THE USE OF MULTI-BEAM RADARSAT-1 FOR TERRAIN MAPPING

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ABSTRACT

Multi-beam RADARSAT-1 satellite imagery has been used as part of a regional terrain mapping program in northern Alberta, Canada. Principal components analysis (PCA) has been applied to ascending and descending standard beam modes with incidence angles of 20-27º (S1) and 45-49º (S7). The resulting components yield imagery that highlights geomorphology, geologic structure, variation in vegetation and a measure of moisture balance in the study area. These features are highlighted due to the interaction of incidence angles and look directions within and between the two beam modes.

1. INTRODUCTION

The use of radar imagery has been commonly employed for mapping geomorphology and geologic structure (Lewis *e*t. al, 1998; Singhroy et. al, 1993; Gupta, 1991, Singhroy and Saint-Jean, 1999, Smith et. al., 1999). The range of incidence angles, all-weather atmospheric penetration, and response to surface morphology give radar imagery significant advantages in measuring surface features relative to conventional fixed beam optical satellites. Radar imagery has been merged with optical and geophysical imagery (Harris et. al, 1994; Mustard, 1994) for the purposes of extracting information based on the synergies provided by the integration. Masuoka et. al (1988) applied the technique of principal components analysis on a radar image composite derived from Shuttle Imaging Radar (SIR-B) and Seasat. While most studies have focused on the use of radar for delineating geologic structure, it has also been used for mapping surficial geology (Graham and Grant, 1994).

RADARSAT-1 image characteristics are summarized by Luscombe et al., 1993. The RADARSAT-1 satellite operates at a single microwave frequency of 5.3 GHz (5.6 cm wavelength), generally known as C-band radar. The microwave transmission operates in H-H polarization mode. RADARSAT-1 Path Image (SGF) georeferenced images using a land based lookup table were provided by Radarsat International and the Canada Centre for Remote Sensing (CCRS). Each Standard Beam image is a composite of 4 looks (Raney, 1998, p. 73). This composite increases the signal to noise ratio at the expense of the spatial resolution. The imagery was provided at a nominal resolution of 12.5m (close to the single look spatial resolution) although the true spatial resolution of the averaged 4 look image is closer to 25m.

This study has focused on the use of principal components analysis (PCA) using RADARSAT-1 standard beam imagery as a tool for mapping surface features and geologic structures over large areas in Alberta, Canada (see Figure 1). Previous studies on the use of PCA with radar imagery (ERS-1 and CCRS C-SAR) found the technique useful for highlighting structural features in the Sudbury area of Ontario, Canada (Moon et. al, 1994 and Harris et. al, 1994). In the study by Moon et. al (1994), different incident angles, look direction, frequencies and polarizations were used to highlight geologic structure.

The detection of geologic structure is partially dependent on the look direction of the satellite (Harris, 1984; Lowman et. al, 1987). Studies have indicated (Harris, 1984) that linear features show up as distinctive lines in radar imagery when the feature is within 20 degrees of the perpendicular to the look direction of the radar sensor. In the case of using multi-beam imagery for RADARSAT-1 data, the identification of linear features is determined by a range of look directions that are different for each beam mode.

Singhroy and Saint-Jean (1999) have shown that variation in RADARSAT-1 incidence angles highlights ground features based on relief and surface texture. For this study, Standard Beam Modes S1 (20-27º) and S7 (45-49º) imagery was used to contrast the radar responses as a function of incidence angle and look direction (ascending-east looking /descending- west looking).

Figure 1.Location map of the study area filled by dark grey.

Figure 2 shows the configuration of beam modes and look direction for the image integration used for this study. Influences on the response are backscatter, which can be attributed to both volume and surface conditions, which in turn, are influenced by topography, vegetation and surface moisture (Raney, 1998). Lowman et. al (1987) describes the effect of incidence angle on the ability to detect

differences in topography in which is expressed by shading controlled by local incidence angle variation. Incidence angles that are shallow (S1) are better suited for highlighting the differences in topography.

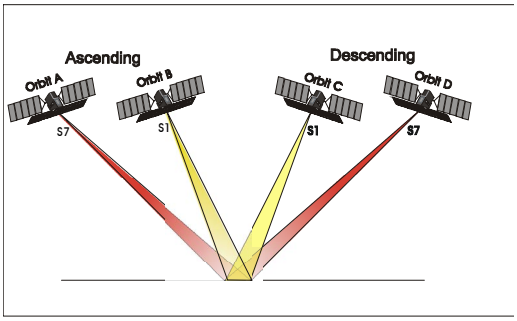

Figure 2. Multi-beam image assembly of RADARSAT-1. Each scene represents a distinct orbit pass. Effects of moisture content, and the state of the vegetation canopy can be different from one scene to the next due to temporal changes.

2. IMAGE ACQUISITION AND PROCESSING

The Alberta Geological Survey acquired RADARSAT-1 imagery for its regional mapping geologic program and for future applications in other areas of environmental monitoring and resource management (Grunsky, 2002). Two hundred and eighty Standard Beam modes S1 and S7 scenes were captured for both ascending and descending passes. Image acquisition was carried out over a ten week period from 01-Oct-1999 to 07-Dec-1999.

Autumn was chosen in order to minimize the effect of vegetation and to maximize microwave response from the ground surface. Although the effects of weather patterns are negligible on the radar response, factors that will affect the response include; the amount of surface moisture from significant rain events, and the loss of leaves in the deciduous foliage. These effects will cause some differences between scenes captured at different times. In this study, these effects have not been examined. However, it is unlikely that these effects would mask variation in terrain morphology or features associated with geologic structures. It is more likely that the loss of foliage will increase the contrast in features associated with structure and geomorphology.

For processing multi-beam radar imagery, the images must be orthorectified in order to minimize the effects of the shortening and layover associated with the difference in incidence angles. Orthorectification of the S1 and S7 imagery was carried out using digital elevation data provided by the Resource Data Division of Alberta Department of Sustainable Development. The data was provided in a grid form at 100 meter resolution.

A Gaussian smoothing filter was applied to the imagery to reduce speckle and highlight ground features. The filter implements a discrete 11x11 pixel (95% area under a normal distribution) Gaussian distribution applied over the image. The application of this filter improves the overall visual quality of the image and provides a closer approximation to a continuous tone surface, which permits identification of geologic structure, surface morphology, vegetation variation and cultural features.

Multi-channel remotely sensed imagery (multivariate data) contains responses that may reflect interactions between channels that are not visually obvious or are difficult to visualize from the individual source channels. A number of methods are suitable for contrasting differences in measurements over geographic areas. When two images are being compared, methods such as ratios or subtraction can be applied and can yield suitable contrasts. When three of more images are compared, contrasts become more complicated and multivariate techniques may be more appropriate. The method of PCA creates linear combinations of variables (channels) based on the covariance of the input channels and is commonly available with satellite image processing packages. The application of principal components is one method that can be used to discover interactions between the multi-channel data. Each successive principal component represents a linear combination of the input channels, which accounts for a portion of the overall variation of the data. The first principal component accounts for the most variation (by definition) followed by successively low order components which account for decreasing variation of the data. Each component can be viewed as a new variable (or channel) that describes relationships of the original variables in the form of linear combinations. Discussions on the use of PCA can be found in Richards (1986) and Gupta (1991).

3. STUDY AREA

In many parts of Canada the glacial surface deposits are characterized by till, sand and clay (Klassen, 1989). Glacial activity modified the surface leaving behind deposits of sand, till and clay along with glacial features such as drumlins, hummocks, outwash fans, and glacio-lacustrine deposits. These features have distinctive ground textures and have the potential to reflect differences in the radar return responses. In addition, the type of vegetation that grows over the glacial deposits is often characteristic to that type of terrain. As a result the variable backscatter associated with differences in vegetation can emphasize differences in the soil surface conditions.

The area chosen to apply the methodology of PCA on multi-beam radar imagery is located in northeast Alberta; National Topographic Series (NTS) Sheet 74L. The geology of the area is at the eastern edge of the Western Canada Sedimentary Basin where the sedimentary cover thins over the earlier Proterozoic Athabasca Basin and crystalline basement rocks. The area is covered with recent alluvial and organic deposits. Pleistocene age deposits include, aeolian sands, moraine, glacio-lacustrine and glacio-fluvial deposits. The surficial geology of the area was previously mapped by (Bayrock, 1971,1972).

4. RESULTS

The PCA methodology that was applied for the imagery used in this study generates eigenvalues and eigenvectors based on a correlation matrix generated from the four images (S1 Ascending/Descending and S7 Ascending/Descending). By definition, each successive component is orthogonal and in decreasing order. The results of the PCA on the correlation matrix are shown in Table 1. The table of R-loadings are the eigenvectors weighted by the contribution of the eigenvalues. Thus, the magnitude and sign of the R-loadings indicate the degree of significance and orientation of each variable (channel).

Table 1 shows that the first component contributes 57.2% of the overall variation in the imagery. The first principal component (not shown) is dominated by S7 Descending (S7D) , S7 Ascending (S7A) and S1 Ascending (S1A). S7A, S7D and S1A all contribute to the overall brightness of the first principal component. S1D makes a smaller contribution. Thus, the range of brightness value is contrasted between incidence angle differences. Look direction does not appear to be as significant. This could imply that the difference between responses between incidence angles is a function of the dielectric constant effect surface roughness, and vegetation differences (density and structure).

The second principal component (24.0% of the total variation) is dominated by S1 Descending imagery (S1D). The R-loading value of S1D shows that it has a magnitude of 0.899 and is at least twice the magnitude of the other channels. S1D is inversely associated with S7A and S7D for this component. This implies that scene brightness and variability is controlled by incidence angle and look direction. The R-loadings also indicate that the S7 images are opposite in sign to the S1 images. This inverse association implies that bright areas in S7 scenes are dark in S1 scenes, and vice-versa. In terms of the relative contributions, more than 80.8% of the variation of the S1D response is accounted for by the second principal component. A comparison of the image of this component (not shown) with the Alberta Land Cover Classification scheme (Alberta Dept. of Sustainable Development, 1999, shows that there is a good discrimination between forest canopy type (open/closed) and grasslands.

The third principal component (15.3% of the total variation) appears to be dominated by S1A. The magnitude of the R-loadings (Table 1) show that the S1D, S7A and S7D images are inversely associated with S1A. This supports the findings by Lowman et. al (1987) where steep incidence angles provide a better response for variation in topography. From the R-loadings shown in Table 1, S1D and S7A, S7D appear to have similar characteristics. The scene variability of the third principal component is controlled by the geomorphology. These relationships suggest that terrain features can be observed by contrasting look directions and is clearly shown in Figure 3. Fields of drumlins, sand dunes, eskers, embankments and other prominent topographic features can be clearly scene in this imagery.

The fourth principal component, which represents only 3.5% of the overall variation, shows little distinction between the channels. The imagery (not shown) shows differences in scene brightness and detailed features that include streams and small lakes. These features can be interpreted as being uncorrelated with other features in the image. The S7 Ascending and Descending channels are dominant over the S1 channels however these differences may be insignificant and might be artefacts of noise in the imagery. The variability of the fourth component is controlled by the contrast between look direction of S7A and S7D. S1A and S1D contribute little to the variability.

5. INTERPRETATION

The application of principal components is inherently dependent on the covariance (correlation) of the variables (imagery channels). Thus, the relative associations of scene response between different beam modes (incidence angles) and look direction, determines the correlations between the variables. Previous work by Singhroy and Saint-Jean (1999) has shown that Standard Beam Mode 1 is useful for identifying features in gently rolling or flat terrain whereas Standard Beam Mode 7 is useful for identifying features in areas of higher relief. The factors that affect these responses are; surface roughness, backscatter from the forest canopy and backscatter due to surface moisture.

Table 2. Eigenvalues, component contribution, and eigenvectors of the principal components analysis.

	λ1	λ2	λ3	λ4
Eigenvalues	2.287	0.958	0.613	0.141
% Contribution	57.190	23.960	15.330	3.530
Cumulative%	57.190	55.960	81.300	100.000
Eigenvectors	PC1	PC2	PC3	PC4
S1A	0.472	0.219	0.851	-0.068
S1D	0.285	0.871	-0.370	0.150
S7A	0.582	-0.382	-0.168	0.698
S7D	0.598	-0.216	-0.331	-0.697
R-Loadings	PC1	PC2	PC3	PC4
S1A	0.709	-0.209	-0.673	0.021
S1D	0.342	-0.899	0.270	-0.046
S7A	0.893	0.320	0.163	-0.272
S7D	0.907	0.188	0.264	0.268

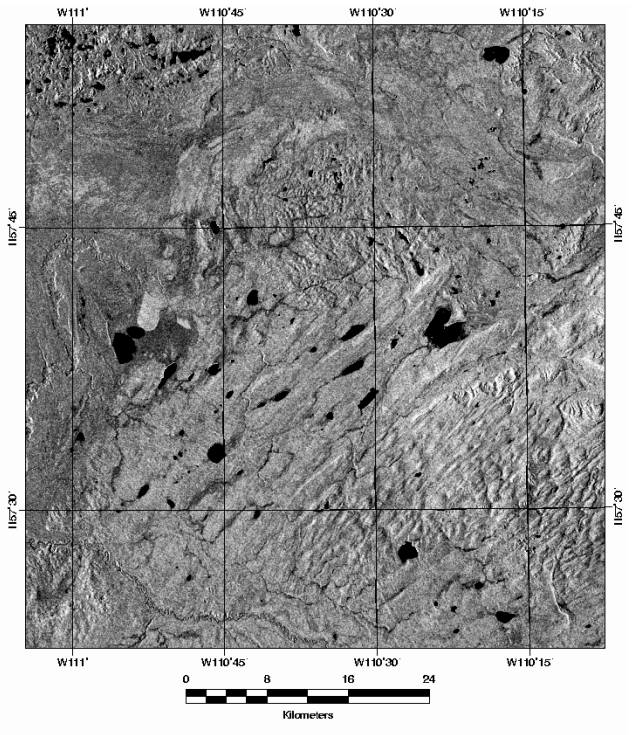

Figure 3. The third principal component of within NTS sheet 74E. Note the close match of glacial features between the geological map of Figure 4a.

Figure 4a shows a colour composite (RGB) image of the first three principal components. Features of geomorphology such as drumlins, ice crevasse fillings, sand dunes, etc. are highlighted through the contrast of the colours. Variation of vegetation shows up as varying amounts and combinations of red, green and blue. Areas of inferred increased moisture and forest canopy type have an overall darker intensity whereas areas that have little surface moisture display a brighter colour value. The colour composite clearly displays variation across the area that can be attributed to vegetation differences, surface roughness, surface moisture and topography. A study by Graham and Grant (1994) showed that X-band SAR imagery was useful for discriminating between different surficial deposits based on roughness and texture of the surface. The colour composite of the C-band RADARSAT-1 shows a range of colour and texture that outlines areas that match several of the surficial units mapped by Bayrock (1971) that is shown in Figure 4b. The areas of glacial outwash, ground moraine, aeolian, and ice contact deposits and fields of drumlins (noted as red ellipses) in Figure 4b stand out clearly in the images of Figures 3 and 4a.

6. CONCLUDING REMARKS

The application of principal components to multi-beam RADARSAT-1 imagery shows promise as a tool for identifying features associated with soil moisture, vegetation type, vegetation density and geomorphology.

As the principal components are based on the correlations of the input channels, the nature of the linear transformations of the original channels will be dependent on the variability of the terrain. In this study it appears that contrasts between S1 Ascending and S1 Descending imagery discriminates the features associated with the vegetation and geomorphology. This is consistent with the findings of Singhroy and St. Jean (1999) that state that the S1 beam mode is useful for evaluating features in gently rolling and flat terrain. Topographic enhancement was noted by Masuoka *et*. al (1988) using SIR-B and Seasat imagery. The topographic effect was the result of two opposite look directions of the Seasat images.

The features displayed by the imagery of the first principal component highlight the major differences between the S1 and S7 beam modes. From preliminary findings, it would appear that the contrast of these two beam modes highlight the difference between dry and wet surface conditions. Further investigations are required to test this interpretation. The use of a multi-beam radar image shows promise as a tool for surficial geological mapping as shown in Figure 3.

The methodology described here can be applied in various terrain types. The features extracted from the principal components will depend on the degree of relief in the area, the incident angles used (RADARSAT-1 beam modes) and look directions. From the work of Singhroy and St. Jean (1999) in areas of higher relief, S7 would likely play a more significant role in feature definition, while S1 would likely be less significant.

This methodology has been applied in the Buffalo Head Hills area of northern Alberta (NTS Sheet 84A/G) (Eccles et. al, 2002; Pagannelli et. al, 2001, 2002), where RADARSAT-1 S1 and S7 imagery were used to study the relationship of geologic structure with the presence of kimberlite intrusions.

The methodology of combining multi-beam RADARSAT-1 imagery using the method of principal components analysis shows promise as a tool for terrain mapping at a regional scale.

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REFERENCES

Alberta Dept. of Sustainable Development, 1999. *Alberta Ground Cover Classification, NE Boreal Region*, Final Report, Dendron Resources Surveys Inc., February 1, 1999, 31p, CD-ROM

Bayrock, L.A., 1971. MAP 140 *Surficial geology of the Bitumount area*, Alberta, NTS 74E.. re-issued 2000

Bayrock, L.A., 1972. MAP 141 *Surficial geology of the Fort Chipewyan area*, Alberta, NTS 74L, Scale 1:250,000

Eccles, D.R., Grunsky, E.C., Grobe, M., and Weiss, J., 2001. Structural Emplacement Model for Kimberlitic Diatremes in Northern Alberta, Alberta Geological Survey, *Earth Sciences Report 2000-01*, 103pp.

Graham, D.F., and Grant, D.R., 1994. Airborne SAR for Surficial Geologic Mapping*, Canadian Journal of Remote Sensing*, Special Issue on Radar Geology, 20(3), pp.319-323.

Grunsky, E. C. in press. Regional Terrain Mapping in Northern Alberta using RADARSAT-1, Alberta Geological Survey *Earth Science Report*.

Gupta, R.P., 1991. *Remote Sensing Geology*, Springer-Verlag, New York, 356 p.

Harris, J., 1984. Lineament Mapping of Central Nova Scotia Using Landsat-MSS and SEASAT-SAR Imagery, *Proceedings of the 9th Canadian Symposium on Remote Sensing*, St. John's, Newfoundland, pp. 359-373.

Harris, J.R., Bowie, C., Rencz, A.N., and Graham, D., 1994. Computer Enhancement Techniques for the Integration of Remotely Sensed, Geophysical, and Thematic Data for the Geosciences, *Canadian Journal of Remote Sensing*, 20(3), p. 210-221.

Klassen, R.W., 1989. Quaternary Geology of the southern Canadian Interior Plains; in Chapter 2 of *Quaternary Geology of Canada and Greenland*, R.J. Fulton (ed.); Geological Survey of Canada, Geology of Canada, No. 1, pp.138-173.

Lewis, A.J., Henderson, F.M. and Holcomb, D.W. 1998. Radar Fundamentals: The Geoscience Perspective, in: *Manual of Remote Sensing : Principles and Applications of Imaging Radar*, 3rd edition Vol. 2, John Wiley & Sons, p 131-181.

Luscombe, A.P., Feguson, I., Shepherd, N., Zimcik, D.G., and Naraine, P., 1993. The RADARSAT Synthetic Aperture Radar Development, , Canadian Journal of Remote Sensing, Special Issue RADARSAT, 19(4), pp.298-310.

Lowman, P.D., Harris., J. Masuoka, P.M., Singhroy, V.H. and Slaney, V.R., 1987. Suttle Imaging Radar 9SIR-B) Investigations of the Canadian Shield: Initial Report, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. GE-25, January, 1987, pp. 55-66.

Masuoka, P.M., Harris. J., Lowman, P.D. and Blodget, H.W., 1988. Digital Processing of Orbital Radar Data to Enhance Geologic Structure: Examples from the Canadian Shield, *Photogrammetric Engineering and Remote Sensing*, 54(5), May 1988, pp. 621-632.

Moon, W.M., Won, J.S., Singhryo, V., Lowman, P.D., 1994. ERS-1 and CCRS C-SAR Data Integration for Look-Direction Bias Correction using Wavelet Transform, *Canadian Journal of Remote Sensing*, Special Issue on Radar Geology, 20(3) ,pp. 280-285.

Mustard, J.F., 1994. Lithologic Mapping of Gabbro and Periodotite Sills in the Cape Smith Fold and Thrust Belt with Thematic Mapper and Airborne Radar Data, *Canadian Journal of Remote Sensin*g, Special Issue on Radar Geology, 20(3)), pp.222-232.

Paganelli, F., Grunsky, E.C., and Richards, J.P., 2002. RADARSAT-1 Principal Component Imagery: a case study in the Buffalo Head Hills area, northern central Alberta, *Canadian Journal of Remote Sensing*, in press.

Paganelli, F., Grunsky, E.C., and Richards, J.P., 2001. Structural Interpretation of Radarsat and Landsat7 TM Images for Kimberlite Exploration in the Buffalo Head Hills Area, North-central Alberta,10th Annual Calgary Mining Forum - *Alberta Geological Survey Minerals Section Open House*, April 18-19, 2001, Calgary, Alberta.

Raney, K.R, 1998. Radar Fundamentals: Technical Perspective, in: *Manual of Remote Sensing: Principles and Applications of Imaging Radar*, 3rd edition Vol. 2, John Wiley & Sons, p 9-130.

Richards, J.A., 1986. *Remote Sensing Digital Image Analysis*, Springer-Verlag, New York, 281 p.

Singhroy, V., Slaney, R., Lowman, P, Harris, J. and Moon, W., 1993. Radarsat and Radars Geology in Canada, *Canadian Journal of Remote Sensing*, Special Issue RADARSAT, 19(4), pp. 338-351.

Singhroy, V., Saint-Jean, R., 1999. Effects of Relief on the Selection of RADARSAT-1 Incidence Angle for Geological Applications, *Canadian Journal of Remote Sensing*, (25)(3), pp. 211-217.

Smith S.K., Grieve, R.A.F., Harris, J.R. and Singhroy, V., 1999. The Utilization of RADARSAT-1 Imagery for the Characterization of Terrestrial Impact Landforms, *Canadian Journal or Remote Sensing*, 25(3), pp. 218-228.

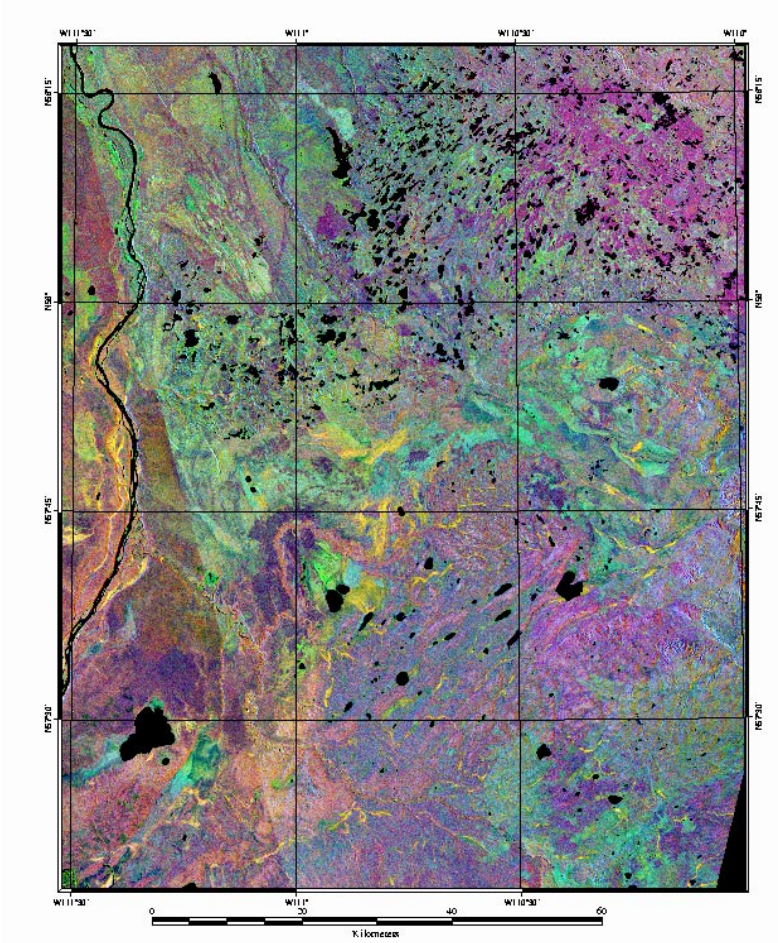

Figure 4a. A colour composite image of the first three principal components (Red – PC1, Green – PC2, Blue – PC3). The variability of colour and intensity displays features related to surface moisture, surface roughness, variation in vegetation and topography. Comparison with Figure 4a reveals features of the surficial geology in this image.match of glacial features between the geological map and the image. The image highlights features that were not noted in the map of the surficial geology.

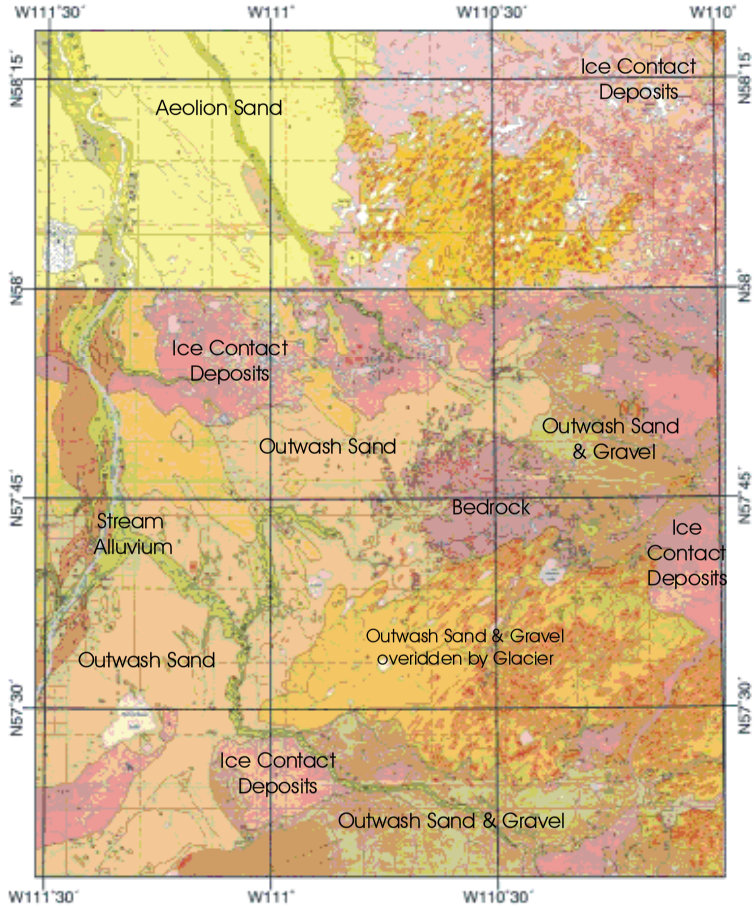

Figure 4b. A portion of the surficial geological map by Bayrock (1971) showing glacial features and major surficial deposits. Drumlins are shown as red elliptical features.