PROJECT ACTION SHEET

RESOURCE EVALUATION BRANCH

PROJECT NUMBER: 9237-P28-1E

COMPANY: PETRO-CANADA RESOURCES

REPORT TITLE: LANDSAT EVALUATION NORTHERN INTERIOR PLAINS DISTRICT OF MACKENZIE,NORTHWEST TERRITORIES

The following action has been taken:

Receipt acknowledged: YES

Reports and maps date-stamped: YES

Reports for review list edited: YES

Inventory sheet made: YES

Mylar: NO

REVIEW AND APPROVAL MADE BY: __________

COMMENTS: THREE COPIES OF REPORTS AND MAPS

PROGRAM NUMBER 9237-P28-1E

AREA DISTRICT OF MACKENZIE, NORTHWEST TERRITORIES

YEAR 1983

E.A. N/A

FILED UNDER: SAME

REPORTS

OPERATIONS REPORT: **NUMBER** 2

-LANDSAT EVALUATION NORTHERN INTERIOR PLAINS DISTRICT OF MACKENZIE NORTHWEST TERRITORIES

INTERPRETATION REPORT: **NUMBER** 0

MAPS

SHOTPOINT MAPS **NUMBER** 8

-LANDSAT LINEAMENT ANALYSIS (8 MAPS)

INTERPRETATION **NUMBER** 0

OTHER **NUMBER** 0

SECTIONS **NUMBER** 0

PROJECT NO: 9237-P28-1E
LANDSAT EVALUATION
NORTHERN INTERIOR PLAINS
DISTRICT OF MACKENZIE, NORTHWEST
TERRITORIES

Submitted By

Petro-Canada Resources
Canadian Frontiers Exploration

Dr. Ulrich Wissner
Petro-Canada Resources

Paul Fuenning, P. Geol.
P. Fuenning & Associates
Under Contract to
Petro-Canada Resources

PROJECT NO: 9237-P28-1E

L A N D S A T   E V A L U A T I O N

N O R T H E R N   I N T E R I O R   P L A I N S

District of Mackenzie, Northwest Territories

Survey Type:	Lineament and Tonal Anomaly pattern from Landsat Remote Sensing Data.
Locality:	The survey area lies within Latitudes 65°00' North to 70°00' North, Longitudes 122°00 West to 132°00 West.
Date of Commencement:	June 1, 1983
Date of Termination:	September 30, 1983
Operator:	Petro-Canada Inc. and, under contract, Paul Fuenning and Associates, Calgary, Alberta
Authors:	Dr. Ulrich Wissner, Petro-Canada Resources Paul Fuenning, P. Geol. Paul Fuenning and Associates

ABSTRACT

Geological reconnaissance mapping from Landsat data was conducted in a portion of the Northern Interior Plains of the District of Mackenzie, N.W.T.

An evaluation in the form of pattern recognition from Landsat imagery on a regional to subregional scale was planned and completed. The geological interpretation of the observed pattern, leading to a prediction of subsurface geological features with prospective merit for hydrocarbon exploration, was the target of this project.

In view of the many claims with respect to quality and geological usefulness of remote sensing data, their critical assessment in the light of more reliable data was of major concern in this study.

The resulting geological interpretation, compared with and checked against the very sparse outcrop control, regional gravity and aeromagnetics, and finally seismic control, indicates the following:

1. Landsat Remote Sensing is a valuable, additional tool for geological reconnaissance mapping in the covered areas of the Northern Interior Plains. Under favourable circumstances, anomalous structural features of prospect dimensions can be outlined on a subregional scale. These anomalies are interpreted as the expression of subsurface structures with prospective merit for hydrocarbon exploration.

2. As a general rule, published geological maps of adequately exposed mountainous regions in Canada cannot be improved upon through the use of Landsat data to a degree worthwhile the effort and expense.

3. In Canada's northern "Midnight Sun" regions Ascending Path data will be of great value for a variety of reasons. They are recorded on special request only, and the authors strongly recommend that CCRS include adequate Ascending Path data in the coverage of Canada's northern regions.

INDEX

LIST OF FIGURES

LIST OF APPENDICES

LIST OF MAPS

ACKNOWLEDGEMENTS

The writers express their thanks and appreciation for the co-operation, help, and advice received from the following institutions and their staff:

Alberta Remote Sensing Centre, Edmonton: Mr. Ken Campbell, Mr. Ian Sutherland, Mr. Gordon Reichert, Mr. Finn McCallum and Ms. Sandra Gabrielson.

Canada Centre for Remote Sensing, Prince Albert, Saskatchewan: Mr. Roy Irwin, Mr. Jerry Bergen, Ms. Susan Ross, Ms. Madeline Lepage.

Canada Centre for Remote Sensing, Ottawa, Ontario: Mr. Ian Press, Mr. Bill Bruce, Ms. Jo Ann Tlumby, Mrs. Jean Heffernan.

Futhermore, we wish to thank our colleagues at Petro-Canada Resources, especially D. G. Wilson, G. Collins, M. Dumitriu and L. McConnell for helpful discussions on a wide range of subjects associated with this project.

SECTION ONE

INTRODUCTION

1.1 Location

This project was proposed to expand and upgrade Petro-Canada's previous Landsat evaluation of the same scope in the area shown on the index map in Figure 1.

1.2 Data Acquisition

The images, purchased from and processed by the Canada Centre for Remote Sensing (CCRS), cover an area of about 190,000 km^2 (73,400 square miles) in the Northern Interior Plains, the Franklin Mountains, and the Mackenzie Plains between 65°00' to 70°00' North and 122°00' to 132°00' West.

A combination of false colour summer and winter scenes were used for maximum expression of geologically relevant features. In addition, black and white Return Beam Vidicon (RBV) images, which are similar to high altitude air photographs, were utilized to verify and/or modify the observed features, especially tonal anomalies. Appendix A contains a complete list of MSS and TM false color prints acquired by Petro-Canada for this study.

Magnetic tapes of selected areas were purchased from CCRS and digital processing was performed on the Aries II image analysis system at the Alberta Remote Sensing Centre (ARSC) in Edmonton. Various avenues of digital processing were investigated in a "trial and error" fashion, using the system's interactive display capabilities. The results ranged from disappointing to very encouraging. Where considered worthwhile, these individually processed subscenes were photographed and are documented and discussed within the text of this report.

The features observed on the images at the scale of 1:250,000 were transferred to topographic work maps of the same scale. The interpreted lineaments with highlighted major trends, tonal anomalies, and glacial directions are recorded on the seven final map sheets. The seven maps were also consolidated into a regional composite map at a scale of 1:500,000.

An earlier study by Kary, 1980, which served as an initial guide for land acquisition in Petro-Canada's exploration effort in the Northern Interior Plains region, concentrated on identification of tonal anomalies, employing techniques similar to those used by Haimila, 1975, and devoted only minor attention to lineaments.

1.3 Interpretation of Tonal Anomalies

Extensive vegetation and recent cover combined with morphologic and subtle topographic expression of glacial land forms mask and modify the underlying bedrock over large areas. Experience from conventional photogeology indicates that tonal anomalies are the weakest category with respect to surface expression of causative subsurface structures. The simplified block diagram in Figure 2 is shown as an example in support of the above statement. It illustrates a geological model for the tonal expression of the Tweed Lake anomaly, a topographic high with an associated drainage anomaly.

The tonal anomaly (summer scene) loosely coincides with, but areally exceeds, the two highs on the topographic map of the area (Figure 3). The two highs are separated and laterally offset by a northeast-striking saddle with associated drainage. Additional topographic and/or morphologic features are not apparent on the topographic map at the 1:250,000 scale. Morphologic criteria interpreted by pattern recognition from the Landsat summer scene (Figure 4) support the theory of a faulted anticline with linear (fault) termination along the eastern flank of the northern hill.

False colour prints of both summer and winter scenes in the Tweed Lake Anomaly area (contrast stretched at the ARSC) are shown as Figures 5 and 6, respectively. The row of very light coloured spots represents either very well drained dry areas, caused by local karst development, or patches of carbonate bedrock along the crest of the postulated anticlinal structure. Narrow bands of different tones, which conform to the general shape of the interpreted structure, are a geologically valid and acceptable pattern in support of the photogeological interpretation, regardless of the data source (airphotos, Landsat or radar imagery). They are most likely the expression of rock units of different lithology, either in outcrop, or subcropping under a thin surficial cover.

The strong expression of a half oval drainage pattern, a deflected drainage anomaly, on the north and west side of the northern hill, on both summer and winter scenes, is a very conspicuous feature in favour of the northern high which dimishes in supportive pattern towards the larger and stronger topographic high in the south. The same is the case for the well displayed radial drainage pattern on the summer scene. It is interpreted as the expression of a distinct type of vegetation which is related to small distributary streams and represents a classic example of radial drainage anomaly.

In conclusion, features which can be related to acceptable geological models are a stronger and more valid argument than tonal anomalies alone, regardless of how large these are and how strong they appear on a remote sensing data base. Therefore, a more conventional, less spectacular, but also less speculative approach to interpretation and evaluation was adopted.

1.4 Geographic Positioning of Scenes

Very early in the planning stage, it became apparent that the strongly recommended emphasis on precise geographic position processing was not as critical for our purpose as anticipated. We adopted the conventional approach of identifying the target features on standard processed, full scene, CCRS images. With the transfer of these features to the corresponding NTS topographic map sheets of the same scale, geographic position processing was of minor concern. Figure 7 gives an example of the actual position error of Kilekale Lake for Image 61-13 between the summer scene, winter scene and the topographic base map, NTS 96-K, Lac des Bois, scale 1:250,000. The offset, or position error, is about 2.5 km relative to matching Tweed Lake and Tunago Lake, which are about 80 km west of Kilekale Lake.

Furthermore, no merger of different scenes of the same image and definitely no merger of different data sets, such as Landsat, gravity, and aeromagnetics, was contemplated. In the writer's opinion, the current and increasingly fashionable approach of merging data sets of different origin and technical quality has as many drawbacks as it has merit for exploration. The danger in this approach lies in the apparent high quality of the low cost reconnaissance-type data, which by its nature remains wide open with respect to meaning and alternatives in interpretation. Their inherent ambiguity (of merged data) is in the final integrated picture, masked and unjustifiably upgraded by the higher quality and increasingly higher cost data such as aeromagnetics, gravity, geochemistry, and finally seismic. In our opinion, each data set has to be evaluated and interpreted on its own merit, allowing for a critical assessment of each set's scientific and technical value for exploration. This approach, its objective being to identify drillable prospects, has the economic advantage of successively selecting preferred areas, which decrease in size with increasing cost of the respective survey. If this can be accomplished--and only then--are we justified in utilizing the low cost reconnaissance-type survey in our exploration effort.

1.5 Digital Processing

Digital processing of selected subscenes at the ARSC included different band combinations and band ratios, directional filtering, and attempts at rock discrimination.

Overall, the project was conducted according to advice given in Slaney, 1981. "All investigations of Landsat imagery should be initiated with a visual analysis which should be the basis for deciding what other forms of analysis, if any, are needed to complete the study".

Mr. Paul Fuenning of Paul Fuenning and Associates in Calgary, Alberta was contracted to advise on, co-ordinate, interpret, and evaluate the image data in co-operation with Dr. Ulrich Wissner, Geological Advisor, Petro-Canada Resources.

SECTION TWO

TECHNICAL SUMMARY

2.1 Study Area

The original proposal to cover the entire Northern Interior Plains of the Northwest Territories could not be achieved and the project was restricted to the area of Petro-Canada's exploratory activity in the Northern Interior Plains. Also, a proposed eastwards extension, designed to include a 10 to 20 km wide strip of the Lower Cambrian and underlying Pre-Cambrian exposures along the Canadian shield, was abandoned.

As the study progressed it became increasingly clear, that dependable rock discrimination could not be achieved. We realized that time consuming field investigations of suitable training areas on the ground with measurements of spectral reflectance of the target formations would have been a prerequisite to determine the existence of specific and significant rock signatures. Time and budget restraints prohibited an additional program of this nature. Without it the targeted recognition of the depositional pattern of the Lower Cambrian Mount Clark sandstones and its relationship to the paleostructural pattern of the underlying Pre-Cambrian unconformity appeared as an "effort in vain".

The well exposed areas of the Mackenzie Mountains, even where covered by the images, were not evaluated, at least not in any detail. The published geological maps of the GSC, the very detailed photogeological maps of V. Zay Smith and Geophoto, and the excellent geological map compiled by Henry Raasveldt for Petro-Canada, cannot be improved upon from Landsat imagery to a degree worthwhile the effort and expense.

The final map sheets which are a composite of the 1:250,000 NTS series without cartographic features, were selected to keep their size manageable and to allow for future expansion.

2.2 Image Type and Selection

Based on P. Fuenning's past experience, and on information from colleagues and publications, a combination of MSS Bands 4, 5, and 7 was chosen as the most suitable band combination for the expression of average geological conditions on false colour prints of summer scenes. A combination of MSS Bands 4, 5, and 6 was used for winter scenes.

Three types of Landsat imagery were used in this study, namely Multispectral Scanner (MSS), Return Beam Vidicon (RBV) and Thematic Mapper (TM). The MSS and RBV imagery were acquired from the Canada Centre for Remote Sensing (CCRS) in Prince Albert, Saskatchewan and the TM Landsat imagery was acquired from CCRS, Ottawa. The MSS satellites carry four channels, the products of which are designated as Bands 4, 5, 6 and 7. The wavelength spans of these four bands are as follows:

Band 4	.5 - .6 millimicrons	- Green Reflectance
Band 5	.6 - .7 millimicrons	- Red Reflectance
Band 6	.7 - .8 millimicrons	- Near-infrared Reflectance
Band 7	.8 - 1.1 millimicrons	- Near-infrared Reflectance

The RBV system, present on Landsat 3, consists of two pan-chromatic cameras mounted side by side with a spectral response of .505 to .750 millimicrons. The TM sensor carries seven channels designated as Bands 1 - 7 inclusive. The wave length spans of these seven channels are as follows:

Band 1	.45 - .52 millimicrons	- Blue-Green Reflectance
Band 2	.53 - .60 millimicrons	- Green Reflectance
Band 3	.63 - .69 millimicrons	- Red Reflectance
Band 4	.76 - .90 millimicrons	- Near-infrared Reflectance
Band 5	1.55 - 1.75 millimicrons	- Mid-infrared Reflectance
Band 6	10.30 - 12.50 millimicrons	- Thermal IR (Heat) Emission
Band 7	2.08 - 3.25 millimicrons	- Mid-infrared Reflectance

The TM sensor functioned partially on the Landsat 4 satellite and is currently functional on the Landsat 5 satellite. The ground resolution of MSS imagery is considered to be 79 metres; that of RBV imagery is 38 metres and that of TM imagery is 30 metres, except for Band 6, which is 120 metres. A comparison of the resolution capabilities of MSS and TM imagery is outlined by Morgan et al, 1985.

The color images are achieved by registering and projecting the various bands through blue, green and red filters, respectively. The conventional false color composite is achieved by using Bands 4, 5 and 7 for MSS imagery and Bands 2, 3 and 4 for TM imagery. RBV images are available only as black and white prints. In actual practice, the MSS summer scenes were made using Bands 4, 5 and 7, while the MSS winter scenes were made using Bands 4, 5 and 6. Vegetation variances are best expressed on MSS Band 5 and TM Band 4. Water records as black on the infrared bands, namely MSS Bands 6 and 7 and TM Bands 5 and 7. Seismic lines are visible on TM Bands 5 and 7.

The ascending path TM imagery is considered significant since it affords another direction of sun illumination. The sun azimuth of the ascending path is N300°, as compared to N161°, sun azimuth of the conventional descending path. Appendices B and C contain index maps of Descending Path and Ascending Path Landsat imagery for the Northern Interior Plains area. The ascending path information is generally collected at night in this area, however, the project area straddles the Arctic Circle which has continuous sunlight at the time of the summer solstice.

To take full advantage of the synoptic view, CCRS standard processed full scenes at the scale of 1:250,000 were chosen for visual examination and subsequent evaluation. As a general rule, all points on these images are properly located within 4 km on the ground relative to the cartographic base. In 1979, CCRS developed a new MSS product, the Digital Information Correction System (DICS) image. It is a subscene of the MSS Landsat image, being one quarter of a standard 1:250,000 NTS map sheet in size. It is since available in increasing coverage, including computer compatible tapes (CCT's). Accurate placement of ground features to ±50 metres is claimed. These DICS products, especially CCT's are in most cases an adequate data base for additional detailed evaluation of anomalies of prospect dimension.

The bulk of the selected images are MSS data and only one TM scene was acquired and evaluated, representing about 3% of the total coverage. The reason for the under-utilization of this undoubtedly superior data base is twofold:

1) TM Landsat imagery is available only on Landsat 4 and 5. Landsat 4 ran into mechanical problems very early and failed in February, 1983. Only a few scenes were recorded until Landsat 5 began operations. The MSS imagery used in this study was ordered prior to January 12, 1984, and Landsat 5 was launched on March 1, 1984.

   Furthermore, TM data were initially printed by CCRS, Ottawa, as subscenes only which are quadrants of the full image. Hence, only subscene TM images were available during the course of this investigation. Currently full scene TM imagery is available from CCRS, Prince Albert, and any future Landsat investigations should utilize full scene TM imagery.

2) Mr. Ken Campbell of the ARSC informed us that past experience shows the probability for a good quality, cloudfree scene to be about 60% for one year and about 90% for two years operation of any one satellite under average weather conditions. For the Northern Interior Plains, the chances are even lower because of the short time span with suitable sun-angles for geological evaluation of Landsat imagery.

Figure 8 illustrates the effect of the Sun's elevation (sun angle) on the perception of detail on the Earth's surface. For hilly terrain, optimum sun angle conditions exist for about six weeks twice a year; for flat terrain the equivalent period is about four weeks, twice a year. With a flightpass every 18 days, this gives, for each of the dominant terrains in the project area, about six images for hilly terrain and about four images for flat terrain per year. The chances for a top quality cloudfree scene are limited accordingly.

The use of both summer and winter scenes for Landsat interpretation was considered a must in this region of mixed hilly and flat terrain. The summer scene, or better, late spring/early fall scene, was best for overall geological evaluation and recognition of tonal anomalies. The winter scene was most useful for maximum resolution of low relief features for lineament analysis. The relative merits of each are quite apparent in Figures 5 and 6.

The selection of high quality, cloudfree images was facilitated by double checking of data quality print-outs from CCRS and EROS. This was followed by an examination of the microfiche at the ARSC for the final selection.

2.3 Digital Processing

Digital processing from CCRS tapes was performed for selected subscenes and is documented and discussed in more detail in Section III. The following methods were tested:

1) **Contrast Stretch**

Intermediate breakpoint contrast stretch was applied, based on the range of brightness or intensity of reflectance values from histograms of each band. It resulted in a crisper image with a more definite contrast than the standard processed CCRS image.

2) **Band Ratio**

A variety of band ratios and ratio combinations were investigated in the Tedji Lake area. The results were disappointing. No new or better defined features emerged.

3) **Directional Filtering**

This method was applied to highlight previously recognized main directions of linears which were enhanced and emphasized. However, the results did not add appreciably to the previous pattern, in particular with respect to the good resolution of linears on the winter scene.

4) **Unsupervised Classification**

This method was investigated in the Tedji Lake area without conclusive results.

5) **Supervised Classification**

The reflectance pattern from known and well exposed outcrops was determined, a distinct colour designated and applied (pixel dump) to the selected subscene with promising results for rock discrimination.

SECTION THREE

EVALUATION OF LANDSAT DATA

3.1 Linear Features

3.1.1 Lineaments

Linear features of variable expression and continuity from false colour MSS summer and winter scenes were recorded on the Landsat imagery and posted on the corresponding NTS topographic maps of the same scale, 1:250,000. In addition, black and white RBV images were used for back up and confirmation. RBV images have better definition - nominal ground resolution is 38 metres for RBV data compared to 79 metres for MSS data.

Two categories, (1) distinct and (2) indistinct lineaments, were designated based on the strength of the individual linears. Major trends were highlighted as the final step in the lineament analysis process.

These major trends are generally interpreted as the surface expression of major fault zones, predominantly wrench faults, which were established in Proterozoic time and were rejuvenated during subsequent periods of tectonic activity up to the Laramide Orogeny of Late Cretaceous to Tertiary age. However, some of these trends could also represent extensively fractured zones in the Cherty Member of the Franklin Mountain Formation of Siluro-Ordovician age and/or karst development in the evaporitic carbonates of the Lower Devonian Bear Rock Formation. Both are either bedrock, under thin surficial cover, or subcrop at the major pre-Cretaceous unconformity, under a thin veneer of Cretaceous clastics.

Obviously, the geological interpretation of these major trends is very subjective. The final judgement is influenced by the interpreter's past experience, his knowledge of the regional geology with respect to the tectono-stratigraphic framework, structural pattern, tectonic history and evolution, and finally the interpreter's bias in favour of certain aspects of this overall geological picture.

Lineaments that are aligned with each other for an appreciable distance, regardless of their expression, are designated as major trend lineaments. Selection of the major trend lineaments is quite arbitrary, as others could have been selected.

We have concluded that the lineaments identified in this study present a structural framework for the area. It is felt that the majority of the lineaments represent either fractures or faults in the subsurface. The major trend lineaments are more apt to represent faults, whereas the shorter lineaments could represent either fractures or faults.

Nevertheless, not every lineament will be a fracture or fault, nor will every fault determined by seismic surveys appear as a lineament at the surface. Where a lineament is substantiated as a fault from seismic or well data, that lineament could indicate the trend and possible length of the fault. Concentrations and intersections of lineaments suggest fracture porosity in the subsurface.

Where seismic programs are planned, it is suggested that the seismic lines be positioned so that they transect lineaments, tonal anomalies and drainage anomalies. This practice was adopted in the layout of Petro-Canada's regional seismic programs shot in 1983. Regional lines were oriented so as to traverse tonal anomalies identified on Landsat by Kary, 1980.

3.1.2 Glacial Lineations

Linear features, which are not as sharp in appearance as lineaments, are a distinct pattern in local areas, frequently associated with rows of narrow, elongate lakes. Figures 5 and 6 show this pattern very well, especially on the west side of Lac Belot. Major directions and subregional departures are primarily related to the topography of the project area. Significant departures between 66° and 67° North and 128° and 130° West could also be related to changes in the subsurface. The gross pattern of these glacial lineations is illustrated in Figure 9. The Glacial Map of Canada, Geol. Surv. Canada, Map 1253A was useful in the identification of glacial lineations in the area.

3.1.3 Drainage Anomalies

An analysis of drainage patterns was made both from Landsat and from 1:250,000 topographic maps. Anomalous arcuate drainage patterns were recognized. Opposing arcuate drainage patterns are designated as deflected drainage anomalies. A series of complementary arcuate drainage patterns are designated as annular drainage anomalies. Annular drainage anomalies are considered to be better indicators of the subsurface structure than are deflected drainage anomalies.

These drainage anomalies may represent the surface expression of subtle differential compaction features in the subsurface caused by facies changes, draping over basement highs, subcrops, or reefs, or collapse features due to removal of salt. These compactional features could be expressed in an overburden of unconsolidated glacial drift by loading of glacial ice and by differential isostatic rebound in post Pleistocene time. A more detailed drainage analysis could be achieved by use of larger scale topographic maps and/or air photographs.

3.1.4 Topographic High Trends

This group of more or less linear features is relatively wide and can usually be identified with confidence on the winter scenes. On the summer scenes they appear as wide linear bands of tonal anomalies frequently interrupted by saddles and river cuts. Similar features of different origin are visible on summer scenes, and confirmation from topographic mapping is needed for proper identification. These linear bands are frequently accompanied by lineaments, a very short distance apart, which are interpreted as major fault zones.

These linear, topographic high trends, generally anticlinal, are geologically well known from surface mapping with respect to structure and stratigraphy. Landsat does not give any new or better information; on the contrary, the well established geology of these linear, anticlinal trends provides the skeleton for a meaningful interpretation of the region's surface geological framework.

The structural interpretation of these trends varies from one region to the other. In the Franklin Mountains they are asymmetric anticlines riding on deep-seated thrust faults which originate in detachment zones in the Proterozoic in the eastern Franklin Mountains. In the northern Franklin Mountains, they are detached in the Cambrian Saline River salt section, or are a combination of both detachment zones, which are a function of compressional tectonics. A similar origin of compressional tectonics during the Laramide Orogeny with a detachment zone in the Cambrian Saline River salt section is advocated for the Colville Hills region. However, it is this author's opinion, that, in this region, there is a high probability that these linear anticlinal trends are a function of wrench fault tectonics, or a combination of wrench fault and compressional tectonics.

3.2 Tonal Anomalies

The recognition of tonal anomalies, in particular, their significance and geological interpretation is very subjective, and the authors exercised considerable restraint in designating such features.

In the project area tonal anomalies are generally the expression of different types of vegetation as it relates to the surficial cover, soil types and conditions, moisture content and so forth. The spectral signatures of the vegetation types are only known in a first approximation and they change considerably with the season and with the health of vegetation. Even with this background knowledge the combination of different types in local ecological communities is subject to many variables. A specific investigation of these variables far exceeded the scope of this project Consequently, this study did not delve into the origin of tonal anomalies.

Over 100 tonal anomalies were mapped in Petro-Canada's previous Landsat study by Kary, 1980, and by D.G. Wilson. They were ranked in four classes: strong, medium, weak and questionable. For many of these anomalies the authors (Fuenning and Wissner) experienced considerable difficulties in detecting a geologically supportive pattern similar to that of the Tweed Lake Anomaly.

However, at a first glance at Landsat imagery, tonal anomalies will always draw the immediate attention of the investigator. They certainly represent anomalies which must be scrutinized and thoroughly investigated regardless of the many possible interpretations as to their origin and geological significance. Despite their cautious attitude and expressed reservations, the authors acknowledge the significant contributions of the earlier studies by Kary, 1980, and Wilson, and the paper by Haimila, 1975.

3.3 Digital Processing

3.3.1 General Comments

A limited number of methods were tested in a "trial and error" fashion to determine the usefulness and limitations of procedures for geological applications.

Our objective was the recognition of the emerging patterns as possible expressions of the subsurface geology. Identification of geologically acceptable features, even where alternate interpretations exist, should aid hydrocarbon exploration in the Northern Interior Plains area.

Using the CCRS standard processed images as our starting point, two improvements were of particular interest:

1) Improvements in overall appearance and clarity aimed at "optimum geological information display", as pointed out by Robinson and Carroll, 1977, who furthermore state: "An optimum system would make use of such facilities in an interactive mode so that enhancement can be done on a step-by-step basis and terminated as soon as the necessary clarity has been obtained".

2) Improvements of a specific nature, such as directional filtering, designed to emphasize a dominant direction or trend of lineaments.

All additional processing methods are subject to the negative aspect of trade offs. The more specific and exclusive the procedure, the more severe the trade off, either in supression of, or even elimination of other information contained in the original data base. For a discussion of trade offs the reader is referred to Sabins', 1978, discussion of "contrast enhancement" (pages 248-253).

The subscenes for additional digital processing were chosen for the reasons given below:

1) **Tedji Lake area**, the only gas discovery well in the Northern Interior Plains with approximate field outline from seismic information.

2) **Tweed Lake area**, a previously identified Landsat tonal anomaly with seismic coverage leading to a drillable prospect which subsequently resulted in a gas discovery.

3) **Hare Indian River area**, well exposed outcrop of Siluro-Ordovician carbonates of the Ronning group to investigate rock discrimination.

Furthermore, a portion of the Thematic Mapper data in the southwest quadrant of Image 56-14 was subjected to a variety of tests in view of the excellent data quality and the well known surface and subsurface geology of this area.

Selected products were documented on Polaroid prints; most were documented on Kodak negative film which proved superior in quality to Polaroid, especially for reproduction.

3.3.2 Contrast Stretch

Intermediate break point contrast stretch was tested in the Tedji Lake area and, in light of the improvement in overall appearance and clarity, subsequently applied to all other subscenes. A comparison of the stretched subscene in Figure 10 with the same area on the CCRS standard processed image in Figure 11 illustrates the improvement. The program was recommended by the staff of the ARSC based on past experience.

The limited range of recorded values from the histogram of each band, illustrated in Figure 12, was stretched over the full range to either side of the break point. Different options are available, and the choice varies with the target as discussed by Sabins, 1978, and shown in the examples in Figure 13. Even in this poor reproduction, the improvement of certain features and the suppression of others (trade off) is quite apparent. In our test cases the degree of improvement varied from one image to another, and no new features of geological significance emerged from this procedure.

3.3.3 Directional Filtering

Orientation filters, their attitudes determined by the structural grain of the particular area under study, were applied separately and in combination with a Band 7 stretch for summer and winter scenes. On-screen comparison with the CCRS prints and with known lineaments from topographic work maps showed no improvement of geological significance with a few minor exceptions. To the contrary, the very strong expression of the arrays of glacial lineations on the Tweed Lake example (portion of Image 61-13) in Figure 14 lacks their typical hazy or smudgy appearance for discrimination from lineaments. While minor lineaments are accentuated by the directional filtering technique, this processing method does not signifantly improve the quality of Landsat imagery. The use of unfiltered winter and summer scenes is adequate for regional lineament analysis work.

3.3.4 Band Ratios

Different band ratios were tested without conclusive results. Ratio images are prepared by dividing the Digital Number (DN) in one band by the corresponding DN in another band for each pixel. A DN indicates reflectance in a given pixel, and may range from 0 for solid black to 35 or higher for solid white. One advantage of ratio images is that a material has the same ratio value, regardless of variations in illumination (Sabins, 1978).

Tonal anomalies can be highlighted on summer scenes. A gross pattern of tonal subregions will emerge, as illustrated in Figure 15, an image produced by a combination of the Band 7/5 ratio and directional filtering.

The TM data in Image 56-14 were investigated on a broader basis. Different band ratios and ratio combinations are described in the literature for specific investigations, such as for rock discrimination, and for recognition of stressed vegetation. In view of the narrower spectral range of individual bands and their larger number compared to MSS data, examination of the resolution and tonal expression of single bands and band combinations was the first step. The results are shown in the black and white photographs in Figures 16 to 19. Bands 4 and 7 have the best imagery. Seismic lines are well displayed on Band 7, which is similar in quality to Band 5. Only a few of the possible number of ratios and ratio combinations were examined.

Band 6, the Thermal IR (heat) Emission band, was examined to investigate the expression of major fault zones (thrust faults) in this area by means of temperature differences caused by the probable ascent of warm water along such faults. This possibility is suggested by the presence of sulphurous hot springs in the Bear Rock Formation which outcrop in the Mackenzie Mountain front about 50 km to the south. A few very light-coloured linear trends are displayed in the image in Figure 21. They coincide (middle left side of photo) with the major thrust fault on the northern flank of the Imperial Anticlinorium, a feature well documented by surface geology and geophysics. Similar linear traces along Mountain River are most likely of the same origin.

3.3.5 Unsupervised Classification

This method was examined on-screen in a few areas, and documented both for the Tedji Lake subscene, and for TM data in the Norman Wells area. A combination of patterns or themes was determined by cluster analysis, and selected patterns were combined with the contrast stretched Band 5 image to generate the two examples in Figures 22 and 23. No pattern of geological significance emerged for this area, which is about 25% covered by some larger lakes and primarily dotted by a multitude of very small lakes. There is no indication for the presence of the Tedji Lake gas field and the displayed pattern has an extremely random texture.

In the display of the second order themes in Figure 23, some linear trends are more clearly outlined. A few additional minor lineaments were detected, compared to the CCRS print. The contrast stretched subscenes in Figures 24 and 25 are included for comparison. No new features resulted from application of the unsupervised classification procedure. Furthermore, the authors conclude that image processing, using supervised classification, will not improve the random texture in this particular area either.

A similar test was performed on the TM data in the Norman Wells area, illustrated in Figure 26. No cluster analysis was run in this case. Instead, band ratio combinations suitable for rock discrimination were selected from the literature and applied to this subscene.

This selection may be considered the initial step leading towards supervised classification to determine the signatures of the well known and mapped outcrops of the Kee Scarp and Imperial Formations at Powell Creek. Band ratio combinations for a false colour display were used to examine the resulting colours, which were expected to be specific and significant for each of the two formations or rock types.

The combination displayed in the left side image of Figure 26 shows distinct purple and white bands along the Kee Scarp outcrop and the image has an overall purple and green appearance. The very limited colour variation, compared with the right side image, and especially with the standard processed CCRS image in Figure 31, is a striking example of the "trade off" involved in special processing. The combination displayed in the right side image displays a distinct, very narrow, reddish-orange band along the Imperial Formation outcrop and has an overall good colour variation.

The carbonate (Kee Scarp) outcrops show a distinct colour tone: purple on the left side and light blue on the right side image. The same colours are well displayed in the bands of carbonate outcrops in the Imperial Hills area to the north, and in the valley fills of Mountain River and Powell Creek. The dominance of carbonate-derived clastics on the valley floor is to be expected. This geologically meaningful pattern indicates a valid signature for the rock types of these two formations and lends support for their use in subsequent applications in supervised classification.

3.3.6 Supervised Classification

3.3.6.1 MSS Data

The first test of supervised classification was performed on the Hare Indian River subscene of image 61-13, shown in Figure 27. The different rock types or formations exposed at the northern end of the Jacques Range, and in the escarpment near the bend in the Hare Indian River, were isolated, and their gross signatures applied to this enlarged portion of the summer scene. The following colours were assigned:

a) RED for the center of the Ronning outcrop in the Jacques Range;
b) GREEN for the scree of the Ronning slope in the Jacques Range;
c) BLUE for the leading edge of the Hume Formation in the Hare Indian River escarpment; and
d) YELLOW for the scree of the Hume slope in the Hare Indian River escarpment.

These morphologically distinct, "carved out" escarpments are very well outlined on the winter scene in Figure 28. The designated green does not show up at all on the classification output. This is probably caused by vegetation. The designated green colour is overprinted by and lost in the olive grey background of the dominating vegetation cover in the area.

The red Ronning signature in Figure 27 shows up over a length of about four kilometers on the northern tip of the Jacques Range and again on the south facing escarpment near the bend in the Hare Indian River.

The blue designated for the Hume Formation extends northwards along this escarpment adjacent to the Ronning. It also shows up in small patches scattered along the Ronning in the Jacques Range. This relationship suggests that the blue represents carbonates of the Bear Rock Formation, which overlies the Ronning and has an average thickness of 250 metres. The Hume Formation, which in turn overlies the Bear Rock, has an average thickness of 100 metres.

The yellow, designated for scree, is scattered in small dots over the entire subscene; mainly in the lighter tone areas which are interpreted as probable bedrock. They could represent patches of weathered carbonate bedrock of different formations which are covered by lichen. In addition, a few red pixels show up in the lighter tone areas on the right side (arrow in Figure 27). This area is a few kilometers west of the geologically mapped Ronning Group which is assumed but not verified on the ground. Similar results were obtained on the Whitefish River subscene, which was not documented due to very poor colour resolution on both Polaroid and Kodak prints.

3.3.6.2 TM Data

The rock signatures for the Kee Scarp and Imperial Formations, which were derived from the unsupervised classification test, were applied to the subscene of the Mackenzie Mountains and the bordering Mackenzie Plains in the Norman Wells area. In Figure 29, the Kee Scarp Fm is displayed in red. It shows up in a relatively narrow band of interrupted clusters west of Powell Creek and is absent along strike eastwards. This termination agrees, as expected, with the abrupt reef edge of the Kee Scarp Fm a short distance to the west of Powell Creek. The prominent red patches in the Mackenzie Mountains are, in all likelihood, Proterozoic carbonates of similar rock signature.

In the image in Figure 30, the indicated distinct rock signature of the Imperial Formation from the 4/1 band ratio was applied in red. It shows up as a very strong coloured band adjacent to the scree of the Kee Scarp Fm dipslope, and replaces the Kee Scarp Fm along strike eastwards from Powell Creek.

Unfortunately, the above interpretation is not only very suspect; it is most likely wrong. The distribution pattern of the strong red signature in the Mackenzie Plains, especially its dominance in relatively large local areas, suggests a distinct type of vegetation in this heavily covered terrain, where outcrops are mainly limited to river cuts. This interpretation is strongly supported by the typical distribution of the same signature in the wide river flats of Mountain River and its tributaries in the Mackenzie Mountains. Furthermore, the signature of the shale-siltstone sequence in the Upper Devonian Imperial Formation could be very similar, if not identical to, that of the Cretaceous shale-siltstone sequence which overlies the Imperial Formation, and is separated from it by the major pre-Cretaceous unconformity.

In conclusion, despite possible pitfalls, the results of these tests are very encouraging. This approach of "maximum likelihood classification" is recommended for any preferred areas in which detailed evaluation is contemplated.

3.4 Thematic Mapper

A high quality, cloudfree summer scene of the southwest quadrant of image 56-14 was purchased from CCRS in tape format and as a false colour print of two different band combinations. One false colour print was produced using a combination of Bands 3, 4 and 5; the second print used a combination of Bands 2, 3 and 4. The high quality of the TM images was self-evident; having provided better ground resolution, as well as having additional bands or channels with narrower and more specific spectral ranges for better discrimination. The TM data were undoubtedly the superior database when compared with MSS data.

The choice of two different band combinations was based on recommendations from the literature; the two selected being the most suitable for geological applications. The combination of TM bands 3, 4 and 5, shown in Figure 31, proved to be superior to the

2, 3 and 4 combination. The latter had an overall brownish colour north of the Mackenzie Mountain Front. Tonal variations within this one colour resulted in an image similar to the black and white, high altitude air photographs typical of terrain within the project area. Consequently, the Band 3, 4 and 5 false colour print is recommended as the initial data base for geological application in the Northern Interior Plains area.

As discussed in Section 3.3, numerous options for improvement exist in digital processing, at least in theory. With open-ended digital processing, and bearing in mind the limitations which are imposed by the surficial cover in the project area, the TM data are a valuable tool for geological reconnaissance mapping in areas of limited exposure.

In the case of in-house processing and/or image analysis systems, DICS products of TM data, especially tapes, are the preferable choice for a geological Landsat evaluation. They are accurate enough in their geographic positioning of observed features that they can be used as overlays for other data, and they can be displayed and mapped automatically at any scale. The digital format of data acquisition and recording lends itself ideally to rigorous processing and evaluation using mathematical algorithms, developed and derived from geological and/or geophysical models. Even the merger with other data, if desired for a final integrated picture, can be easily accommodated.

3.5 Ascending Path Data

During the investigation of the thermal heat emission band of the TM data (Figure 21) the observed criteria that deep-seated thrust faults can be expressed by a very light tone, representing the ascent of warm water along fault planes, was considered. Mr. K. Campbell of the ARSC suggested using Ascending Path data to test this concept. These data, which are recorded at night, are normally not available. They are only recorded on special request. Unfortunately no cloud-free scene of this particular area became available during the time of recording by CCRS in Prince Albert.

However, the black and white check print of the TM data of the Ascending Path Image 133-230 in Figure 32 shows in the cloud-free portions that good quality images can be achieved. The opportunity for low sun angle images during the summer season with a different sun direction could become important with respect to features of a general west-east strike and northerly slopes which will be illuminated for maximum expression only by Ascending Path data.

Furthermore, mapping of thermal heat emission requires both day time and night time IR imagery. Should such data be required for specific investigations, the probability of obtaining a good quality cloud free scene within several weeks or months will be very low. Therefore, the authors strongly recommend that CCRS include Ascending Path coverage for at least two years during the summer season to assure the availability of these data for Canada's northern regions.

SECTION FOUR

GEOLOGICAL VERIFICATION OF LANDSAT INTERPRETATION

Regional reconnaissance mapping from Landsat data was the objective of this project. It was hoped that the observed patterns would lead to a subsurface representation of sub-regional features with prospective merit for hydrocarbon exploration. Surface geological maps, geophysical control from aeromagnetic, gravity and seismic surveys, and limited well control existed in the project area. Attempts at verification of the interpreted Landsat features in the light of these "reliable" data are outlined in the following brief discussion.

4.1 Surface Geology

Surface geological maps are to a large part derived from photogeology with more or less limited outcrop control. They are therefore a very weak independent criterion for verification.

4.2 Aeromagnetic Survey

Aeromagnetic surveys were not available in-house, but the total magnetic intensity map of the Colville Hills, which was published by Davis and Willott, 1978, is reproduced as Figure 33.

An area, about 80 kilometers wide and 120 kilometers long shows a strong magnetic response in the southern and eastern Colville Hills area. If, as suggested, the causative magnetic bodies are the equivalents of the thick Coppermine River basalts, the pattern could represent two smaller elongate basalt sheets adjacent to a large, central sheet of flood basalt. The presence of Proterozoic volcano-clastics in the subsurface at the northern fringes of the central sheet lends support to this interpretation. To date, no isotopic age is available for these volcano-clastics, which were cored in the PCI Canterra Tweed Lake M-47 gas discovery well.

Igneous rocks are absent in the Paleozoic and Mesozoic section, but areally extensive and thick basic extrusives (flood basalt) and thinner intrusives (sills and dykes) are reported from the Proterozoic in the adjacent Canadian Shield and in the Mackenzie Mountains 350 kilometers southwest of the Colville Hills. Isotopic ages for the Coppermine River basalt and a series of diabase dykes which cut the older Hornby Bay Group and the overlying Coppermine series, range from 1,065 million years to 1,315 (diabase dykes) million years (Davis and Willott, 1978). Whatever the exact age of these Proterozoic units, it differs markedly from that of the Hadrynian igneous rocks in the Mackenzie Mountains, assigned an isotopic age of 770 million years, by Armstrong et al, 1982.

In accordance with the interpretation of Davis and Willott, 1978, the very strong, linear, magnetic anomalies are caused by the vertical displacement of these magnetic bodies along major fault zones. Minor departures in pattern, as well as changes in intensity along the strike of major trends, may be the result of differences in the amount of vertical displacement along strike - a common feature of wrench faults. The large difference in age between the

the Coppermine River basalt, sills and dykes, together with the well documented intra-Proterozoic Rapitan unconformity in the Mackenzie Mountains, allow a wide range of alternate interpretations of the present day magnetic expression of faulting at the Coppermine River basalt level in this area. Intrusion of dykes along pre-existing faults, faulting at times of significant tectonic activity during the Proterozoic, and rejuvenation or partial rejuvenation in subsequent times up to the Laramide Orogeny of Late Cretaceous to Tertiary age can be considered.

It should be noted that the major fault zones in Figure 34, as interpreted from the Landsat lineament analysis, do not necessarily coincide with the linear magnetic anomaly trends when overlain on Figure 33. Where they do match, the interpretation favours steeply dipping to near vertical major strike-slip or wrench faults cutting deep into the Proterozoic section. Whether they are very young (Laramide), or rejuvenated older zones of weakness, cannot be determined.

In the case of absence of magnetic response, two alternatives exist: (1) absence of magnetic rocks in the subsurface; or, (2) decollement at the Cambrian Saline River salt level without displacement at the deeper magnetic horizon. The latter would imply a non-prospective regional structure for the primary objective, potential reservoir sands of the Lower Cambrian Mount Clark Formation.

4.3 Gravity Survey

A regional Bouguer gravity map of the Colville Hills area, published by Hornal et al, 1970, is reproduced in Figure 35. It shows clearly, that this regional gravity survey with 10-km spacing of control points, gives only a very coarse picture of regional lows and highs. In most cases control point spacing exceeds prospect dimensions. The existence of local lows and highs remains open to interpretation.

Several lines of geological evidence indicate that this regional gravity pattern is caused by Proterozoic, even intra-Proterozoic features. The previously discussed tectono-stratigraphic skeleton of the upthrusted, thick, Paleozoic carbonates at the topographically high, anticlinal ridges, has no expression at all. A striking example is the Mackay Range in the Mackenzie Plains (center at 64°40' North and 125°40' West). High density Paleozoic carbonates are displaced against a low density shale-sandstone sequence of Cretaceous-to-Tertiary age, up to 2000 metres thick.

Therefore, the regional gravity pattern can not be used to confirm the Landsat pattern in the true sense of verification. In this case both surveys complement and support each other. Major Landsat lineaments define the position, direction and length of major fault zones, and gravity contributes the necessary and geologically valid structural information needed to outline and define, for example, low Graben or high Horst features in the subsurface, thus reinforcing the final geological interpretation.

4.4 Seismic Coverage

Seismic coverage in the project area ranges from widely spaced regional surveys to detailed evaluations in subregions of indicated prospective merit. In areas of widely spaced, regional seismic control, the Landsat pattern, especially well defined significant lineaments, can assist in the interpretation of faults or fault zones with respect to strike and continuation, or give alternate choices for interpretation. Consequently, verification of the interpreted Landsat pattern from widely-spaced regional seismic lines is of doubtful value. It can at best be considered a probable support but not a verification.

The mapped Landsat lineaments have an average spacing of about 6 $\pm$ 2 kilometers and the Tweed Lake Landsat Anomaly is about 20 kilometers long and 10-km wide. Therefore, seismic coverage of about 10 kilometers line spacing with adequate tie-lines is considered the minimum requirement for a meaningful verification of the interpreted Landsat features.

Seismic reflectors, which are mapped over the entire project area, are limited to the top of the Saline River or base of the Franklin Mountain Formation of Upper Cambrian age and to the top of the Proterozoic or base of the Cambrian, a major unconformity.

Therefore, a verification of the interpreted Landsat features from seismic is restricted to relatively deep subsurface structures at the lowermost Paleozoic or older levels. Subsequent geological events, such as tectonic, depositional and erosional processes, can not be assessed unless they affected these old stratigraphic horizons.

The composite, stratigraphic section in Figure 36, with annotated gross lithology and unconformities, gives a regional background for these modifying geologic processes with some comments relevant to the interpretation of Landsat data. The most important event in this context is the long lasting period of non-deposition, exposure and erosion, associated with the major pre-Cretaceous unconformity. This hiatus (non-deposition and/or erosion) involves a timespan of about 180 million years from the Pennsylvanian to the end of the Jurassic Period.

Consideration of these modifying processes, combined with the effects of glaciation and surficial cover, all masked by vegetation over most of the project area, will be a reminder of the inherent ambiguity of the geological interpretation derived from the Landsat pattern.

To reiterate from Page 15 -- "We have concluded that the lineaments identified in this study present a structural framework for the area. It is felt that the majority of the lineaments represent either fractures or faults in the subsurface. The major trend lineaments are more apt to represent faults, whereas the shorter lineaments could represent either fractures or faults.

Where seismic programs are planned, it is suggested that the seismic lines be positioned so that they transect lineaments, tonal anomalies and drainage anomalies".

REFERENCES

Armstrong, R. L., G. H. Eisbacher and P. D. Evans, 1982. Age and Stratigraphic-Tectonic Significance of Proterozoic Diabase Sheets, Mackenzie Mountains, Northwestern Canada; Canadian Journal Earth Sciences, v. 19, p. 316-323.

Davis, J. W. and R. Willott, 1978. Structural Geology of the Colville Hills; Bulletin of Canadian Petroleum Geology, v. 26, no. 1 (March, 1978), p. 105-122.

Haimila, N. E., 1975. Possible Large Domal Structures along a Regional Arch in the Northern Interior Plains; Geological Survey of Canada, Paper 75-1C, p. 63-68.

Hornal, R. W., L. W. Sobczak, W. E. F. Burke and L. E. Stephens, 1970. Preliminary Results of Gravity Surveys over the Mackenzie Basin and Beaufort Sea; Gravity Map Series, Earth Physics Branch.

Kary, W., 1980. Northern Interior Plains - Anomalous Areas as Interpreted by use of Landsat Images. Internal Petro-Canada Report.

Morgan, K. M. et al, 1985. Recent Advancements In The Resolution of Landsat Imagery for Geologic Mapping; Oil and Gas Journal, v. 83, no. 51, Dec. 23, 1985, p. 66-67.

Robinson, J. E. and S. Carroll, 1977. Software for Geologic Processing of Landsat Imagery; Computer Geosciences, v. 3, Pergamon Press, p. 459-464.

Sabins, F. F. Jr., 1978. Remote Sensing, Principles and Interpretation; W. H. Freeman and Company, San Francisco.

Slaney, V. R., 1981. Landsat Images of Canada - A Geological Appraisal; Geological Survey of Canada, Paper 80-15.

GLOSSARY OF REMOTE SENSING ACRONYMS

CCRS	Canada Centre for Remote Sensing
CCT	Computer Compatible Tape
DICS	Digital Information Correction System
EROS	Earth Resources Observation Systems U.S. Department of the Interior, Administered by the U.S. Geological Survey
GSC	Geological Survey of Canada
MSS	Multispectral Scanner
NTS	National Topographic Series
RBV	Return Beam Vidicon
TM	Thematic Mapper

APPENDIX A

List of MSS and TM false color prints acquired by Petro-Canada for the 1983-86 Landsat evaluation of the Northern Interior Plains, N.W.T.

Image Number	Date	Identifier Number	Products Additional To False Color Prints	Sun Angle Or Elevation	Sun Direction Or Azimuth
		MSS IMAGERY			
59-13	21-02-1980	30718-19020		09°	N161°
	30-08-1978	30178-19070		29°	N165°
59-14	03-04-1978	30394-19071		N/A	N/A
	07-07-1978	30124-19064		N/A	N/A
59-15	06-03-1974	10591-19140		17°	N161°
	07-07-1978	30124-19071		45°	M157°
61-13	23-02-1980	30720-19132	Tapes, RBV	10°	N161°
	09-07-1978	30126-19175	Tapes, RBV	42°	N161°
61-14	23-02-1980	30720-19135	RBV	11°	N160°
	09-07-1978	30126-19181		43°	N159°
62-12	01-03-1979	30361-19235	Tapes	N/A	N/A
	14-07-1979	21634-19163	Tapes	41°	N162°
63-13	26-03-1976	20429-19251		23°	N162°
	12-08-1977	20933-19053		34°	N154°
64-11	06-02-1982	22572-19331		02°	N167°
	16-07-1979	21636-19273		N/A	N/A
64-12	09-03-1976	20412-19305		15°	N164°
	15-08-1975	11118-19203		33°	N165°
64-13	19-03-1981	22248-19331		20°	N163°
	13-08-1977	20934-19111		34°	N155°
64-14	19-03-1981	22248-19333		21°	N161°
	13-08-1977	20934-19114		35°	N152°

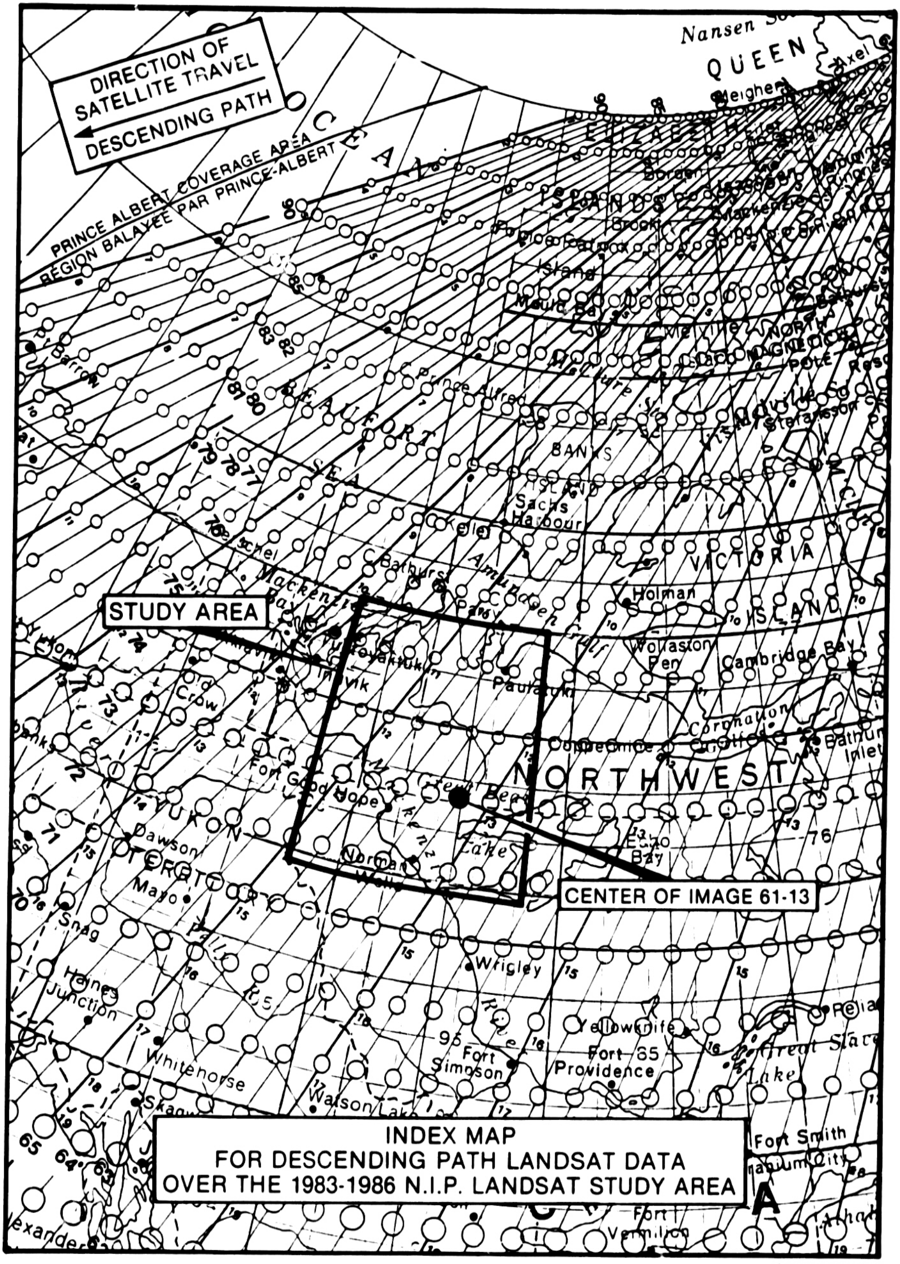
TM IMAGERY

Image Number	Date	Identifier Number	Products Additional To False Color Prints	Sun Angle Or Elevation	Sun Direction Or Azimuth
56-14 Quad 3	22-05-1984	50082-19200	Tapes	18°	N161°

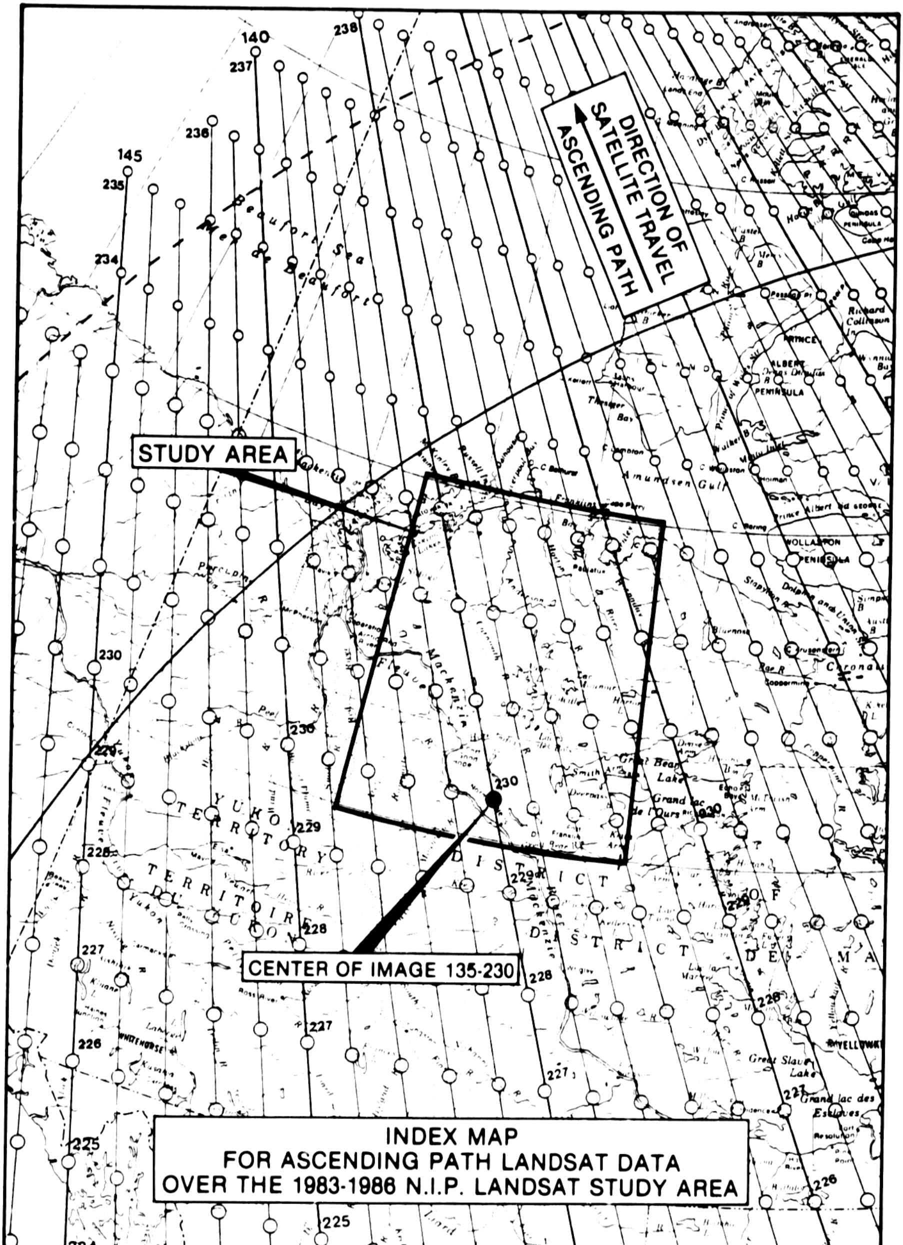
TM IMAGERY (ASCENDING PATH)

Image Number	Date	Identifier Number	Products Additional To False Color Prints	Sun Angle Or Elevation	Sun Direction Or Azimuth
135-230 Quad 3	20-06-1986	50476-045647		12°	N300°

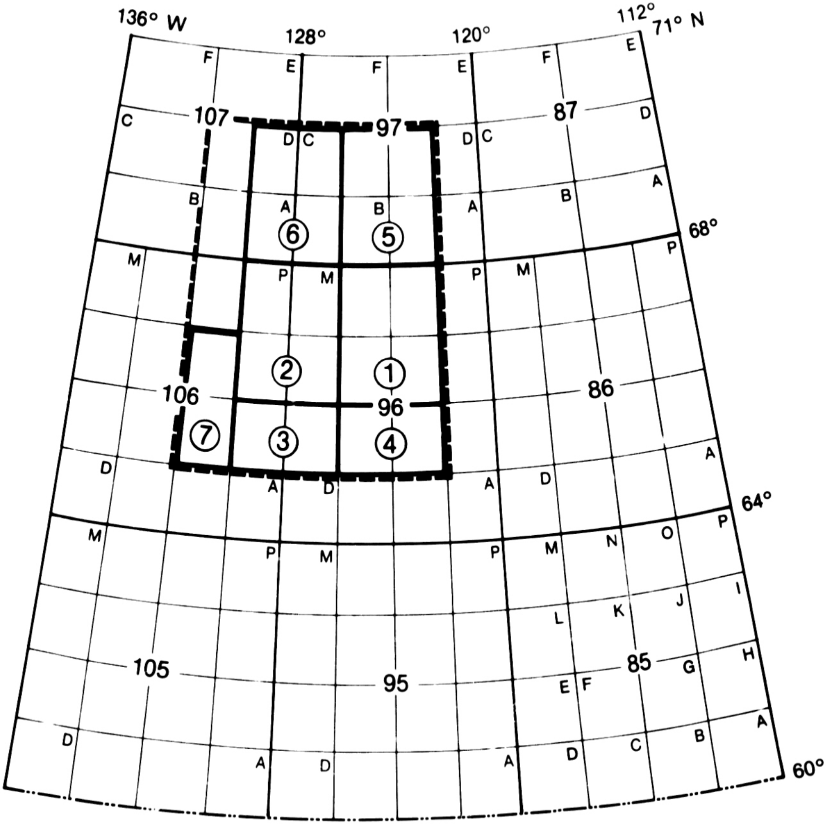
Note: The initial number in the Identifier Number indicates the number of the satellite involved.



INDEX MAP
FOR DESCENDING PATH LANDSAT DATA
OVER THE 1983-1986 N.I.P. LANDSAT STUDY AREA



INDEX MAP
FOR ASCENDING PATH LANDSAT DATA
OVER THE 1983-1986 N.I.P. LANDSAT STUDY AREA

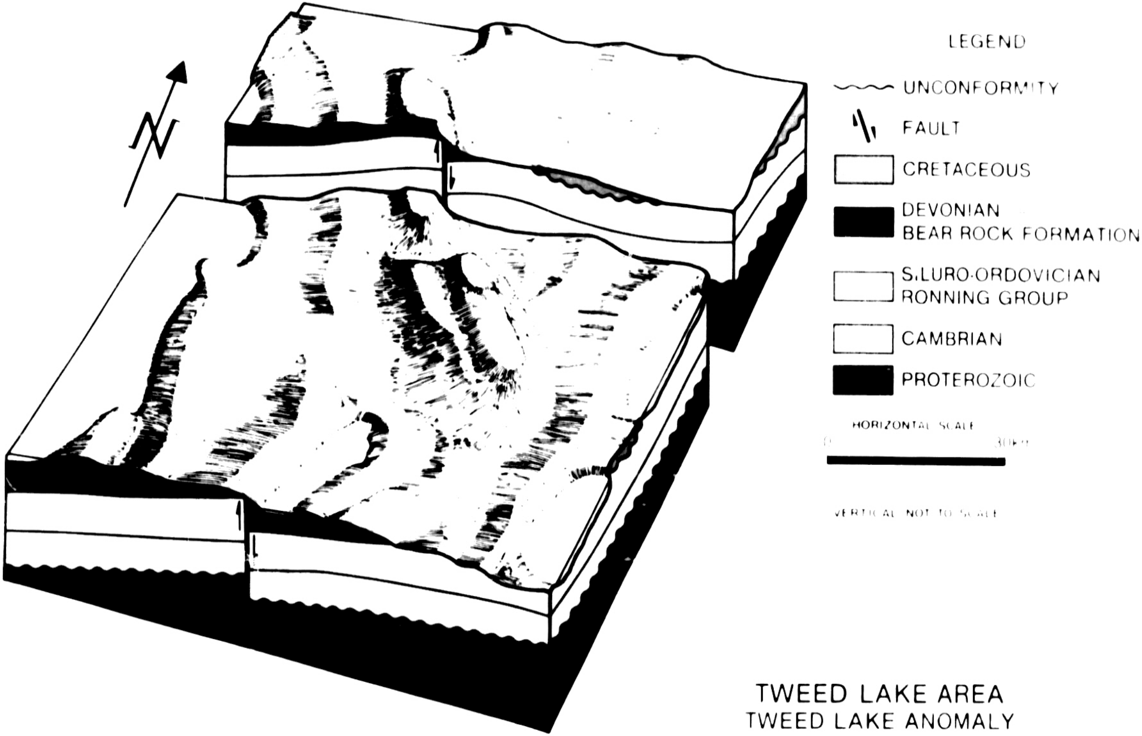


INDEX MAP
LANDSAT LINEAMENT ANALYSIS

eg.: ① - Number of Mapsheet

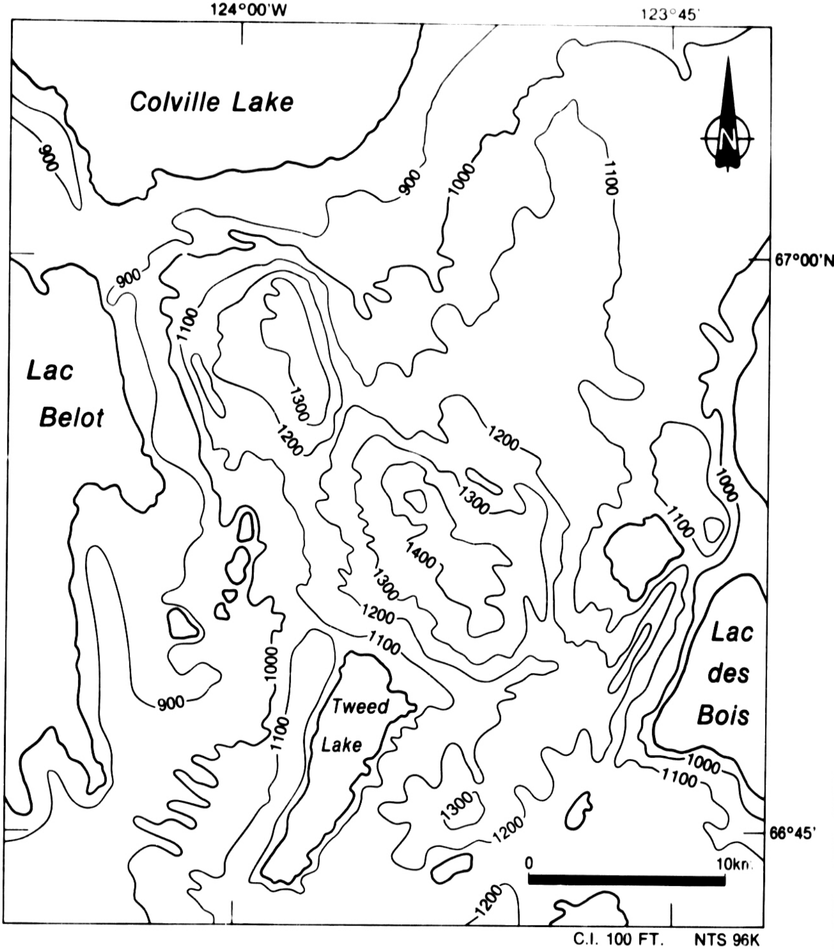
--- **Boundary of Mapsheet 8**

Figure 1



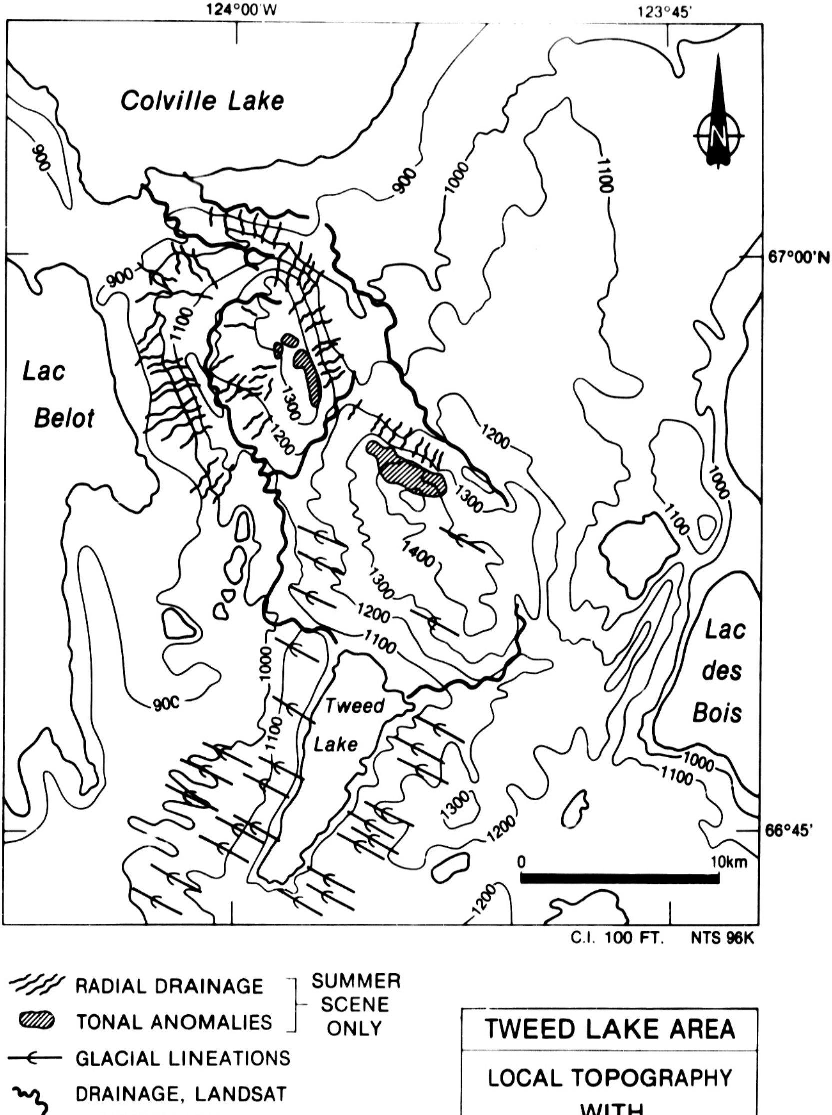
TWEED LAKE AREA
TWEED LAKE ANOMALY
GEOLOGICAL SCHEMATIC BLOCK DIAGRAM

Figure 2



TWEED LAKE AREA

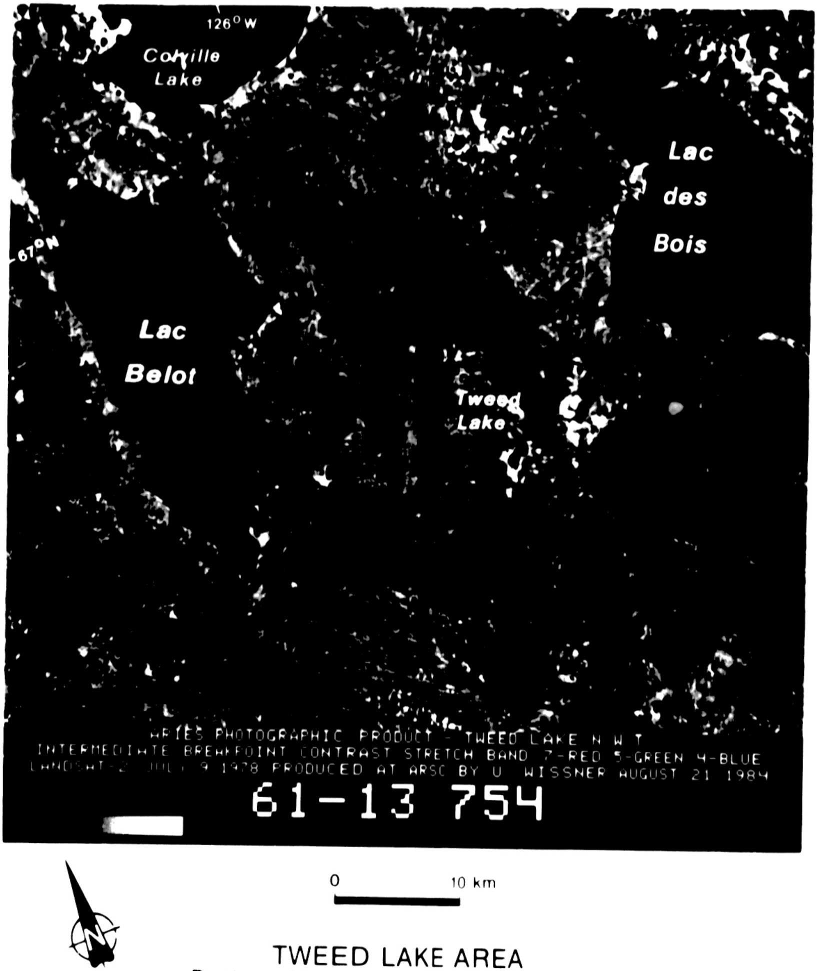
LOCAL TOPOGRAPHY



TWEED LAKE AREA

LOCAL TOPOGRAPHY WITH LANDSAT FEATURES

Figure 4

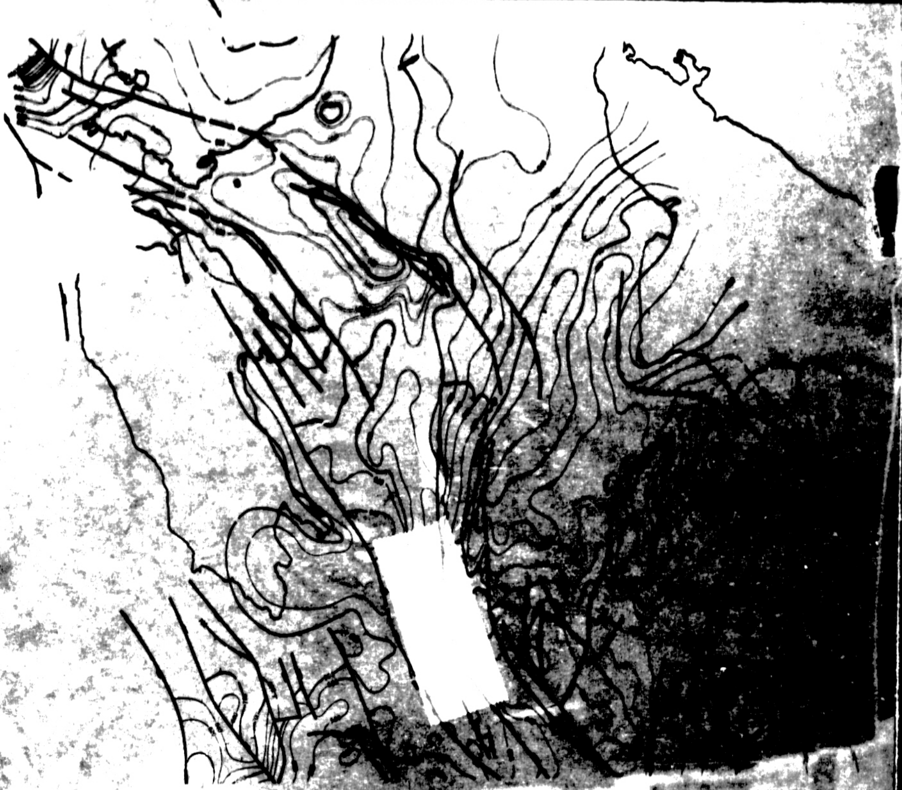


TWEED LAKE AREA

Portion of image 61-13, Summer Scene

Note: The weaker expression of linears compared to the winter scene and the tonal expression of topographic highs which is open to interpretation without the cartographic base in contrast to the winter scene. The drainage deflection around the Tweed Lake anomaly is visible on both scenes, but the radial drainage anomaly which lends strong additional support to the postulated Tweed Lake sub-surface structure is present only on the summer scene. The areas with reddish brown tone, which are related to type of vegetation, coincide with dominating snow cover on the winter scene. This could well be a function of shelter from wind effects similar in its end result to the sediment baffling of turtle grass on shallow carbonate shelves.

Figure 5

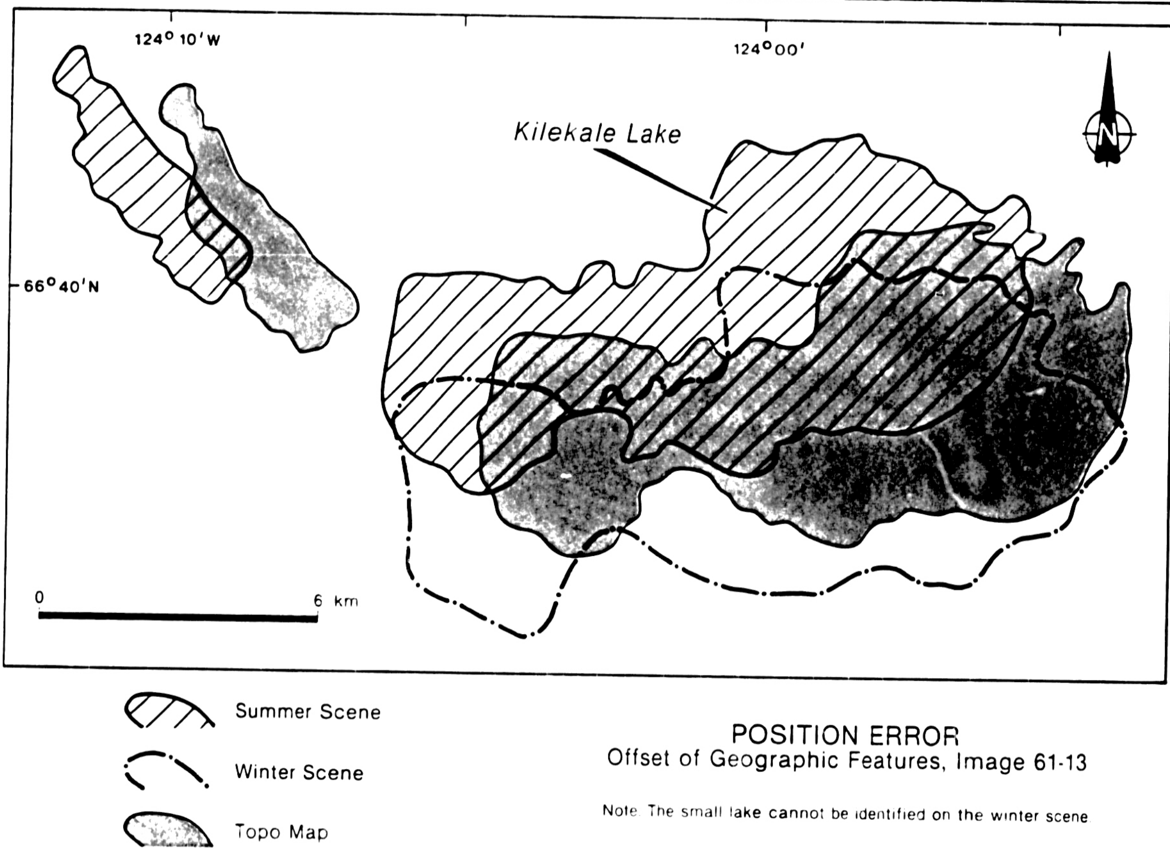


Overlay for Figures 5 and [illegible]
Time Structure — [illegible]
[illegible]

TWEED LAKE AREA

Portion of image 61-13. Winter Scene

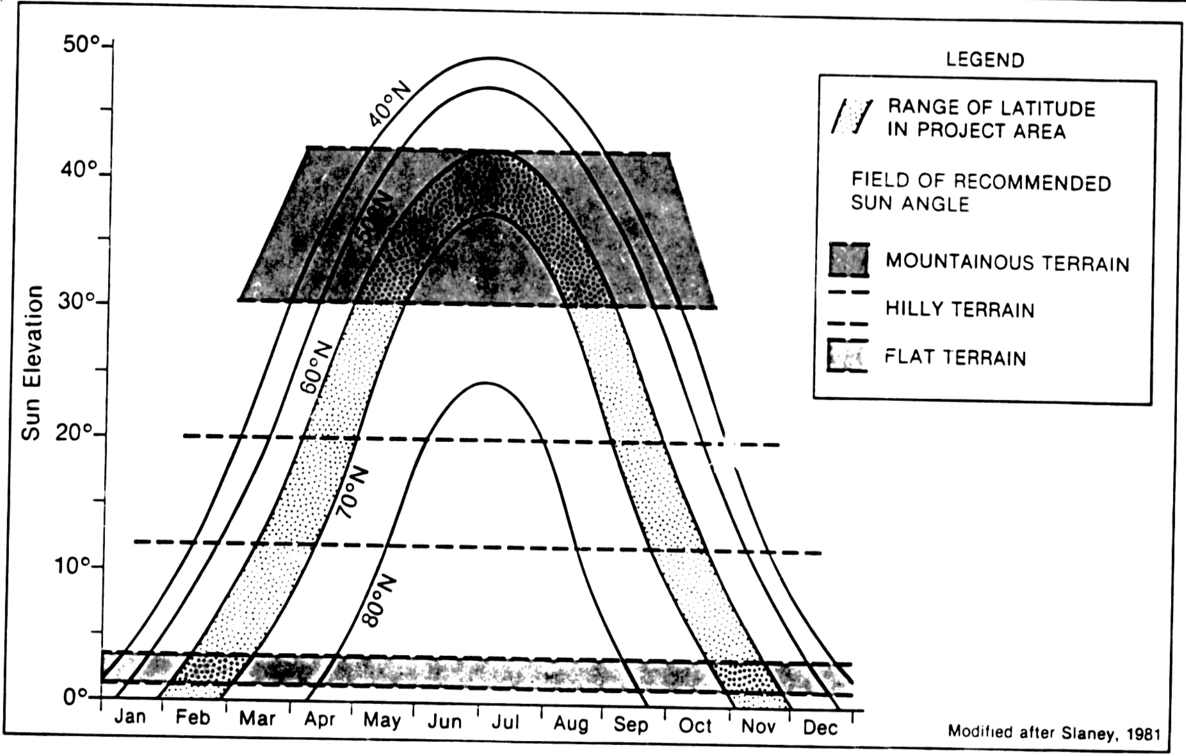
Note: The strong expression of linears, including the glacial pattern and the morphologic appearance of the chain of hills along the west side of Lac Belot. It has the appearance of an east facing escarpment with a dark coloured western dipslope in the shade, caused by the [illegible] sun angle of 10 degrees. Sun direction or azimuth is the same for both scenes, 161 degrees. The black line in the northern west half is an error in one mirrorscan (six lines). The pattern of reflectance values is recorded correctly but is offset 56 kilometers (35 miles) laterally [illegible] through the entire image and was here partially eliminated by digital [illegible] through interpolation with the adjoining lines on each side.



POSITION ERROR
Offset of Geographic Features, Image 61-13

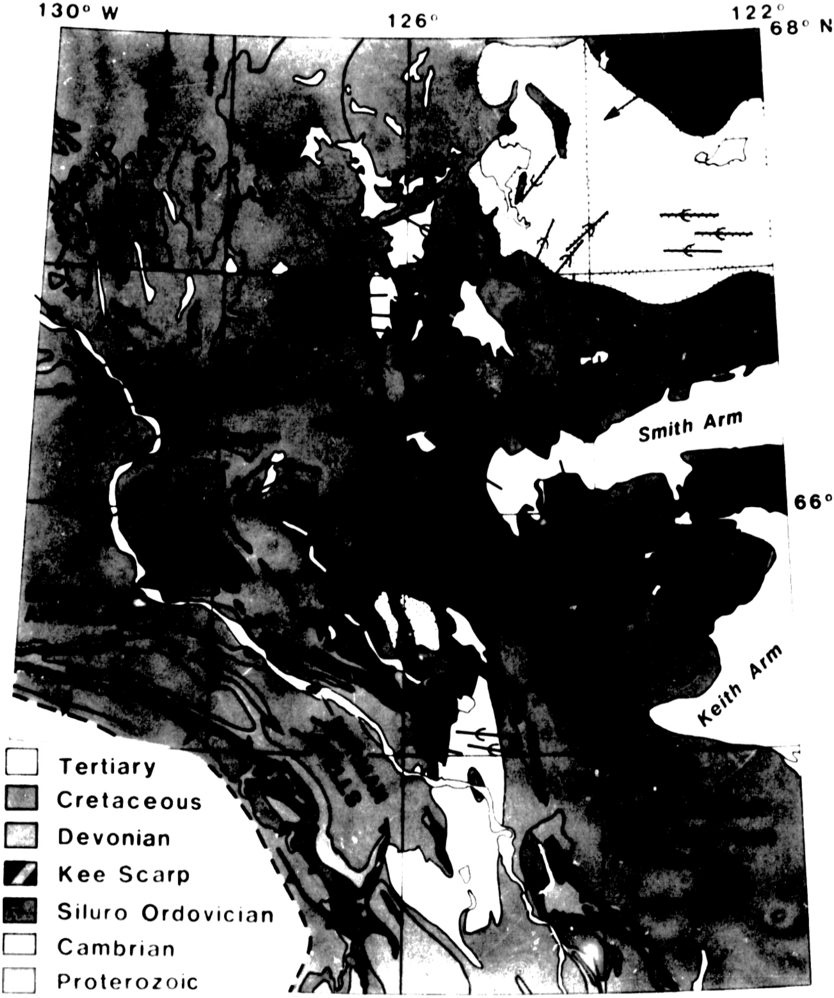
Note. The small lake cannot be identified on the winter scene.

Figure 7



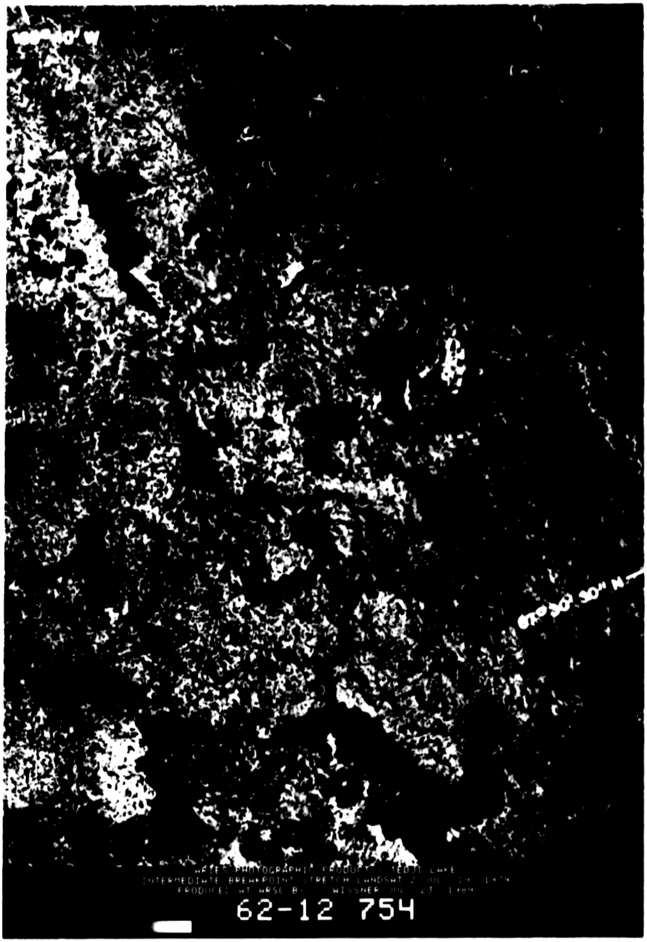
TWEED LAKE AREA
SUN'S ELEVATION (ANGLE) ON EARTH'S SURFACE

Figure 8



NORTHERN INTERIOR PLAINS-MACKENZIE MOUNTAINS
SURFACE GEOLOGY (SIMPLIFIED)
GLACIAL LINEATIONS FROM LANDSAT

Figure 9



0 60km

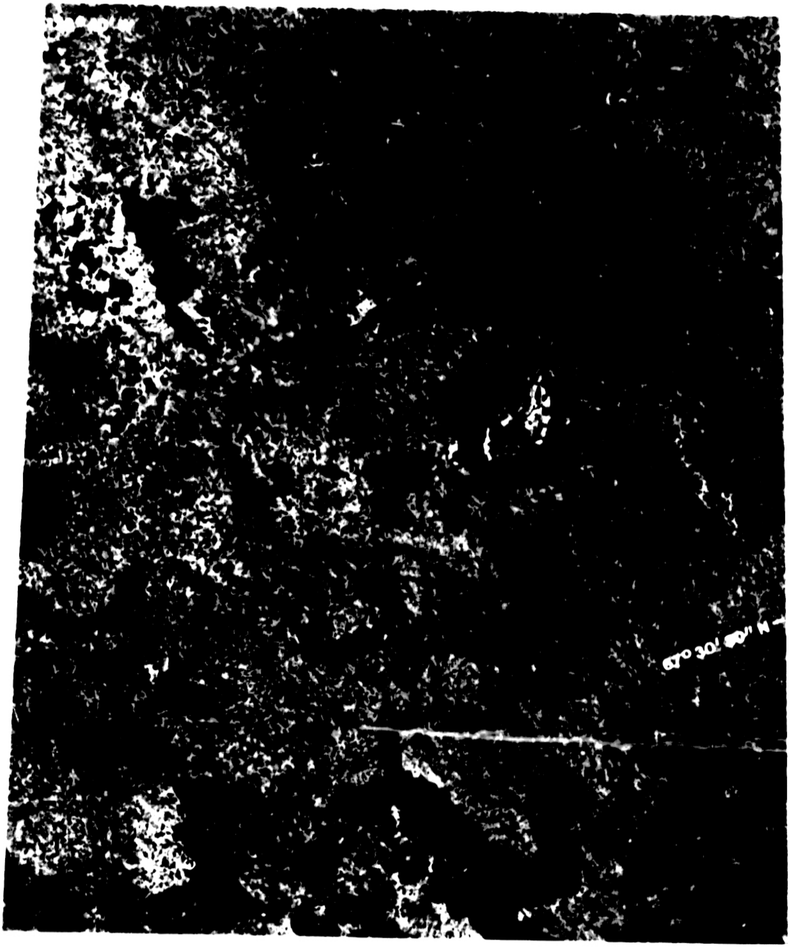
TEDJI LAKE AREA

S.W. portion of image 62-12, Summer Scene

CONTRAST STRETCHED

Note: improved colour tone and separation compared to the standard processed CCRS print of Figure 4

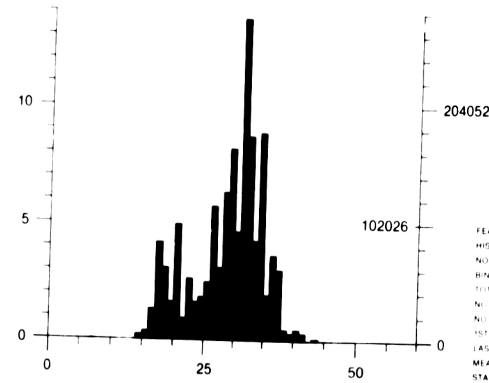
Figure 10



TEDJI LAKE AREA
S.W. portion of image 62-12 Summer Scene

CCRS FALSE COLOUR PRINT, MSS BAND 4, 5 & 7
SUN ELEVATION 41°, AZIMUTH 162

BAND 4

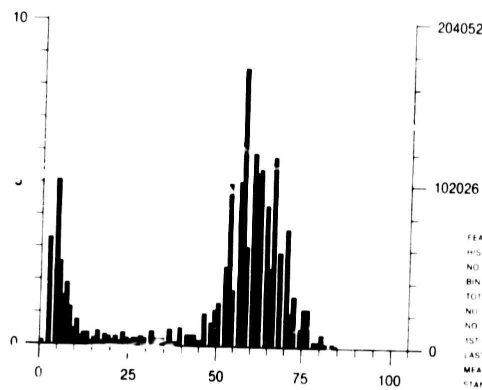


FEATURE FILE NAME	PUWFFBND4	
HISTOGRAM RANGE	0 TO 255	
NO. OF VALUES IN HISTOGRAM	256	
BIN SIZE FOR HISTOGRAM	1	
TOTAL NO. OF POINTS READ FROM FEATURE FILE	2040520	
NO. OF POINTS OVERFLOWED AND PERCENTAGE	0	0.000
NO. OF POINTS IN HISTOGRAM AND PERCENTAGE	2040520	100.000%
1ST NON ZERO VALUE	0	
LAST NON ZERO VALUE	69	
MEAN OF VALUES IN HISTOGRAM	28.4466	
STANDARD DEVIATION	5.8596	

PUWFFBND4 SUMMED OVER 1 BINS = 1 GREY LEVELS

SH TYPE 'X' TO CONTINUE (X) =

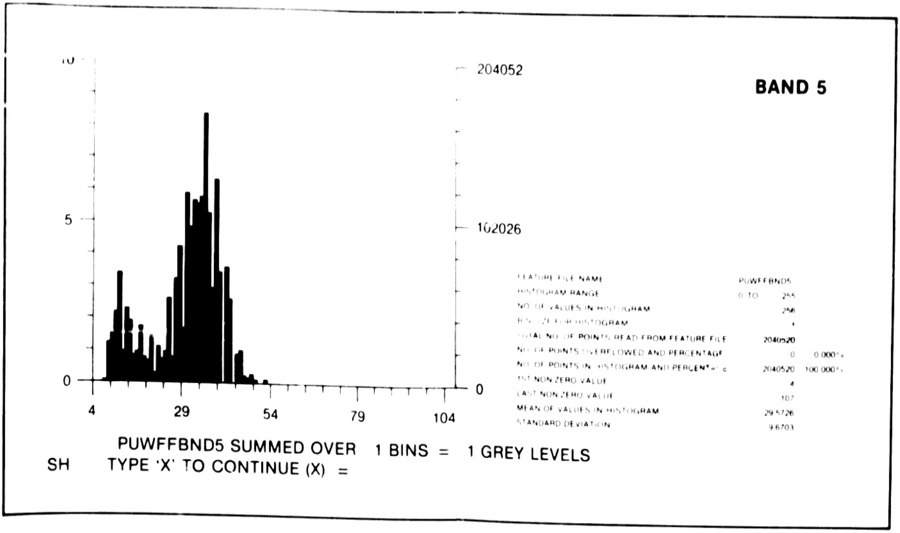
BAND 6

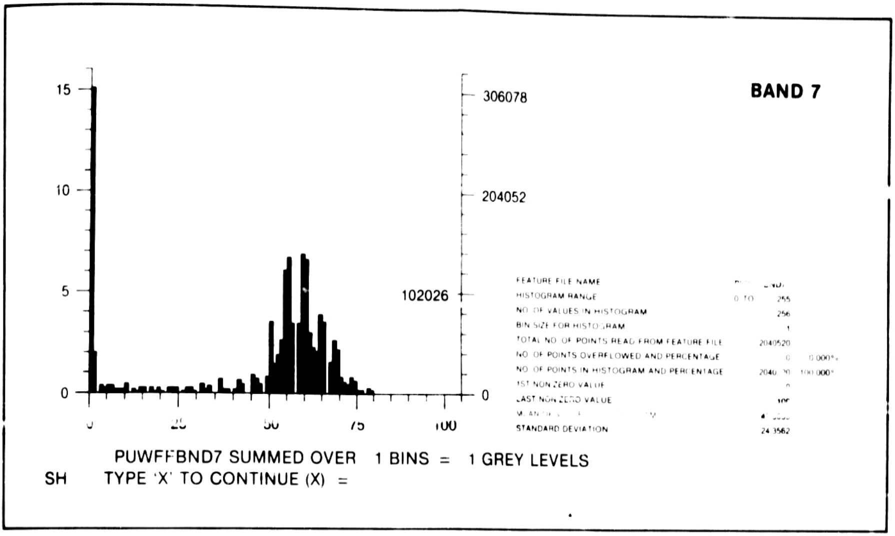


FEATURE FILE NAME	PUWFFBND6	
HISTOGRAM RANGE	0 TO 255	
NO. OF VALUES IN HISTOGRAM	256	
BIN SIZE FOR HISTOGRAM	1	
TOTAL NO. OF POINTS READ FROM FEATURE FILE	2040520	
NO. OF POINTS OVERFLOWED AND PERCENTAGE	0	0.000%
NO. OF POINTS IN HISTOGRAM AND PERCENTAGE	2040520	100.000%
1ST NON ZERO VALUE	0	
LAST NON ZERO VALUE	118	
MEAN OF VALUES IN HISTOGRAM	48.2460	
STANDARD DEVIATION	23.0339	

PUWFFBND6 SUMMED OVER 1 BINS = 1 GREY LEVELS

SH TYPE 'X' TO CONTINUE (X) =

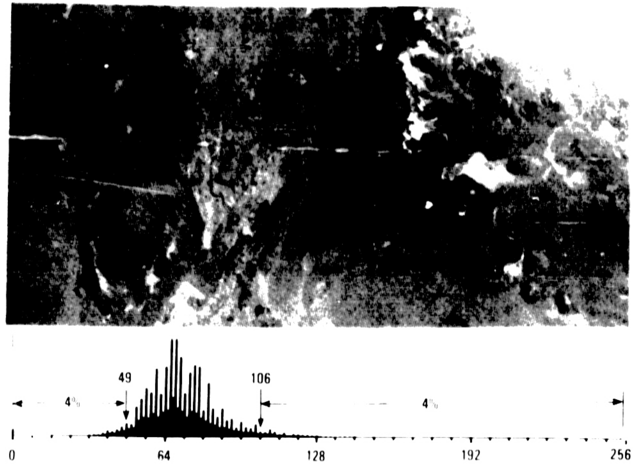




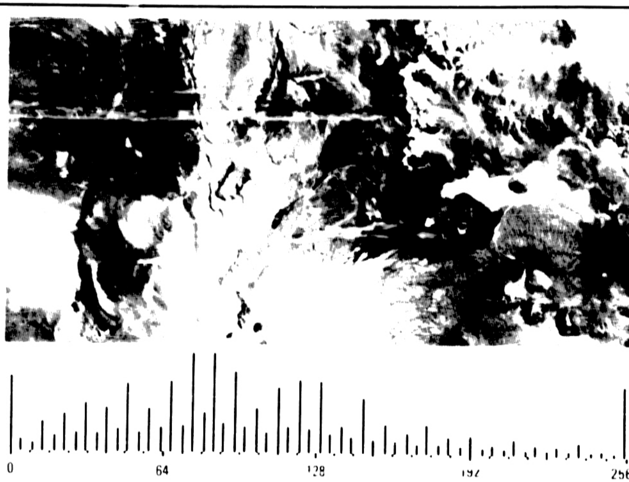
TEDJI LAKE AREA
Portion of image 62-12, Summer Scene

HISTOGRAMS OF RANGE BRIGHTNESS (REFLECTANCE VALUE) OF MSS BANDS

Figure 12



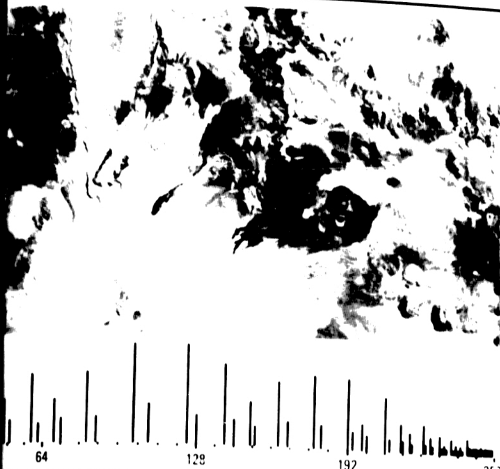
A ORIGINAL IMAGE WITH NO CONTRAST ENHANCEMENT



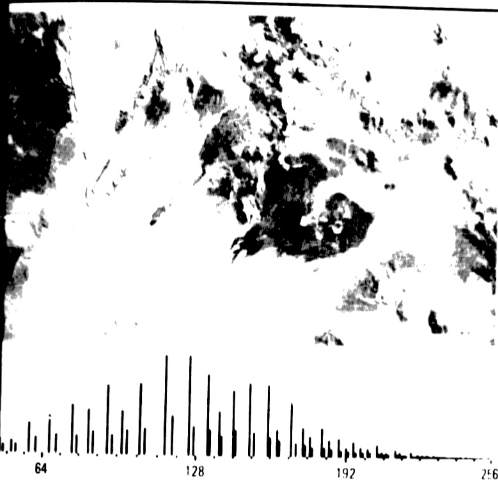
B LINEAR CONTRAST STRETCH WITH LOWER AND UPPER FOUR PERCENT OF PIXELS SATURATED TO BLACK AND WHITE RESPECTIVELY

C. UNIFORM DI

D. GAUSSIAN S

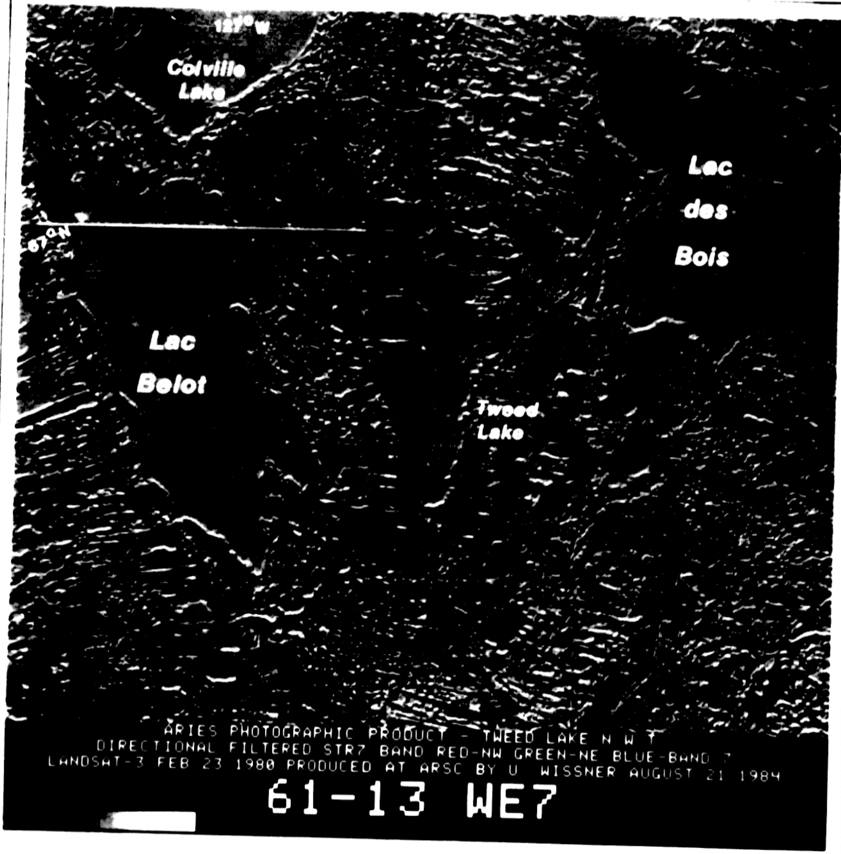


TRIBUTION STRETCH



RETCH

EXAMPLES OF DIFFERENT CONTRAST STRETCH METHODS
(Copied from Sabins, 1978)

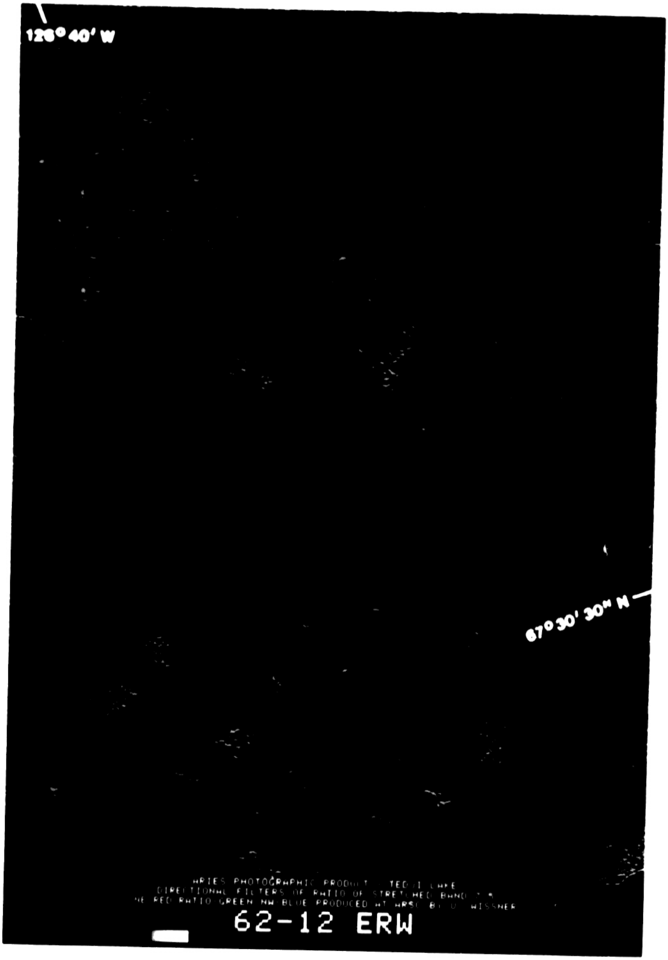


0 10 km

TWEED LAKE AREA
Portion of image 61-13, Winter Scene

FILTER OF 2 DIRECTIONS COMBINED WITH STRETCHED BAND 7.

Note: The very similar expression of Lineaments and Glacial Lineations compared to the contrast stretched Winter scene of Figure 6. Also, the topographic high ridge on the west side of Lac Belot shows [illegible] trend similar to the tonal band on the summer scene. However, the very distinct [illegible] expression of the ridge on the contrast stretched Winter Scene [illegible].



TEDJI LAKE AREA

S.W. portion of image 62-12. Summer Scene

DIRECTIONAL FILTER COMBINED WITH BAND 7/5 RATIO

10 11

NORMAN WELLS AREA

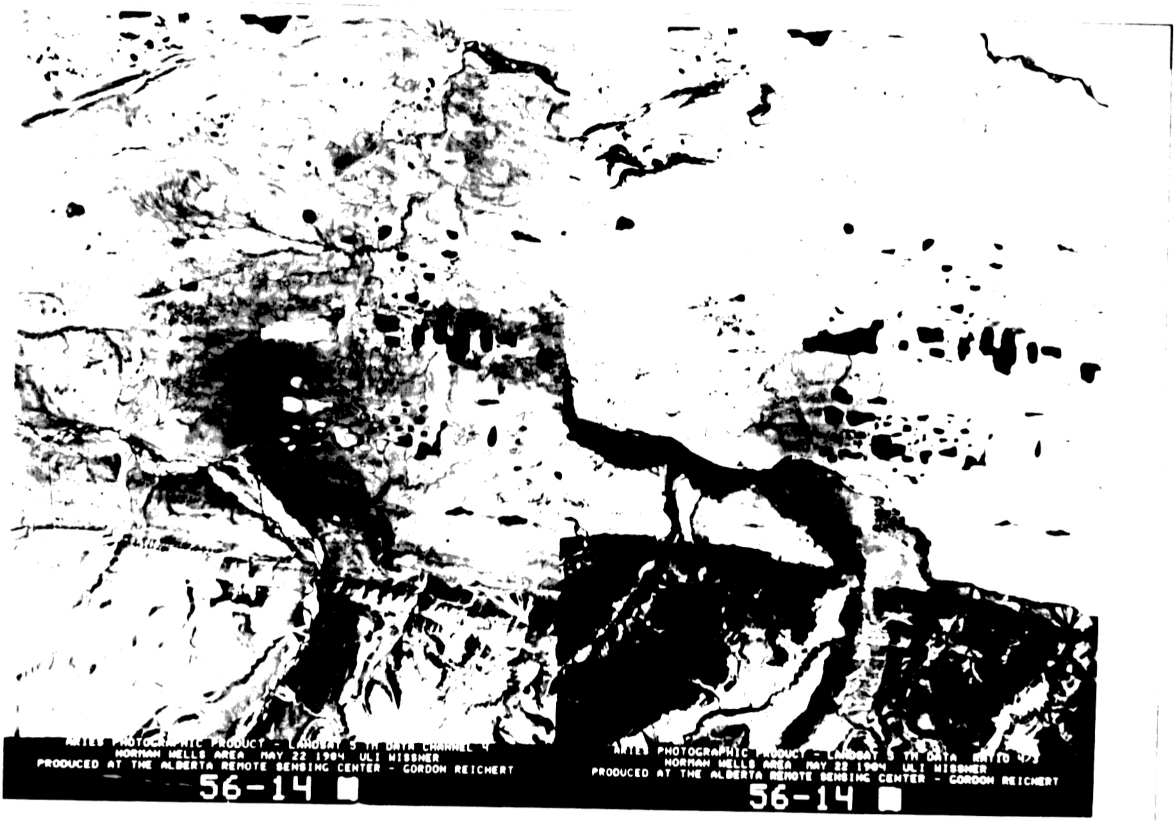
Portion of image 56-14 Summer Scene

0 10km

NORMAN WELLS AREA

Portion of image 56-14, Summer Scene

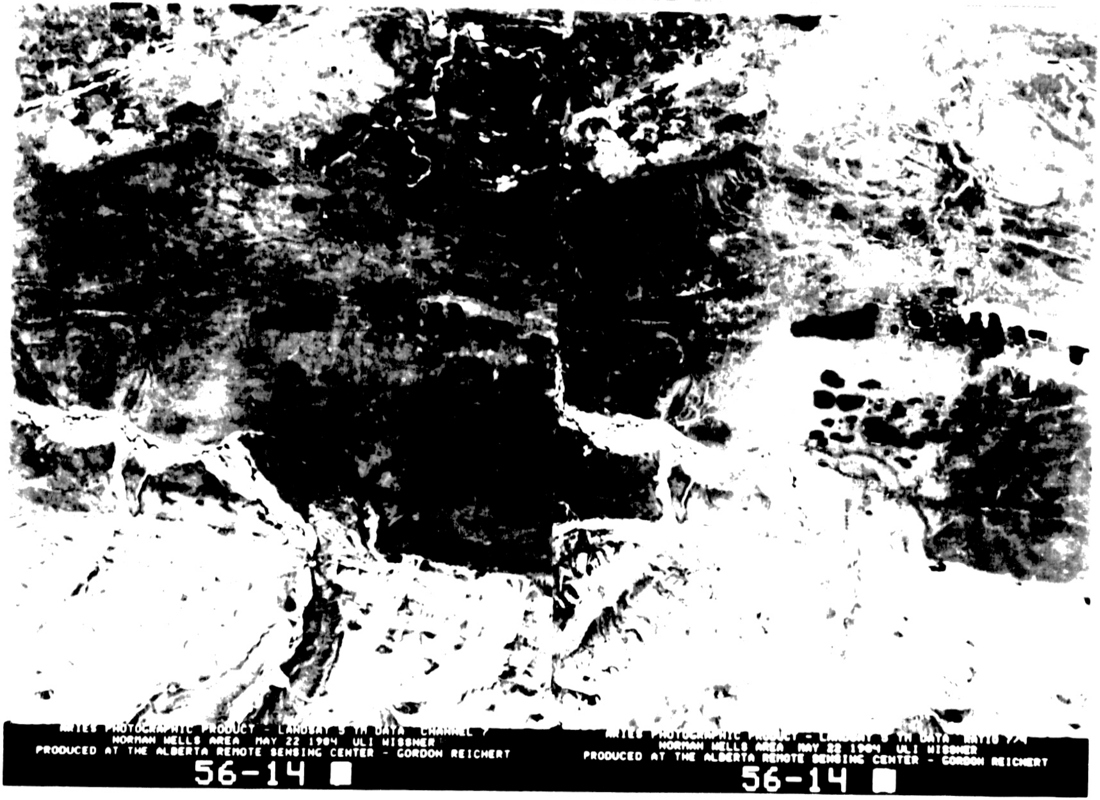
Figure 17



NORMAN WELLS AREA

Portion of image 56-14. Summer Scene

Figure 18



0 10km

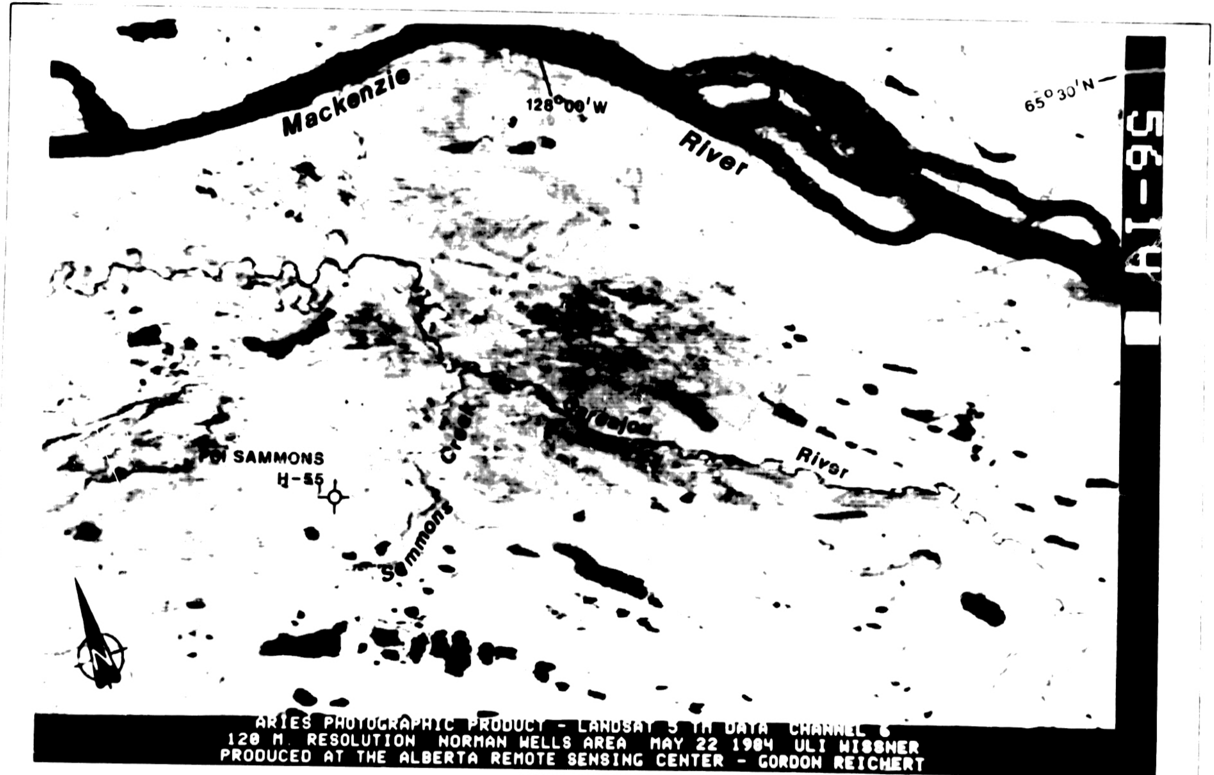
NORMAN WELLS AREA

Portion of image 56 14. Summer Scene

Figure 19

Overlay for Figures 16 to 19

(indicating major geographic and structural features)

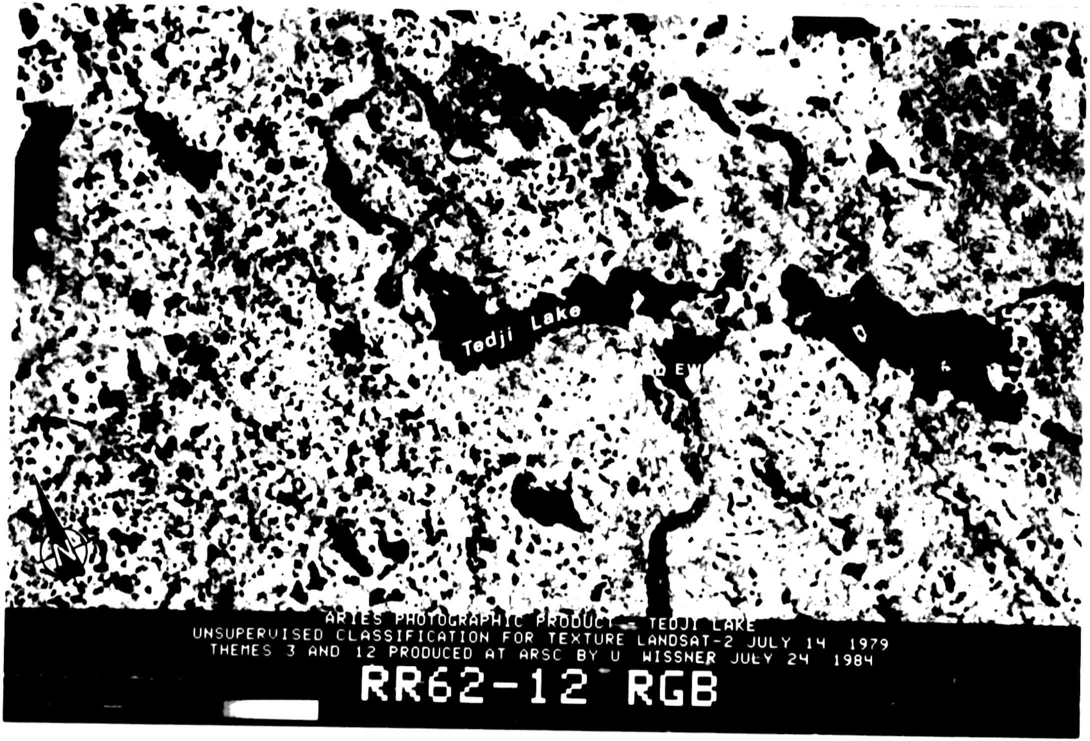


NORMAN WELLS AREA
Portion of image 56-14. Summer Scene

TM DATA, BAND 6 THERMAL HEAT EMISSION

Exploratory Well D&A

Figure 21



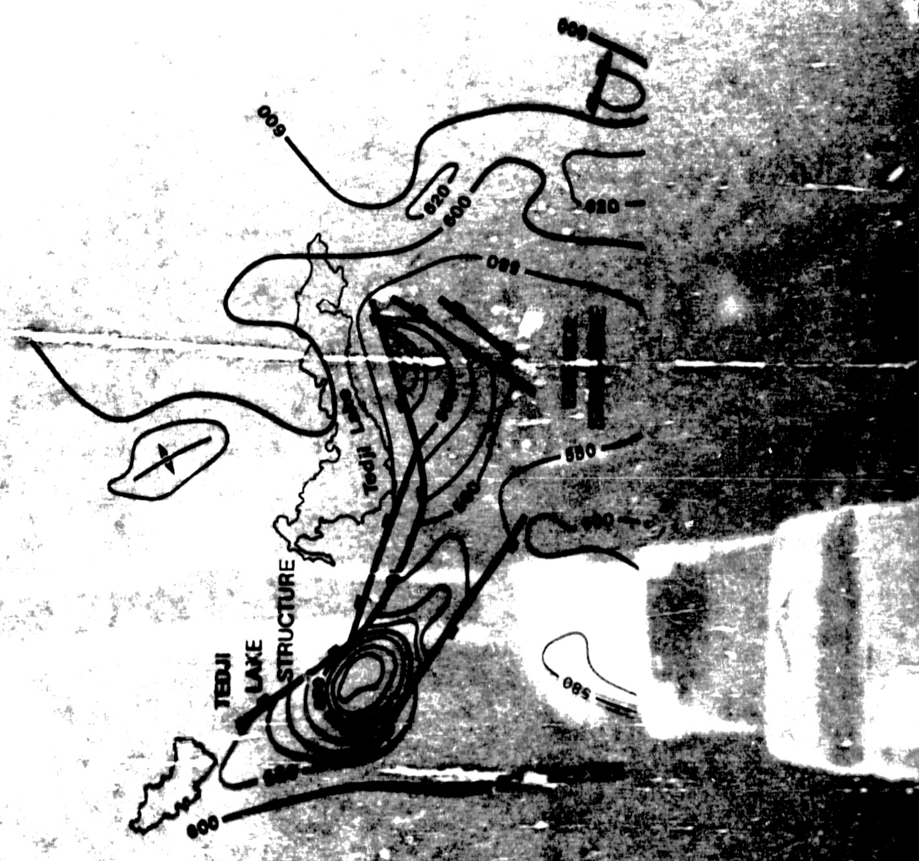
TEDJI LAKE AREA
Image 62-12

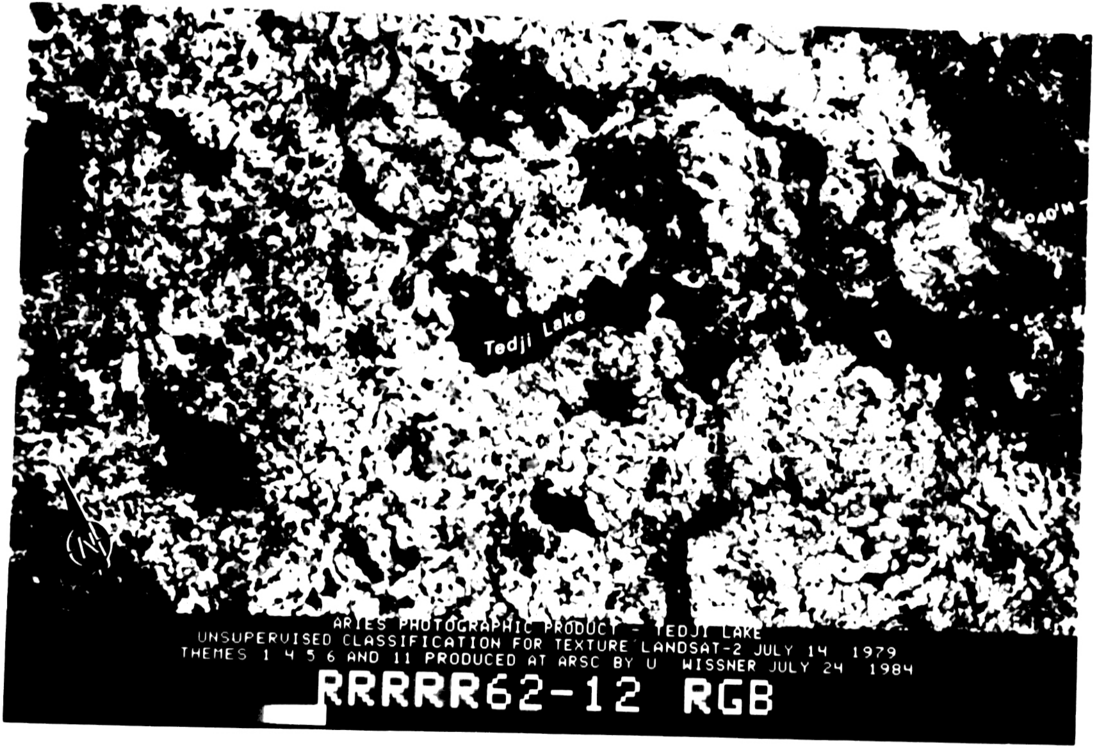
UNSUPERVISED CLASSIFICATION

Figure 22

Overlay for Figures 22 to 25 Showing Seismic Time Structure — Top Proterozoic

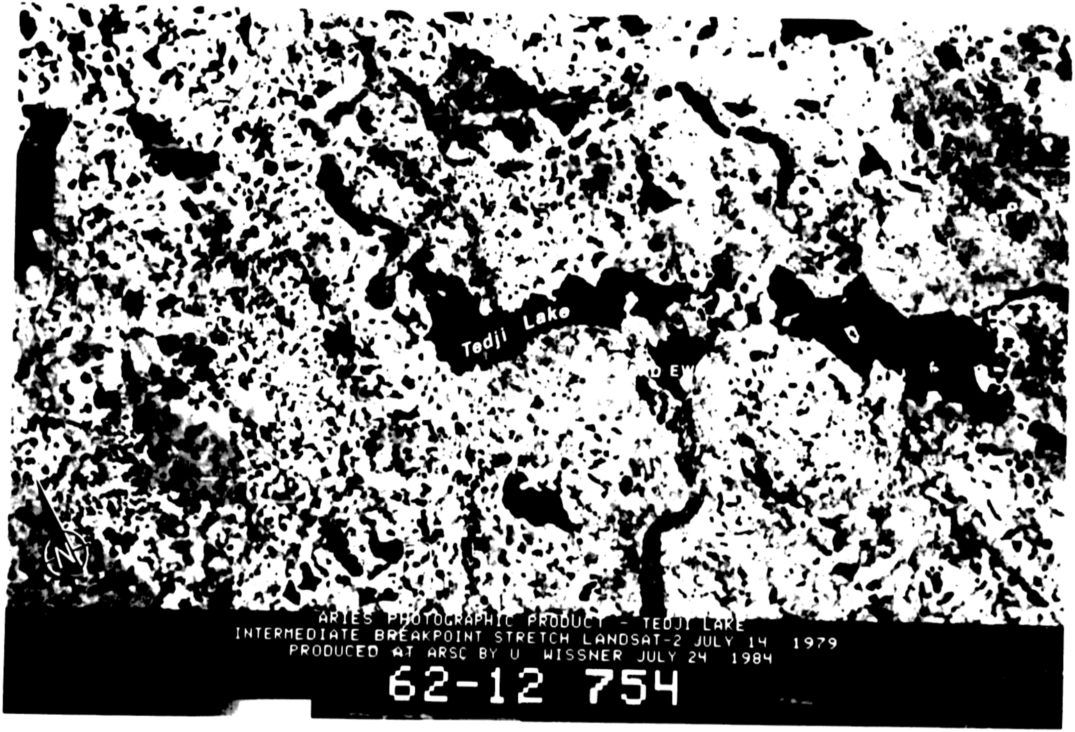
Figure 22a





TEDJI LAKE AREA

Portion of image 62 12 Summer Scene



TEDJI LAKE AREA
Portion of image 62-12. Summer Scene

CONTRAST STRETCHED

Gas Dis[illegible] [illegible]

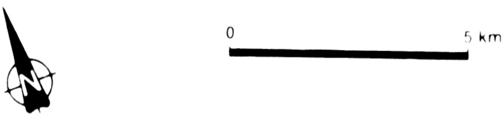
Figure 24

TEDJI LAKE AREA
Portion of image 62-12. Winter Scene

CONTRAST STRETCHED

NORMAN WELLS AREA
Portion of image 56-14

TM DATA, BAND RATIO COMBINATIONS



HARE INDIAN RIVER
Portion of image 61-13. Summer Scene

SUPERVISED CLASSIFICATION

0 — 20 km

HARE INDIAN RIVER

Portion of image 61-13, Winter Scene

SUN ELEVATION 10 DEGREES

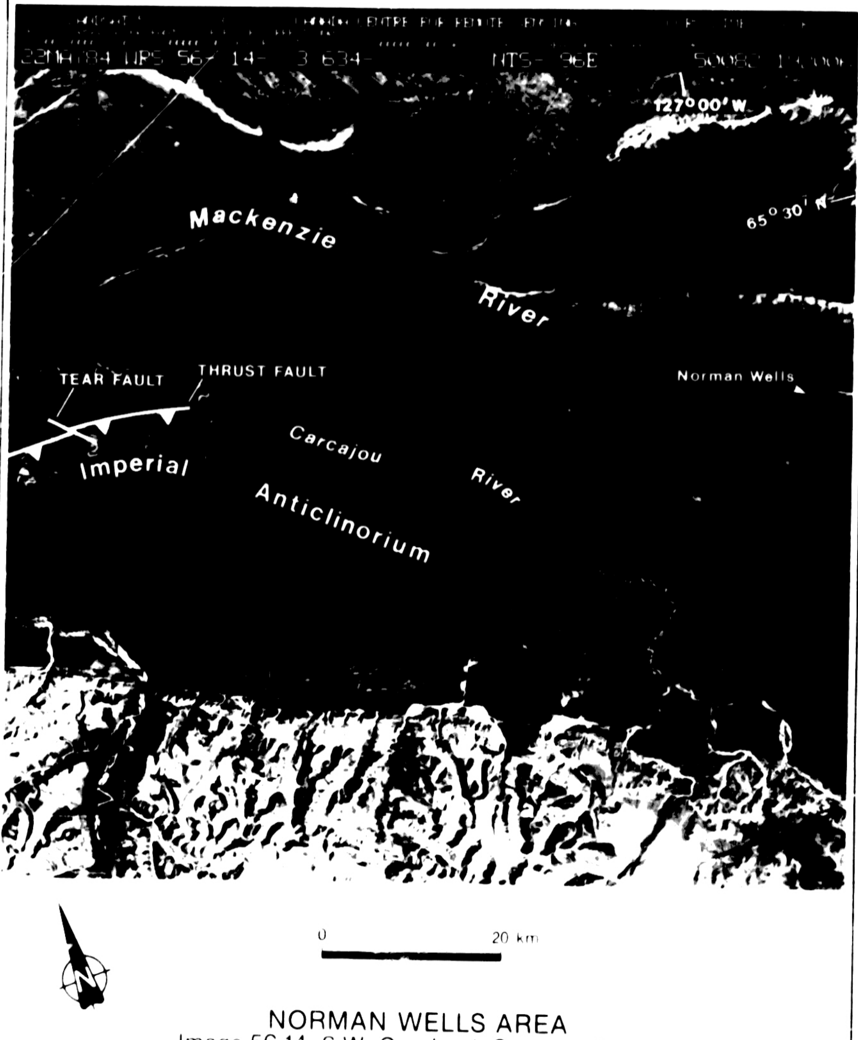
Note The well expressed east facing escarpments [illegible] Devonian Carbonates with gentle, west dipping slopes in the western third (left side) of the image

NORMAN WELLS AREA
Portion of image 56-14, Summer Scene

CLASSIFICATION FOR ROCK SIGNATURE

NORMAN WELLS AREA
Portion of image 56-14, Summer Scene

CLASSIFICATION FOR ROCK SIGNATURE



NORMAN WELLS AREA
Image 56-14. S.W. Quadrant, Summer Scene

THEMATIC MAPPER

Figure 31

NORMAN WELLS AREA
Image 133-230, Summer Scene

TM DATA, ASCENDING PATH

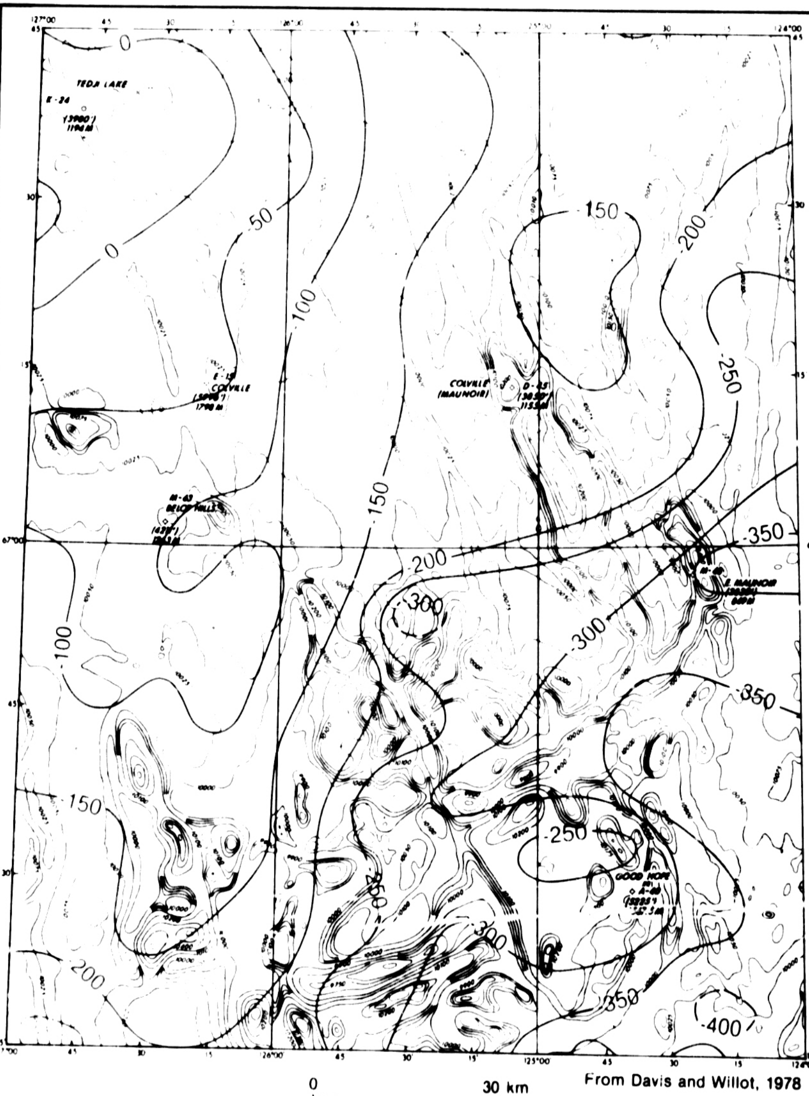
From Davis and Willot, 1978

COLVILLE HILLS
TOTAL MAGNETIC INTENSITY

Figure 33

From Davis and Willot, 1978

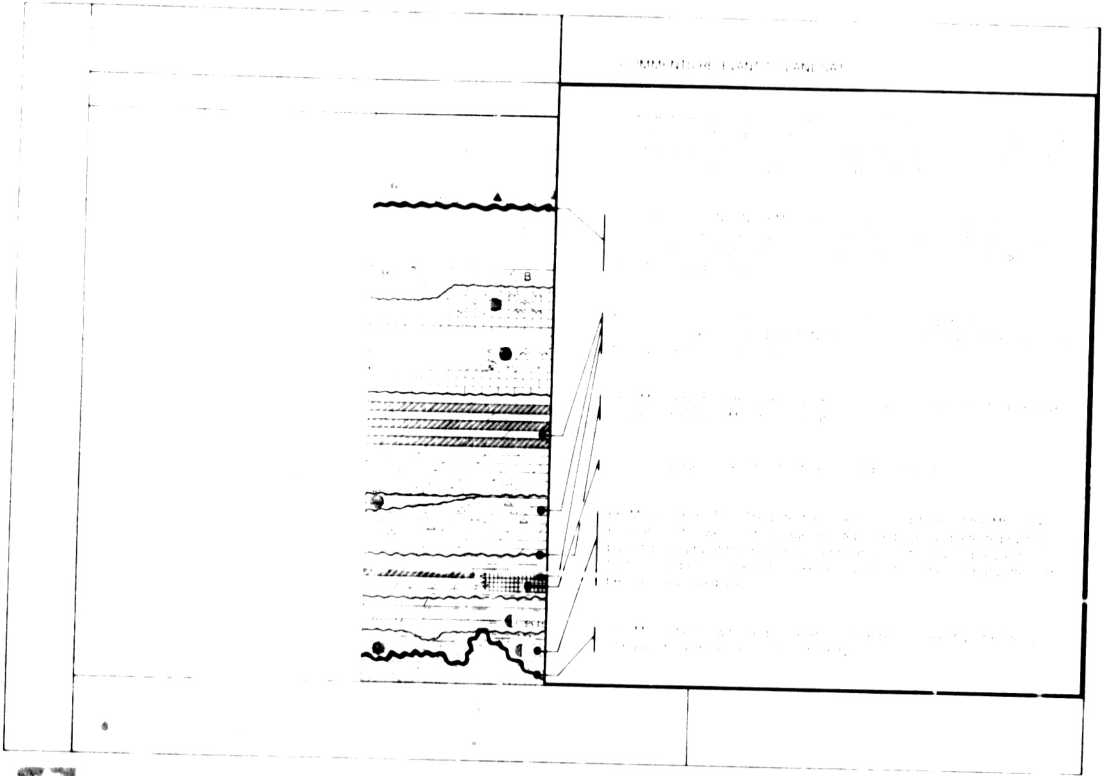
COLVILLE HILLS
LANDSAT PATTERN



From Davis and Willot, 1978

COLVILLE HILLS
BOUGUER GRAVITY

NORTHERN INTERIOR PLAINS



PETROCANADA

Figure 36