in the study area are 1) Paleozoic carbonate rocks; 2) Mesoproterozoic silicate, carbonate, and volcanic rocks; and 3) Archean volcanic and siliciclastic rocks (Table 1). The area is mainly underlain by the Bylot Supergroup (group 2 above), a late Proterozoic (Neohelikian) assemblage that Jackson and Sangster (1987) divided into three groups — a lower clastic group (Eqalulik), a middle carbonate platform (Uluksan), and an upper clastic group (Nunatsiak). The Archean rocks (group 3 above) are mostly migmatite but also include orthogneiss. Granitic intrusions are also present as aplite dykes, plutons and dykes of granite-granodiorite. There are early Paleozoic basin and shelf sediments (group 1 above) in the northern part of the study area.

For the most part there is very little vegetative cover. In places the Arctic Bay Formation supports a relatively lush cover of sedges, grasses, and heath plants. Lichens cover some of the rock surfaces although the carbonate rocks are generally lichen free.

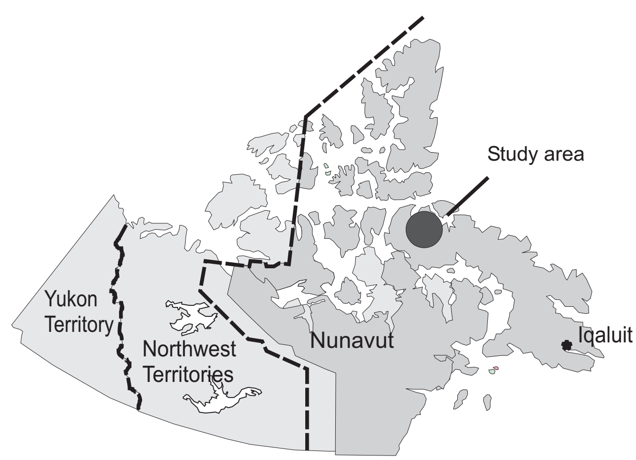


***Figure 1.*** *Location of study area in Borden Peninsula, Nunavut.*

**Table 1.** List of major bedrock map units for the study area on northern Baffin Island Island, Nunavut. Map units are from Scott and De Kemp (1998).

| Age | Group | Formation | Map unit | Index | Lithology |
|---|---|---|---|---|---|
| Paleozoic | Admirality Group | Frobisher Bay Fm | Ofb | 9 | Limestone |
| | | Ship Point Fm | Osp | 10 | Sandstone, dolomite |
| | | Turner Cliffs Fm | COtc | 14 | dolostone |
| Proterozoic | Bylot Supergroup | | | | |
| | Nunatsiak Group | Elwin subgroup | mPBel | 20 | Feldspathic sandstone quartz arenite |
| | | Strathcona Sound Fm | mPBss | 22 | Undivided, dolostone, shale, sandstone |
| | | Athole Point Fm | mPBap | 26 | Limestone |
| | Uluksan Group | Victor Bay Fm | mPBvb | 27 | Undivided limestone and shale |
| | | Society Cliffs Fm | mPBsc | 28 | Dolostone |
| | Eqalulik Group | Fabricious Fiord Fm | mPBff | 18 | Feldspathic sandstone arkose (more feldspar) |
| | | Arctic Bay Fm | mPBab | 32 | Shale |
| | | Adams Sound Fm | mPBas | 25 | Feldspathic sandstone |
| | | Nauyat Fm | mPBna | 36 | Basalt, siltstone |
| Archean | Mary River Group | Mary River (undivided) | AMu | 52 | Mainly basalt |
| | | (Gneiss) | Amn | 41 | Gneiss |
| | | Plutonic rocks | Agr | 68 | Granitic |

The major lithological groups within each of the formations are also presented in the Table 1. These were derived from Scott and de Kemp (1998).

### *Data*

LANDSAT TM data were acquired July 22, 1998. The data were collected over an area of approximately 180 km by 180 km with a spatial resolution of 30 m. Data are collected in seven different wavelengths: 0.45–0.52 µm, 0.52–0.60 µm, 0.63–0.69 µm, 0.76–0.90 µm, 1.56–1.75 µm, 2.08–2.35 µm, and 10.5–12.0 µm. E. de Kemp (pers. comm., 1999) provided a digital elevation model with a spatial resolution of 200 m. The digital geology was derived from de Kemp and Scott (1998).

Ground visits were made in 1998 and 1999. Several sites for each of 14 bedrock map units were visited (Table 1). At each site a rock sample was taken and geological description and geographic location were recorded. Samples will be analyzed for spectral response (0.4–2.5 µm), chemistry (major oxides), and mineralogy.

## RESULTS

Images produced from the LANDSAT data show a strong visual correlation to the 1:25 000 geology map (Jackson and Sangster, 1987). This indicates that the data are responding to geological phenomena and therefore the data should be useful in the production of geological maps. The analyses of the data were designed to assess which bands of data (i.e. what wavelengths and therefore what absorbance features) are significant and to identify the underlying rationale as to what the LANDSAT data are actually ‘seeing’. This was addressed by first looking at the variables one at a time and then in a multivariate sense.

### *Single variable analysis*

Box and whisker plots are effective tools to compare differences between rock types on a band-by-band basis. Figure 2 illustrates the comparison for 14 map units (plus water and vegetation) for several of the bands. Individually the bands show certain differences between the rock groups that are characteristic of the properties of the particular wavelength. For example data for band 6 (thermal emissivity) reflects differences between the three major divisions in the rock types. The ‘hot’ rocks are generally the gneissic and volcanic rocks of the basement group; the ‘cold’ rocks are carbonate and siliclastic rocks of Paleozoic age whereas the carbonate rocks within the Bylot Supergroup are intermediate. There is also a marked difference in thermal response amongst rock types 9, 10, and 14 within the Paleozoic group. The plots illustrate the ‘outliers’ which may represent sites that were not correctly classified on the original 1:250 000 geological map or they represent a facies of the formation that was mapped. Alternatively they may represent sites where environmental factors are affecting their spectral properties such as topographic position, vegetation cover, moisture, atmosphere, or weathering. Band 1 data illustrate higher reflectance for the Paleozoic rocks as a group but very little difference within that group. The higher reflectances are a result of the absence of any absorbing minerals in the rocks.

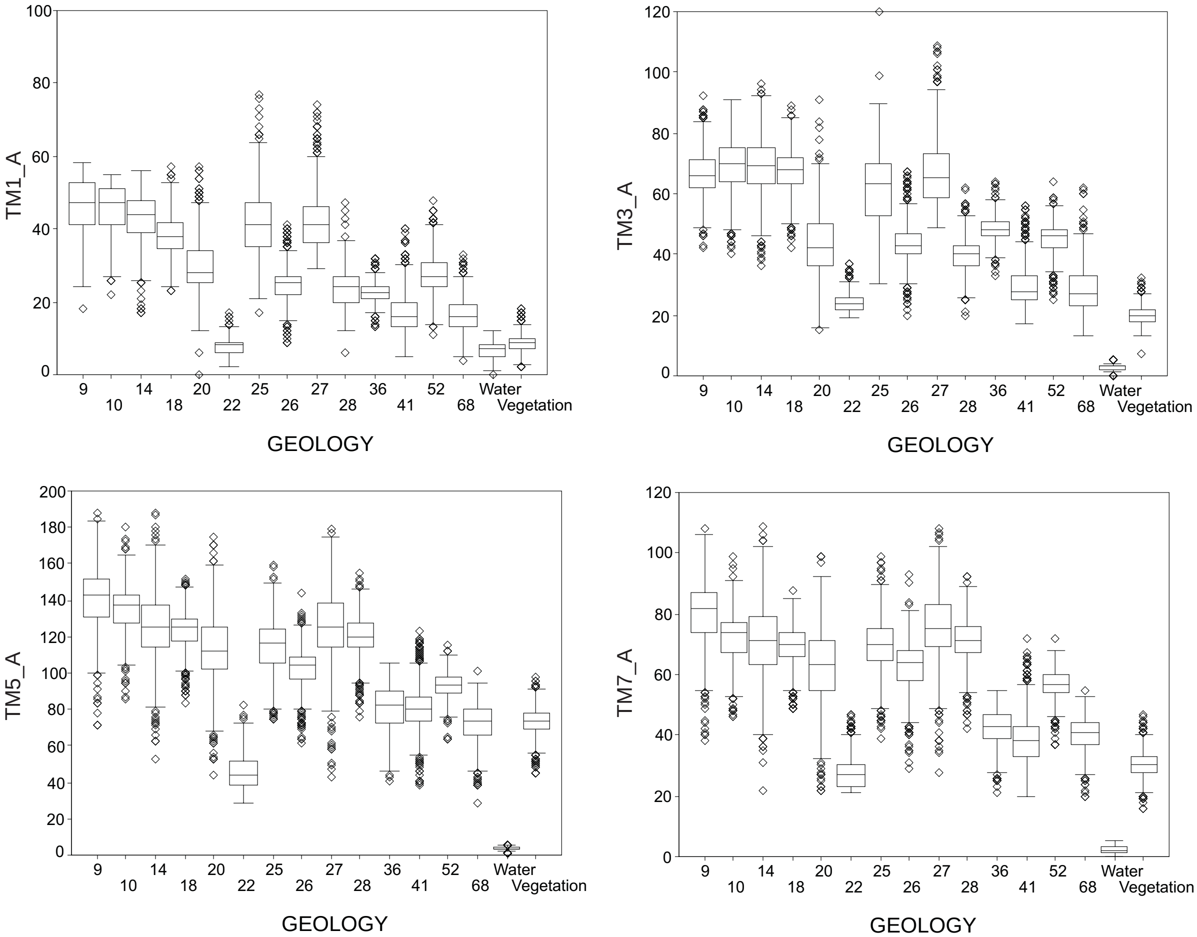


***Figure 2.*** *Box and whisker plots of LANDSAT TM data versus geological map unit for Borden Peninsula study area, Nunavut.*

Preliminary investigations to identify the geological rational behind the different reflectances are proceeding along several lines. First an attempt has been made to test whether data could be separated into silicate rocks or carbonate rocks. Table 1 illustrates the major lithologies within each of the formations. Knowledge of the lithology is important as each lithology has a characteristic mineralogy and chemistry whereas the formation, as a whole, will have a mixture of lithologies. In the study area there are two broad lithological groups, silicate and carbonate rocks. The carbonate group includes dolostone and limestone; whereas the silicate group includes sandstone, shale, basalt, and feldspathic sandstone. There is not a clear separation of the reflectances based on this broad grouping (i.e. silicate versus carbonate), possibly because these groups have a high degree of variation. For example the sandstone (silicate rocks) may contain up to 98% $SiO_2$ whereas the shale (also a silicate) are typically much lower (around 55% $SiO_2$). Further breakdown of the silicate group into several broad groups (shale, basalt, and sandstone) and carbonate into limestone and dolostone did not demonstrate any overall patterns. For example two formations that are dominantly limestone, Athole Point Formation (index no. 26, Table 1) and Frobisher Bay (index no. 9, Table 1) are distinctly different on all seven bands whereas compared to a dolostone dominated lithology (Society Cliffs, index no. 28, Table 1) the Athole Point Formation is similar on bands 1, 2, 3, and 4 and is only different on bands 5, 6, and 7. It is clear that the LANDSAT sensor must be responding to mineralogy but more in-depth analyses are required to isolate the specific target. Further insight into the underlying principles should be derived from chemistry (major oxides), mineralogical details, and spectral data and this will be addressed in future papers.

## *Multi-variable analysis*

### "3-D" scatter plots

Scatter plots using 1000 training sites were selected from the digital compilation for each of 14 different bedrock map units. This data were plotted using three LANDSAT TM channels at a time to determine if the data clustered into groups that reflected geological differences. For presentation purposes, data from only five geological formations and 100 sites (therefore 500 points) are presented in Figures 3 and 4. Figure 3, a plot of LANDSAT bands 4, 5, and 7, clearly illustrates that the data form relatively distinctive clusters that reflect the bedrock map units. The dashed lines around the clusters are subjective approximations of the limits of a bedrock map unit. The variation in the clusters, as with the box and whisker plots, identifies the need to examine and refine the geological classification and the need to quantify the influence of environmental variables.

Figure 4 (LANDSAT band 4, and band ratios for 5/7 and 3/1) illustrates the relationship for different map units than those used in Figure 3. Again there are five relatively distinctive clusters that correlate with the five map units: Turner Cliffs Formation, Society Cliffs Formation, Archean granite, Strathcona Sound Formation, and the Nauyat Formation. As in Figure 3, the spread in the data produces some overlap between the different groups.

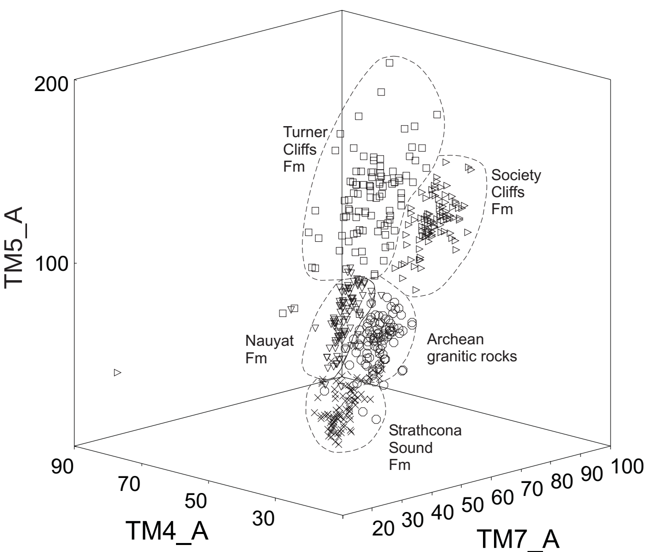


***Figure 3.*** *3-D scatterplots of LANDSAT TM data (bands 4, 5, and 7) for five geological map units.*

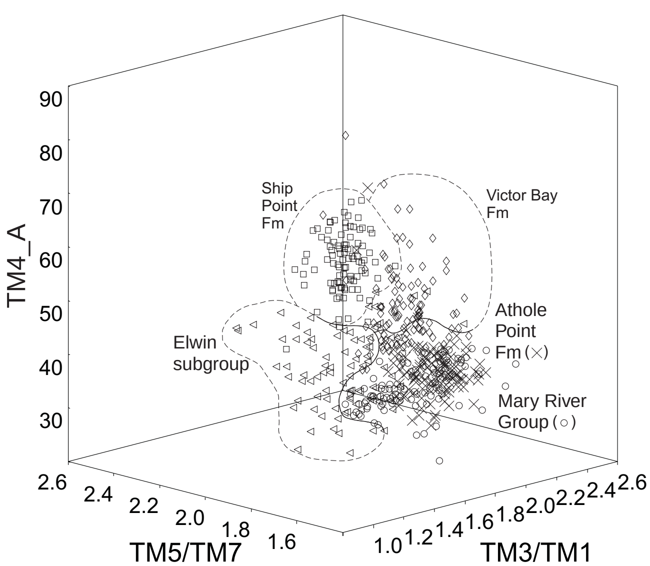


***Figure 4.*** *3-D scatterplots of LANDSAT TM data (bands 4, and ratios of 5/7 and 3/1) for five geological map units.*

## Discriminant analysis

Discriminant analysis is a multivariate technique that will classify data into various groups. This analysis is based on training sites from which a set of functions are derived that best discriminates the independent variable (bedrock map units) using a defined set of dependent variables (LANDSAT TM data and topographic data). These functions can then be used to predict a map unit based on the same set of input variables.

Table 2 provides classification results for 14 different bedrock map units based on different sets of input variables. The initial step in the process is to calculate functions that will best discriminate the independent variable based on a given set of input variables. The functions can then be used to classify each pixel into a corresponding bedrock class. Tables 2 and 3 list classification results for predicting the geology of the data used for training sites (in this case 100 training sites were used for each bedrock map unit). Depending on the set of variables, classification accuracy ranged from 48% to 91%. Variables included the seven bands of LANDSAT TM; TM ratios for TM bands 5/7 and 3/1, albedo, and several variables derived from the digital elevation model. The variables derived from the digital elevation model were slope and aspect, two factors that affect the absolute amount and wavelength of light energy that is reflected. A measure of albedo was calculated for each pixel by summing the six channels (excluded the thermal band as it measures emissivity as opposed to reflectivity). Prior to summing, each value was divided by the mean value for that channel. This variable was included to test the effects of total reflectance on the classification results.

There was an overall accuracy of 79.1% when only the seven bands of LANDSAT data were used in the classification. This was improved to 91% when information derived from the digital elevation model and a measure of albedo was

**Table 2.** Classification accuracies for bedrock map units using discriminant analyses.

| Variables | Per cent correctly classified |
|---|---|
| tm5/7, tm3/1, slope | 47.7 |
| tm5/7, tm3/1, aspect, slope | 49.4 |
| tm5/7, tm3/1, relief, aspect, slope, albedo | 64.2 |
| tm1–7, tm5/7, tm3/1 | 80.0 |
| tm1–7, tm5/7, tm3/1, aspect | 81.0 |
| tm1–7, tm5/7, tm3/1, slope | 84.3 |
| tm1–7, tm5/7, tm3/1, relief | 81.8 |
| tm1–7, tm5/7, tm3/1, albedo | 86.1 |
| tm1–7, tm5/7, tm3/1, albedo,relief | 86.2 |
| tm1–7, tm5/7, tm3/1, albedo, relief, elevation | 90.1 |
| tm1–7 | 79.1 |

**Table 3.** Classification results for predicted bedrock map unit (across top) versus classified map unit (along side) using discriminant analyses. *See* Table 1 for bedrock units.

| INDEX | 9 | 10 | 14 | 18 | 20 | 22 | 25 | 26 | 27 | 28 | 36 | 41 | 52 | 68 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **9** | **92.0** | .0 | 6.0 | .0 | .0 | .0 | .0 | .0 | 1.0 | 1.0 | .0 | .0 | .0 | .0 | **100.0** |
| **10** | .0 | **97.0** | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | 1.0 | 1.0 | 1.0 | **100.0** |
| **14** | 5.2 | .0 | **94.8** | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | **100.0** |
| **18** | .0 | .0 | .0 | **83.0** | .0 | .0 | 3.2 | 6.4 | 7.4 | .0 | .0 | .0 | .0 | .0 | **100.0** |
| **20** | .0 | 2.0 | .0 | .0 | **88.1** | .0 | .0 | 1.0 | 1.0 | 2.0 | .0 | 3.0 | .0 | 3.0 | **100.0** |
| **22** | .0 | .0 | .0 | .0 | .0 | **95.6** | .0 | .0 | .0 | .0 | .0 | 2.2 | .0 | 2.2 | **100.0** |
| **25** | 1.1 | .0 | .0 | 8.6 | .0 | .0 | **65.6** | 1.1 | 2.2 | .0 | .0 | .0 | 21.5 | .0 | **100.0** |
| **26** | .0 | .0 | .0 | .0 | .8 | .0 | 2.5 | **85.6** | 3.4 | 2.5 | .0 | .0 | 4.2 | .8 | **100.0** |
| **27** | 6.7 | .0 | .0 | 4.4 | .0 | .0 | 4.4 | 3.3 | **80.0** | .0 | 1.1 | .0 | .0 | .0 | **100.0** |
| **28** | .0 | .0 | .0 | .0 | 2.4 | .0 | 1.2 | 1.2 | .0 | **95.3** | .0 | .0 | .0 | .0 | **100.0** |
| **36** | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | **100.0** | .0 | .0 | .0 | **100.0** |
| **41** | .0 | .8 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | **98.3** | .0 | .8 | **100.0** |
| **52** | .0 | .0 | .0 | .0 | .0 | .0 | 5.8 | .0 | .0 | .0 | .0 | .0 | **94.2** | .0 | **100.0** |
| **68** | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | 9.1 | .9 | **90.0** | **100.0** |

incorporated. Incorporation of the albedo appeared to have limited affect while the majority of the increase (79.1% to 90.1%) is related to incorporation of slope, aspect, and elevation information.

A confusion matrix for the classification using LANDSAT TM, albedo, elevation, and aspect illustrates the 'correct' classifications as well as the classes to which 'incorrectly' classified pixels are grouped. This set of variables represents the highest overall accuracy (91%) from Table 2. The range of classification accuracies ranged from 65% (Adams Sound Formation) to 100% for the Nauyat Formation. The majority of the error in the Adams Sound Formation was due to misclassification into the Mary River Group.

The discrimination is evident in the plot of scores from function 1 versus function 2 from the discriminant analyses (Fig. 5). Although there are fourteen groups (therefore 1400 points) there is, for the most part, a clear separation of the pixels based on the map unit. The numbers on the plot represent the cluster centres for each of the map units (*see* Table 2 for number representations). These functions will be applied to the entire data set to produce a predictive map of the geology.

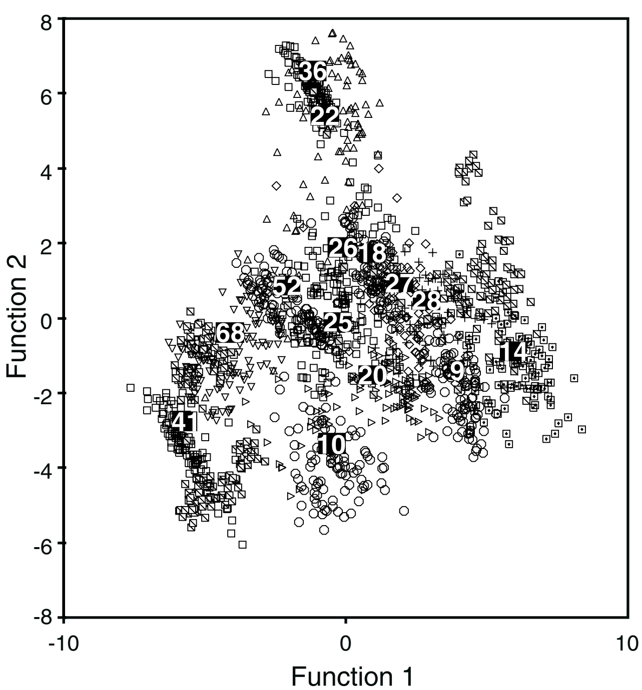


***Figure 5.*** *Function 1 versus function 2 from discriminant analyses of different bedrock map units. Numbers represent bedrock types as defined in 'index' column of Table 1.*

## DISCUSSION

In the study area there is a clear separation of the bedrock map units based on LANDSAT TM data. A random sample of 100 pixels from each map unit was classified into the 'correct' class with an overall accuracy of 79% using discriminant analyses of the seven bands of LANDSAT data. The accuracy was improved to 91% when information derived from the digital elevation model and albedo information was incorporated into the discriminant analyses. These results suggest that LANDSAT data should be effective tools in producing predictive maps of geology in the study area and possibility in other arctic areas. The role of vegetation including lichens and other environmental interferences does not appear to preclude the use of LANDSAT data for the discrimination of different bedrock types. The underlying explanation as to what the LANDSAT data are responding to is not clear. It is hoped that mineralogical identification, chemical analyses, and spectral analyses will indicate to what component of the different rock types that LANDSAT data are responding. Incorporation of radar data will also permit the role of texture (weathering patterns) to be included in the prediction.

The accuracy of the analyses was based on a 1:250 000 compilation that provided bedrock information at the formation level. LANDSAT data, with a pixel resolution of 30 m, may provide more detail than is presented at this scale. It is probable that the LANDSAT data are effective in identifying facies within this classification. For example Jackson and Sangster (1987) identify several groups within the Strathcona Sound Formation. On the digital map used in this study (Scott and de Kemp, 1998) these have been grouped into one, which was sufficient for a 1:250 000 scale. The spread in the reflectance data for this group may, in part, reflect the underlying differences in the geology. Further testing will concentrate on identifying the source of the variation for all the rock groups.

## REFERENCES

**Clark, R.**
1999: Spectroscopy of rocks and minerals and principles of spectroscopy; Chapter 1 *in* Manual of Remote Sensing: Remote Sensing for the Earth Sciences, (ed.) A.N. Rencz; John Wiley and Sons, New York, New York, p. 3–52.

**Chung, C., Gong, P., Rencz, A., and Schau, M.**
1992: Geologic mapping in Melville Peninsula, Northwest Territories, Canada using multi-source remote sensing and geophysical data; *in* Proceedings of International Geoscience and Remote Sensing Symposium, August, Japan, p. 913–916.

**de Kemp E. and Scott, D.**
1998: Geoscience compilation of Northern Baffin Island and Northern Melville Peninsula, Northwest Territories; Geological Survey of Canada, Open File D3636.

**Jackson, G.D. and Sangster, D.F.**
1987: Geology and resource potential of a proposed National Park, Bylot Island and Northwest Baffin Island, Northwest Territories; Geological Survey of Canada, Paper 87-17, 31 p.

**Kruse, F.**
1999: Visible-Infrared sensors and case studies; Chapter 11 *in* Manual of Remote Sensing: Remote Sensing for the Earth Sciences, (ed.) A.N. Rencz; John Wiley and Sons, New York, New York, p. 567–611.

**Sabine, C.**
1999: Remote sensing strategies for mineral exploration; Chapter 8 *in* Manual of Remote Sensing: Remote Sensing for the Earth Sciences, (ed.) A.N. Rencz; John Wiley and Sons, New York, New York, p. 375–447.

**Scott, D. and de Kemp, E.**
1998: Bedrock compilation North Baffin Island and northern Melville Peninsula, Northwest Territories; Open File 3633, scale 1:500 000.

Geological Survey of Canada Project 840051