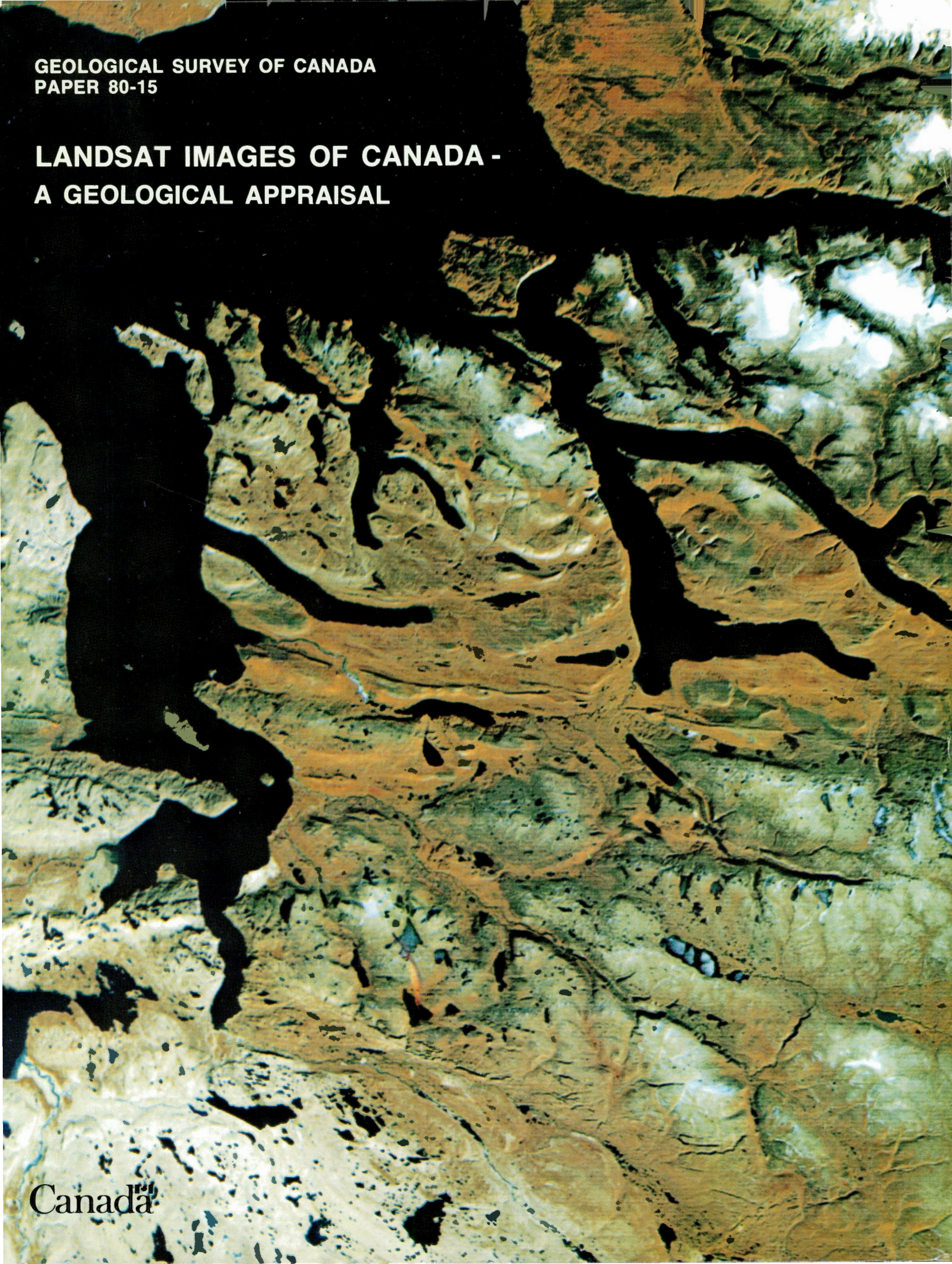
GEOLOGICAL SURVEY OF CANADA
PAPER 80-15

LANDSAT IMAGES OF CANADA - A GEOLOGICAL APPRAISAL



Canada

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LANDSAT IMAGES OF CANADA - A GEOLOGICAL APPRAISAL

V.R. SLANEY

1981

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Critical Readers

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FOREWORD

Most adults take a conservative approach towards ideas and gadgets with which they are unfamiliar. Earth scientists are no exception to this general rule. The rate of acceptance of new techniques is influenced by a great variety of factors, not all of which are of a scientific or economic nature. The response of the geoscience community to the usefulness of Landsat imagery in the study of Canadian geology has been a good example of these mixed reactions. This natural scepticism has tended to be compounded by the periodic simplistic generalizations of satellite technology salesmen who have encouraged the popular belief that all the Earth's natural resource problems were about to be solved by the pinpointing of ore bodies and oil fields from space. In fact satellite imagery provides an ideal reconnaissance technique for unknown or little known regions. Recent planetary missions provide excellent examples of this. Satellite imagery provides a quick means of classifying broad areas, and tracing linear features. It is ideal for developing countries which lack basic mapping. In Canada, where conventional reconnaissance mapping had been completed only a short time before the first ERTS satellite was launched, Landsat imagery arrived too late to contribute to this primary task.

This volume was conceived several years ago with two objectives in mind. To outline the characteristics of the Landsat imagery, including its advantages and limitations, and to provide commentaries by experienced geologists on their view of the significance of the imagery with respect to areas with which they are familiar. These geologists were given the opportunity to comment on the extent to which the imagery reflected known geology, and the extent to which previously unrecognized features might be seen. The overall impression is that apart from gross physical features, the imagery tends to accentuate surficial geology at the expense of bedrock geology. It should be emphasized that no advanced processing techniques were available to the 31 contributors. Thus the commentaries are based solely on "eyeball analysis". Complex digital techniques for the further manipulation of Landsat data are now relatively accessible, and additional beneficial results in the future are a distinct possibility.

In the meantime, this volume serves as an introduction to the geology of Canada as seen from space, and illustrates the excellence of Landsat imagery as a base for many purposes.

A.G. Darnley
Director
Resource Geophysics and Geochemistry Division

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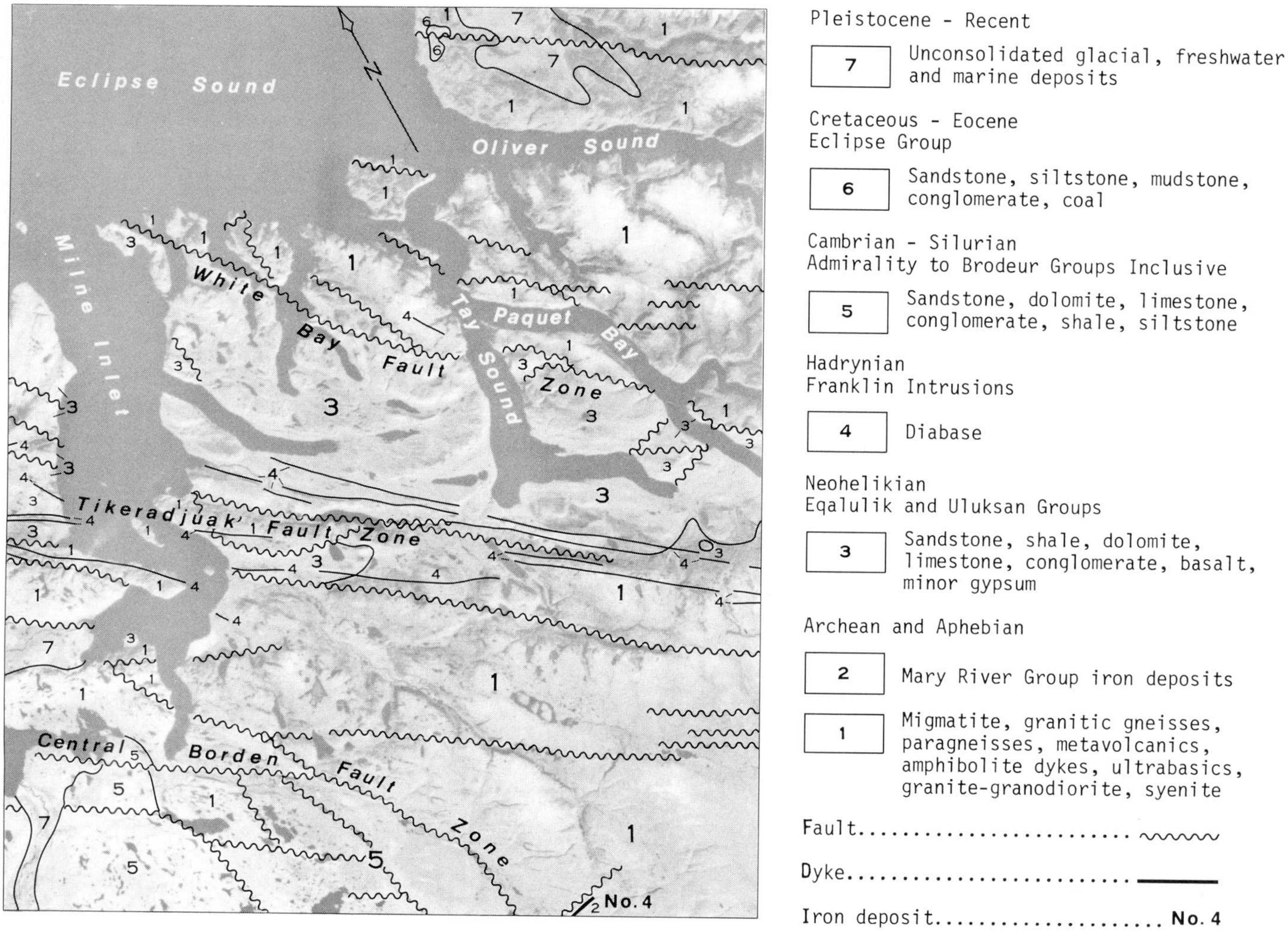
IMAGES AND COMMENTARIES



Cover Image

The scene on the cover shows a portion of the northwest coast of Baffin Island in the Canadian Arctic.

The largest of the many fjords present is called Milne-Inlet which opens into Eclipse Sound. West, south and immediately east of Milne Inlet the highly disserted plateau surface is 3-500 m above sea level. Most of this plateau area is underlain by nearly flat lying sediments (sandstone, shale, limestone, and basalt) of Neohelikian to Eocene age. Numerous northwest trending diabase dykes can be seen intruding the sediments. Southeast of Milne Inlet, a wedge shaped area, part of the Baffin Uplands, rises sharply to heights of 1000 m or more. This area is underlain mainly by a metamorphic complex of Archean and Aphebian gneisses and intrusions that include the Mary River Group of metasediments, metavolcanics, ultrabasic rocks and iron formation. Some of the highest grade iron deposits in the world occur in the iron formation.

The snow and ice covered mountains seen in the northeast quadrant of the image represent part of the Davis Highlands, part of which are more than 1500 m above sea level. The highlands are underlain in the main by the same rocks found farther south in the Baffin Uplands.

The whole region is crossed by numerous steep, northwest trending faults that were initiated in Helikian (mid-Proterozoic) time and have been active up to recent time. Most of them can be seen on this image. These faults have divided the region into the alternating horsts and grabens that make up the North Baffin Rift Zone. The basic dykes refered to earlier, were emplaced, some along and same parallel to these faults (G.D. Jackson).

LANDSAT IMAGES OF CANADA – A GEOLOGICAL APPRAISAL

Abstract

Landsat technology, satellites, and techniques used to analyze imagery of various types of terrain, are discussed.

Through descriptions of selected images of interesting geological and geomorphological features from across Canada, geologists evaluate the effectiveness of Landsat imagery as an aid in the geological appraisal of the area. Although most metalliferous deposits are too small to be identified on images due to the modest spatial resolution of the images, Landsat imagery does provide the geologist with a new perspective of his field area; the earth scientist can now identify large regional lineaments, fracture patterns, many structural and lithologic units, and the distribution of glacial and surficial materials.

Future satellite-borne sensors are expected to have better resolution, operate at a greater range of frequencies, and possibly may provide stereo coverage.

Résumé

On traite de la technologie Landsat, des satellites et des techniques utilisées pour analyser l'imagerie de divers types de terrain.

Par des descriptions d'images présentant des particularités géologiques et géomorphologiques de toutes les régions du Canada, les géologues évaluent l'efficacité de l'imagerie Landsat en tant qu'aide à l'étude géologique de la région. La plupart des dépôts métallifères sont de trop faible étendue pour être identifiés sur les images, en raison de la faible résolution spatiale de ces dernières, mais l'imagerie Landsat fournit vraiment au géologue une nouvelle perspective du terrain étudié; le géologue peut maintenant identifier les linéaments régionaux de grande étendue, les réseaux de fracture, de nombreuses unités structurales et lithologiques et la répartition des matériaux glaciaires et les dépôts de surface.

On estime que les prochains détecteurs transportés par satellite auront une meilleure résolution, fonctionneront sur une plus vaste gamme de fréquences et permettront probablement une couverture stéréoscopique.

INTRODUCTION

In 1966, the United States Government initiated a new activity called the Natural Resources Program under the control of the National Aeronautics and Space Administration (NASA). The program's task was to determine the feasibility of monitoring the earth's natural and cultural resources by remote sensing from space. As a result of this study, the first Earth Resources Technology Satellite (ERTS-1), which was launched in 1972, was developed. Since 1972, there have been two more satellites in the series, the name of which has been changed to 'Landsat'. Of the 3 Landsats, two (Landsats 2 and 3) are still operational. All 3 Landsats were given almost identical instrument packages and the same general orbital characteristics. Landsat is useful to Canadian scientists for the following reasons:

- The satellite orbit ensures that virtually the whole country is reached by its sensors;
- The entire country is overflown every 18 days, which is particularly valuable for investigating cyclic or seasonal phenomena and also ensures that every part of country will eventualy be viewed free of cloud, haze and seasonal snow;
- Every Landsat carries at least one imaging sensor recording reflected solar energy at 4 different wavelengths. This multispectral capability has direct value for many agriculture, land-use, forestry and hydrology applications and to a lesser extent, to the earth sciences. The main limitation of the Landsat Program so far has been the modest spatial resolution of its imaging systems.

The Canadian response to the American space program was positive and enthusiastic. A Canadian ground receiving station recorded its first satellite image within hours of the first image produced in the United States. There are now two ground receiving stations in Canada and a very extensive national program for the acquisition of remotely sensed data from satellites and aircraft. The program is co-ordinated by a single Federal agency, the Canada Centre for Remote Sensing.

This country has no control over the U.S. space program, but it is clear that short of national disasters, the Americans are already committed to continuing their space probes beyond the mid-1980s. However, this does not assure the continuity of any specific sensor package into the indefinite future. Eight to ten years is a reasonable estimate for the life span of even the most successful system, since in this time, technological advances bring pressures for replacement by better, quicker, and cheaper techniques. It takes one to two years for scientists to evaluate a remote sensing system. It may take a much longer time than this for the working scientist to develop confidence in the new data and to find ways to incorporate them into his ongoing programs. This time problem will not be solved in the immediate future. There are plans for more satellites carrying an ever-widening range of sensors. With sensor diversification there will be more data to transmit, more data processing, storing and accessing facilities will be needed, and it will be even more difficult for working scientists to maintain sufficient contact with the new technologies to utilize fully the new data sets.

This report comprise a collection of Landsat Multispectral Scanner (MSS) images preceded by a review of the Landsat technology. The review provides a broad overview of the satellites and their imaging systems and discusses the various techniques used to analyze images as well as the kinds of natural features that can be recognized on these images. Throughout the review emphasis is placed on those aspects of the technology considered most important to earth scientists. The collection of images following this review, has been evaluated by geologists using simple, visual techniques. It will be evident from the descriptive part of this report that despite all the sophisticated devices for image enhancement that have been developed, in the great majority of cases the best results are achieved by giving a top quality image to an experienced scientist.

The collection is presented for a number of reasons: the need for a basic collection of Landsat imagery that may be used for teaching and for reference purposes; to provide an introduction to the various classes of Canadian Landsat imagery; and that the geological commentaries will promote discussions and perhaps focus the opinions of other geologists on the applications of Landsat images for geoscience.

The images have been chosen to illustrate the many lithological, structural and geomorphological features found in Canada. Many images, like those of Manicouagan and the Central Labrador Trough (Fig. 1.9, 1.3), have the kind of visual appeal, combined with scienctific interest, that would qualify them for a place on any list. Others were included to show distinctive structural or lithological environments. Whenever possible the choice was made with an eye to visual appeal as well as to scientific interest. Nine images are presented as colour composites. Regrettably reproduction costs inhibited the printing of most of the images in colour. Five monochrome mosaics are also included. Most of them are composed of 2 or 3 images only, so that the scale of reproduction is only marginally less than that of the single prints. Only the Belcher Islands mosaic (Fig. 1.1), constructed from 10 prints, is reproduced at an appreciably reduced scale.

All the images were reproduced from the same negatives that are used to produce prints for the general public.

The commentaries, which accompany the images, were written by geologists with many years of experience working in the area each described. Many of the authors are in fact the prime geological authority for their image area, and all are either presently employed by the Geological Survey of Canada, or have at some time in the past been associated with the Survey. For most of them this was the first time they used Landsat imagery although they were all familiar with the uses of conventional aerial photographs. The collection of commentaries has value as the first response of 31 geologists to a new form of imagery. Every author has been free to treat the subject as he wished within the limitation of a two page presentation.

Editing has been kept to a minimum, and because some of the writers were uncertain about the usefulness of Landsat, their adverse comments have also been retained. None of the commentaries should be regarded as the 'final word', this is precluded by the lack of space. Most commentaries end with a short list of references which are intended to provide access to the literature for those interested in pursuing further studies.

BASIC FACTS ABOUT LANDSAT

Landsat-1, which was launched on 23 January 1972 performed magnificently before its final shut-down on 6 January 1978. Landsat-2 was already operational by this time, having been launched on 22 January 1975. Landsat-3 joined Landsat-2 in space on 5 March 1978. Landsats 2 and 3 are expected to continue functioning into the early 1980s.*

The information gathering systems of all three satellites are nearly identical, consisting of a Multispectral Scanner (MSS), Return Beam Vidicon television cameras (RBV), and an electronics package for a ground data collection system (DCS). Every Landsat also carries two video tape recorders by which MSS or RBV data can be stored for later transmission to earth.

Orbit Pattern

All three Landsats have identical circular, near-polar orbits circling the earth every 103 minutes at altitudes between 890 to 940 km. Because the orbits are not truly polar, 'world' coverage refers to all parts of the world between latitudes 81°N and 81°S. Every 24 hours, each satellite circles the earth 14 times of which 4 or 5 daytime passes cross Canada. The orbital pattern of each satellite progresses westwards in such a way that all 'day 2' orbits lie immediately west of 'day 1', and 'day 3' orbits are again west of those of 'day 2' (Fig. 1). It takes 18 days (and 251 orbits) for the globe to be viewed by the two imaging sensor systems on board each satellite. Each 18 day cycle is repeated with great accuracy, the satellites retracing every orbital track within 37 km in the cross-track direction. Landsats 2 and 3 are 9 days apart within their respective orbit cycles so that by using images taken from both satellites, world coverage is obtained every 9 days. The satellite orbits are also designed to be sun-synchronous, that is, all daytime orbits cross points on the same latitude at the same solar time. This ensures that imagery from adjacent or near-adjacent orbits acquired at the same time of year will have the same sun elevation and, therefore, will have the same distribution of shadows. The satellites cross Canada in the daytime about 9:05-9:15 a.m. solar time continuing southwards to cross the equator at 9:30 a.m. solar time. Figure 2 shows the variation of the sun's elevation at 9 a.m. solar time selected latitudes throughout the year. The main orbit parameters are summarized in Figure 3.

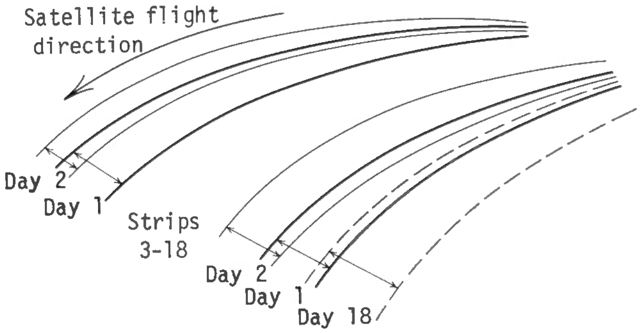


Figure 1. *Flight path pattern of satellite showing westward progression of orbits. The earth can be scanned in 18 days (251 orbits).*

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* Landsat MSS and RBV systems have performed magnificently, significantly better than design estimates. Sub-system failures must be expected and several have occurred, especially during the past year. The Cornell Remote Sensing Newsletter dated March 1981, provides an update on the status of Landsat imaging systems.

The MSS on Landsat-3 has been shut down because of system malfunction. Landsat-2 MSS is still functioning for direct readout to ground stations. RBV cameras on Landsat-3 are working. The U.S. will try to acquire worldwide cover of RBV data converted to digital format. Landsat-D, the next satellite of the series, is to be launched in 1982 and is still expected to have on board a multispectral scanner and thematic mapper.

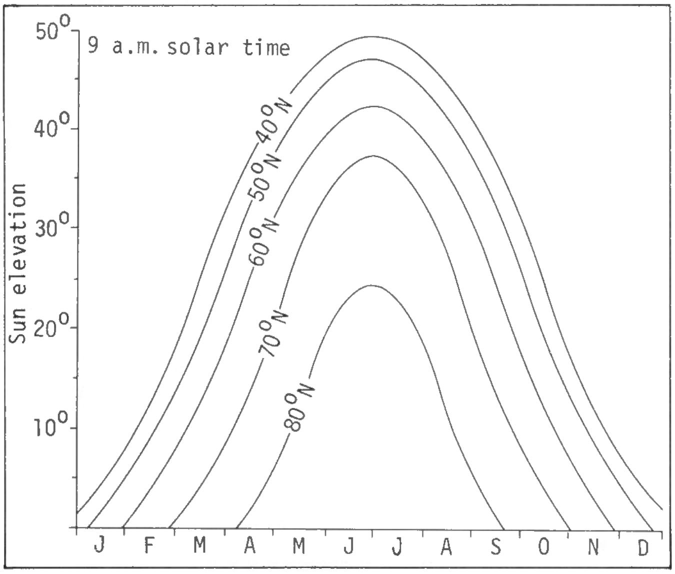


Figure 2. Change in the sun's elevation (at 9 a.m. solar time) with the season at selected latitudes.

The Multispectral Scanner

The multispectral scanner (Fig. 4) is an instrument that uses an oscillating mirror to scan, sequentially, narrow strips of ground perpendicular to the direction of travel of the satellite. The movement of the satellite provides for the buildup of a continuous strip of imagery. Solar energy reflected from the ground is reflected in turn by the mirror through an optical system which disperses the energy into its several wavelengths, directing select wavelengths onto a series of detectors each of which records the intensity of radiation received. All three Landsats are equipped with an identical MSS system which detects radiation at 4 different wavelengths, two of which are in the visible part of spectrum (Bands 4, blue-green and 5, orange-red) and two in the near-infrared part of the spectrum (Bands 6 and 7). Landsat-3 is equipped with an additional channel to detect thermal-infrared radiation (Band 8) but this channel failed soon after launch. There are 6 detectors for each of the 4 bands, arranged in such a way that with every scan of the MSS mirror, 6 lines of information are recorded in each of the 4 channels.

The MSS system produces a continuous strip image of the earth's surface 185 km wide at four different wavelengths. Each image is made up of picture elements called pixels; each pixel represents an area on the ground of 79 by 79 m. The data sampling rate is high enough that there is a 28 per cent overlap of the area sampled by each adjacent pair of pixels. There is no overlap between sequential lines. The effective area of the earth's surface represented by each pixel is thus 70 m along track and 57 m in the cross-track direction. Every pixel is recorded at one of 64 (0-63) possible brightness levels.

For convenience in handling, the data stream is separated at the ground receiving stations into segments called scenes, each of which represents a 185 km length of the imaged swath. Every scene shows an area 185 by 185 km and includes 10 per cent duplication of the image which precedes it and 10 per cent of the image which follows. Every scene is normally published in four bands (or channels) which in all, total 30.4 million pixels. Because the image swath is broken up at the same set of latitudes, the image centres form rows which cross the orbit paths more or less orthogonally. This has led to a world reference system for MSS images. Orbit tracks are numbered sequentially, increasing westwards, whereas rows are numbered from '1' at 80°N increasing southwards. Every image centre can be uniquely referenced by its orbital path number followed by a row number. Index maps for Canada can be obtained on demand from the Canada Centre for Remote Sensing in Ottawa.

Inclination	99° (nearly Polar)
Elevation	890-940km
Period	103 minutes
Area Covered	81°N to 81°S
Global Coverage	251 revolutions in 18 days
Ground Speed	6.5 km/second
Orbit Repeat Accuracy	37km across track
Approx. Time of Descent over Canada	9:10-9:15 a.m. (solartime)
Passes over Canada to obtain full coverage	75 in 18 days

Figure 3. Summary of orbit characteristics.

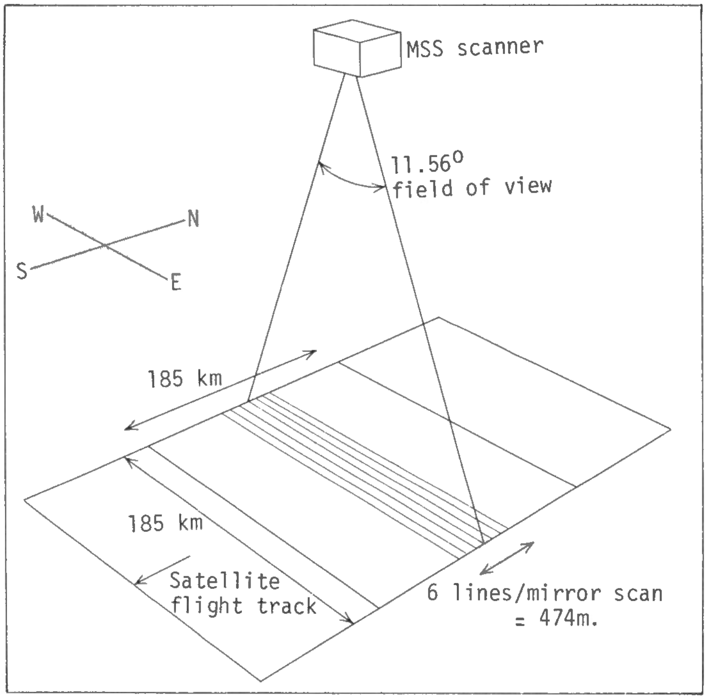


Figure 4. Geometry of the multispectral scanner flight path.

Images acquired from adjacent orbits show a degree of sidelap which varies with latitude. At the equator, images sidelap 14 per cent of their swath width. Within Canada, sidelap ranges from 40 to 85 per cent as shown on Figure 5. Thus much of the Northwest Territories can be imaged by scenes taken from every second or third orbit. Around Ellesmere Island in the high arctic, images from every fifth or sixth orbit will provide full coverage.

The ground resolution of MSS images has been defined as an area 79 by 79 m. Most natural objects are recognized in part by their size and shape and partly because of the contrast in reflectance between each object and its background. There is, in fact, a trade-off between size and contrast. The smaller an object is, the greater must be the contrast with its background if it is to be seen. Conversely, a large object may be recognized even though the contrast with its surroundings is moderate to low. According to information theory, a natural object within the normal range of reflectances needs to be at least 3 pixels (240 m) across before it may be described as having a recognizable shape. Landsat resolution has been defined in photograhic terms by Colvocoresses (1972) who calculated that a low contrast subject (1.6:1) should be at least 316 m wide to be recognized whereas a subject with high contrast (1000:1) need only be 224 m wide.

There are a number of occasions when a subject (often a bridge or a road) smaller than 79 m in one direction, has been recorded on an image. In every case the object is seen because of the very high contrast between it and its background (Bochofer, 1973; Wallace and Peakes, 1974; Lansing and Cline, 1975). While smaller than one pixel in physical size, the object is nevertheless, always recorded as filling at least one pixel.

The most common scale for the production of Landsat prints is 1:1 000 000. Enlargements of portions of images to a scale of 1:50 000 or larger are not uncommon. Many Landsat users would suggest that a scale of around 1:250 000 is, for most applications, a reasonable maximum useful scale. Further increases have little or no effect on resolution. Even at a scale of 1:250 000 individual picture elements are 0.32 x 0.23 mm, just barely visible to the eye without the use of a lens.

More information of geological value is gained from studying the topography of an area than any other single aspect. Unfortunately Landsat images are generally inadequate for true stereoscopic analysis. Two factors contribute to this:

a. Imagery from adjacent orbits is needed to form the stereo model. The amount of sidelap between adjacent orbits varies with latitude as discussed previously (Fig. 5). The minimum 50 per cent sidelap needed to ensure complete stereo cover is found in all areas north of 54°N, which effectively excludes the southernmost third of Canada.

b. The topography in the stereo-image of a normal pair of air photos is exaggerated by a factor of 2 to 3 times or more, depending on the ratio of the air base (the distance between two consecutive exposures) to the flying height. This is known as the Base/Height ratio. As the Base/Height ratio increases, so does the vertical exaggeration, so that slopes appear steeper and hills higher in the stereo-image. This effect makes the topography easier for the viewer to analyze. With normal air photos, which have 60 per cent overlap, Base/Height ratios mostly range from 0.3 to 1.0, depending on the focal length of the lens. The Base/Height ratio for Landsat imagery with 60 per cent sidelap is 0.08, increasing to 0.1 where the sidelap is 40 per cent. Such Base/Height ratios offer little assistance to the interpreter.

Williams (1973) reported that vertical differences of as little as 100 m have been recognized, but for most purposes, 200 to 400 m probably represents the smallest vertical difference that can be recognized on an MSS stereo pair using standard photogrammetric techniques.

An alternative approach to this problem is described by Batson et al. (1976) whereby parallax proportional to the terrain elevations is introduced into an image at the time the image is printed out from magnetic tape. The elevation data

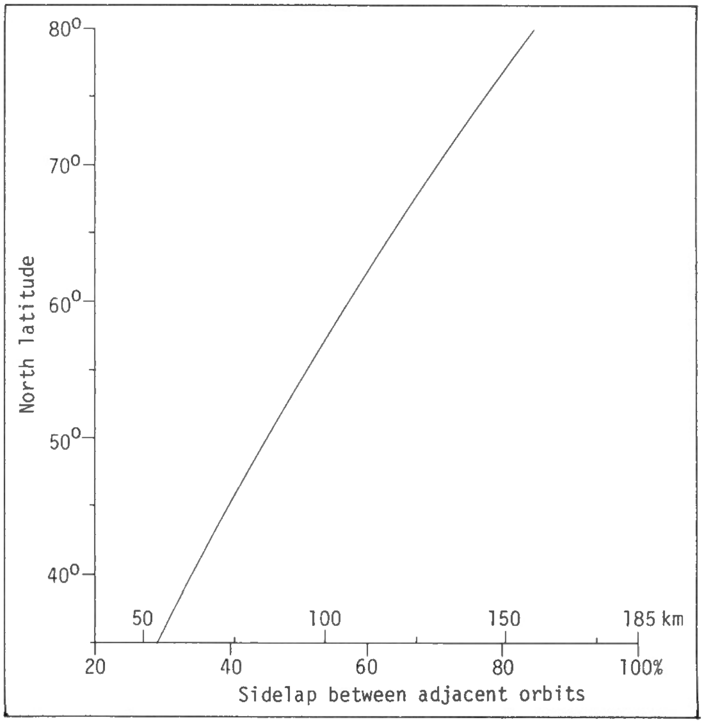


Figure 5. *Variation in sidelap with latitude.*

LANDSAT 1 and 2

Mirror scan rate	13.6 scans/second
Number of detectors in each band	6
Bands per scene	4
Scene overflight time	26 seconds
Area of scene	185 x 185 km (includes 10% repeat of previous scene)
Pixels per scan line	3240
Lines per band	2340
Pixels per band	7.6 million
Pixels per scene	30.4 million
Area of pixel on ground	79 x 79m
Area of pixel excluding overlap	79m (along track) x 57m (across track)

SPECTRAL BANDS

4. 0.5 - 0.6 microns	4. 0.5 - 0.6 microns (Green)
5. 0.6 - 0.7 microns	5. 0.6 - 0.7 microns (Red)
6. 0.7 - 0.8 microns	6. 0.7 - 0.8 microns (Near
7. 0.8 - 1.1 microns	7. 0.8 - 1.1 microns Infrared)

LANDSAT 3 MSS is indentical to earlier Landsats except for an additional Thermal-Infrared band (10.4-12.6 microns) which has 2 detectors and therefore only one third the resolution of the other bands. This band developed problems and was shut down very early in the mission.

Figure 6. *Multispectral scanner characteristics.*

	LANDSAT 1 and 2	LANDSAT 3
Number of cameras	3	2
Lines/Frame	4125	4125
Field of View	16.2^{0}	8.6^{0}
Effective Focal Length	126mm	236mm
Readout time	3.5 seconds	3.5 seconds
Area of image	185 x 185km	98 x 98km
Nominal ground Resolution	45m	24m
Spectral bands	4 .475 -.575 microns (Blue - green) 5 .580 -.680 microns (Orange - red) 6 .690 -.830 microns (Solar - infrared)	4 and 5 .505 - .75 microns (Green, red, solar - infrared)

Figure 7. *Return beam vidicon camera characteristics.*

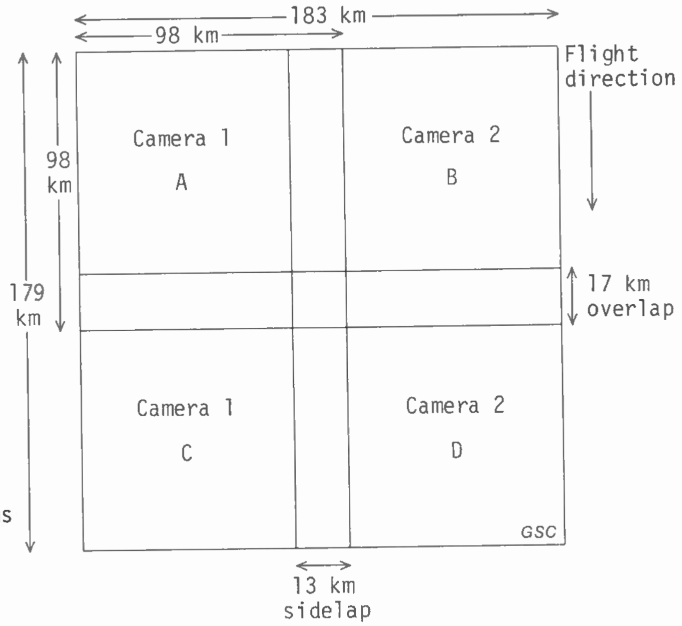


Figure 8. *Landsat-3 return beam vidicon scanning pattern.*

are obtained from published topographic maps. Two prints of the same image, one with parallax and one without, provide a three dimensional view of the scene when viewed under a stereo-scope. The amount of parallax introduced into the one half of the stereo pair can be varied so as to control the vertical exaggeration of the topography in the stereo model.

The main characteristics of the multispectral scanner are summarized in Figure 6.

Return Beam Vidicon Cameras

Each Return Beam Vidicon (RBV) camera has a shutter, that, when activated, exposes briefly the raster surface of the vidicon tube. The scene stored on the raster face is then read out, line by line, for transmission to earth, or for storage by the video-tape recorder.

Landsats 1 and 2 each have 3 RBV's bore-sighted to observe the same area of ground. Each camera is sensitive to a different part of the energy spectrum which, as Figure 7 shows, corresponds fairly well with bands 4 (green), 5 (red) and 6 (near-infrared) of the MSS system.

The cameras are fired simultaneously to provide correlatable data, and at sufficient time intervals to ensure 10 per cent forward overlap. Each exposure records a ground scene 185 by 185 km, exactly the same as an MSS scene.

All RBV cameras have 4125 scan lines and each line contains a similar number of pixels. Thus each pixel represents the energy received from an area of 45 by 45 m on the ground. The RBV cameras on Landsat-1 were turned off a month after launch because of a malfunction. The Landsat-2 cameras are operational but are only turned on over Canada during the summer.

Landsat-3 has only 2 RBV cameras. These cameras have longer focal length lenses so that each images an area of only 79 by 79 km. The cameras are also sighted to view the MSS system swath width in two, side by side and slightly overlapping, frames. The two cameras are fired simultaneously at sufficient time intervals to produce coverage equal to one MSS scene (Fig. 8) from every group of 4 images. The two cameras also have the same spectral sensitivity as panchromatic film which is used in aerial cameras. As originally conceived, the RBV system was an alternative to MSS. The latter, however, proved more reliable in space, and because it has a single optical system, the several spectral bands are more easily and more accurately correlated. As a result, where MSS and RBV systems have comparable functions, MSS data acquisition and production is given priority over the RBV in both Canada and the United States. On Landsat-3, the RBV's have a different function to the MSS system. The RBV's have a much higher resolution, and because each scene is exposed at a single instant of time, an improved geometry. It may even be possible to overlay high resolution panchromatic RBV images with MSS data.

Video Tape Recorders

MSS and RBV data are normally transmitted directly to ground stations in line of sight. When imagery is required from areas where there are no ground stations, up to 30 minutes of data can be recorded on a VTR for transmission to earth at a later time. Landsats 1, 2, and 3 earch carry 2 VTR's.

Data Collection System

The Landsat satellites are able to collect data transmitted from scattered, and often remotely located, ground sites for re-transmission to Landsat ground receiving stations. Data collection sites operate automatically and are usually used to collect environmental information, often from weather stations and from sites where stream or lake levels are monitored.

GROUND RECEIVING STATIONS

There are two Government operated receiving stations in Canada; one is located at Prince Albert, Saskatchewan and the other at Shoe Cove near St. John's, Newfoundland. Imagery of Canada, Iceland, most of Greenland and the west coast of Ireland can be received by these stations.

The United States has three ground receiving stations, located at Fairbanks, Alaska, at Goldstone, California, and at Greenbelt, Maryland.

In the last few years receiving stations have been built in Argentina, Australia, Brazil, India, Italy, Japan and Sweden, and similar facilities are being planned for Thailand and Upper Volta in 1980.

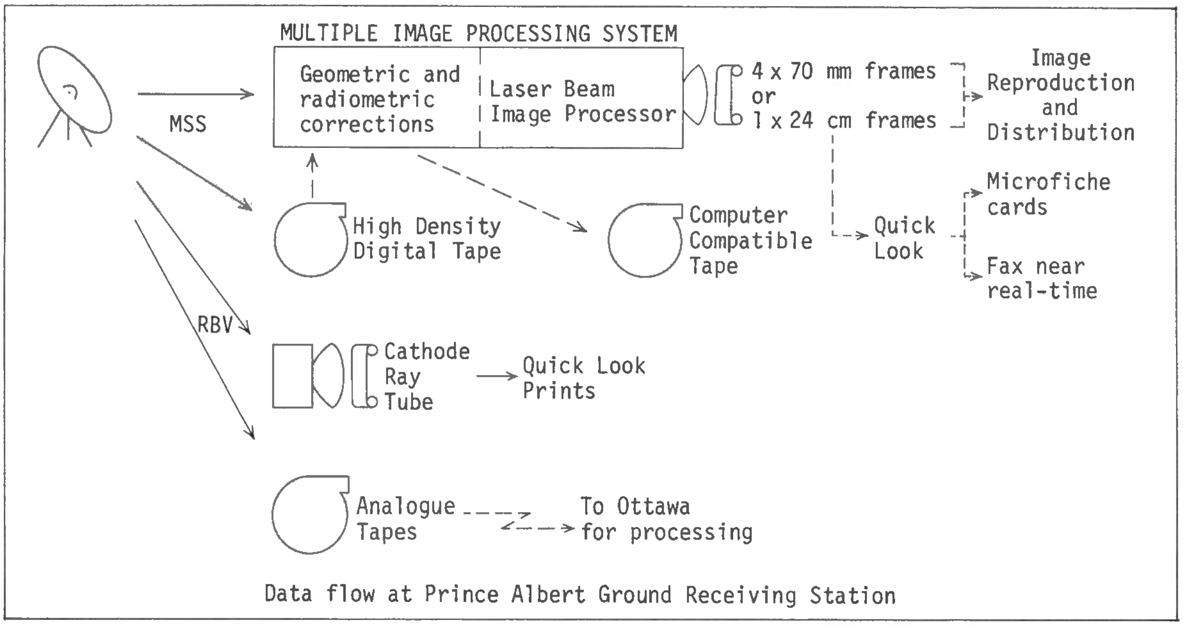


Figure 9. *Flow chart showing the method of processing data at Prince Albert.*

MSS Data

Until late 1978, MSS data received at Prince Albert and Shoe Cove were recorded on High Density Digital Tapes (HDDT) which were flown daily to Ottawa for processing. In 1979 new data handling systems were introduced at both ground receiving stations in Canada (Fig. 9, 10). At Prince Albert (Fig. 9) most of the monochrome imagery is produced in real time using the new Multiple Image Processing System (MIPS). This system applies radiometric and geometric corrections to the MSS data as they are received, passing on the corrected data to a Laser Beam Image Processor which simultaneously produces four 70 mm frames (bands 4, 5, 6, and 7) for each scene. MIPS can also be used in an off-line mode to produce a single 18.5 cm monochrome transparency. False colour composite images may be produced from three 18.5 cm monochrome transparencies (bands 4, 5, 7) by sequential printing onto colour film, using blue light to print band 4, green light to print band 5 and red light to print band 7. In parallel with the MIPS system, the incoming data stream is also stored on HDDT's which can be used later for processing by MIPS to imagery or for the production of Computer Compatible Tapes.

Many users need access to the imagery within a few days of its reception. To satisfy these customers. 'Quick Look' prints (one band from each MIPS scene) are prepared for shipping wihtin 24 hours of the data being received.

Some agencies need imagery for analysis within hours of its reception at the ground station. For these users, there is a Fax (facsimile) service by which Quick Look images are transmitted by telephone from the ground station direct to the user. Quick Look prints are also reproduced in 16 mm format as microfiche records. Each microfiche card carries one day's production of MSS data, about 70 scenes. MSS data are processed at Shoe Cove (Fig. 10) in a way similar to that at Prince Albert, except that the Shoe Cove facility has no processor for printing high resolution images. Instead, a second tape recorder produces HDDT's that are air-freighted to Prince Albert for full processing. Quick Look prints are obtained using a cathode-ray tube display. These are then mailed to some users, transmitted via the Fax sequence to others, and are reproduced for microfiche.

Geometric corrections are applied to MSS data to produce an image that is reasonably compatible with the standard National Topographic Series (NTS) map sheets. This is mainly achieved by correcting for the effects of earth rotation. The earth's rotation introduces a lateral shift in the sequence of strips of ground viewed by the MSS scanning mirror. When the image is reconstituted, this shift must be re-introduced. The corrected image has a skewed shape which varies in degree with latitude. Corrections are also applied to allow for the earth's curvature, for variations in the speed of the scanning mirror, and for variations in scan-line length. This provides an image on which all points are said to be properly located within 4 mm (4 km on the ground)

Radiometric corrections are carried out to produce an image that is visually pleasing. In Canada, one radiometric correction is applied which allows for differences in the individual response of the 24 detectors. The MSS system carries an internal, calibrated light source to which the detectors are exposed after every alternate scan. Their responses are then passed to the ground receiving station with the image signal. The correction derived from this internal calibration system is used to remove most of the striping that would otherwise affect the image. Residual striping often remains and can sometimes be removed by further processing. A grey scale calibration wedge is added to the edge of the destriped image when it is written onto film. This grey scale is used to control tape to film exposure and film reproduction, including the preparation of colour composites.

A new MSS image product, the 'DICS image' was developed in 1979. Every DICS image (Digital Information Correction System) is a subscene of a Landsat image representing the area of a quarter of a standard 1:250 000 NTS map sheet. DICS images (and associated CCT's) have a much improved geometry which is due to 30 to 50 ground control points used in their construction. Accurate placement of ground features to ±50 m (~ 0.5 pixel) is claimed. With such precision it is far easier to work with images of the same area obtained on different dates. Standard radiometric corrections are applied to DICS images and CCT's. In addition, the images (not the CCT's) are band stretched.

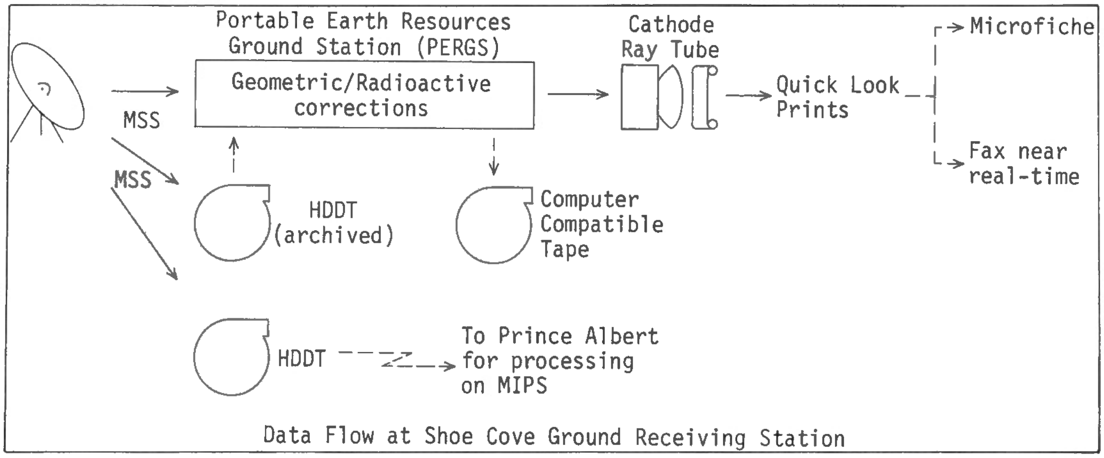


Figure 10. *Histogram of MSS Band 4 scene shows how haze is removed from this scene by subtracting 5 brightness values from every pixel.*

Histograms showing the distribution of brightness values in a scene (Fig. 11) commonly indicate that the MSS data take up less than half of the full range of brightness values available. This process is commonly called band stretching.

Computer Compatible Tapes of MSS scenes are offered in three standard forms, as raw data tapes, without corrections of any kind; as system corrected tapes, in which standard radiometric and geometric corrections have been applied; and as DICS tapes which are subscenes with standard radiometric and precise geometric corrections.

RBV Data

Selected RBV scences are received only at Prince Albert. The scenes are recorded on analogue tapes and simultaneously processed on a cathode ray tube device which provides immediate, uncorrected, 'Quick Look' prints. The analogue tapes are sent to Ottawa for processing on a high resolution printer. Here, the images are archeved and the tapes returned for re-use.

Summary of Standard Canadian Landsat Products

MSS Imagery	Transparancies/Prints, 4 bands, 70 mm or 18.5 cm format Colour composites, bands 4, 5, 7, 18.5 cm format DICS Prints/transperancies 1:500 000 Quick Look prints, 18.5 cm format Fax (facsimile) of Quick Look Microfiche of Quick Look. Mosaics of Canada, 1:10, 1:5, 1:2.5 million scales.
MSS Computer Compatible Tapes	Raw Data CCT, Full scene, no corrections System corrected CCT, Full scene, standard radiometric/geometric corrections DICS CCT, Partial scene, standard radiometric, precision geometric corrections.
RBV data	Prints 1:500 000 scale.

The United States also has a very sophisticated system for processing HDDT's to imagery at the EROS Data Center in Sioux Falls. This system, called the EROS Digital Image Processing System (EDIPS), became operational in January 1979. A description is contained in Landsat Data Users Notes, Issue 3, for November 1978.

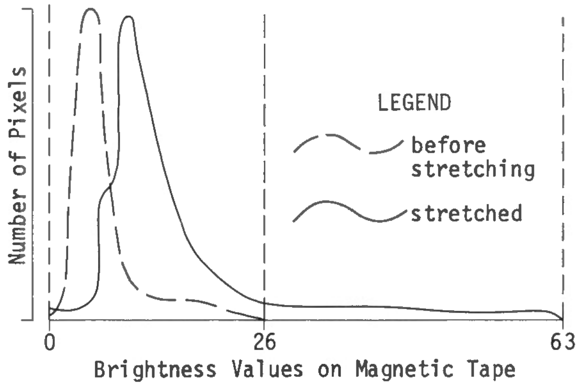


Figure 11. *Histograms of MSS Band 7 scene before and after stretching. Data are normalized for comparison.*

ANALYTICAL TECHNIQUES

In the past few years there has been a remarkable increase in the number, variety, and sophistication of equipment for the analysis of images, especially images from space. It is particularly important to determine why one approach should be used rather than another. The choice of method should not rest solely on the availability of equipment but on the aim of the analysis itself.

The principal techniques used to analyze images are summarized here in three sections, visual methods, computer methods, and a third mixed group using photographic, optical or electronic techniques.

Visual Method

Visual analysis of the satellite image is still by far the most important method for a number of reasons.

It is the simplest, most freely available technique requiring the minimum of equipment. Although a hand lens is generally sufficient, a light table for transparencies and a stereoscope preferably with zoom lens provide reasonably adequate basic support. For geoscientists the main source of information in Landsat is found in the distribution of textural patterns and linear features. Abstracting this class of information – as with aerial photographs – is still accomplished most efficiently by visual analysis, because the human eye is more skilled than any computer in being able to recognize a wide variety of patterns and to detect their relevance. The eye can also cope with unforeseen occurrences and deal with events which have a low probability of recurrence.

Landsat imagery with its four spectral bands is designed specifically for the investigation of reflectance characteristics. Although spectral discrimination techniques applied to the study of rocks or to surficial materials have not been investigated in Canada as thoroughly as the subject deserves, there are few grounds for believing that such techniques will provide more than a generalized basis for automatic mapping of the terrain even in northern Canada (Boydell, 1974; Siegel and Abrams, 1976). The reasons for this are that in most of southern Canada a heavy forest cover or deep soil cover derived from glacial material allows little scope for the recognition of the underlying rocks through differences in reflectance. In northern Canada the situation is much more favourable in that the percentage of rocks outcropping is in many places high and different classes of surficial materials may be characterized by a particular type of vegetation. Even here, however, no one type of vegetation is restricted to one class of surficial material, and most of the exposed rocks are obscured by an irregular cover of lichens, are stained by carbonaceous material derived from the lichen cover, and also have a chemically weathered outer surface. The effect of these factors is to reduce considerably contrasts in reflectance between rock types. 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.

Computer Method

Computers are employed to modify the data to present information in a more meaningful (interpretable) way. This is accomplished by suppressing or eliminating some information or by combining data, particularly those from different bands, in some selective way. Measurements and statistical information relating to the image also can be obtained. Standard computer systems can be used although there is now a growing number of computers dedicated to the specific task of analyzing imagery. Scientists who have had some experience with computers are now able to handle such systems either themselves or with the assistance of an operator.

As the use of a computer is relatively expensive, the scientist must devote time to become acquainted with the system used and its capabilities. A computer undoubtedly offers the most comprehensive and thorough approach to image analysis based on reflectance values. However, its application to linear and textural features (faults, fold traces, bedding and schistosity trends) is usually rather poor.

The approaches most commonly used are:

1. Automatic classification of reflectance data. Many mathematical procedures have been developed, most of which may be grouped into two broad categories. Supervised classifications are carried out using natural classes derived from field work or form published information. Unsupervised classifications are applied without reference to information obtained from the area itself (Goodenough et al., 1974; Taylor, 1974; Kalenski and Wightman, 1976).
2. Combining spectral bands. These may be added, subtracted or ratioed, and either positive or negatives of bands can be used. False colour composites can be generated by exposing two or three monochrome bands or ratios of the same scene through differently coloured light sources onto colour film (Vincent, 1973).
3. Edge enhancement. Grey tone boundaries or gradients are emphasized, so that textures and linear features stand out on the image: a directional control may be introduced to select linear features with a specific orientation.
4. Density slicing. The number of grey tones present in an image is grouped into a series of density steps each of which has known upper and lower limiting values. Each density step may be coded with a distinct colour, which facilitates visual recognition of areas with a similar density distributed throughout an image.
5. Adjustments to the density gradient (Billingsley, 1973; Goetz et al., 1973). In cases where a particular class of information is recorded in one part of the density range of the image, it is possible to expand that range of densities so that small density differences are emphasized and so more easily recognized. Band stretching and haze removal techniques fit in this category.
6. Mensuration. Subjects that have distinct reflectance characteristics like water, can be measured with some accuracy. Other subjects may be confused by false correlations. Measurements of linear or textural features are still extremely difficult to accomplish and the methods that exist are still experimental.

Photo-Optical-Electronic Methods

The third alternative represents a mixture of systems whose common characteristic is that the input is an image. The techniques used to handle the image may be grouped into:

a. Purely photographic (darkroom) techniques. A skilled technician can achieve results which closely approximate those obtained using the very expensive optical, electronic and computer-based devices mentioned here (Lamar and Merifield, 1973; White, 1973; Nielson, 1974; Colvocoresses, 1975; Ross, 1976).

b. Optical techniques. These include additive viewers, which are multiple projection devices, allowing the simultaneous registration of up to 4 transparencies onto a single screen. Different filters can be introduced into each of the optical trains. False-colour displays can be constructed by the scientist with an absolute minimum of training. The other main optical technique involves Fourier analysis (Arsenault, 1974; Pincus and Dor, 1974; Ulaby and McNaughton, 1975). Fourier transforms are produced from images. The transforms are filtered, after which the filtered transform is reconstituted to form a filtered image. This technique is particularly suitable for the study of intersecting patterns of linear features.

c. Electronic devices, most of which scan an image with a flying spot scanner or a television camera, using a monochrome or colour television monitor to display the output signal. The input signals can be processed in a variety of ways (White, 1973; Reeves, 1974); the most common treatment being to break up the input signal into a range of levels or 'slices' each of which can be assigned a colour on the display monitor. Systems are usually modular in design so that their functions can be extended to include new capabilities as such are needed. Many systems now include mini-computers. The range of tasks is less than that of the dedicated computer and the results are also limited by the quality of the image used as input to the system. Perhaps it is because of the limitations of the film input, that these electronic systems rarely provide any real discoveries. They do serve admirably to emphasize features that are already known. They are also able to provide colourful displays which, hopefully, will illustrate some significant event more vividly than is possible with monochrome material.

CHOOSING AN IMAGE

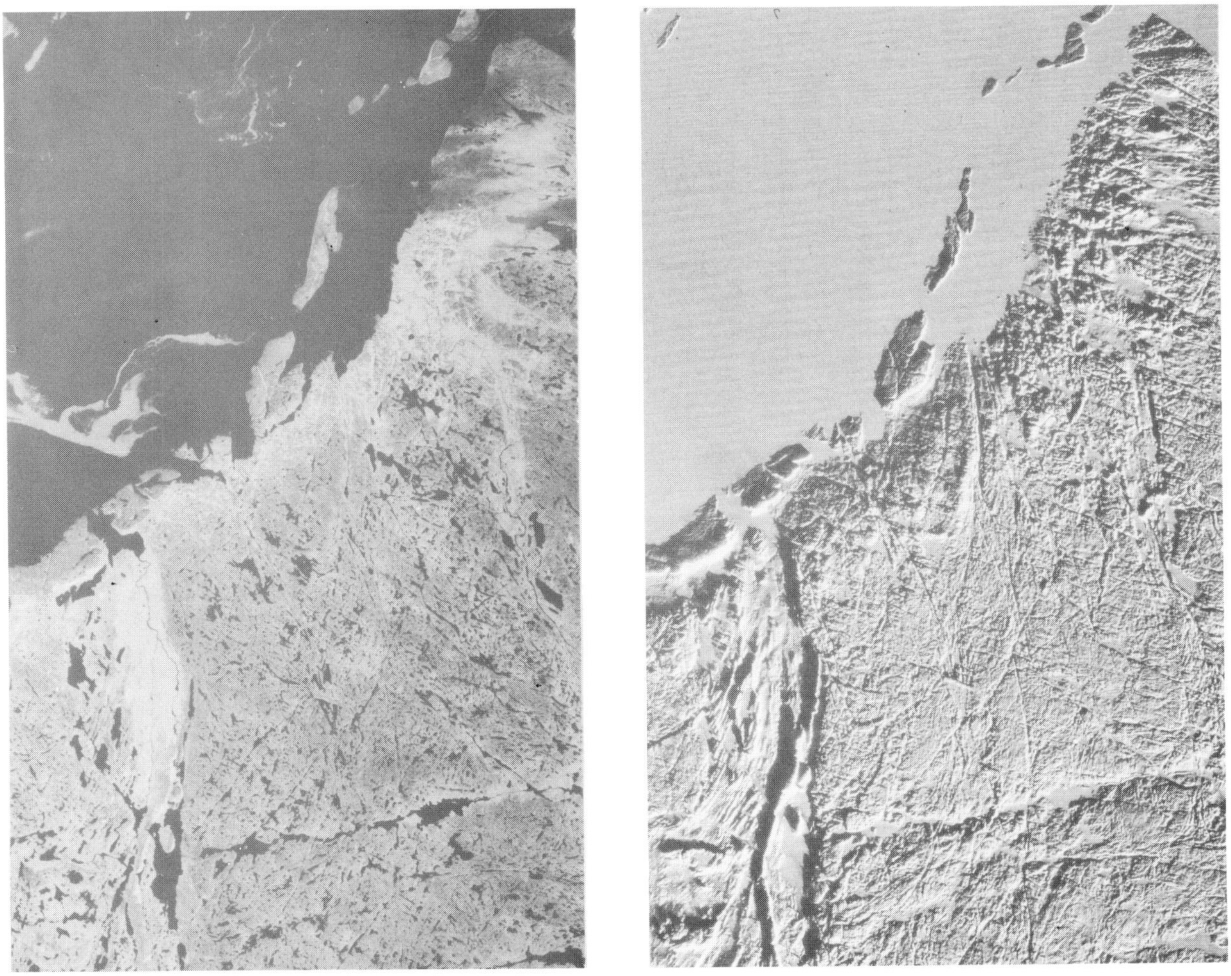
Getting the most information from an image is the aim of every image-analyst, so the way an image is chosen deserves more than a little thought. Picking an image acquired at the 'right' time of year can be vital. It is also very important to understand the various kinds of information available in the different MSS bands and band combinations.

Seasonal Changes

Landsat imagery changes in appearance with the seasons. Most of these changes are due to variations in sun elevation, to the presence of snow, and to changes in the vegetative cover.

Because of the nature of the satellite orbit, sun elevations will be constant within any short time period for a given latitude, but will be different for different latitudes, and will also vary according to the season. The magnitude of these variations is shown in Figure 2.

When an image is needed for the study of reflectance differences, one with a minimum amount of shadow, that is, with as high a sun angle as possible, should be selected. When a study is more concerned with visualizing the topography imagery with sufficient shadow present to bring out topographic detail should be chosen. The most favourable sun angle for any given area will depend on the steepness of the slopes present in that area. In general a suitable sun angle will be 2-3° less than the slopes on the ground that are of particular interest to the investigator. If the sun angle is too high, too many slopes facing away from the sun will be illuminated. If the sun angle is too low, shadows may obscure the terrain rather than reveal it. In mountainous terrain, sun angles of 30° or even more may be required whereas in hilly country, suitable sun elevations may range between 12° and 20°. In flat to gently rolling terrain, very low sun angles, even less than 5°, may be desirable.



E-1729-19344 Band 7
22 July 1974
Sun Elevation – 42°

E-1189-18432 Band 7
28 January 1973
Sun Elevation – 3°

A portion of the Precambrian Shield in the Northwest Territories bordering on Coronation Gulf and west of Bathurst Inlet is illustrated.

The left hand (summer) image of this little known area reveals details of the drainage pattern. The land area is made up of a variety of grey tones which are largely related to differences in the nature of the vegetative cover. The right hand (winter) image is snow-covered and was obtained when the sun was 3° above the horizon. This image can reveal differences of only a few tens of metres in the topography of this barren landscape.

Figure 12. *Effect of sun's elevation on details of the terrain revealed by image.*

A heavy cover of snow results in a high contrast image in which very dark tones representing topographic shadows and forests stand out against the bright snow background. Except for the tree cover most of the non-topographic detail is effectively suppressed and the image is simplified. Shadow patterns are far easier to analyze on a uniform snow covered surface. A suitably low sun elevation with heavy snow cover is often the best combination for viewing surface topography (Gregory, 1973). This effect is demonstrated in Figure 12 where a summer and a winter image are shown for comparison. A light snowfall in early winter tends to be retained in valleys rather than on the upland interfluve areas. Such images may be preferred for fracture analysis studies since the valleys appear outlined in white in contrast to the medium to dark grey tones representing the interfluve areas.

Few geoscientists are working on the relationships of plant associations to soils or to the underlying lithology. Most data come from agriculturalists (Westin, 1973), and and foresters (Sayn-Wittgenstein and Wightman, 1975). Canada has been divided up very broadly into forest regions and subregions or sections, based on climate, topography, soils, ground moisture, and geology (Rowe, 1972). Few of these units are sufficiently distinctive to be recognizable on Landsat imagery (Nielson, 1974). The problem lies in the inhomogeneity of woodland areas. A forest stand rarely consists of a single species of tree having the same age throughout. Most often a forest stand consists of a variety of trees differing in age, often with a variable bushy undergrowth. In addition, the density of the trees varies from stand to stand (Lawrence and Herzog, 1975), and because the proportion of three types also differs, so does the shadow component. Because single trees are not large enough to fill a picture element, species recognition using Landsat is extremely uncertain. In practice Canadian foresters are only able to differentiate with confidence predominantly coniferous from predominantly deciduous stands (Kirby, 1974). Given so few variables, (coniferous trees, deciduous trees, no trees) it is understandably rare that the nature of the tree cover can be used to recognize changes in the underlying lithology. The exceptions are usually cases where trees occur over one rock type and not over an adjacent rock type (see Fig. 6.4).

Where the tree cover has been removed permanently, it is usually because the soils are deep enough to be used for farming. In Canada, most agricultural districts are located on soils derived from glacial overburden. Once again, the agricultural pattern, whether it be grasses or crops or bare soils, generally provides little information about the underlying lithology by its reflectance alone (Kristof and Zachary, 1974; Evans, Head, and Dirkzwages, 1976). Significant information about structures underlying glacial material, however, can often be obtained by studying drainage patterns, the distribution of surficial moisture, and the topography.

North of the tree line, which includes roughly the northern half of the Precambrian Shield and Arctic Islands, the vegetation cover is far more closely related to the surficial environment. Here, many terrain types have a distinctive vegetation cover (Anderson et al., 1973). In a number of such cases, the reflectance characteristics of such areas may be unique to that region (Boydell, 1974). The quality and reliability of automated terrain classifications based on reflectance can be improved by using imagery from different times in the growing year (Kalenski and Scherk, 1975), and by using aerial photographs to monitor the homogeneity of the reflectance classes.

Image Formats

Single Bands

MSS scenes are most commonly processed as 4 separate monochrome images. The most obvious characteristic of the four frames is that bands 4 and 5 look similar to each other, as do bands 6 and 7. The greatest spectral contrast is found by comparing band 4 or 5 with band 6 or 7 (Crain, 1974).

The spectral characteristics of each of the four bands can be understood more easily by reference to Figure 13 in which the 4 spectral bands are related to a series of generalized spectral curves for five broad classes of surface cover – soils, vegetation, a general group comprising roads, built-up areas and exposed sandy areas, water, and snow and ice.

Band 4

Soils, fresh green vegetation, roads and urban areas, and ice or snow features are all more or less distinguishable on this band. Water is transparent, and so although water boundaries are difficult to locate, suspended sediment and shelving sandy bottoms in coastal areas can be recognized. This is sometimes considered the best general purpose band for earth scientists. Unfortunately this band is also the one most strongly affected by atmospheric moisture, which often superimposes a haze and sometimes a heavy fog on the image signal. The loss of image contrast can be regained by suitable processing, but this is not normally done in Canada at present.

Band 5

Vegetation is hardly distinguishable from soils but roads, urban areas and sandy beaches have a much brighter signal and usually contrast strongly with their surroundings. Areas of snow and ice are also clearly seen, but have hardly any internal structures or textures. Suspended material in large water bodies can also be seen in the band although in less detail than band 4. Band 5 is affected far less by atmospheric moisture so it is frequently preferred as an all-purpose image.

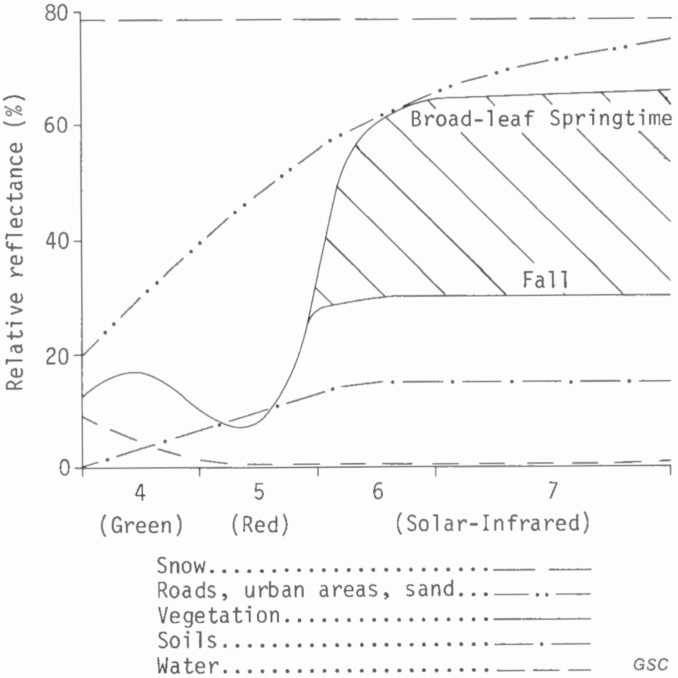


Figure 13. *Idealized curves showing relative reflectance of main cover types.*

Bands 6 and 7

Vegetation, water, and shadows are the significant features of this band. Fresh green vegetation reflects solar-infrared energy very strongly. Peaking in spring, the energy return gradually falls away through summer into fall. Soils are most easily distinguished from vegetation in springtime. At this time, roads, towns and even beaches may disappear from view because their signal response is often too close to that of the vegetation.

Water absorbs solar-infrared radiation and so appears dark on the imagery, and shows no sign of suspended sediment loads. These are the bands for delineating drainage systems and water bodies. Free moisture may reduce the grey-tone contrast of snow or ice fields with their surroundings. Areas of sea-ice commonly have very distinctive water patterns on their surfaces which may be used to separate different generations of ice. There is little scattered solar-infrared energy in areas not illuminated directly by the sun. As a result shadows appear darker and contrast more strongly with illuminated areas. One of these bands is usually chosen for lineament studies because both the topography (defined by shadows) and the drainage are most clearly recognizable.

Ratios

These images are produced by dividing the brightness values of one band, with those of another. Photographic methods may be used to do this, but the computer is most efficient. Ratios emphasize the differences in energy return between the two constituent bands and minimize the energy changes in each band due to the surface topography (Taranik, 1978). On the negative side, the analyst may be confused because objects with the same ratio may be derived from very different ranges of brightness level. Band ratios are frequently introduced into research projects but their application is still a matter of 'try it and see'. The most successful uses of ratios in geology studies have been in poorly vegetated terrain. For example, ratios 5/4 and 4/5 have been found to accentuate the contrast between hematite-rich red beds and surrounding non-ferruginous rocks in sparsely vegetated areas of Arizona (Goetz et al., 1973) and Wyoming (Vincent et al., 1975; Offield, 1976).

Ratio 7/6 was found to improve the contrast of yellow limonitic rocks with surround rocks in Wyoming (Offield, 1976).

Ratio 7/5 was used by Bølviken et al. (1977) in Norway to discriminate between grasses growing on copper-rich soil and those growing on normal soils.

The reverse form of the same ratio (5/7) has been found to correlate well with the volume of green vegetation, the biomass, present in any area. The ratio or a modified form of it is also used to monitor the progress of the springtime, 'green wave', and the fall, 'brown wave' (Ashley and Rea, 1975).

Band Combinations and Complex Ratios

The number of combinations that can be derived from four bands is almost infinite. The sequential exposure of two or more bands or ratios are almost always done using different colours to represent each component band. Such colour composites can be produced in a variety of ways but mostly they are special products, created by the researcher.

Once again, no general rules have been found, and with one exception (the standard 3 band colour composite) successes tend to be related to specific situations.

Where a simple ratio is known to be useful correlations may be eliminated by using a colour combination consisting of the ratio and one of its constituent bands. The combination 4/5 + 5 has been used by Taranik (1978) for separating rocks and soils from vegetation. Examples of some of the more complex ratio colour combinations which have been used are: 4/5 + 4/6 + 6/7 for recognizing red sandstone aquifers in Arizona (Goetz et al., 1973) and 4/5 + 5/6 + 6/7 for distinguishing rocks affected by hydrothermal alteration in the Goldfield district of Nevada (Rowan et al., 1974).

There is a widespread agreement that the best way of presenting MSS data is in the form of a colour combination using bands 4, 5, and 7, where blue represents band 4, green band 5, and red band 7. Such images are already standard products in the United States and Canada. These prints contain all the information present in each of the constituent bands. Carter (1973) has even claimed that colour combined scenes from South America provide at least 40 per cent more information than do individual monochrome bands. In such prints, the vegetation domain is clearly defined in red to magenta colours, the non-vegetated land areas are equally recognizable by their pale blue-white and brown tints, and the water domain varying from black to blue containing pale blue stream lines which indicate suspended sediments. It is not suggested that colour prints are always essential to a study. Lineament studies need an image which emphasizes the topography and the drainage pattern, both of which are found in bands 6 and 7. Some parts of the Canadian Shield are covered totally by uniform forest growth which causes the colour combination to appear entirely monochrome.

The widest range of colour is found when there are large differences in grey tone between the bands used to produce the composite image. This occurs most commonly in areas where the vegetation cover is variable or is irregular in distribution, commonly in areas of extensive agricultural development and in tundra and arctic regions.

In 1977 the Geoscience Working Group, a subcommittee of the Canadian Advisory Council on Remote Sensing declared itself strongly in favour of the colour combination as the most useful MSS product for earth scientists. The need for special preprocessing of the imagery was recognized; in particular the need to remove haze, to stretch the range of brightness levels in each band, to apply some edge enhancement and to use prints at a scale of 1:2 million for analysis. In addition, the Working Group also recommended that at least one complete set of such colour prints should be prepared for the whole of Canada using images that are known to be free of haze and cloud and to have minimal seasonal snow cover. Such a collection would form a readily accessible data base. Beginning in 1979, the United States will be producing a colour product very similar to that described by the Working Group. Even in 1978, images of this kind were being made available on an experimental basis, to geologists in Australia (Smith et al., 1978). No country yet recognizes the need for a national collection of best quality colour combined images.

THE INTERPRETATION OF MSS IMAGERY

Lithology

Sedimentary Rocks

The appearance of sedimentary rocks on MSS imagery varies greatly. Where sediments are well exposed, the effects of differential erosion of the harder and softer rock strata may reveal bedding planes and fold structures – strong indicators of the origin of these rocks. Although the sedimentary origins of these rocks can frequently be recognized, or at least inferred, the rock type cannot be determined by its spectral characteristics.

Some sediments are recognized and mapped because of distinctive differences in their drainage and fracture patterns. The dolomite, sandstone and shale visible in the Coppermine River image (Fig. 1.4) are fine examples of this.

Some sediments are recognized as such by the presence of linear topographic features. The Front Range of the Rocky Mountains appears on the Fort St. John image (Fig. 6.1) as a series of long ridges in which bedding trends parallel to the length of the ridge are clearly recognizable, although individual beds can rarely be traced along strike. If the units in a rock sequence offer nearly uniform resistance to erosion, as happens in the case of the Main Range, shown on the Fort St. John image, little information can be obtained about the nature of the rocks or of their structure. Similarly, the Quesnel Lake image (Fig. 6.7) represents two parts of the interior system of the Cordillera, the Cariboo Mountains and the Interior Plateau. Except for bedding trends in the Cariboo Mountains, there is little or no evidence to suggest the number of rock types and the fold structures known to exist in this region.

Sediments on occasion, can, be recognized by differences in reflectance. One example of this occurs in the Dubawnt Lake image (Fig. 1.5) which shows the well exposed Dubawnt sandstone to be nearly devoid of topogrpahic or drainage features. The sandstone, however, can be distinguished from the surrounding rocks by its higher reflectance – especially in band 4 and 5. On Bathurst Island (Fig. 4.1), almost completely exposed and highly reflective Paleozoic carbonate and sandstone alternate with darker coloured and partially vegetated mudstone. The sandstone and the carbonate, however, cannot be separated visually. An interesting problem arises in the Ogilvie River image (Fig. 6.5), where there is a wealth of contrasting fold patterns and reflective differences in the Paleozoic and Mesozoic clastics and carbonates, yet rock units established in field mapping procedures cannot be recognized on the image. When the fresh green vegetation cover exceeds 10% of the surface area, the reflectance characteristics of the outcrops and bare soil may be changed significantly (Siegal and Goetz, 1977) making it virtually impossible to recognize the rock by its reflectance alone. In vegetated areas, sedimentary units must be distinguished by textural information derived from the drainage pattern, linear topographic features and by variations in the vegetation pattern. The Bathurst (N.B.) image (Fig. 2.1) is totally covered with vegetation, yet some distinctions can be made between quartzite and greywacke of early Paleozoic age because of different drainage patterns and minor changes in the vegetation pattern.

It is also rather easy to draw misleading conclusions from the study of Landsat images. There is, for example, an area of highly reflective, well exposed limestone which appears on the Frobisher image (Fig. 4.4). A second bright area, this time representing glacial drift, appears on the same image. The two areas can be distinguished only by a pattern of parallel grooves in the area of moraine, which is believed to be due to vegetation growing within linear hollows.

Igneous Rocks

Large bodies of igneous rock may be recognized by their irregular shape, sometimes combined with a distinctive image texture derived from the topography and in places showing crosscutting relationship to structural trends in the adjacent rocks. A pluton may outcrop more or less extensively than the surrounding lithology which will result in reflectance contrasts. This may also occur when a pluton has a sufficiently different mineral composition than its surrounding rocks to support a distinct vegetation cover.

When exposed, basic plutons generally have a lower reflectance than the rocks that surround them. This is evident in the case of an amphibolite body in the Cape Smith Fold Belt image (Fig. 1.2) and a gabbro-troctolite in the Nutak image (Fig. 1.10).

Virtually all of the more acidic plutons are recognized by textural rather than reflectance characteristics. Acid plutons in the Cape Smith Fold Belt image (Fig. 1.2) are recognized by their lack of foliation lineaments and by the rectangular grid pattern produced by intersecting sets of major joints. On the Frobisher Bay image (Fig. 4.4) a granite is characterized by the large number of ponds scattered about the surface. A nearby hypersthene granite has a rolling topography but few ponds. In neither case is the light vegetation cover different to that of the surrounding rocks. The Dubawnt Lake image (Fig. 1.5) includes a granite pluton recognized by a series of arcuate lineaments said to be related to banding in the rock.

Basic dykes are easily picked out on the Hamilton Inlet (Fig. 1.6) and Bylot Island (Fig. 4.3) images. In all cases they are relatively resistant to erosion and form linear ridges. Most of those visible are more than 60 m wide and at least 30 to 50 m high. Recognition is improved when the sun elevation is very low so that the dyke is outlined by its shadow. Sills are more difficult to recognize unless they are inclined, and therefore, have characteristics similar to dykes. Inclined sills appear on the Coppermine (Fig. 1.4) and the Lakehead (Fig. 1.8) images. The Central Labrador Trough image (Fig. 1.3) contains spectacular examples of strongly folded gabbro sills.

Metamorphic Rocks

Metamorphic rocks are widely distributed in Canada. Although they are best displayed within the Canadian Shield they also underlie large areas of the Cordillera. They are perhaps the most difficult of all rocks to recognize and to analyze, both for rock type and for structure.

The increasing metamorphic grade of a rock sequence, broadly speaking, reduces the differences in the physical properties of the rock types, which in turn, causes them to have a more uniform resistance to erosion. Where the mineral compositions of the various rock types are similar, the soil and vegetation cover are also more uniform.

Individual foliation planes or planes of schistosity are rarely, if ever, recognizable on Landsat imagery. However the regional foliation direction is generally nearly parallel to any banding or sequence of lithological units that may be present. Differences in the resistance to erosion of a rock series results in an alternation of hollows and ridges which may be occupied by streams or by elongate lakes. Where such a linearity is repeated across an area, it is reasonable to infer that the regional foliation or schistosity is parallel to the macro-texture produced by ridges, streams and lakes. The eastern half of the Wopmay Fault image (Fig. 1.12) shows a gneiss with a well developed foliation which is easily recognized because of the drainage and lake pattern.

Complex fracture patterns, which are multi-directional, intersecting constantly, and commonly with recognizable offsets, are typical of the metamorphic rocks of the Shield. The western part of the Wopmay Fault image (Fig. 1.12) is underlain by massive granitic rock with a well developed complex fracture pattern characteristic of the western Precambrian Shield. Foliated rocks of the Churchill tectonic province are also recognizable by their characteristic lake pattern on the Nutak image (Fig. 1.10). In other parts of the Canadian Shield (e.g., the Central Labrador Trough Fig. 1.3) there are areas of Archean gneiss where directional textures and fracture patterns are hardly apparent.

Both the Frobisher Bay (Fig. 4.4) and the Dubawnt Lake (Fig. 1.5) images include examples of lineated and nonlineated granitoid gneisses.

Structures

Folds

Individual bedding planes in sedimentary rocks are rarely if ever visible because few are sufficiently exposed for the resolution of the Multispectral Scanner. Where folds in sedimentary rocks are recognized it is because particular rock units have distinct reflectance, vegetation cover, or topographic form.

In metamorphic rocks, individual foliation planes due to schistosity or to gneissosity are also not visible on the images. It is often possible to recognize ribbed or linear textures in metamorphic rocks representing discontinuous ridges in the topography parallel to the regional gneissosity or schistosity as recorded in field observations. These ridges evidently have a rather greater resistance to erosion and are thus lithological in nature. Flexures or folding observed in such units may indicate a similar flexuring or folding of the foliation planes associated with the ridging. A fold must be about 0.5 km wide before it can be recognized with reasonable confidence.

The Bathurst Island image (Fig. 4.1) shows a series of sediments folded in two nearly orthogonal directions. The Belcher Islands – Richmond Gulf image (Fig. 1.1) pictures skeletal islands consisting of tightly folded plunging anticlines and synclines. Alternating sediments and gabbro sills in the Labrador Trough image (Fig. 1.3) are folded and sheared in comple forms which differential weathering displays in great detail. Tight isoclinal folding gives a ribbed appearance to similar rocks of the Cape Smith image (Fig. 1.2) but only a few fold closures can be seen here. More dome-like folds with doubly plunging axes are prominent within the Grenvillian rocks of the Lac Simard image (Fig. 1.7). The Wopmay Fault image (Fig. 1.12) shows the refolding of foliated rocks. The largest single structure is the Ogilvie deflection, most of which is shown on the Ogilvie River image (Fig. 6.5). This large open fold contains a wide variety of smaller fold structures, the most remarkable of which is the series of en echelon folds comprising the Taiga ranges.

Fractures

Fractures may be recognized on Landsat imagery by abrupt changes in the topography, lithology, drainage, vegetation, or land use patterns. In the great majority of cases, a fracture is indicated by a linear hollow which may or may not be occupied by a stream or lake. The hollow represents the differential erosion of rocks weakened by fracturing along a steeply dipping plane.

Abrupt changes in rock type across a linear boundary may indicate a fault particularly when structural elements (bedding, folds) on opposing sides of the junction have a different orientation. Such features can be seen clearly in the folded sediments of the Bathurst Island image (Fig. 4.1) where offsets to lithological boundaries permit rough estimates to be made of the amount of horizontal movement along some fracture planes.

The orientation and intensity of near vertical fracturing within the rocks of the Canadian Shield may be used in conjunction with structural trend patterns to characterize the various structural provinces.

The complexity of a major fracture system in rocks of the Canadian Shield shows clearly in the Wopmay Fault image (Fig. 1.12). A 10-15 km wide zone of fractures occurs in basal Grenville rocks along the line of the Grenville Front (Lac Simard image, Fig. 1.7). Low angle thrust faults are especially common in Cordilleran rocks but are rarely recognized on satellite imagery. Vertical thrust faults can be seen in amazing detail on the Central Labrador Trough image (Fig. 1.3) and somewhat less obviously on the Cape Smith image (Fig. 1.2).

Both the Bylot Island (Fig. 4.3) and Frobisher Bay (Fig. 4.4) images are crossed by parallel steeply inclined faults separating horst and graben structures.

In the Cordillera of Western Canada the most interesting structures are the great trench fault systems which separate major structural units. Lateral movements of hundreds of kilometres have been reported for a number of these trenches. The Tintina trench as shown on the Ogilvie River image (Fig. 6.5), the Shakwak trench appears on the Fort St. John (Fig. 6.1) and Quesnel Lake (Fig. 6.7) images and the Fraser Fault system appears on the Lytton image (Fig. 6.3).

Arcuate or circular structures appear on three images. By far the largest and the most striking is formed by the entire east coast of Hudson Bay (Belcher Islands – Richmond Gulf image, Fig. 1.1). The Manicouagan image (Fig. 1.9) presents a fine example of a circular (or polygonal?) structure whereas an oval-shaped feature also appears on the Hamilton Inlet image (Fig. 1.6).

Glacial Features

Most of the features which characterize a glacial landscape may be seen on MSS imagery.

Two images show permanent ice fields with marginal valley glaciers. The Kluane Lake image (Fig. 6.2) shows the St. Elias mountain ice field which includes Mt. Logan, the highest peak in Canada. The Byam-Martin ice field is portrayed on the Bylot Island (Fig. 4.3) image. Median, lateral and terminal moraines are clearly visible as well as numerous piedmont forms due to the coalescing of ice from two or more glaciers.

The Lytton (Fig. 6.3) and Prince Rupert-Terrace (Fig. 6.6) images show the glaciated landscape of the Coast Mountains of British Columbia. In the latter image, some of the U-shaped valleys are flooded to form a fiord coastline. In less mountainous terrain ice movement has produced a general deepening of the landscape as shown in the coastal lakes of the Western Newfoundland image (Fig. 2.3) and the broad open inlets of Bathurst Island (Fig. 4.1). In fairly flat terrain, a crag-and-tail landscape is produced, as illustrated by the Manicouagan image (Fig. 1.9) which also shows marked grooving in the andesites at the centre of the circular structure.

Moraine deposits of all kinds are visible on many images. Several forms of hummocky ground moraine can be seen on the Brodeur Peninsula (Fig. 4.2), Dolphin and Union Strait (Fig. 5.1), Fort Providence (Fig. 5.2), Dubawnt Lake (Fig. 1.5) and Neepawa (Fig. 5.5) images. Ridging and drumlinoid features are illustrated on the Uranium City (Fig. 1.11), Frobisher (Fig. 4.4), Nutak (Fig. 1.10) and Coral Rapids (Fig. 3.1) images. Coppermine River image (Fig. 1.4) shows two sets of intersecting drumlinoid ridges as well as washboard moraines. The latter feature also occurs on the Central Labrador Trough image (Fig. 1.3). Eskers are visible on the Dubawnt Lake (Fig. 1.5) and the Coral Rapids (Fig. 3.1) images.

There are two instances where a linear morainic topography is present but cannot be recognized. Both of these images – Quesnel Lake (Fig. 6.7) and Medicine Hat (Fig. 5.4) – have a sun elevation of 45° or more.

Glacial lakebeds with spillways, meltwater channels and raised beaches, frequently at several elevations, can be seen on the Lakehead (Fig. 1.8), Neepawa (Fig. 5.5), Fort Providence (Fig. 5.2), Wekusko Lake (Fig. 5.6), and Coral Rapids (Fig. 3.1) images.

Surficial Features

A wide variety of surficial features can be recognized on MSS-images with a high degree of confidence.

Areas covered by alluvium commonly can be recognized by their flatness, smooth tones, generally with a more developed land use, by drainage characteristics, and by their shape and location. Thus the alluvial flatlands of the Mackenzie Delta (Fig. 5.3) are recognized by their association with the mouth of a major river, by the large numbers of lakes and drainage channels, and by the appearance of a lush growth of vegetation. Alluvium derived from the reworking of glacial material can be seen on the Fort Providence image (Fig. 5.2).

Sand plains have a distinctively high reflectance in all bands. They may be confused with fresh snow but are unlikely to be mistaken for older, compacted, snow or wet snow because of meltwater and drainage patterns which characterize the surface of older snow. Examples occur on the south shore of Lake Athabasca (Uranium City image, Fig. 1.11) and adjacent to the coast on the Hamilton Inlet image (Fig. 1.6). Beaches have similar reflectance characteristics and are shown on the Uranium City, Hamilton Inlet, and Prince Edward Island images (Fig. 1.11, 1.6, 2.2, respectively).

Saline lakes appear on the coloured Medicine Hat image (Fig. 5.4) with a distinctive pale blue colour edged with white. The blue colour is due to suspended solids associated with the saline waters.

Sediment plumes are visible on the Mackenzie Delta (Fig. 5.3) and south James Bay (Fig. 3.2) images.

Few cultural features have a direct interest for the geologist. It is always useful to be able to recognize a few of the more common features which might cause some confusion. One of these is the fire burn, especially typcial of images of the Shield. A burn usually appears as an irregularly shaped patch commonly covering an area of 100 km^2 or more. Soon after a fire, the burned out areas are very dark on all bands. As a fresh growth of vegetation develops the burned area may appear brighter than its surroundings especially in bands 6 and 7. In area where forest fires are very common, whole images may consist of a ragged sutured mosaic of variously toned fire burns, each tone representing a different age of burn. Burns can be seen on the Fort Providence (Fig. 5.2), Wekusko Lake (Fig. 5.6) and Wopmay Lake (Fig. 1.12) images.

Areas where extensive logging operations are in progress may be recognized by the network of access roads and by the geometrically shaped areas of cleared forest.

Most roads, many power lines, pieplines, and cut seismic lines cna be seen either because of the exposure of non-vegetated surfaces or because of the clearing of the vegetation cover along a linear track.

Mineral Exploration

No mineral deposit has yet been discovered using MSS imagery alone. It is most unlikely that one ever will be, because few orebodies at the surface of the ground are as large as a single resolution element. The best that can be hoped for is to find signs of secondary alteration, either the discolouration of exposed rocks and their weathered products or perhaps some distinctive change in the reflectance of the vegetative cover that may be related to unusual concentrations of metallic elements in the soil. Satellite observations of either condition are rare, nonetheless Lyon (1975) found anomalous reflectance values in pine and juniper trees over soils with high molybdenum content, and Vincent (1973) described ferruginous haloes surrounding known deposits of sulphide in the well exposed near-desert environment of Wyoming. Haloes of the kind occurring in hot desert areas are not, of course, found in Canada.

Despite the vast amount of wilderness in Canada, there are very few areas that have not been explored thoroughly for signs of surface mineralization. Most conventional forms of exploration are now directed to finding orebodies that do not appear at the surface of the earth. Landsat MSS images may still have a significant role to play in this form of exploration. In the search for industrial minerals, MSS images have been used to help located areas underlain by limestone (Awald, 1974). However, it was not possible to judge the quality of the limestone, as this required the application of more detailed methods.

For coal exploration, Landsat images may be used to delineate regional fracture patterns which may result in understanding regional structures (Wier et al., 1973). Most coal mining areas are too well known for this imagery to provide much useful lithological information. Open pit mines larger than 10 acres (Wier et al., 1973) can be recognized on the imagery, so that the broad effects of coal mining on the landscape can be monitored (Anderson and Schubert, 1976).

For oil exploration, MSS imagery may be useful to separate basement rocks from sedimentary cover and to recognize structural units such as typically large basins and domes within the sediments (Halbouty, 1976). These are best displayed where exposures are reasonably good or where a lithological unit has a distinctive vegetative cover. Linear structures may exert considerable control over the definition of a favourable environment (Collins, 1973; Erickson et al., 1975). Such features commonly are visible even where cover material has been derived from elsewhere (Saunders et al., 1973). Studies are most effective when information from all sources, geophysical and geological, are used. In the Umiat district of northern Alaska, Lathram (1974) has used Landsat MSS imagery with geophysical and geological information to infer possible extensions to oil fields as well as the possible location of new ones.

In the search for base and precious metals, Landsat imagery may best be applied to locate environments favourable to mineralization. The Precambrian rocks of Ontario can be grouped into granitoid rocks, metavolcanics, metasediments and sediments. Bodies of massive sulphide, gold, iron and nickel are concentrated in the metavolcanics whereas uranium, nickel-platinum and copper are found in the sedimentary and metasedimentary rocks. Each of these major environments can be recognized with a fair degree of confidence (Palabekiroglu, 1974). This confidence is improved substantially when other geophysical information, particularly aeromagnetic and possibly gamma radiation, is incorporated into the analysis. Many ore deposits are known to be related to fractures, either directly or indirectly (Abdel-Gowad and Silverstein, 1973; Lathram, 1974; Offield, 1976). Most of the major regional fractures can be recognized and plotted even when there is an overburden of glacial material or a heavy vegetative cover.

For geothermal sources, MSS imagery has been used to locate areas deserving more detailed study, such as those showing signs of recent or active volcanism combined with recent faulting (Lepley and Doss, 1975). Individual hot spots are rarely recognized although areas of warm ground may often be picked out from an image after a light snowfall, or in the case of lakes, because of delayed freezing in fall, or early thawing in spring (Reynolds and Wagner, 1975; Williams et al., 1973).

SUMMARY

Landsat MSS imagery is useful in a wide variety of ways which are considered under the following headings.

The Regional Overview

There has always been a need to visualize an entire working area on a single image. Photo mosaics are rarely available or adequate for this purpose. Using Landsat imagery it may be possible to see the relationship of geological features to the immediate region, to the geological province and even to the nation. With such material so readily available on a worldwide scale, there is no reason why major structures should not be traced across continents and between continents, in a way that was previously impossible. Access to this kind of information must lead to a broadening of views within the geological community. This facility to see areas far greater than one is ever likely to be able to visit and study in detail will lead to the generation of ideas. Following up these ideas may require other more detailed sources of information. If Landsat is used only as a catalyst to stimulate the geological imagination it will have been successful.

Environment Mapping

MSS imagery may be usefully applied as a first stage rapid mapping technique, most effective at scales of 1:250 000 or smaller, in areas where previous information is sketchy or in situations where it is desired to extend an investigation from the known into the unknown (van der meer Mohr, 1974). The possibility should not be overlooked that information may be recognized on satellite imagery that has not so far been recognized by field work or on aerial photographs (Lathram, 1974).

Satellite imagery is of greatest assistance in the mapping of broad regional structures such as tectonic provinces or domains (Viljoen and Viljoen, 1973) and in the delineation of regional fault and lineament patterns (Abdel-Gowad and Tubbesing, 1974; Werner, 1975). The imagery has many applications associated with the mapping of topographic and surficial elements in the terrain. This may include the recognition of geomorphological units (Short and Lowman, 1973; Parry, 1976), glacial phenomena (Isachsen et al., 1973), and the analysis of drainage systems and of erosion processes (Morrison and Hallberg, 1973). There is a particularly valid application associated with the study of dynamic processes like sediment plumes (Bukata et al., 1974), the movement of sediment in coastal waters (Williams, 1973), and even the analysis of areas subject to landslides (Gagnon, 1974) or to earthquakes (Gedney and Van Wormer, 1973; O'Leary and Simpson, 1976).

Rock units with similar topographic or weathering characteristics may be recognized by a particular texture or pattern produced on the image when such rocks underlie several hundred square kilometres. Recognition of rock types by their spectral reflectance alone is not a particularly promising technique in Canada at present.

Landsat imagery can be used for the editing and revision of maps (Short and Lowman, 1974). With the help of imagery it may be possible to add much structural information, revise the position of some lithological boundaries, and perhaps confirm the existence of features only suspected or half-recognized from field work.

Mineral Exploration

MSS images may help locate environments favourable for further exploration particularly when these are linked to an analysis of other geophysical, geochemical, and geological data. They may also help improve established metallogenic concepts and exploration hypotheses or help to develop new ones. They may also help monitor the environment associated with mining developments and provide logistical information for planning field operations. The latter may consist of information about the advance and retreat of the snow line, knowledge of lake thaw and freezing and the location and movement of ice in arctic waters.

Photomaps and Educational Material

Enlarged MSS prints or mosaics, may be used as photomap underlays to geological or geophysical data at scales up to 1:250 000.

MSS imagery provides an excellent portrayal of the ground surface with more detail than can be found on any topographic map. Such images represent a very valuable aid to the teaching of geomorphology, and structural and regional geology.

ORDERING IMAGES

When ordering prints or transparencies, the first, and biggest, step is to find the identification number for an image that most closely meets one's requirements. This may be done through a telephone call or a letter, requesting a computer search, to the Canada Centre for Remote Sensing in Ottawa, or to one of the satellite receiving stations, preferably the one at which the data were received. Search requests should include information about the location of the area of interest (by latitude and longitude or by orbit path and row number), the time of year, and the upper limit of cloud cover that is acceptable (2% cloud = 1 sq. inch = 7 cm^2).

Paper prints and transparencies (monochrome and colour), microfiche and Computer Compatible Tapes may be ordered from:

Prince Albert Satellite
Receiving Station,
P.O. Box 1150, Prince Albert,
Saskatchewan, S6V 5S7

Phone: (306)764-3636 (-3602)
Telex: 084-2942

Shoe Cove Satellite
Receiving Station,
P.O. Box 160, Pouch Cove,
Newfoundland, A0A 3L0

Phone: (709)335-2831
Telex: 061-4971

Canada Centre for Remote Sensing
2464 Sheffield Road,
Ottawa, Ontario, K1A 0Y7

Phone: (613)993-0121
Telex: 053-3777

Price listings are also available at these locations.

Landsat MSS mosaics of Canada at scales of 1:10 million, 1:5 million and 1:2.5 million can be ordered from:

National Air Photo Library,
615 Booth Street,
Ottawa, Ontario K1A 0E8

Telephone: (613) 995-4560

The Canada Centre for Remote Sensing maintains browse files of Canadian MSS images, both in colour and black and white, complete microfiche records, and a computer file of all available MSS images. Index maps showing the location of image centres, image listings and information bulletins are also published periodically.

All 3 U.S. Ground Receiving Stations include parts of Canada in their reception areas. Imagery of the Yukon, southern British Columbia and Alberta, the Maritimes and southern parts of Quebec and Ontario can be obtained from:

EROS Data Centre,
Sioux Falls,
South Dakota, 57198
U.S.A.

Telephone: (605) 594-6511

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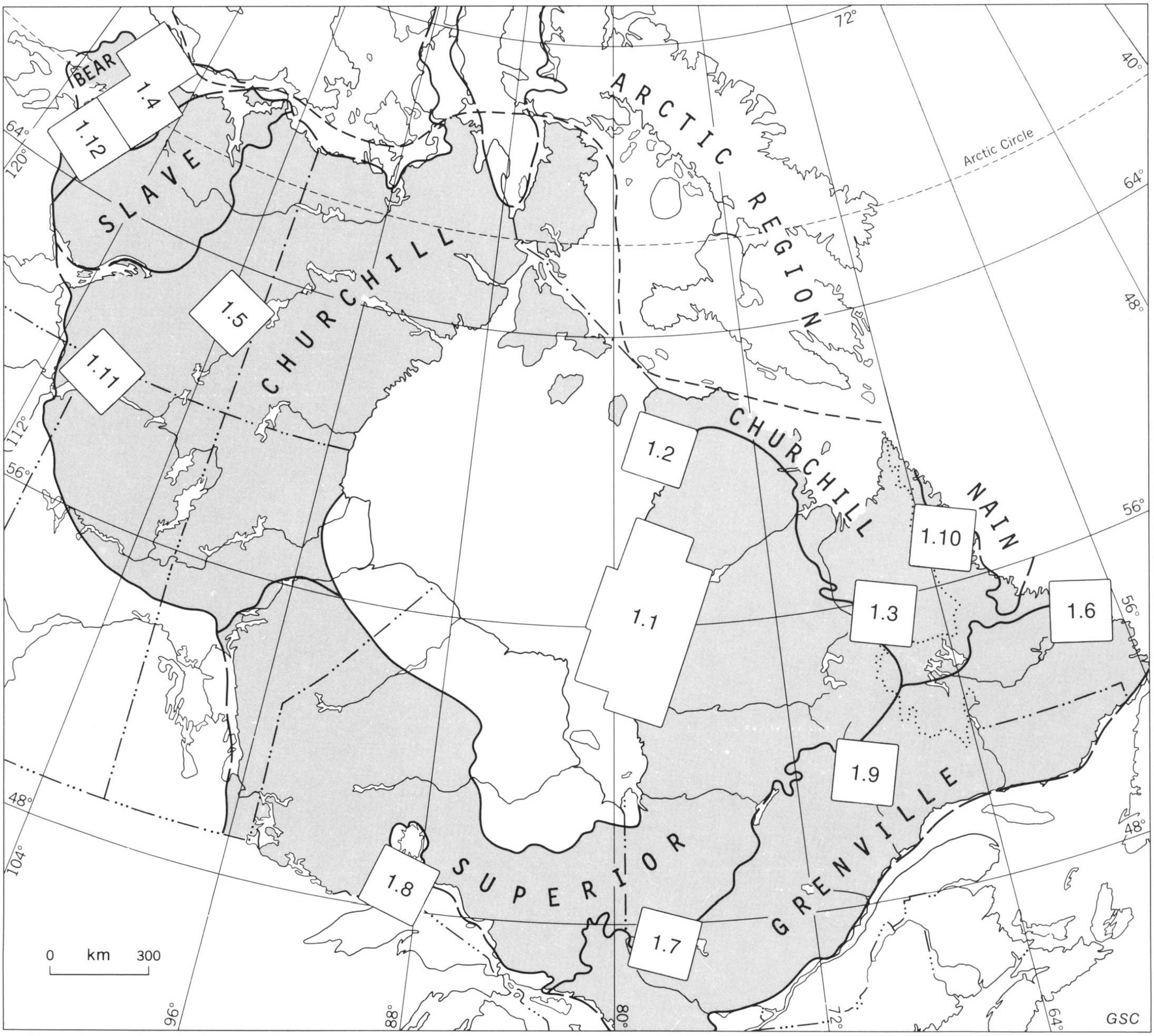
THE CANADIAN SHIELD

Section 1



1.1 Belcher Islands – Richmond Gulf
G.D. Jackson

1.2 Cape Smith
F.C. Taylor

1.3 Central Labrador Trough
W.R.A. Baragar

1.4 Coppermine River
W.R.A. Baragar

1.5 Dubawnt Lake
K.E. Eade

1.6 Hamilton Inlet
I.M. Stevenson

1.7 Lac Simard (Ontario and Québec)
A.J. Baer

1.8 Lakehead area of Northern Ontario
M.J. Frarey

1.9 Manicouagan
E.R. Rose

1.10 Nutak
F.C. Taylor

1.11 Uranium City, Saskatchewan
L.P. Tremblay

1.12 Wopmay Fault System
John McGlynn

BELCHER ISLANDS – RICHMOND GULF

G.D. Jackson

Part of the east coast of Hudson Bay forms a near-perfect arc, the centre of curvature of which lies immediately west of the North Belcher Islands (Fig. 1.1, 1.1A). The contact between Archean gneisses to the east and Aphebian strata to the west deviates little from this arc except at Richmond Gulf.

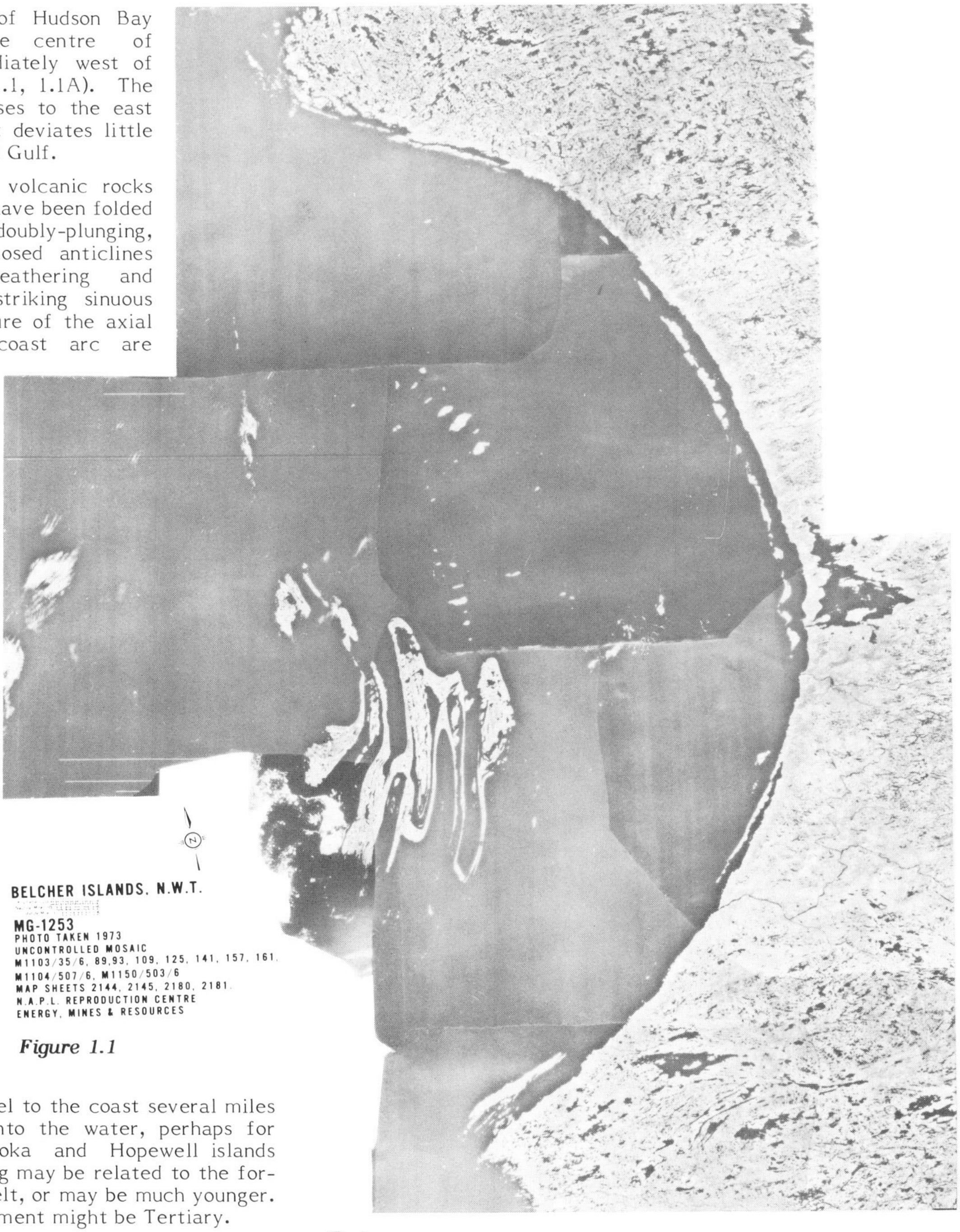


Figure 1.1

Aphebian sedimentary and volcanic rocks on the low-lying Belcher Islands have been folded accordian-like into a series of doubly-plunging, arcuate, open synclines and closed anticlines (Fig. 1.1B). Differential weathering and submergence has produced a striking sinuous pattern. The centres of curvature of the axial plane traces and the east coast arc are subparallel, and their centres of curvature are aligned roughly along an east-west line. Belcher Island folds are part of the S-shaped Belcher Fold Belt that extends from west of James Bay northward to the Ottawa Islands and Cape Smith. Intensity of folding appears to decrease eastward from the Fold Belt toward the east coast of Hudson Bay.

Several hypotheses have been postulated for the origin of Hudson Bay and/or the east coast arc, none of which need be mutually exclusive. It is interesting to note that little mention has been made of the much larger, and nearly as perfect, arc outlined by the northwest coast of Hudson Bay and the Paleozoic-Precambrian boundary on Southampton Island and southwest on Hudson Bay. The main hypotheses are:

1. The east coast arc reflects arcuate faulting accompanied by westward tilting of Aphebian sediments. The The main fault extends parallel to the coast several miles inland with parallel faults into the water, perhaps for example between the Nastapoka and Hopewell islands and the mainland. The faulting may be related to the formation of the Belcher Fold Belt, or may be much younger. In either case the latest movement might be Tertiary.
2. The arc is a relict from the impact of a huge meteorite prior to the deposition of the Aphebian sediments and volcanics.
3. Hudson Bay is the former site of Precambrian plume activity.
4. Hudson Bay as a whole, or only its eastern arc, represents a line of junction of two pieces of continental crust along a line of former island arcs through the Bay.

Whatever the origin of Hudson Bay and the east coast arc, the present configuration is probably related to arcuate faulting that was initiated during or after deformation of Aphebian rocks to form the Belcher Fold Belt.

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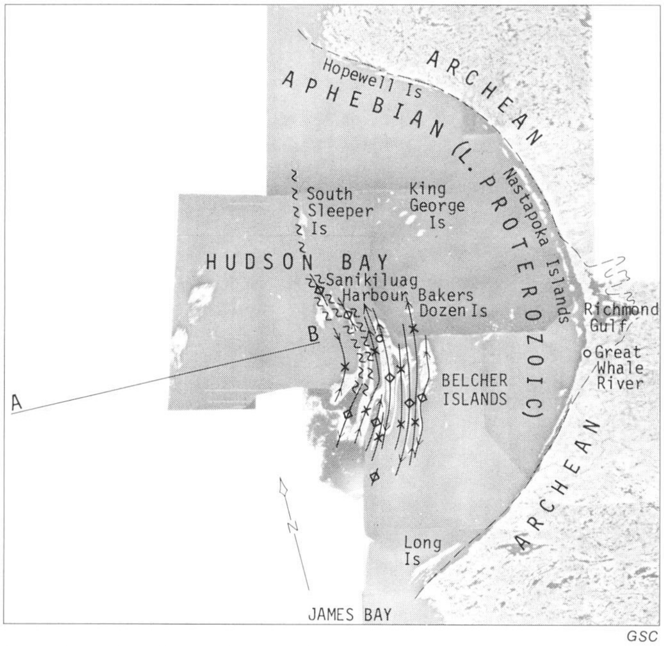

Approximate boundary between Archean gneisses and Aphebian sedimentary and volcanic rocks................

Syncline (direction of plunge shown)........................ —×→

Anticline (direction of plunge shown)....................... —◇→

Centres of curvature of axial planes approximately along this line.............................. A B

Figure 1.1A

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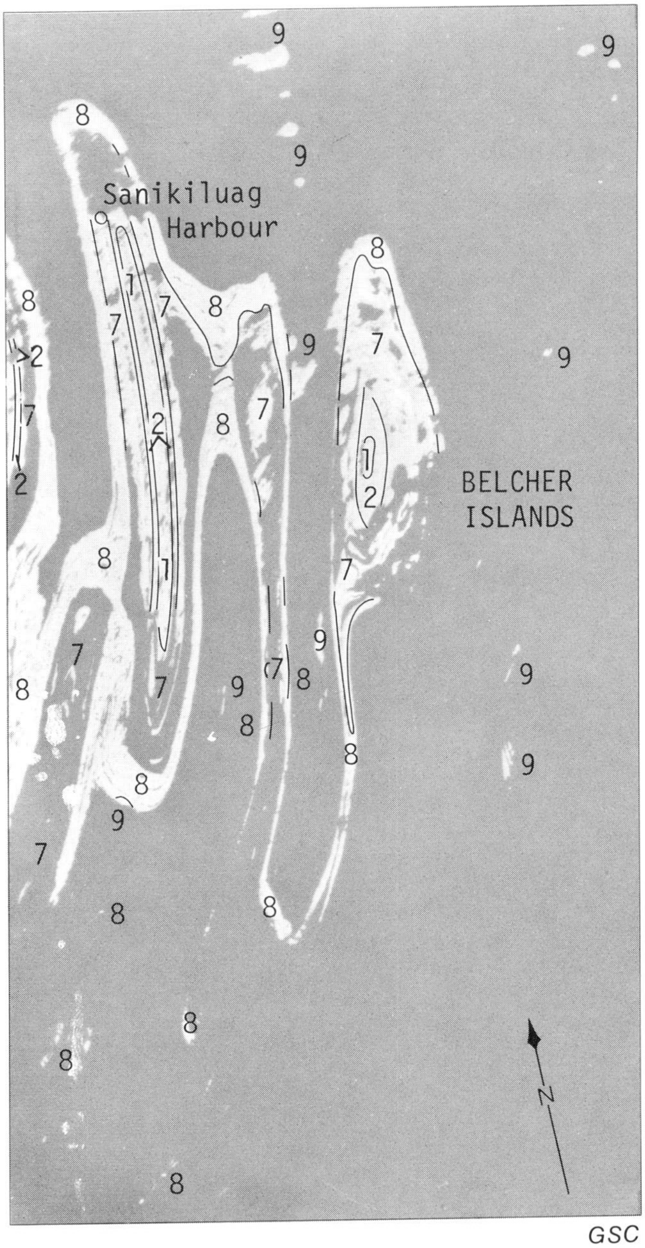

APHEBIAN

9	Greywacke, argillite, tuff, arkose, quartzite, conglomerate
8	Basalt, tuff, agglomerate, feldspar porphyry, breccia
6	Dolomite, quartzite, conglomerate, arkose, slate, limestone, tuff, iron-formation
5	Basalt, tuff, breccia
3	Dolomite, lumpy-bedded limestone and dolomite, argillite, slate, quartzite, sandstone, arkose
2	Basalt, tuff, agglomerate, feldspar porphyry, quartz latite, arkose, iron-formation
1	Dolomite, limestone, quartzite, tuff, argillite

7 Undivided 3,6; 5 is absent

4 Undivided 1-3

Figure 1.1B

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1.2 CAPE SMITH

F.C. Taylor

The Cape Smith Fold Belt which crosses the centre of Figure 1.2 is a part of the Circum-Ungava Geosyncline. The Fold Belt and the rocks to the north belong to the Churchill Structural Province (Fig. 1.2A). The area to the south of the Fold Belt is underlain by rocks of the Superior Structural Province. The boundary between the two provinces is partly a fault and partly an unconformity. Although the boundary is clearly recognizable on the image, it is rarely possible to distinguish faulted sections from sections where there is an unconformity.

In the Superior Province, rocks of Archean age (± 2600 Ma) have a prominent northerly trend. An area of massive to poorly foliated granitic rocks, located about 25 km northeast of the mouth of the Sorehead River, can be recognized on the image by a grid pattern of fractures. This region also has paler grey tones which are presumed to represent differences in the vegetation cover.

Churchill Province is divisible into two parts, the Cape Smith Fold Belt adjoining the Archean rocks and an area of gneisses north of the fold belt. The fold belt is largely composed of basic volcanic rocks with a few intercalated sedimentary horizons. Many of the subparallel valleys, which give the area its distinctive texture, are formed in the most easily eroded sedimentary rocks. There are a number of strike faults within the Cape Smith Fold Belt, the most prominent of which can be recognized by the convergence of valley linears. The northeastern quadrant of the image represents an area largely underlain by amphibolite derived from volcanics. The grey tone of the amphibolite and of the volcanics is dis-tinctly darker than that of the paragneiss and granitic gneisses to the west and the north. The contact between the Cape Smith Fold Belt and the gneissic terrane to the north is known from field work to be a gradational one and cannot be recognized on the image. The structure of the gneisses and amphibolite has been described by field geologists as "chaotic".

Even a brief study of the image does suggest a) the presence of a series of dome-like structures adjacent to the fold belt, and b) the regional trends of the fold belt and the feldspathic gneiss are essentially parallel.

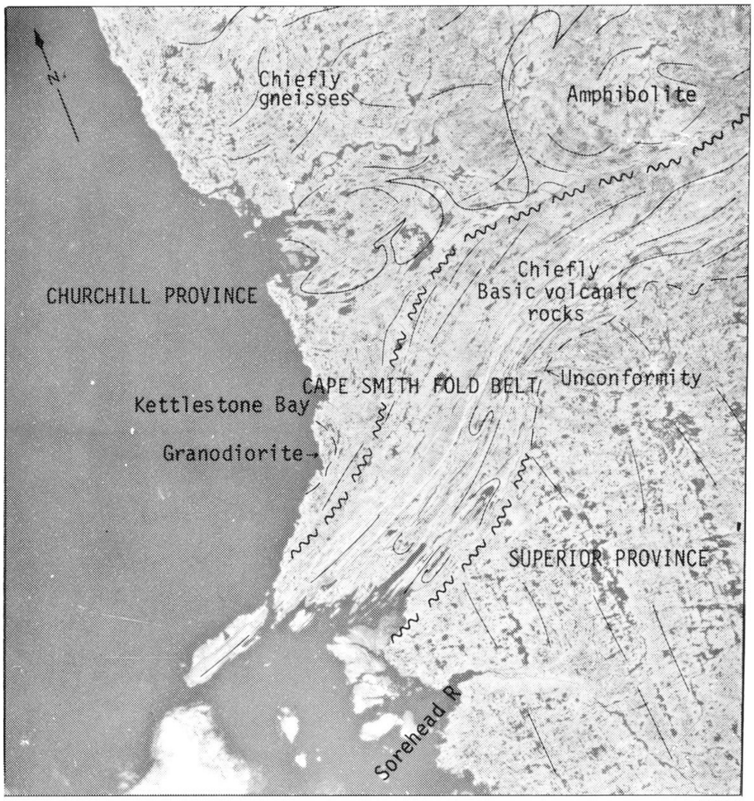

Figure 1.2

GSC

A granodiorite stock south of Kettlestone Bay is difficult to recognize by reflectance alone. Superficial geology landforms that are prominent both on the ground and on 1:60 000 scale airphotos cannot be seen at all.

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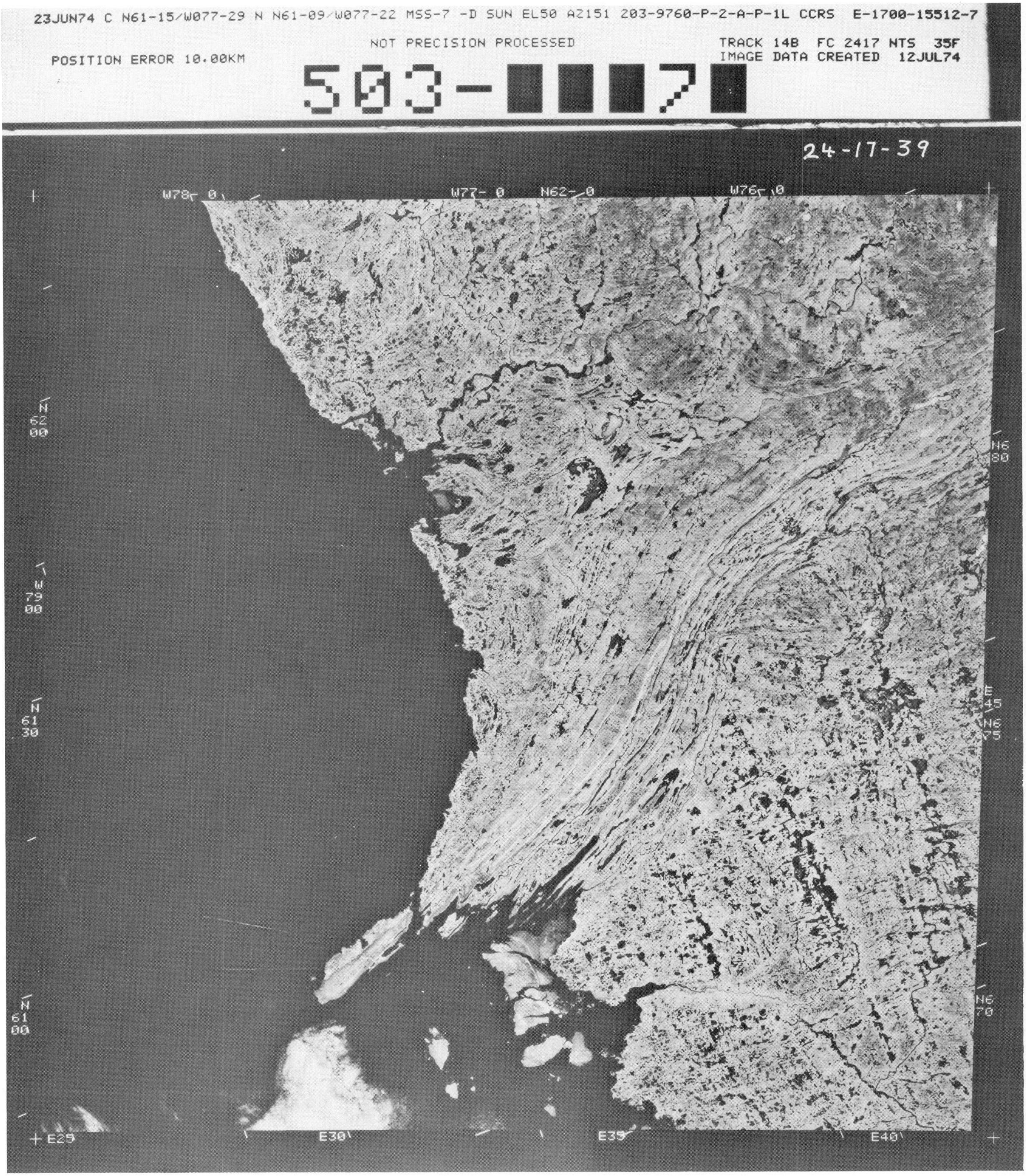
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N 62 00
W 79 00
N 61 30
N 61 00
N6 80
E 45
N6 75
N6 70
E25
E30
E35
E40

Figure 1.2 A

1.3 THE CENTRAL LABRADOR TROUGH

W.R.A. Baragar

The image (Fig. 1.3) captures a segment of the Labrador Trough. The trough deposits – the Kaniapiskau Supergroup – rest unconformably upon an Archean basement of granitic rocks (unit 1) on its southwestward side and merge into a complex assemblage of high-grade granite and paragneiss (unit 8) on its northeastern side (Fig. 1.3A). In this distance the grade of metamorphism increases from sub-greenschist to granulite facies. The relationships are well shown on the image, where on the southwest, the corrugated topography of the trough abuts the smooth, massive surface of the granitic basement, and on the northeast, interfingers with a weakly foliated terrane.

Within the trough, the Kaniapiskau rocks are presented in a succession of thrust slices which are readily distinguishable in the image. The westernmost slice, which is composed entirely of sedimentary rocks (unit 2) – greywacke, shale, dolomite, quartzite, and iron formation – has in general, a finely laminated texture, in places so fine as to appear almost massive. This is succeeded eastward by fault slices dominated by closely-spaced gabbro sills and interlayered sediments (unit 5). These impart to the region a beautiful corrugated topography that emphasizes the underlying structure. Note particularly the interlacing folds traced by gabbros sills northwest of Attikamagen Lake. The third major thrust fault, northeastward from the boundary of the trough, is an obvious dêcollement; southwestward-plunging folds of high amplitude in the overlying strata "bottom-out" along this surface. This and the easternmost fault are high-angle thrust faults which accounts for their linear trace on the image. The slice enclosed by the two faults is predominantly volcanic; pyroclastic rocks (unit 3) and pillowed and massive basalts (unit 4) separated by a shaly formation profusely intruded by mafic and ultramafic sills (unit 6). Unit 6, etched in marked relief by erosion, traces out the fold pattern with remarkable clarity. The lavas are more massive but still unmistakably stratified. The easternmost fault marks the limit of what is generally called the Labrador Trough. Eastward the schists and gneisses (unit 7a) are not markedly foliated on the image except for the band of paragneiss (unit 7b) at the eastern limit of readily recognizable Kaniapiskau strata.

The most notable glacial deposits visible on the image are the washboard moraines evident as fine chatter marks in the northern part of the image.

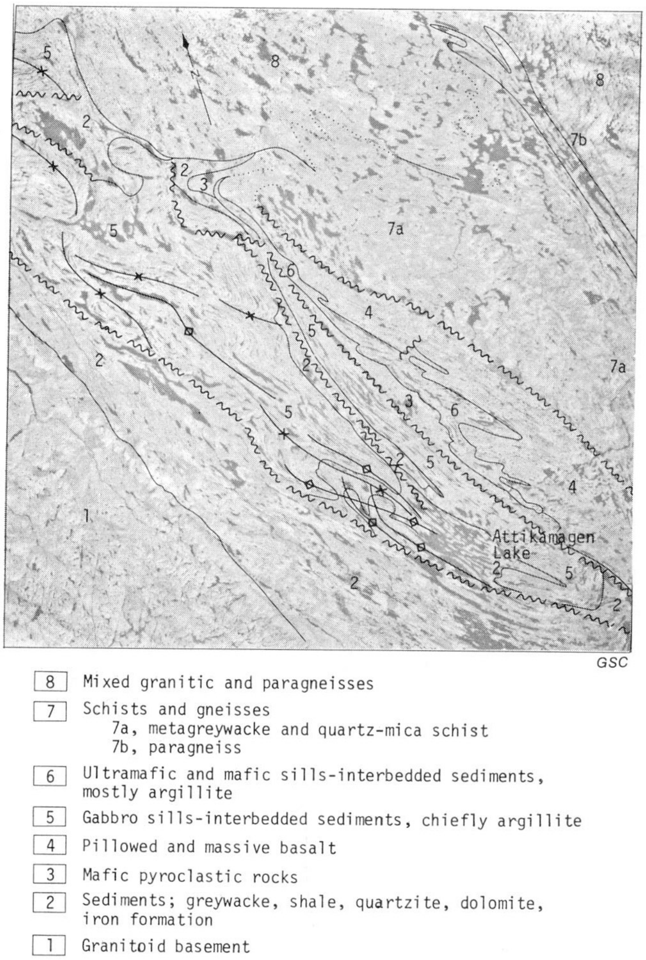

Figure 1.3

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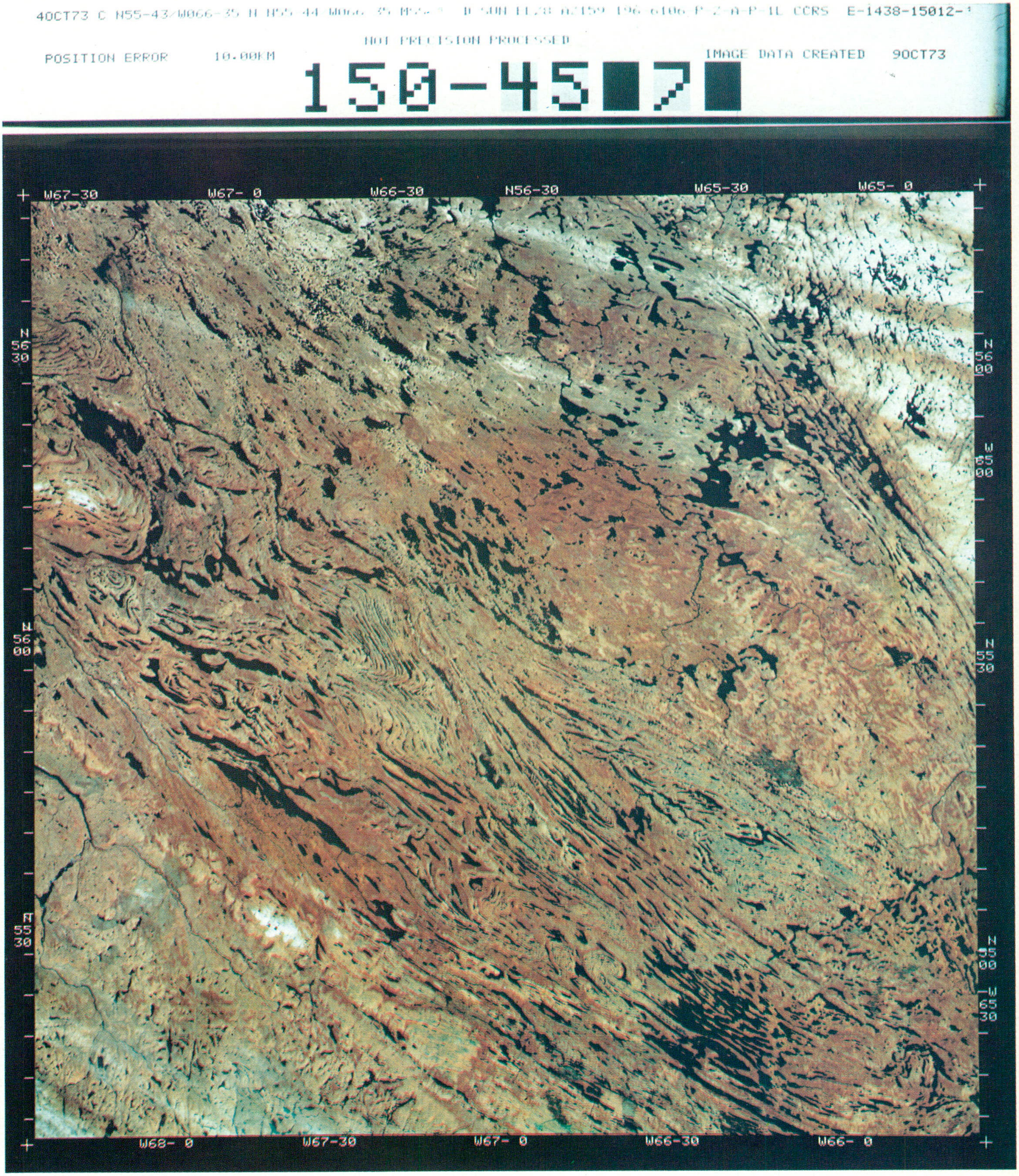
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W67-30
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W66-30
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Figure 1.3 A

1.4

COPPERMINE RIVER

W.R.A. Baragar

All the major geological divisions of the region are clearly distinguishable on the mosaic (Fig. 1.4). The Epworth Group and the late Aphebian granites, feldspar porphyries, and metamorphic rocks are each characterized by distinctive landscape textures; the former by pronounced, northwesterly trending lineations and the latter by a vaguely bulbous, dimpled surface (Fig. 1.4A). They are separated by the Muskox Intrusion which is not distinguishable on the image.

The Hornby Bay Group is marked by a smoothly textured land surface of few lakes and the Dismal Lakes Group by its lighter tone. The finely corrugated landscape presented by the plateau basaltic sequence of the Coppermine River Group can be seen on the image. It forms an open, gently northward-plunging trough that is truncated by the unconformably overlying Rae Group. Major faulting which offsets the Coppermine River and earlier units does not penetrate the Rae Group and so can be assumed to be earlier. On aerial photogrpahs the Coronation Sills which pervade the Rae Group have a marked expression and give it a distinctive appearance which appears to be lacking on the Landsat image. Here the sills are expressed chiefly by the islands in Coronation Gulf. The essentially flat-lying Paleozoic dolomite like other dolomites of the region is light in colour but any surface distinctions it may have are obscured by glacial deposits.

Glacial markings and deposits are notable in three places on the image; within the Paleozoic dolomite, at the western end of the Coppermine River and Rae groups, and at the eastern end of the Coppermine River group. They are mostly drumlinoid ridges and flutings but several end moraines can be seen west of the west end of Coronation Gulf. The interference pattern in the drumlinoid ridges just north of the west end of Coronation Gulf is presumed to be due to the superimposed ice-flow directions.

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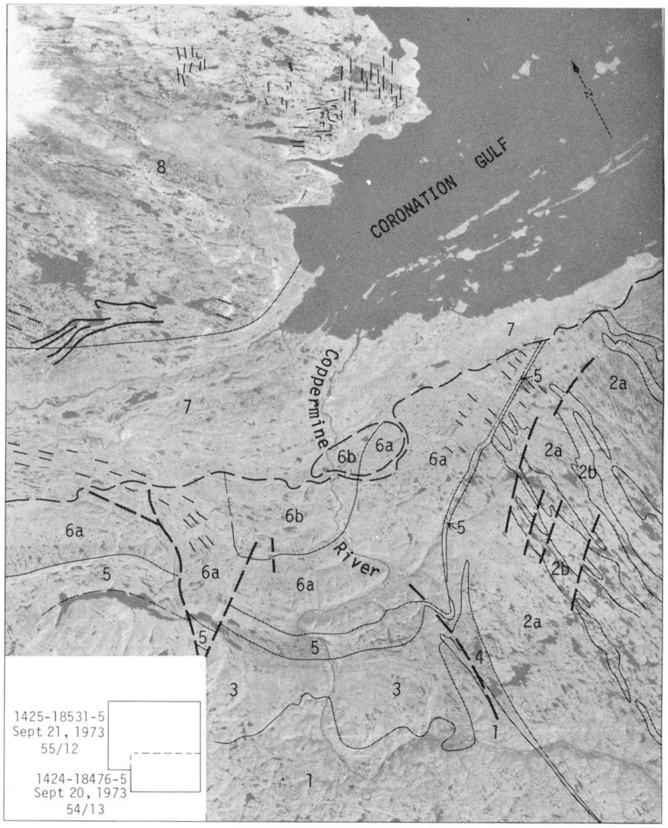


LOWER PALEOZOIC
8 Dolomite

HADRYNIAN
7 Coronation Sills: Dolerite
Rae Group: Mixed sediments

NEOHELIKIAN
6 Coppermine River Group:
b, Interlayered red sandstones and basalt flows
a, Basalt flows

5 Dismal Lakes Group:
Predominantly dolomites

PALEOHELIKIAN
4 Muskox Intrusion:
Ultramafic, gabbroic, granophyric rocks

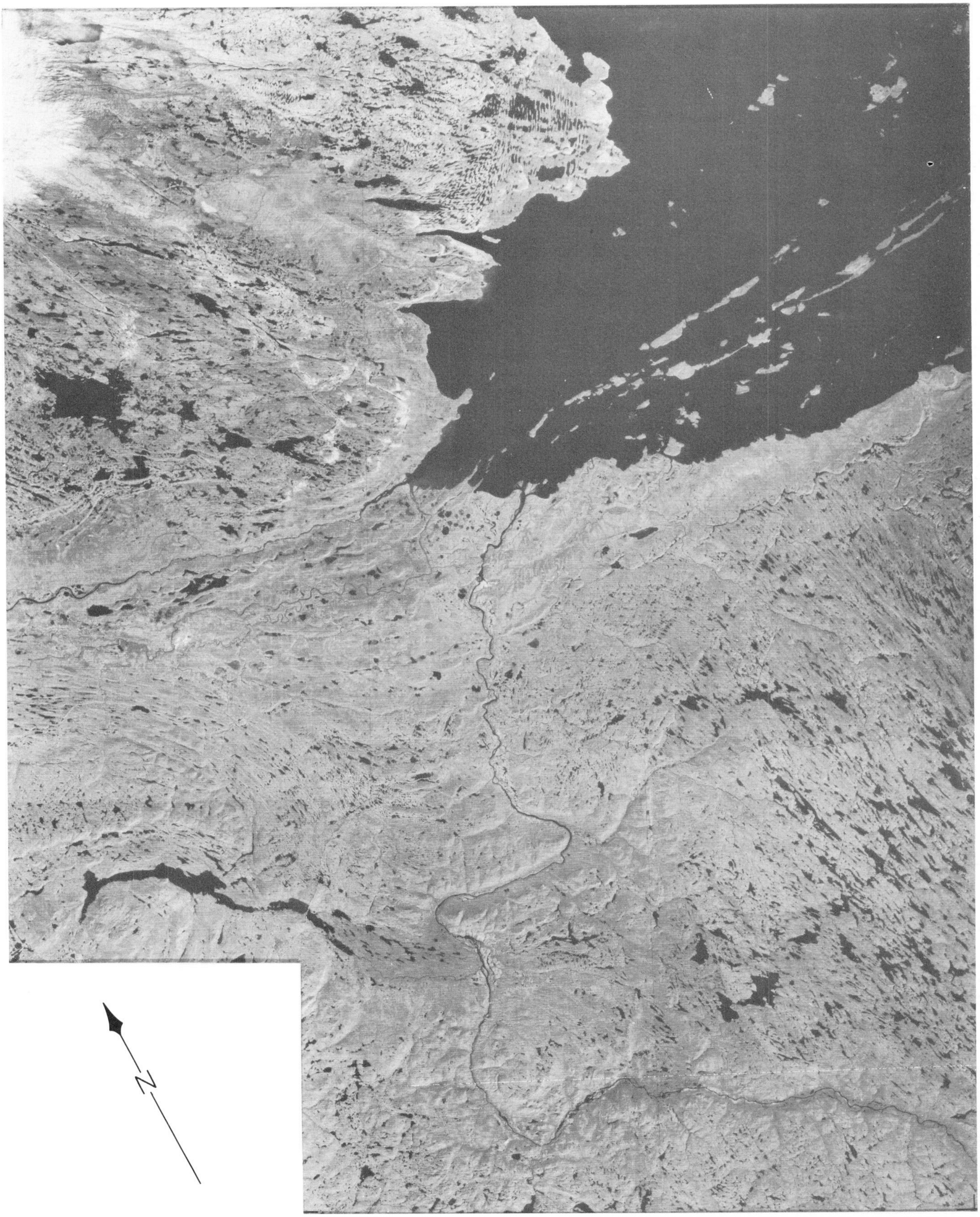
3 Hornby Bay Group: mainly sandstones

APHEBIAN
2 Epworth Group:
b, Dolomite
a, Mixed arenites and shales

1 Granites, quartz porphyries, and metamorphic rocks

Lithological boundaries........................ ∼
Fractures...................................... — — —
Drumlinoid ridges.............................. – – – –
End moraines................................... ⌒

Figure 1.4



SCALE 1:1,000,000 ECHELLE

Figure 1.4A

1.5

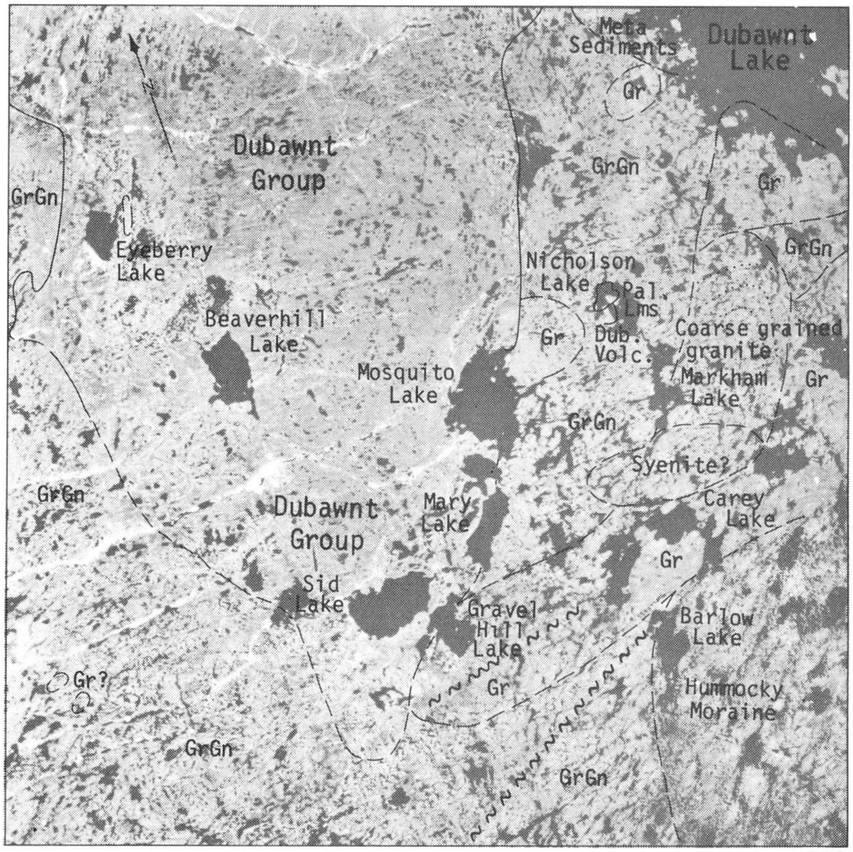
DUBAWNT LAKE

K.E. Eade

The image (Fig. 1.5) lies in the central part of the Churchill Structural Province in the districts of Mackenzie and Keewatin. For most of the area south of 63°N, geological ground control is minimal, being limited to observations made on geological reconnaissance surveys (Wright, 1967). North of latitude 63°, additional data are available (Donaldson, 1969).

Geological features visible on the image add little to our geological knowledge of the region. The major feature of the image is the contact of the Dubawnt Group sedimentary rocks (chiefly sandstone) and the underlying rocks of the Hudsonian orogen. The contact is in places obvious but elsewhere is diffuse, particularly on the south and east. Eastward glacial transport of large amounts of the easily-eroded sandstone is responsible for the apparent displacement of the contact as seen on the image, from its known position. The southern part of the contact is obscure both on the image and on the ground due to heavy glacial cover.

Certain features other than the Dubawnt Group can be recognized. North of Carey Lake, Wright (1967) described the Carey Lake complex, the southwestern third consisting of syenites, granites and gabbroic rocks and the remainder, coarse grained granite. The pluton is visible, and the contacts of the complex can be slightly modified from those of Wright by interpretation of the image. Arcuate lineaments within the pluton, visible on the image, suggest sheeting or banding within the coarse grained granite. Small granite plutons east of Mosquito Lake and west of Dubawnt Lake are visible on the image although they are not obvious.



GSC

Figure 1.5

On the published geological map, most of the basement rocks are undivided granitic gneiss. In the eastern part of the image some differences are apparent in the basement rocks and, using the original field data, contacts between more massive granite and granitic gneiss have been interpreted on the overlay. Two faults have also been interpreted southwest of Carey Lake. The more northerly fault is based on limited field evidence as well as the image. No ground control is available in the area of the southern fault but aeromagnetic data (not available when the field work was done) does support this interpretation.

In the lower left corner of the image, two small plutons of granite, within the granitic gneiss terrane, have been recognized. There are very limited field data to support this interpretation.

Eskers, all mapped previously by Wright, are prominent. In the lower right corner of the image an area of peculiar texture has been outlined. Ground observations suggest this is due to hummocky, boulder-rich, moraine.

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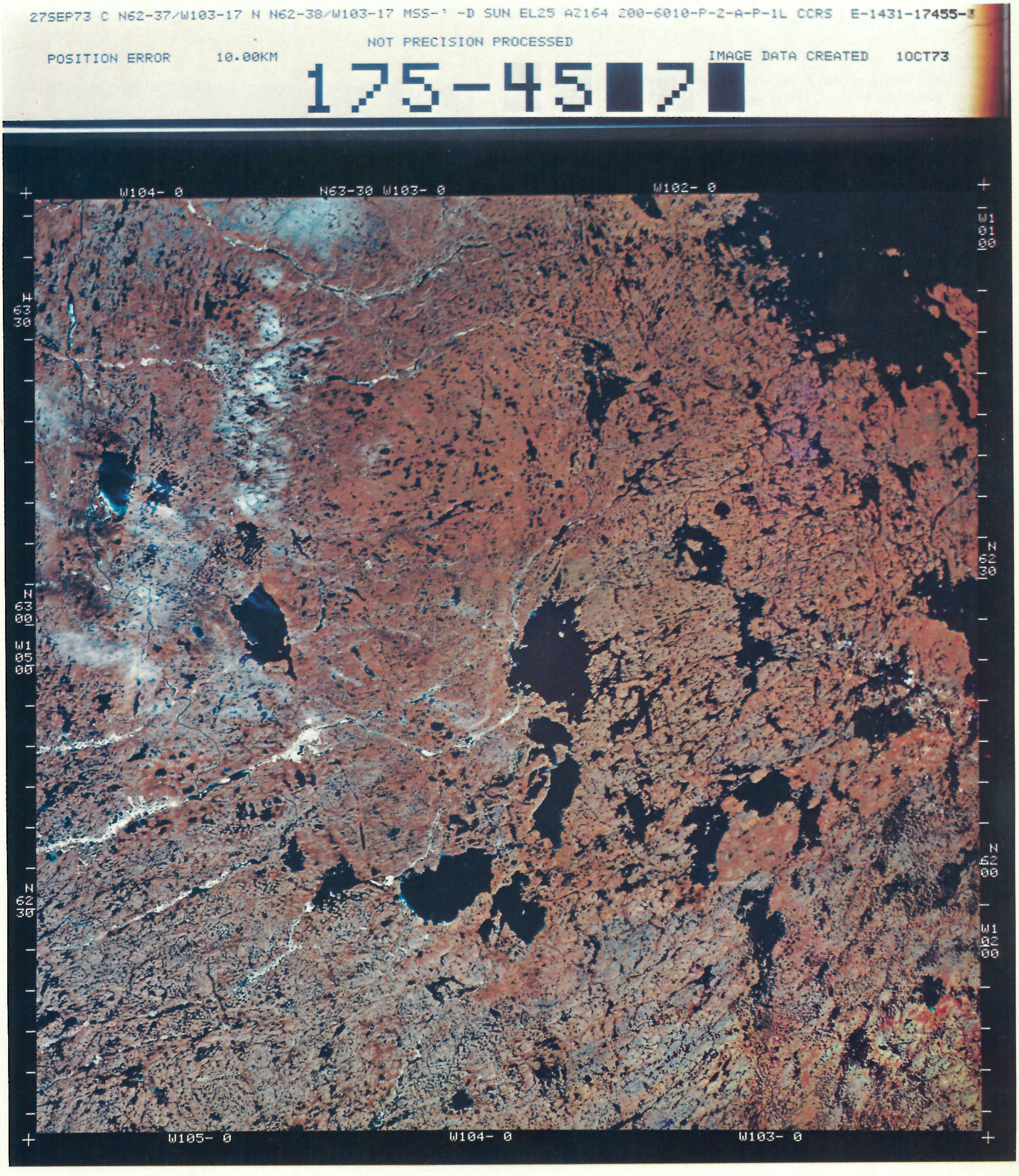
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Figure 1.5A

]

1.6

HAMILTON INLET

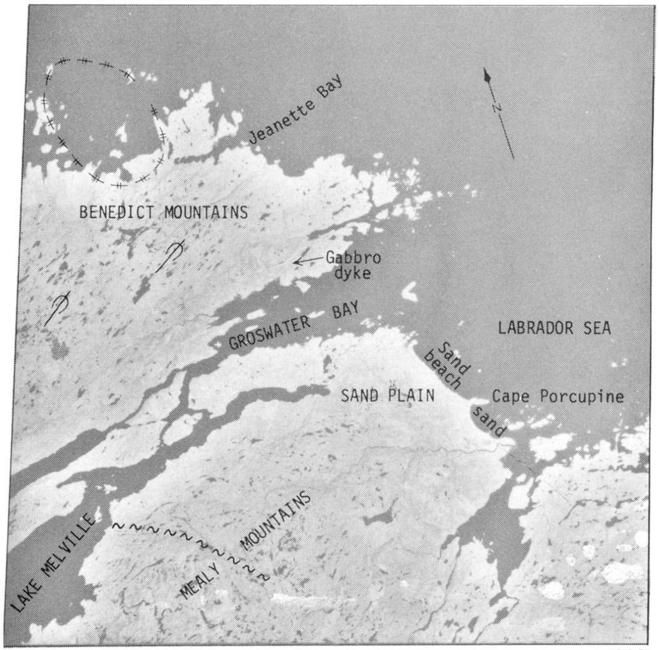
I.M. Stevenson

The most recent GSC maps of the Hamilton Inlet area were published by Eade (1962) and Stevenson (1970).

Northeast-striking structural trend of gneisses of Grenville age in the north half of the area is particularly evident Fig. 1.6, 1.6A. Ground examination indicated that evidence of this trend has been accentuated by glacial action. Massive granitic rocks of Benedict Mountains are readily apparent. Traces of a large oval structure of unknown origin may be seen northwest of Jeanette Bay. The sinuous gabbro dyke which trends in an east direction north of Groswater Bay for some 40 km is particularly obvious.

The greater part of the southern half of the Landsat image area is underlain by a complex of massive basic rocks that form the Mealy Mountains. This region has been extensively faulted, and one of the most prominent fault traces may be readily seen extending southeast in a gentle curve from the south shore of Lake Melville. The light coloured area between Labrador Sea and the east end of Lake Melville is a vast sand plain which forms extensive beaches on either side of Cape Porcupine.

In general, the Landsat image of this region shows only gross structural and morphological features. For purposes of geological mapping, standard 1 inch to 1/2 mile airphotos provide considerably more detail than does Landsat imagery.



GSC

Figure 1.6

References

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1970: Rigolet and Groswater Bay map-areas, Newfoundland; Geological Survey of Canada, Paper 69-48.


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E35
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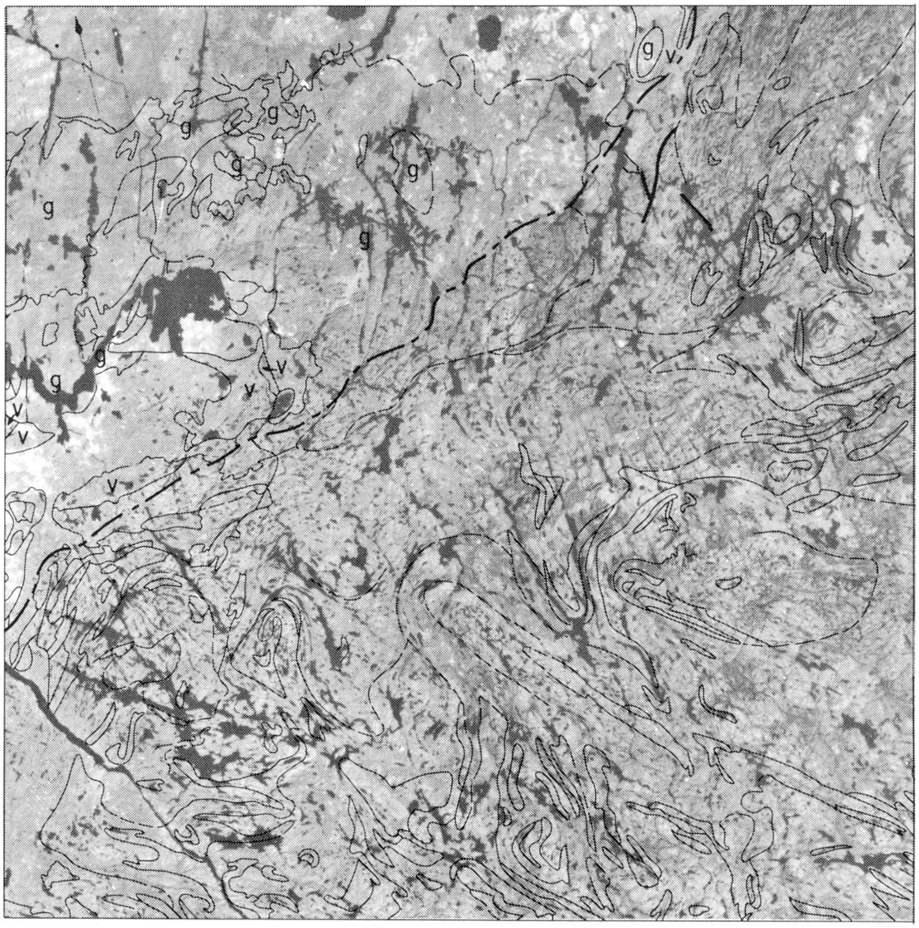
E40
E45
E50

Figure 1.6 A

LAC SIMARD (ONTARIO AND QUÉBEC)

A.J. Baer[1]



GSC

Grenville front......................................

Granitic rocks.......................................g

Volcanic rocks.......................................v

All unlabeled rocks north of the Grenville Front are metasediments.
Rocks south of the Front are gneisses and granitic rocks.

Figure 1.7

Two structural provinces are represented on this image, the Superior in the northwest and the Grenville in the southeast. The Grenville Front is made prominent by the contrast in topography between the Pleistocene cover of the Superior Province and the rocky hills of the Grenville Province. Gneissosity, foliation, and fractures stand out, in as much as lakes, swamps or valleys follow them. Structures and lithological contrasts that are not morphologically recognizable cannot be seen.

There is a strong correlation between the fold pattern, as seen on the Landsat image and the aeromagnetic pattern of the rocks from this area, as seen on 1:250 000 map sheets, suggesting that large-scale contrasts in bedrock lithology are in fact reflected in the topography.

The major structural features of the Grenville Province are clearly visible on Figure 1.7. In the southeast corner of the image, there are several major fold systems with a southeast trend. The folds are isoclinal and have sharp fold hinges which stand out clearly. Closer to the Grenville Front lies a zone which appears largely devoid of structural features. This zone correlates broadly with the aeromagnetic low shown on the Aeromagnetic Map of Canada (Map 1255A). The strong northeast-trending fractures associated with the Grenville Front itself show up well, particularly in the northeastern corner of the image. Finally, the area underlain by the Superior Province appears to be almost totally lacking in major structural elements and/or contrasting rock types.

The distribution of major geological units in both the Superior Province and the Grenville Province are shown on Figure 1.7A. They are taken from a compilation of a geology map (scale 1:1 million) by Baer et al., 1977. This compilation was prepared without the benefit of Landsat imagery. Comparison with the image shows how much of the geology and the structure is visible from the air in the Grenville Province, and how little in the Superior Province. This may in a sense reflect the different grades of metamorphism, as high-grade gneisses resist weathering better than low-grade rocks.

Among observable features of lesser interest to geologists are the logged-out areas and areas of exposed rock, both of which are shown as a white or cream colour, and muddy water, which appears as a red-brown colour in some of the larger shallow lakes in the northwestern part of the image. Small, high contrast objects such as log-booms on the Ottawa River, are recognizable, as well as most of the towns, villages and railway lines.

References

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McGrath, P.H., Hood, P.J., and Darnley, A.G.
1977: Magnetic Anomaly Map of Canada; Geological Survey of Canada, Map 255A, 3rd Edition. 1:5 million.

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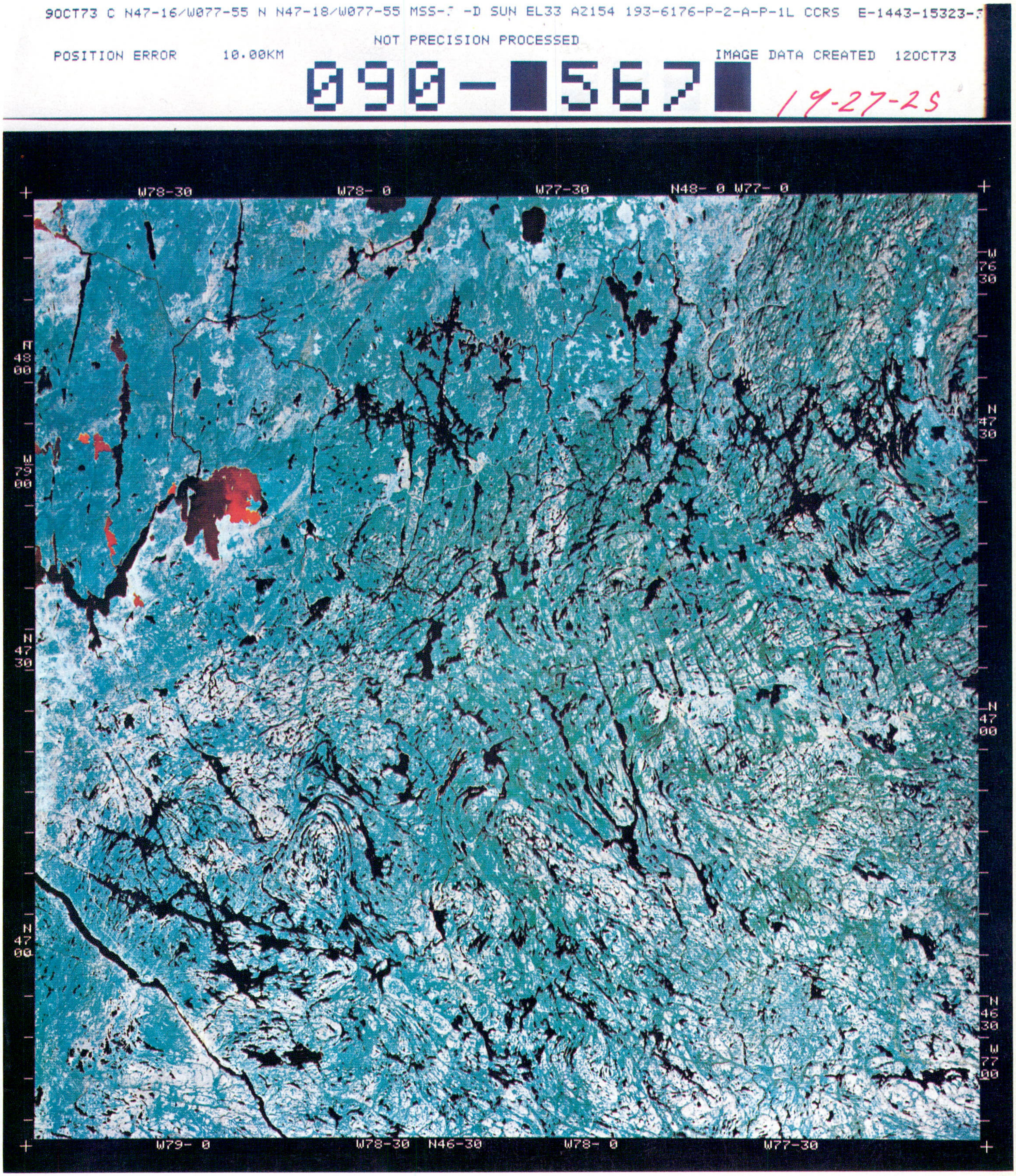
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N 46 30
W 77 00
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W78-30 N46-30
W78- 0
W77-30

Figure 1.7 A

LAKEHEAD AREA OF NORTHERN ONTARIO

M.J. Frarey

The image covers the lakehead area of Ontario including the city of Thunder Bay together with a small part of the adjacent United States.

Three major geological terranes of different character and age can be distinguished on the image (Fig. 1.8, 1.8A). Area A, comprising most of the image, is underlain by a complex of migmatite, granite, sediments and volcanic rocks, all of Archean age deposited prior to 2560 Ma ago. The image shows conspicuous faults cutting the Archean rocks, as well as the general east- to east-northeast-trending structural grain.

Area B is underlain by sedimentary rocks of the Animikie Group, which were deposited between 2560 and 1800 Ma ago, and lie with great unconformity on the Archean rocks to the northwest. The contact between the Archean and the Animikie is in part obscured southwest of Thunder Bay by glacial lake deposits which are largely cultivated and are well-marked on the image. The Animikie sediments are relatively susceptible to erosion, and their structural and stratigraphic features are not well-shown. Clearly shown because of their topographic relief are clusters of diabase sheets and dykes near the southern edge of Area B. These include the well-known Logan sills.

Area C comprises sedimentary rocks of the Sibley Formation, volcanic rocks of the overlying Osler Formation, and younger diabase masses of the Logan diabase group, all of Helikian age. Trends of Sibley sedimentary rocks and Osler volcanic flows are shown with remarkable clarity, the former on the Sibley Peninsula, and the latter on the peninsula to the northeast and on Isle Royale. The southern margin of the great Logan diabase that surrounds Lake Nipigon is clearly shown for a distance of some 30 km near the northern edge of the image.

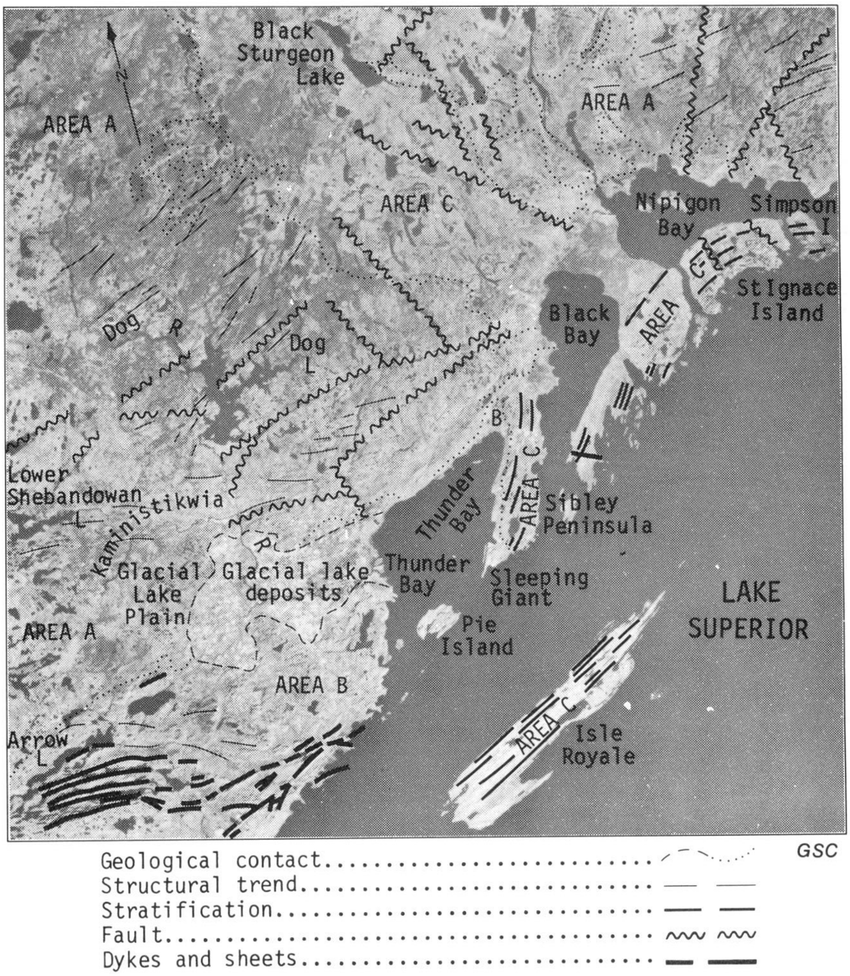

Figure 1.8

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Ontario Department of Mines and Northern Affairs
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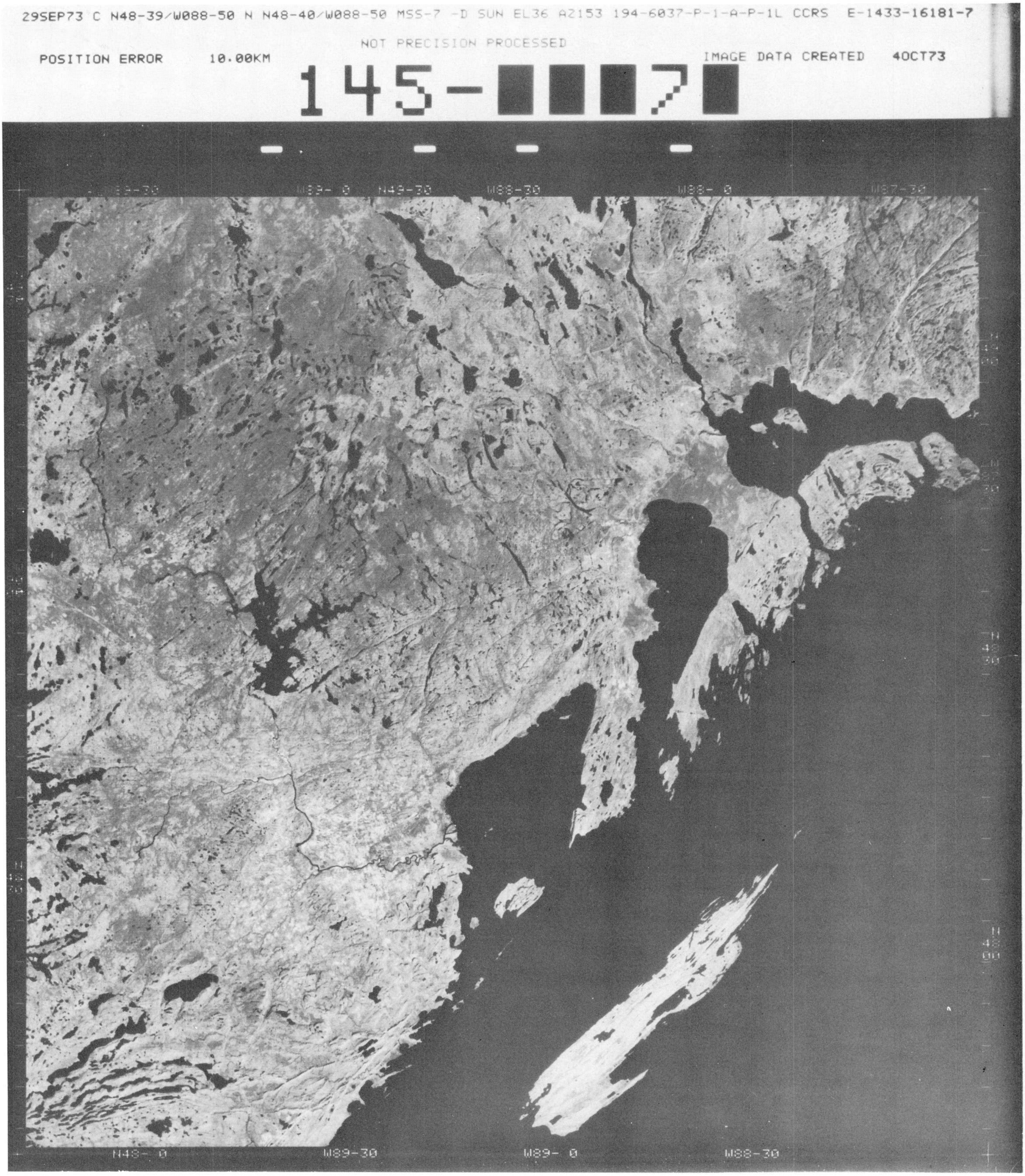
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Figure 1.8A

1.9

MANICOUAGAN

E.R. Rose

This spectacular feature, more than 60 km in diameter, is centrally located in the Grenville Geological Province of the Canadian Shield (Fig. 1.9). The great ring of water occupies the site of two former narrow, crescent lakes, Manicouagan and Mushalagan, that were flooded in 1964 following the construction of Manic 5, a Quebec-Hydro dam.

The ring of lakes is deeply incised (possibly below sea level in places) in structurally and lithologically complex Precambrian Grenville-type gneisses, intrusives, crystalline limestone, quartzite and amphibolite (Fig. 1.9A). Remnants of crumpled Middle Ordovician sedimentary rocks rest unconformably on the eroded surface of the Precambrian rocks. The interior of the ring is occupied mainly by andesitic rocks of probable Mesozoic (Triassic) age, that form a plateau around an elevated core of older, anorthositic rocks. The 'crag and tail' appearance of the landscape and the prominent grooving of the andesites within the circular lake are the result of ice movement from north to south.

Manicouagan has been variously described as an impact crater and as a resurgent caldera. More complex histories have also been proposed. Shock textures of extra-terrestrial origin have been found in the area. However the structure is not truly ring-shaped but appears to be controlled by fracture systems which trend northeast and northwest. This same fracture pattern dominates the whole region. The presence of volcanic and ultrabasic intrusions in this structural environment is also strictly 'normal' for the Canadian Shield.

Two other major circular (polygonal) structures can be seen adjacent to Manicouagan (I, II) but very little is known about either of them.

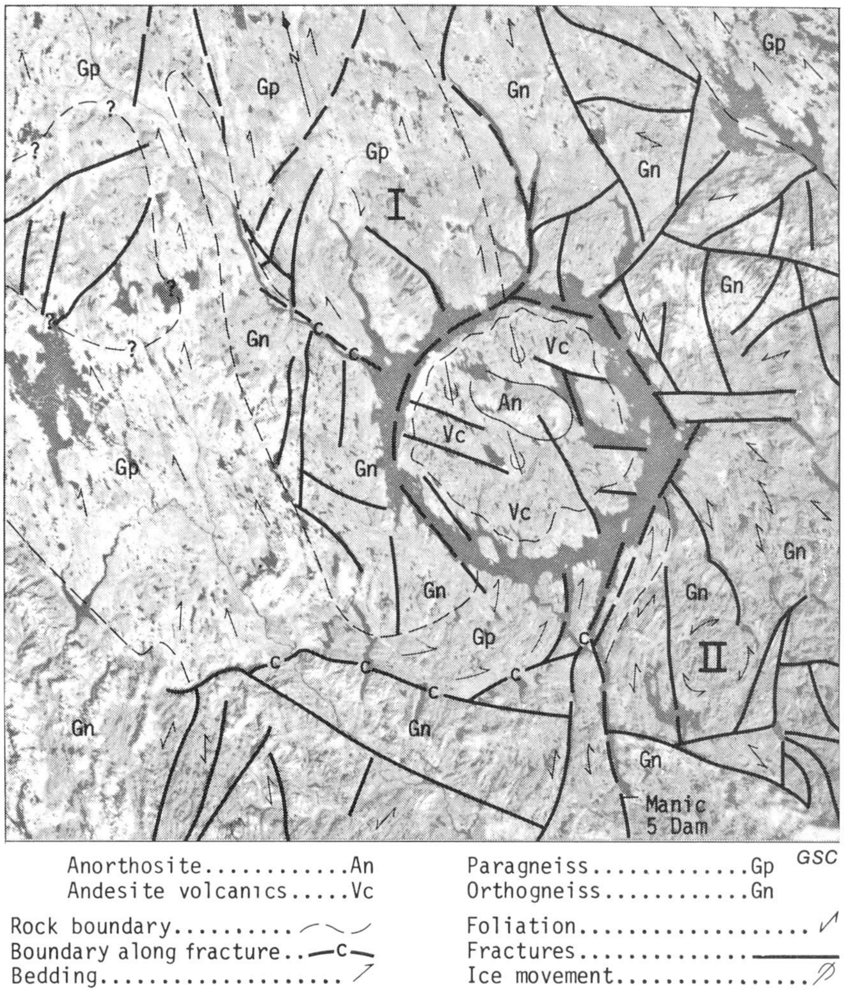

Figure 1.9

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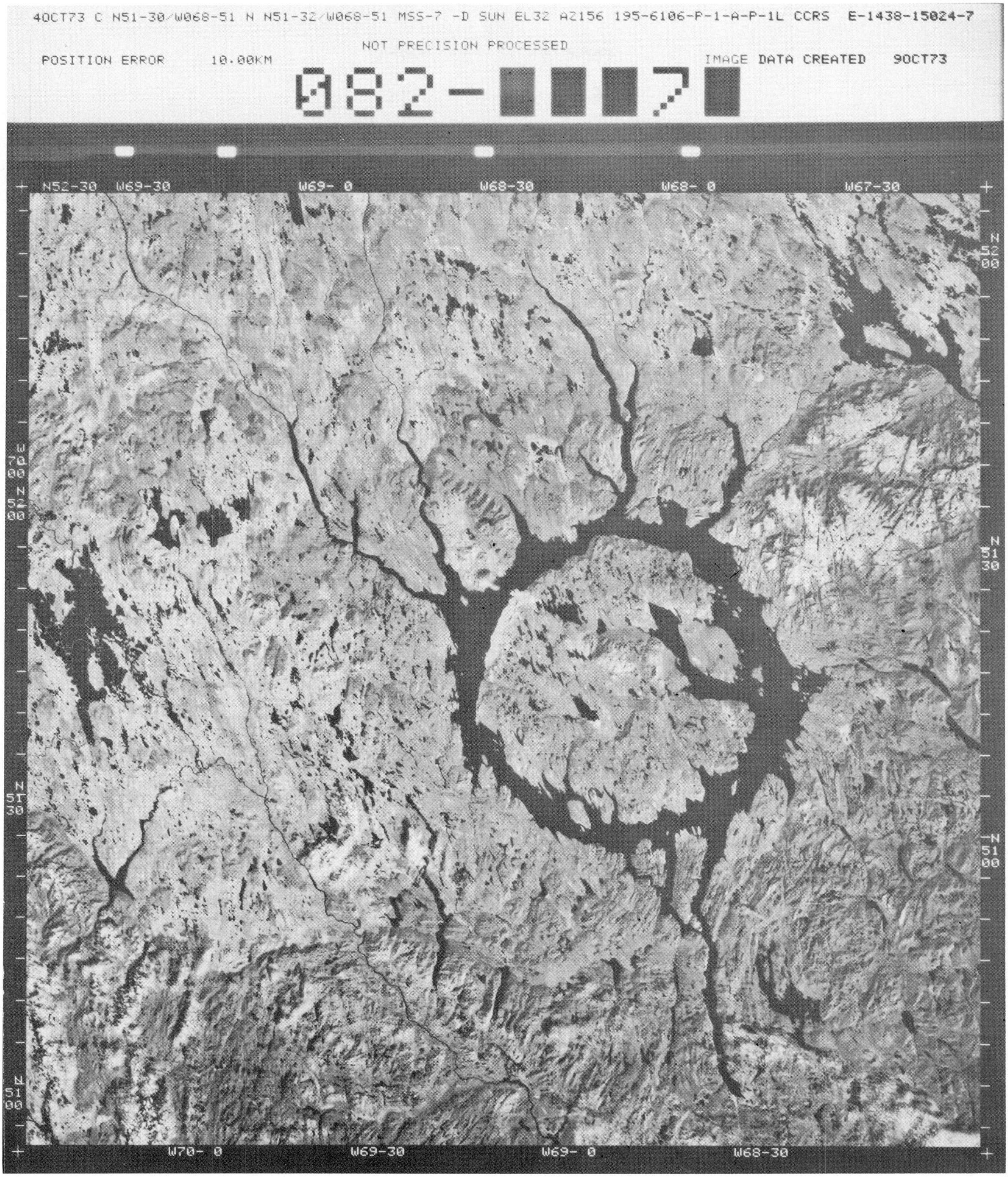
1955: Manicouagan Lake – Mushalagan Lake area, Quebec; Geological Survey of Canada, Paper 55-2, map with marginal notes.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W70- 0
W69-30
W69- 0
W68-30

Figure 1.9A

1.10

NUTAK

F.C. Taylor

This image covers a section of the Nain-Churchill Structural Province boundary in northern Labrador (Fig. 1.10, 1.10A). The boundary is obscured by an intrusion of anorthosite and adamellite except at the upper centre, where it can be recognized as a change from a linear topographic pattern in the Churchill province to a more massive pattern in the Nain province.

The rocks of the Nain province, chiefly migmatites, have a general northerly trend but this shows only south of Snyder Bay and in most places cannot be distinguished from the anorthosite-adamellite intrusive rocks. The rocks of the Churchill province are chiefly well-layered granulite, garnet-quartz-feldspar gneiss, and migmatite. The gneissosity and fold structures in these rocks are well displayed. In general, Churchill rocks appear darker grey on the image. The anorthosite and adamellite cannot be distinguished from one another but the contact between the adamellite and layered rocks of the Churchill province shows quite well. The Kiglapait pluton, a gabbro-troctolite layered intrusion, is visible on the right. The contact between this pluton and the Archean migmatite is readily identified by the textural contrast.

The great east-trending valleys on the lower edge of the image are post-adamellite faults, probably of a hinge type, with the axis of rotation under the cloud cover at the lower left. East-northeast-trending drumlinoid ridges in the lower centre are indicative of the easterly flow in this region.

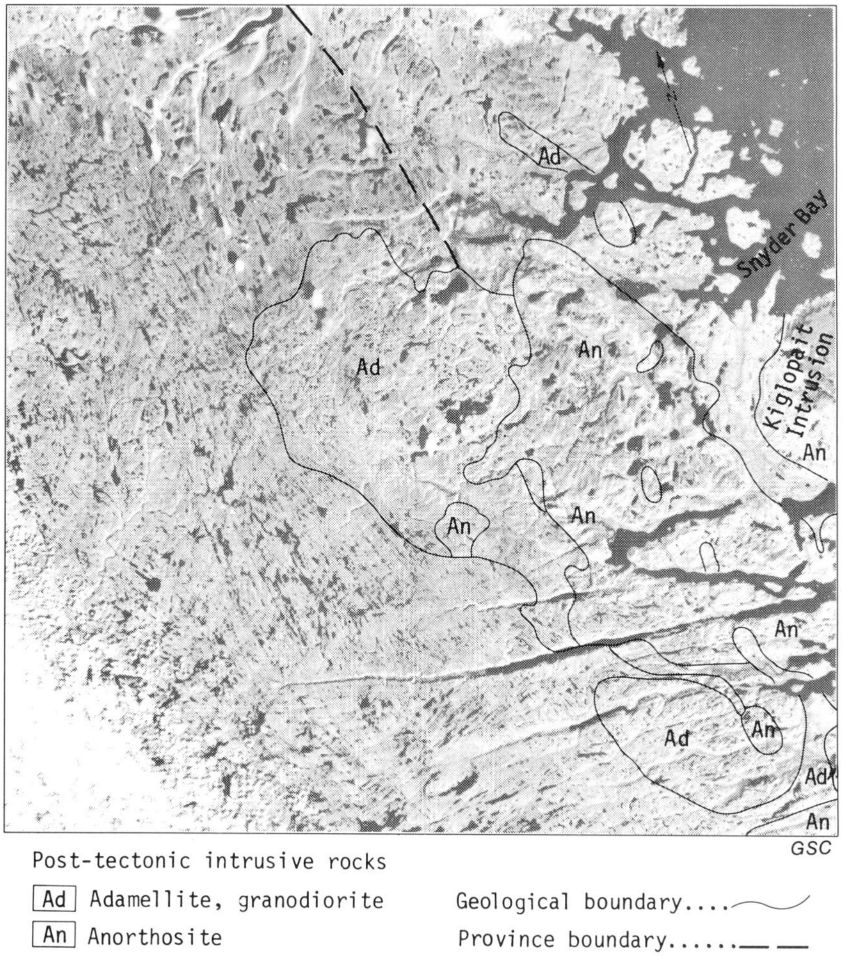

Figure 1.10

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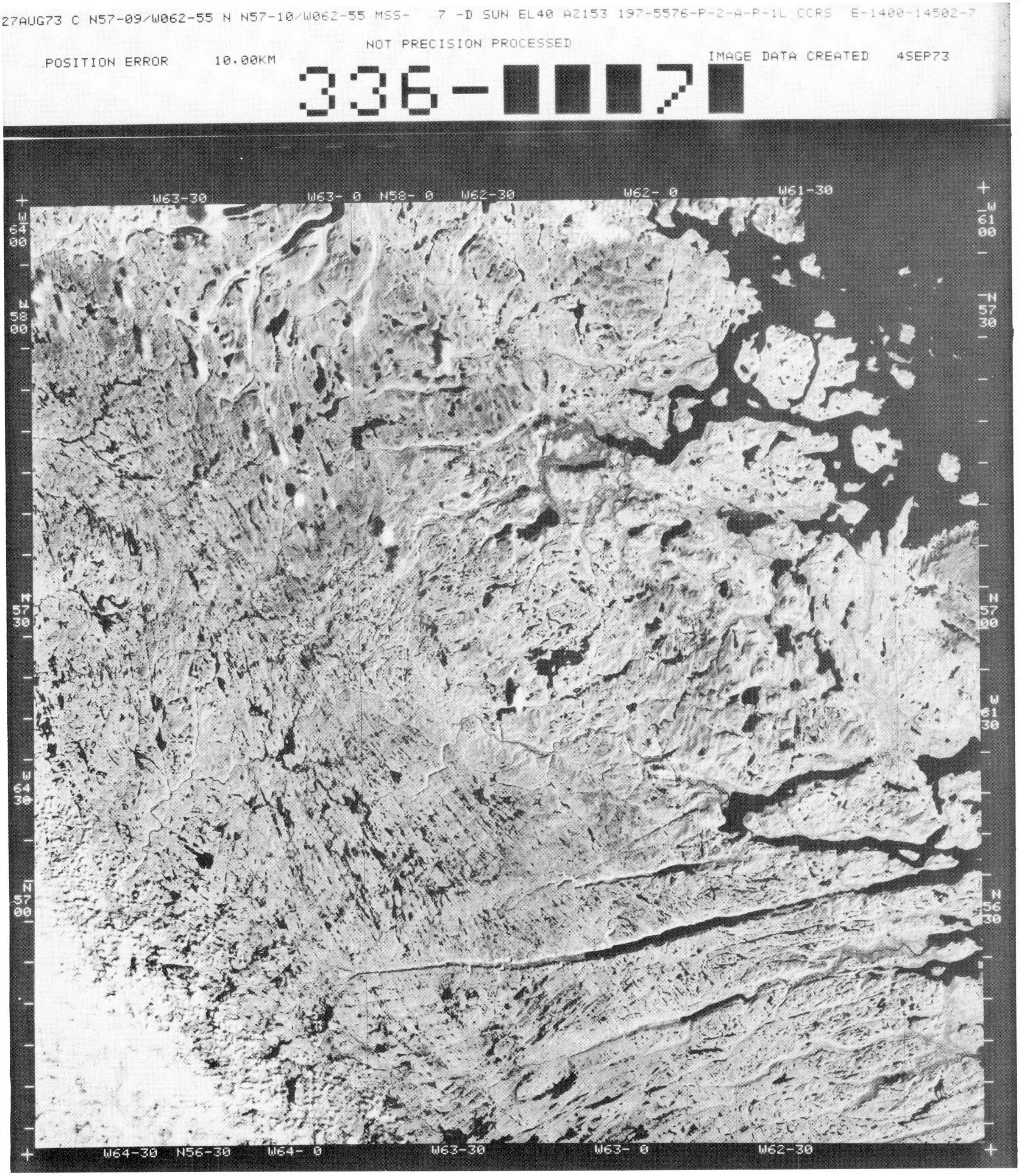
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W63- 0
W62-30

Figure 1.10 A

1.11

URANIUM CITY, SASKATCHEWAN

L.P. Tremblay

The image (Fig. 1.11, 1.11A) shows four distinct domains.

Domain 1, south of Lake Athabasca, corresponds to the Athabasca Formation. This domain differs from the other three by the apparent scarcity of rock exposures, and by the glacial flutings, characteristic of drift near the ice terminal.

The other three domains occur north of Lake Athabasca.

Domain 2 follows the north shore of the lake and extends northward in an irregular fashion. It represents a mobile belt, as its rocks are intensely deformed and much dissected. Much contortion and fracturing characterizes this domain. In the south, the rocks are typically heterogeneous, becoming more homogeneous towards the north. This change corresponds to a gradual increase in the intensity of metamorphism and granitization approaching domains 3 and 4. Several major fractures can be traced which correspond to known major faults of the area. However, the St. Louis Fault, which has some economic significance does not show at all clearly on the image.

Domains 3 and 4 lie north of domain 2. In general, they are more homogeneous and massive looking. Their appearance suggests stable blocks. They are either gneiss, dome like, or intrusive bodies. Fracturing is also a common feature, but not as striking as in domain 2. The fractures resemble joints in massive homogeneous bodies. They are more regular in trend and form sets.

Economically this area is known for its uranium mineralization whose occurrences are known to occur mainly in the area of domain 2.

The boundaries of domains 2, 3, and 4 do not correspond exactly to those shown on the geological and tectonic maps of Canada.

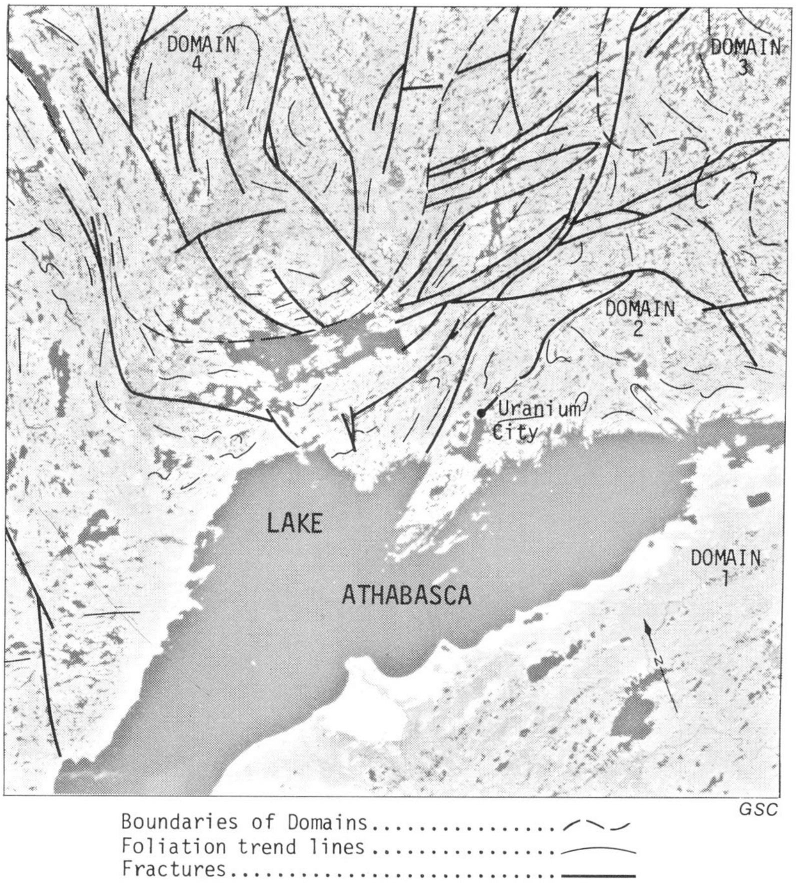

Figure 1.11


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N6 60
E 70
N6 55
E55
N655
E60
E65

Figure 1.11A

1.12 WOPMAY FAULT SYSTEM

John McGlynn

The Wopmay fault system separates two very distinct geological environments in the Bear Structural Province, and is the dominant feature of this image (Fig. 1.12). The fault system trends in a northerly to east of northerly direction separating rocks of the Hepburn Metamorphic-Plutonic Belt east of the fault from the Great Bear Batholith, west of the fault. These two belts are major tectonic units of the Bear Structural Province.

The fault system itself is expressed as a narrow, linear feature. Within this zone are sedimentary and volcanic rocks of the Aphebian Snare Group that are in fault contact with, or overlain unconformably by, younger sedimentary and volcanic rocks of the Great Bear Batholith. The Snare strata are cut and metamorphosed by granodiorites which do not intrude the younger strata.

East of the fault zone in the Hepburn complex are gneisses and migmatites intruded by massive granodiorites and quartz monzonites. The gneissic structures can be seen in the image. The obvious fold structures are second folds that refold older folds in the complexly deformed gneisses. West of the fault zone are massive granodiorites, quartz monzonites and granites, and associated intermediate to acidic subaerial volcanic rocks of the Great Bear Batholith. Major structures to be seen in these rocks are northeast-trending linears, some of which are known to be late faults which die out as they approach the Wopmay fault.

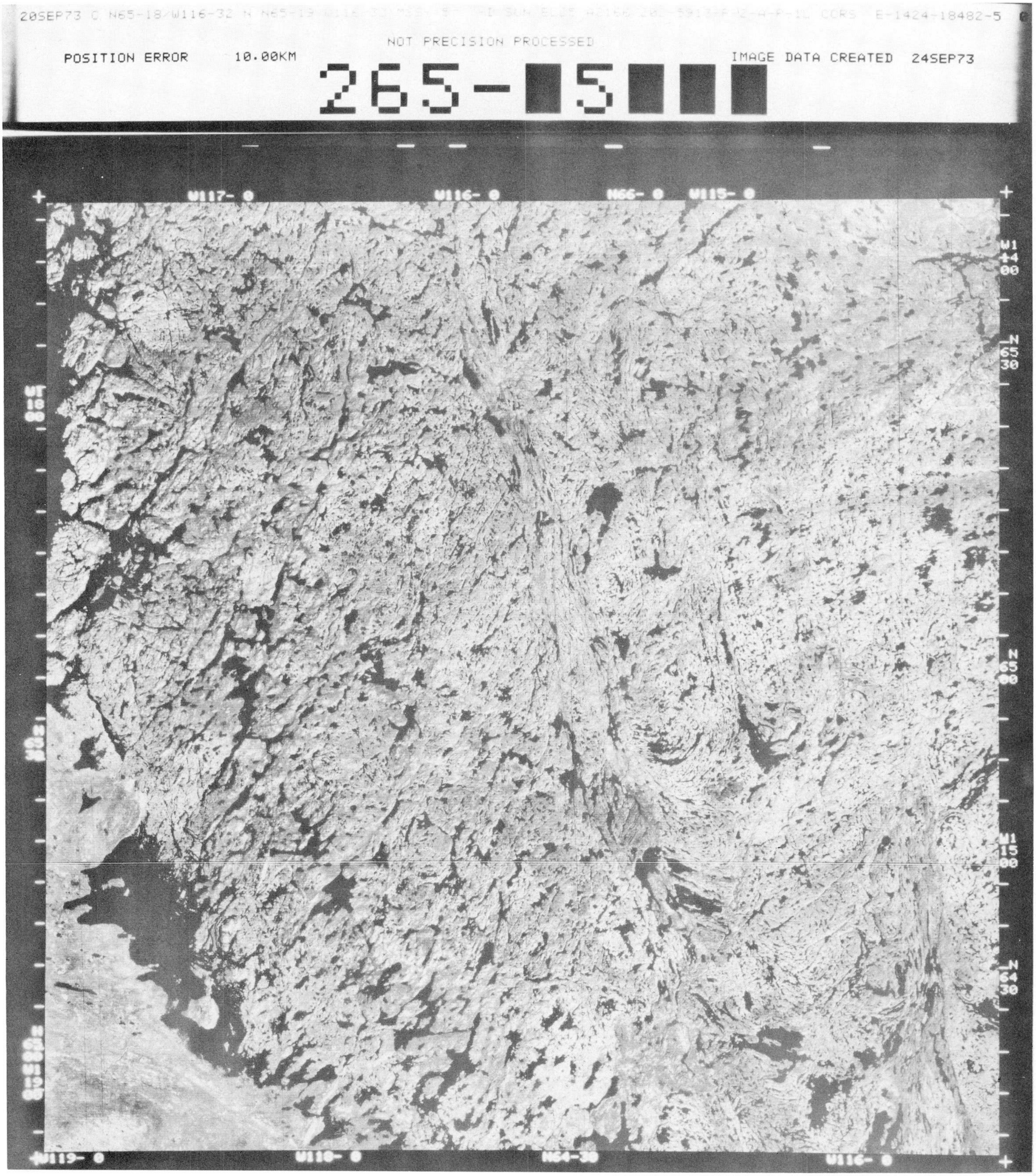
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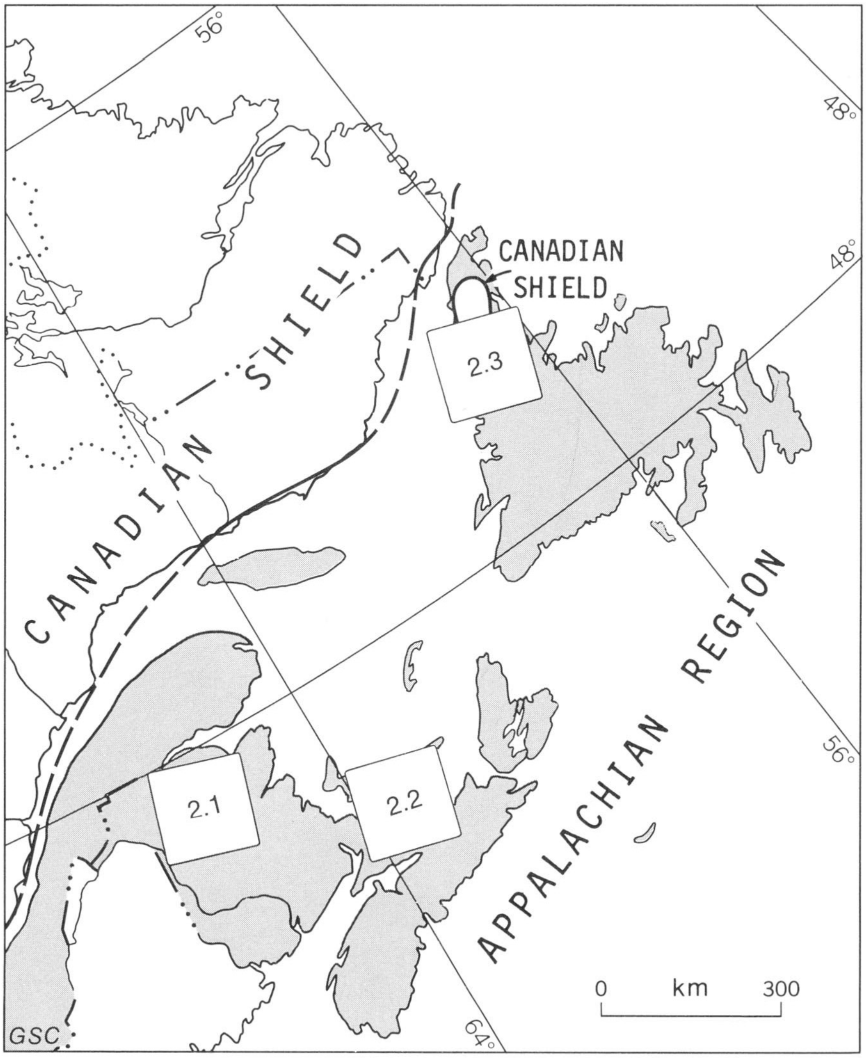
Figure 1.12

THE APPALACHIAN REGION

Section 2



2.1 Bathurst, New Brunswick
W.H. Poole

2.2 Prince Edward Island and Northeastern Nova Scotia
D. Benson

2.3 Western Newfoundland
L.M. Cumming

2.1

BATHURST, NEW BRUNSWICK

W.H. Poole

This image (Fig. 2.1) of northwestern New Brunswick represents an area of sediments, volcanics and granitoid rocks of Paleozoic age (Fig. 2.1A).

The youngest rocks are flat lying Carboniferous sediments which underlie the eastern edge of the image area and form an outlier near Grand Falls in the southwestern part of the image. Because of the continuity of the vegetation pattern between Carboniferous and the surrounding older rocks, the boundary of the youngest rocks is hardly ever distinguishable. In addition, there is an east to north arcing lineation evident in the area south of Bathurst, the result of glacial scouring, which makes boundary definition even more difficult.

The oldest rocks represented in the image are the Tetagouche series (Os, Ov) and granites (g) which have different terrain characteristics to that of the younger Ordovician to Devonian rocks (Os, S, Di, s and v). The Tetagouche and granites have a generally homogeneous texture in the image, owing perhaps to the multiple deformation and low-grade metamorphism commonly found here. Linear ribbing can be seen in the younger rocks which are mixed sediments and volcanics with simple structure and slate-grade or lower metamorphism. Silurian sediments in the southeast (Ss) do not have a ribbed texture, perhaps because they consist of a uniform greywacke-slate assemblage.

Lineaments are plentiful in the younger strata on the northwest and west. Most fine lineaments probably reflect bedding. Others are strike-faults; some have been mapped. One major fault shown on the lineament overlay as a boundary (dotted) in the northwest corner separates Ds and OSs strata with a slight colour difference on the image. The Rocky Brook Millstream Break extends into one of the prominent lineaments extending southwest as depicted on the geological map.

Within the Tetagouche-granite terrane, the Catamaran Fault (C) is prominent on the image as far east as the unconformably overlying Carboniferous (Cs); a southwest extension to Saint John River appears possible from the image. Several lineaments, some of which are probably faults, appear in the Tetagouche-granite terrane in the central part of the image. Some lineaments or parts of some have been mapped as faults, others have not.

A curious doughnut-shaped feature, 3 mm in diameter (circled on the lineament overlay) in the west-central part of the image is an isolated mountain, Bald Peak, rising 1000 feet (300 m) above the countryside and lacking trees on its top.

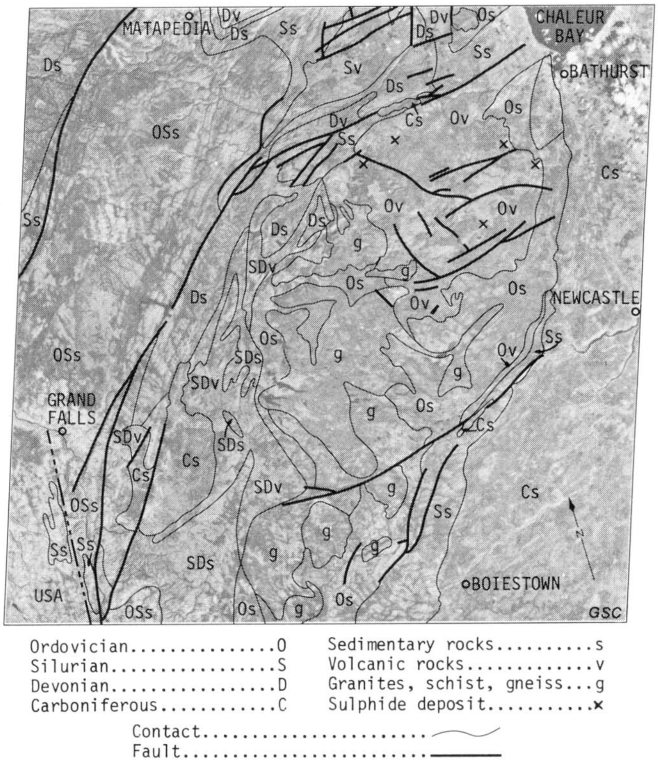


Figure 2.1

The usefulness of Landsat imagery to geology in the Bathurst area is limited. The geology has been mapped in most areas at a scale of 1 inch to 1 mile, and many parts at a scale of 1/4 inch to 1 mile. Trends within and granite contacts against Tetagouche rocks cannot be identified. Boundaries of the Carboniferous terrane cannot be reliably identified. On the other hand, some lineaments, possibly faults, can be identified, and as such, focus the attention of regional geologists to search for an explanation. One such lineament trends eastwards towards the Brunswick No. 6 mine, 30 km south-southeast of Bathurst. Airphotos taken from an aircraft at 70 000 foot altitude would be more valuable in this part of New Brunswick.

Reference

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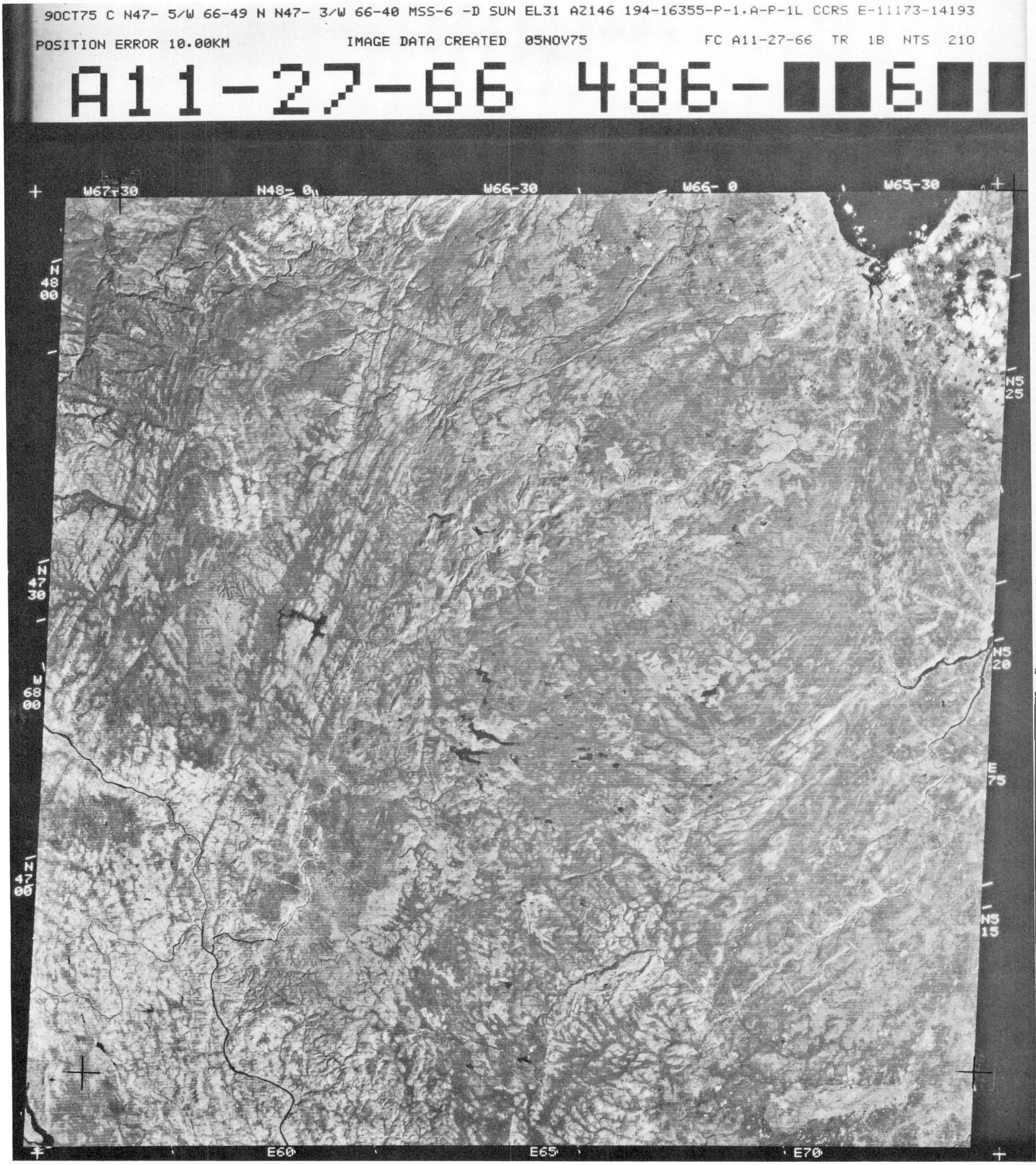
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Figure 2.1A

PRINCE EDWARD ISLAND AND NORTHEASTERN NOVA SCOTIA

D. Benson

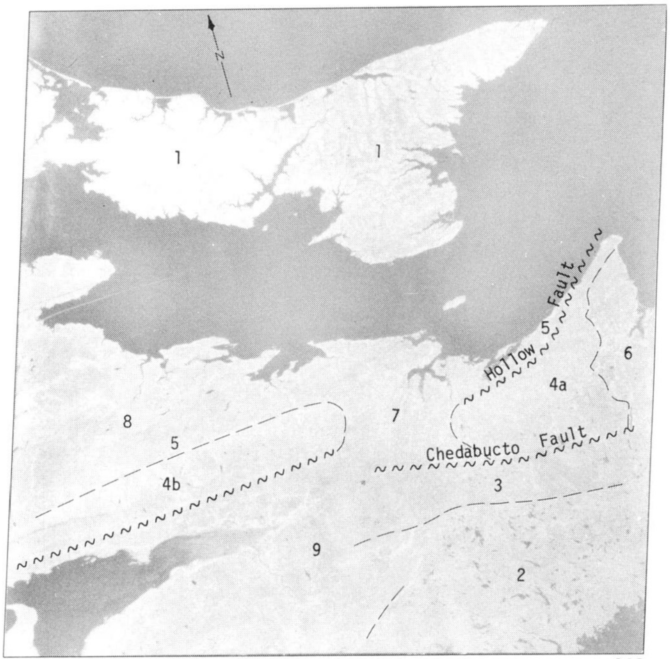
Prince Edward Island is underlain by easily eroded Carboniferous and Permian sediments. The image (Fig. 2.2) does not reflect the bedrock but does show very clearly areas under cultivation as well as numerous beaches.

Nova Scotia is largely underlain by lower Paleozoic to Triassic rocks (Fig. 2.2A). The southeast part of the image depicts quartzite and subgraywacke of the Cambro-Ordovician Meguma Group, intruded by Devonian granite. The streams follow fracture patterns in the bedrock and most lakes lie in depressions and are dammed by glacial debris or by beaver dams.

North of the Meguma rocks, a narrow band of darker grey tones indicates a trough (St. Mary's Graben) of Carboniferous sediments. The eastern half of the trough has a sharp fault-bounded northern contact. The southern boundary is an unconformity.

The Antigonish Highlands to the north, and the Cobequid Mountains to the west are underlain by Paleozoic volcanic-sedimentary complexes intruded by several different types of igneous rocks. Their complex structure is indicated by a non-directional drainage pattern. The southern faulted boundary of the Cobequids disappears under the Carboniferous Pictou Basin to reappear as the Hollow Fault separating the Antigonish Highlands from Silurian and Devonian sediments which follow the coast.

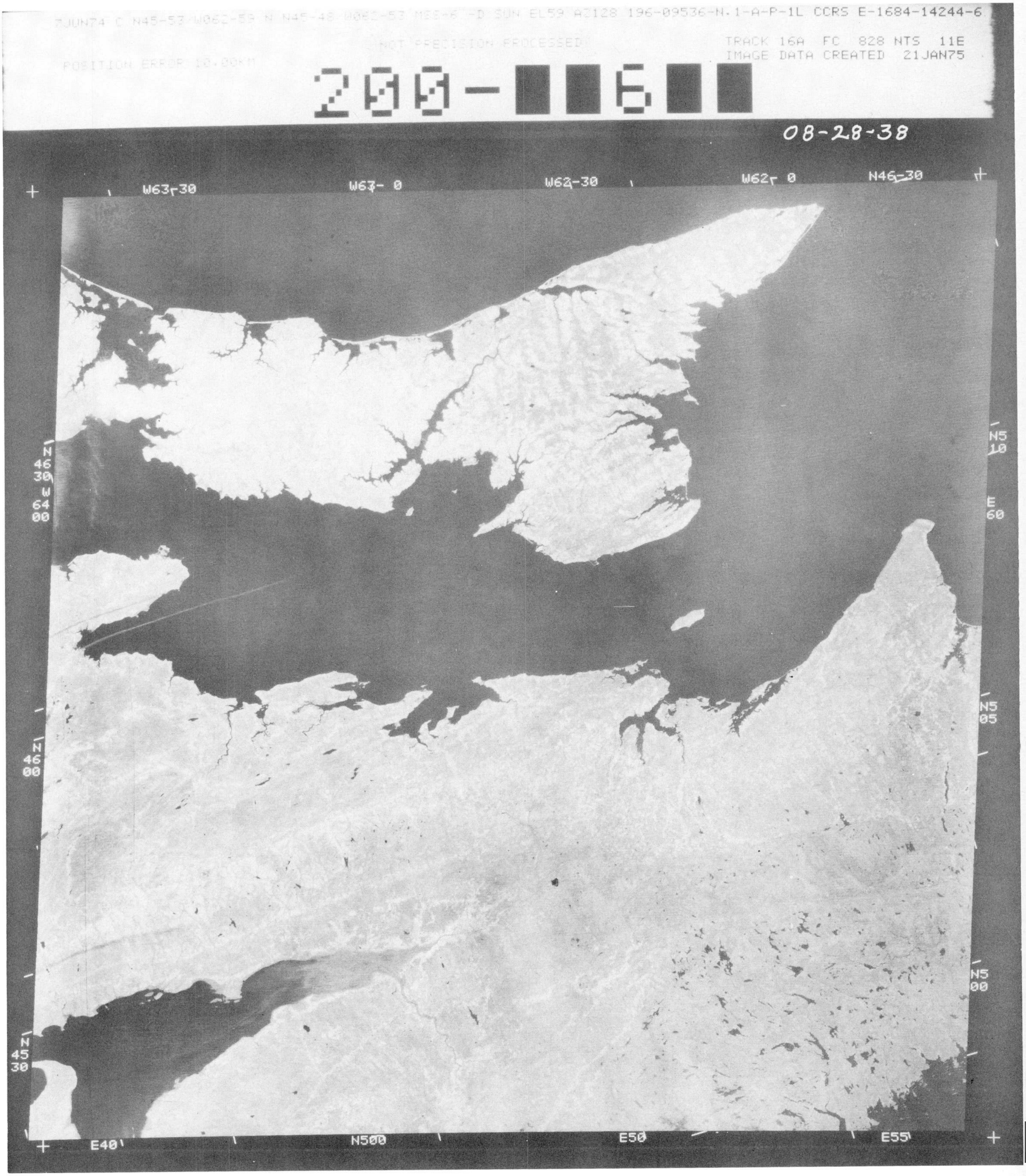
The three large Carboniferous basins, Antigonish, Pictou and Cumberland have well defined contacts with the older rocks about them.



GSC

1 Prince Edward Island
2 Meguma Rocks
3 St. Marys Graben
4 a, Antigonish Highlands
b, Cobequid Mountains
5 Coastal Region
6 Antigonish Lowlands
7 Pictou Basin
8 Cumberland Basin
9 Central Lowlands

Figure 2.2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N5 05
N5 00
E40
N500
E50
E55

Figure 2.2 A

WESTERN NEWFOUNDLAND

L.M. Cumming

This image Fig. 2.3 shows a portion of western Newfoundland where the V-shaped indentation of White Bay separates Burlington Peninsula from the northeast-trending Great Northern Peninsula.

A lowland area extending south from White Bay is underlain by the youngest sedimentary rocks of Carboniferous age in Newfoundland (Fig. 2.3A). However, land areas flanking White Bay are underlain by some of the oldest and most metamorphosed rocks in Newfoundland. These rocks are the Fleur-de-Lys Group exposed along the west side of Burlington Peninsula and the Long Range Precambrian Complex which forms the high plateau of the Great Northern Peninsula.

The overall significance of the distribution of rock types and landforms within the broad area of the image may be summarized using plate tectonics. The area east of White Bay is considered to be the margin of an oceanic plate and the area west of White Bay to be the margin of a continental plate. This oceanic plate abutted against the continental plate and was forced (or underthrust) beneath it. The edge of the oceanic plate then had the configuration of a west dipping slab of relatively dense "oceanic" rocks. This local doubling of the thickness of the crust of the earth provided the buoyancy necessary to later uplift the entire Long Range as a coherent block. The average width (50 km) of the Long Range is a function of the angle of plunge of this underthrust slab.

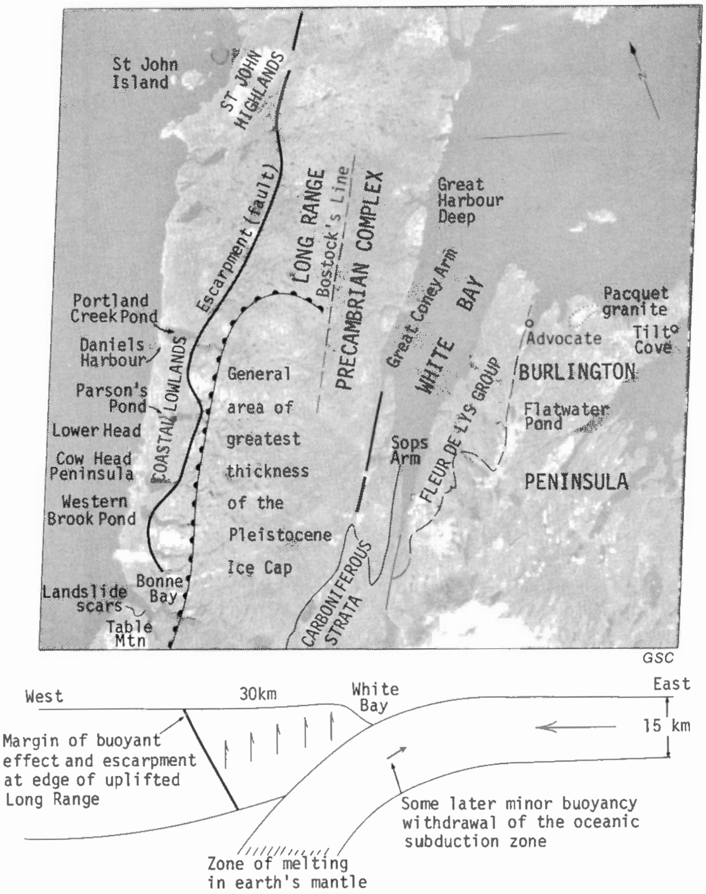
A smaller portion of the oceanic crust was also overthrust onto the edge of the continental plate, forming high land such as Table Mountain (in the southwest corner of the image) which is underlain by ultrabasic rocks.

These thrusting events took place in Ordovician time and the huge trough-shaped depression formed along the junction of the two plates later became filled with sediments of Carboniferous age.

The two-fold composition of the Great Northern Peninsula is revealed by the juxtaposition of a narrow western coastal lowland and a high plateau. These are underlain respectively by relatively soft Paleozoic carbonate rocks and by resistant Precambrian gneisses and intrusive granites.

To the east of Cow Head a series of parallel stripes are the traces of imbricated thrust faults, which repeat the succession of transported carbonate rocks. Farther north the St. John Highlands are capped by resistant white quartzite of the Lower Cambrian Hawke Bay Formation.

The Precambrian crystalline backbone of the Great Northern Peninsula is divided lengthwise into two equal parts by "Bostock's Line". The eastern part is characterized by darker tones (indicative of greater amounts of vegetation) and corresponds to the area affected by Paleozoic metamorphism. A swarm of narrow, northeast-trending diabase dykes can be seen in the northern part of this area. They also extend into the western part which contains an outlier of flat-lying arkose of the Lower Cambrian Bradore Formation, which shows as a circular barren patch near the west escarpment of the Long Range. A lake, 17 km southeast of this outlier, contains numerous islands which represent a zone of intense deformation of the granitic rocks of the local area. An oval-shaped burned-over area is evident along the eastern coast near Great Harbour Deep. Straight-line contacts representing normal faults between Precambrian and Paleozoic rocks are shown between Sops Arm and Great Coney Arm in the southeast, and near Leg Pond in the northwest.



CROSS-SECTION OF ORDOVICIAN UNDERTHRUSTING
Western Newfoundland

Figure 2.3

Glaciers flowing west to the sea gouged out the "biscuit-board" topography of this scenic area. The six finger lakes which characterize this area, are now inland bodies of fresh water, due to a 300 foot rebound of the land after the melting of the glacial ice.

South of Bonne Bay the ultrabasic rocks of the Bay of Islands Complex show as an area of bare rock at Table Mountain. East of Bonne Bay is Gros Morne National Park dedicated in 1973.

Features Visible on the Image

Tonal Contrasts

Lightest tones – Burned over areas.

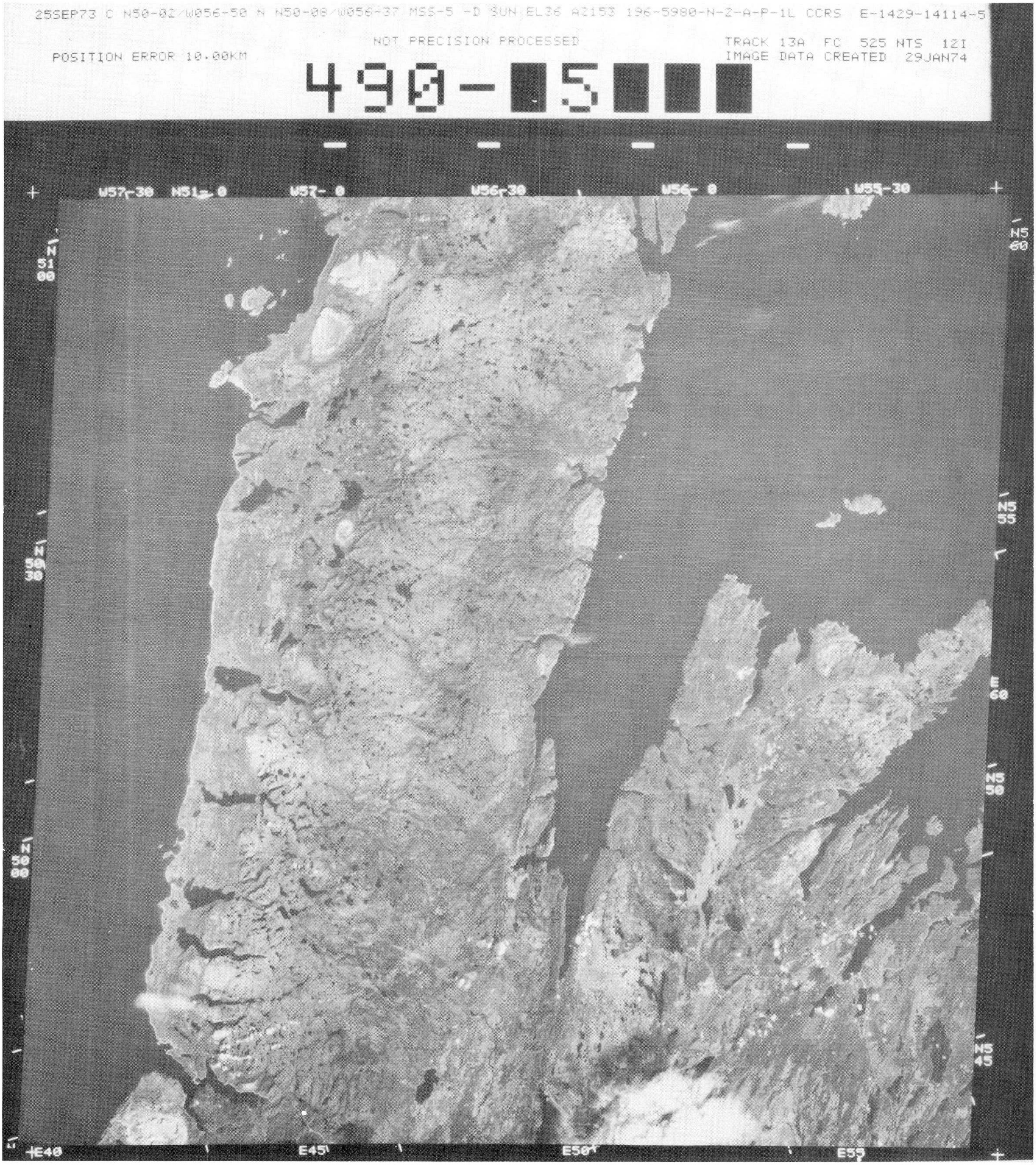
Hawke Bay Quartzite, Bradore Arkose, Pacquet granite body and Palaeozoic limestones, all light toned.

Carboniferous strata.

Darkest tones related to wet or moist areas rather than specific rock group, i.e. not to change in metamorphism east of Bostock line.

Drainage

Lake distribution and pattern on Precambrian is characteristic.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N 50 00
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N5 55
E 60
N5 50
N5 45
E40
E45
E50
E55

Figure 2.3 A

Larger lakes along west margin of Great Northern Peninsula due to greater ice erosion on softer limestone sediments.

Polygonal pattern near north end of Great Northern Peninsula due to greater thickness of periglacial deposits?

Drainage pattern generally fracture controlled, plus erosion along foliation or banding in Precambrian gneisses.

Erosion

Coast line erosion on Burlington Peninsula shows difference between massive and banded gneisses well.

Uplift along west coast of Great Northern Peninsula well seen, also general tilt of the peninsula to southeast.

Scarps formed by hard beds of Hawke Bay Quartzite and Bradore Arkose well developed.

Structures

Fracture pattern well displayed.

Distinction between dykes and fractures not always clear. 'Swirls' around the Pacquet granite and elsewhere on the Burlington Peninsula well seen.

Precambrian Complex of the Long Range generally more massive than the Fleur-de-Lys Group.

Hawke Bay Quartzite faulted against the Precambrian Complex but Bradore Arkose may rest unconformably on Precambrian Complex.

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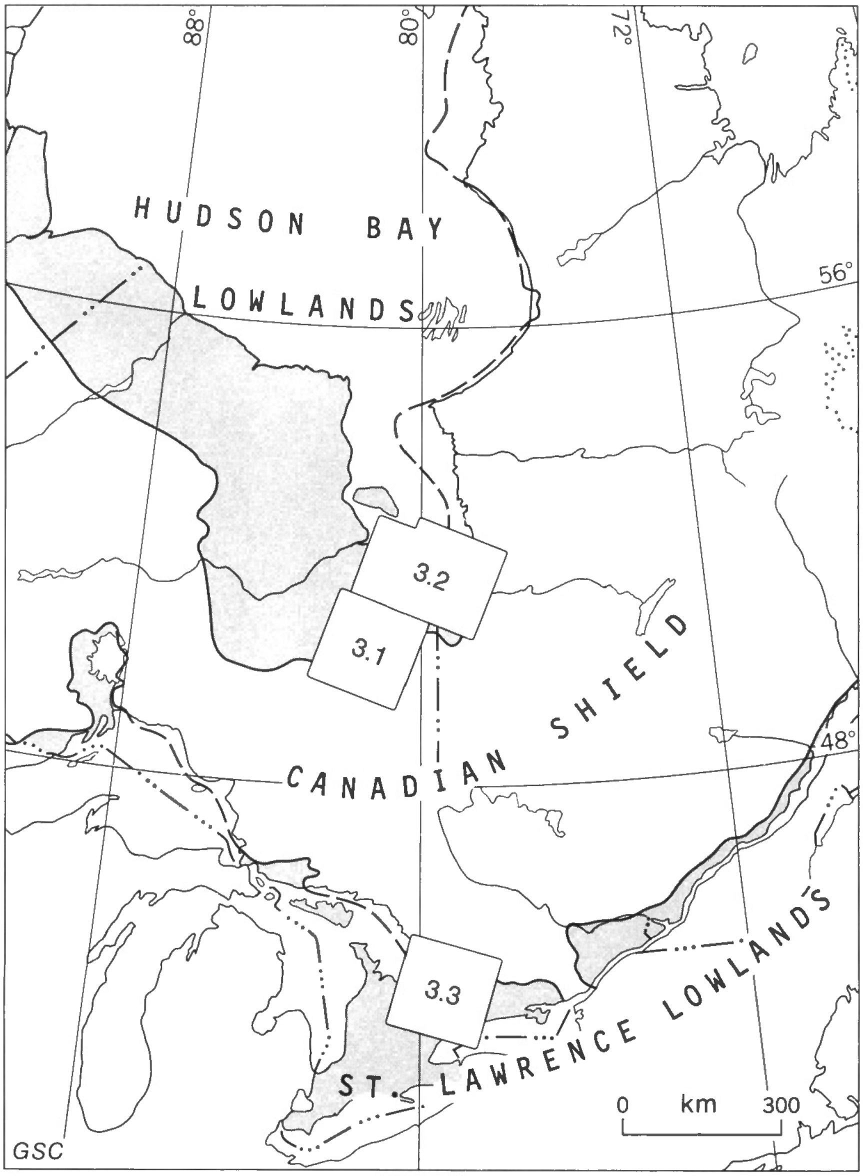
ST. LAWRENCE AND HUDSON BAY LOWLANDS

Section 3



3.1 Coral Rapids, Ontario
R. Skinner

3.2 South James Bay
R. Skinner

3.3 Toronto
B.A. Liberty

3.1

CORAL RAPIDS, ONTARIO

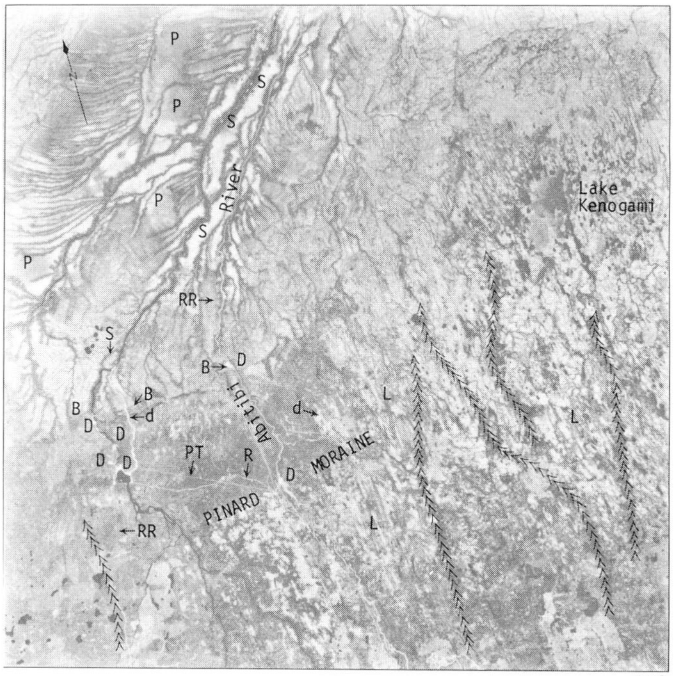
R. Skinner

This image covers the boundary between two principal physiographic regions of Canada, the Canadian Shield to the south, and the Hudson Bay Lowlands to the north (Fig. 3.1, 3.1A). Rivers flowing northward over the relatively resistant crystalline rocks of the Shield form rapids and falls where they drop down into the lowlands, which are underlain by relatively flat-lying limestone, shale and sandstone. Seven dams (D) have been constructed along this "fall-line" demonstrating how man has utilized this important physiographic boundary. Striking differences in the patterns of vegetation and stream drainage as well as difference in frequency of lakes distinguish the two physiographies. These contrasts are due, in part, to the differing underlying rocks, but also reflect different late and post-glacial processes in the area. The darker (better forested) sinuous, linear areas (E) are eskers clearly distinguishable on Band 7 as a string of parallel or twin and elongated kettle lakes. The darker colour reflects a relatively dense forest consisting primarily of jack pine whose growth is favoured by the well-drained sands compared to lower adjacent till and clay plains.

The lineations (L) are giant striae and drumlinoid features resulting from a late glacial readvance (the Cochrane) of the James Bay lobe of the continental ice sheet about 8500 years ago. The southern limit of this readvance is just south of the area contained in this frame. It is believed that this readvance was a glacial surge perhaps triggered by an over steepened profile due to rapid melting and oblation of the ice margin in extensive glacial lake Barlow-Ojibway. The surge overrode the eskers (e.g. near L at middle of image). Following the surge (and there were probably many others along the front of the ice sheet at that time) the Tyrrell Sea inundated the northern portion of this area up to about 500 feet which more or less coincides with the Precambrian – Paleozoic contact. Beach deposits (B), particularly thick where rivers emptied into the Tyrrell Sea, have provided convenient sources of aggregate for the construction of dams at the fall line and for railroad beds also visible on the image (RR). Marine clay, deposited in the Tyrrell Sea, blanketed the flat-lying Paleozoic rocks of the lowlands. The gentle slope, poor drainage of these clays and perhaps the maritime influence of the Bay to the north have led to the accumulation of peat bogs (P) shown as light, highly reflective areas between streams in this area. The banks of rivers in the lowlands are better drained and are therefore, forested, and appear darker in colour.

Human activity is clearly visible on this image. Two diversions (d) for hydroelectric generation are visible. Both have resulted in greatly accelerated erosion indicated by the light, highly reflective bare soil. In the diversion known as the Adam Creek Diversion in the western part of the image, vast amounts of glacial marine clay, till and sand have been eroded by the excess discharge during spring flood. Highly reflective sandbars are visible for miles downstream (S). These have formed since the diversion in the early 1960's (Skinner, 1974).

At the time the image was produced (August) most streams and lakes in this region are clear, therefore they show as black, with the exception of the Abitibi River which in Cree means "dirty" or "muddy" river. The Abitibi drains the major part of the glacial lake Barlow-Ojibway clay plains (Abitibi Clay Plain). Clay eroded from the banks and beds of lakes and streams is kept in suspension in the Abitibi accounting for its high turbidity. Lake Kenogami is a shallow kettle lake in glaciolacustrine clays. Its turbidity is due to wave action which keeps the clays eroded from the banks in suspension.

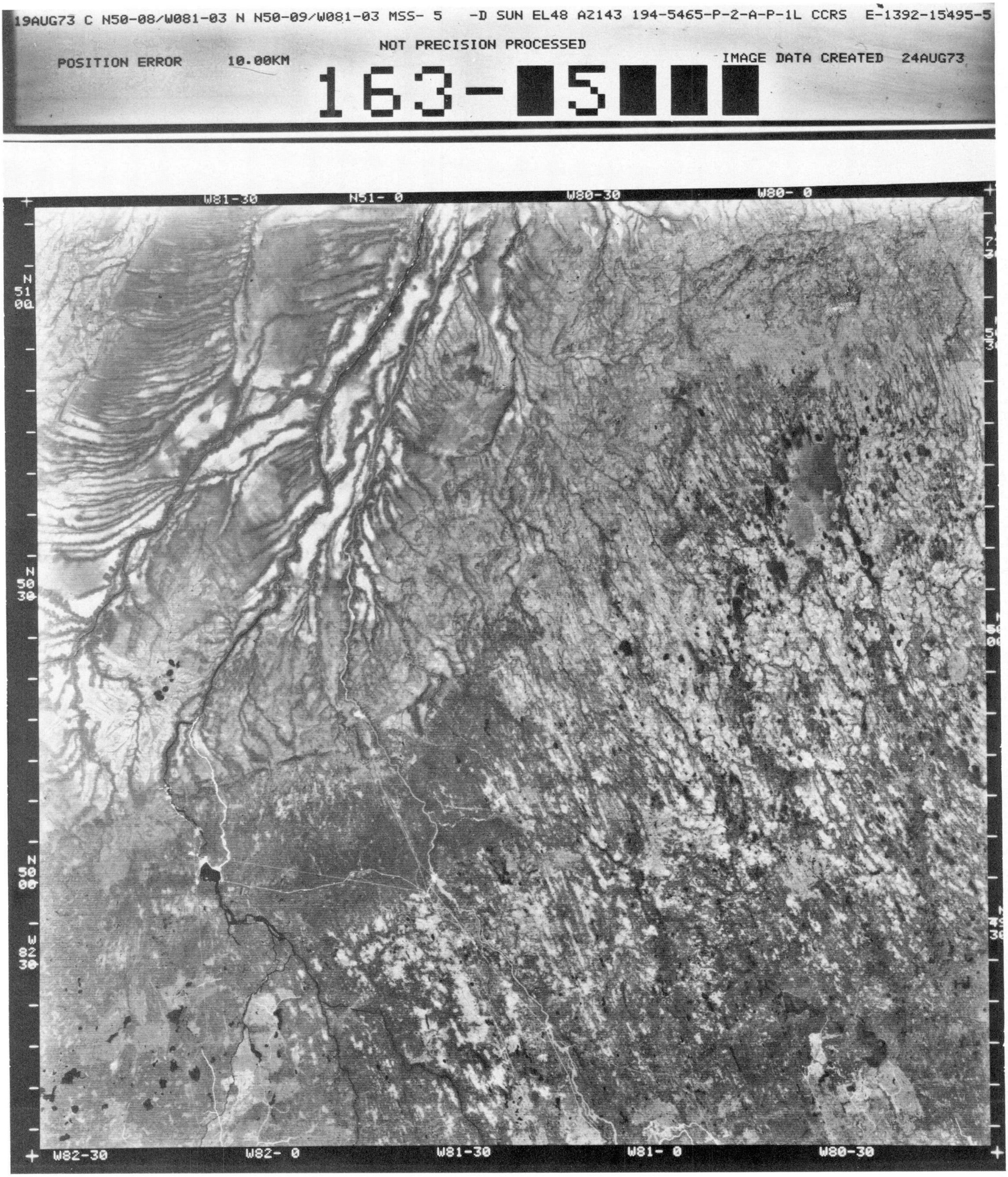


GSC

Figure 3.1

Finally, the large light patches along the southern margin of the photo are vast areas cleared of trees for pulp and paper. New logging roads can be seen trending northward, one in the southwest corner, taking advantage of the natural roadbeds provided by the eskers. Other roads (R) and Power Transmission lines (PT) are indicated on the photo, most distinguishable where they cut across the "Pinard Morraine," a broad delta moraine just south of the Precambrian-Paleozoic contact. It too, composed of sand and gravel yet overridden by the Cochrane surge and capped with a thin till, is relatively well-drained, and therefore supports a relatively heavy stand of trees.

Although detailed timber surveys are carried out by pulp and paper companies and provincial forestry departments, Landsat images offer an inexpensive means of charting on a periodic and synoptic basis, the clearing of forests, the area burnt by forest fires, and after a quick means of forecasting road requirements and other land use pressures. The ease with which this scale and quality of imagery can be quickly examined and natural phenomena interpreted would be of tangible benefit in any regional land use assessment.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W81- 0
W80-30

Figure 3.1A

3.2

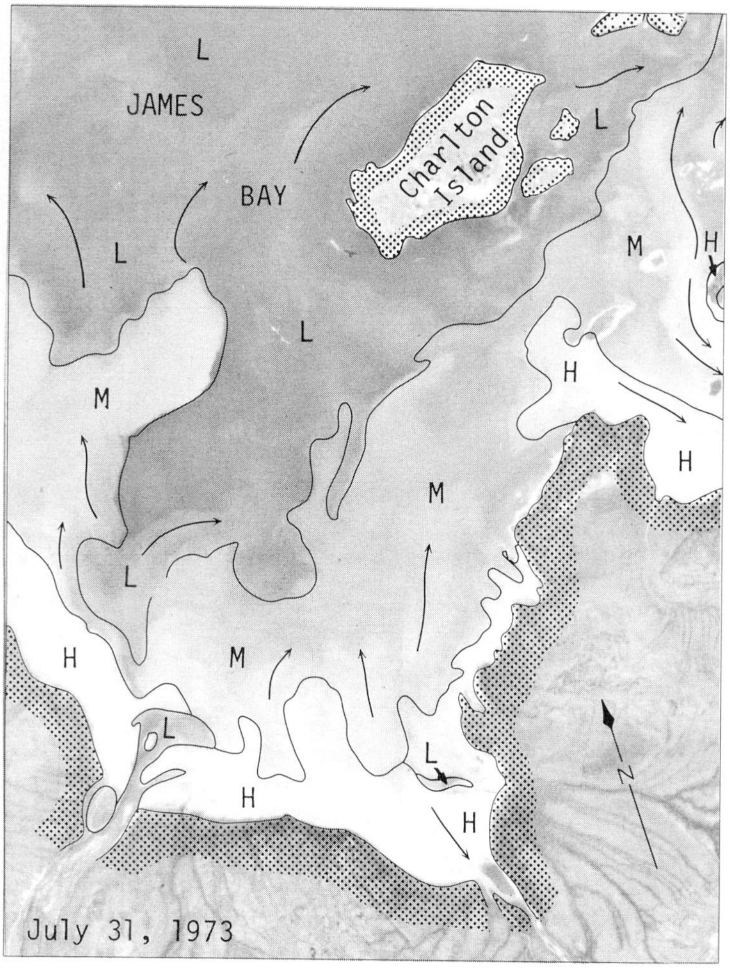
SOUTH JAMES BAY

R. Skinner

The extensive sediment plumes in James Bay are the most striking feature of Figures 3.2A, 3.2B. This sediment, derived from the lowlands and the Abitibi Clay plains on the Shield to the south is resident in this coastal environment for some time. Because the regional slope out to sea is so gradual, vast areas of mud flat are exposed at low tide. Wave action, during rising and falling tides whips the mud into suspension which is subsequently extended by currents into spectacular sediment plumes, convoluted by eddies in the current. In late July, when this image was created, the rivers entering the bay were relatively clean, as indicated by the darker coloured plume moving out from the mouth of the Moose River into the more turbid water at sea.

On land, one can trace contact between the Paleozoic rocks of the lowlands and the harder rocks of the Canadian Shield. Raised beaches are also discernible on the lowlands. The blanket of marine clay covered by muskeg (light) crossed by streams (darker) indicate the differences in vegetation patterns.

By studying the juxtaposition of sediment plumes on successive images it is possible to gain a first order approximation of the nature of currents along the coast of Hudson and James Bay (Fig. 3.2, 3.2A). The summer of 1973 was characterized by long cloud-free periods and it would be possible to assemble plume pattern changes for this period. Supplemented by data from subsequent seasons and ship-acquired data, this use of Landsat images is potentially a highly cost-effective means of gathering surface current information. By repeating such studies from month to month and year to year, a fairly good impression of current patterns could be gained.



GSC

Figure 3.2

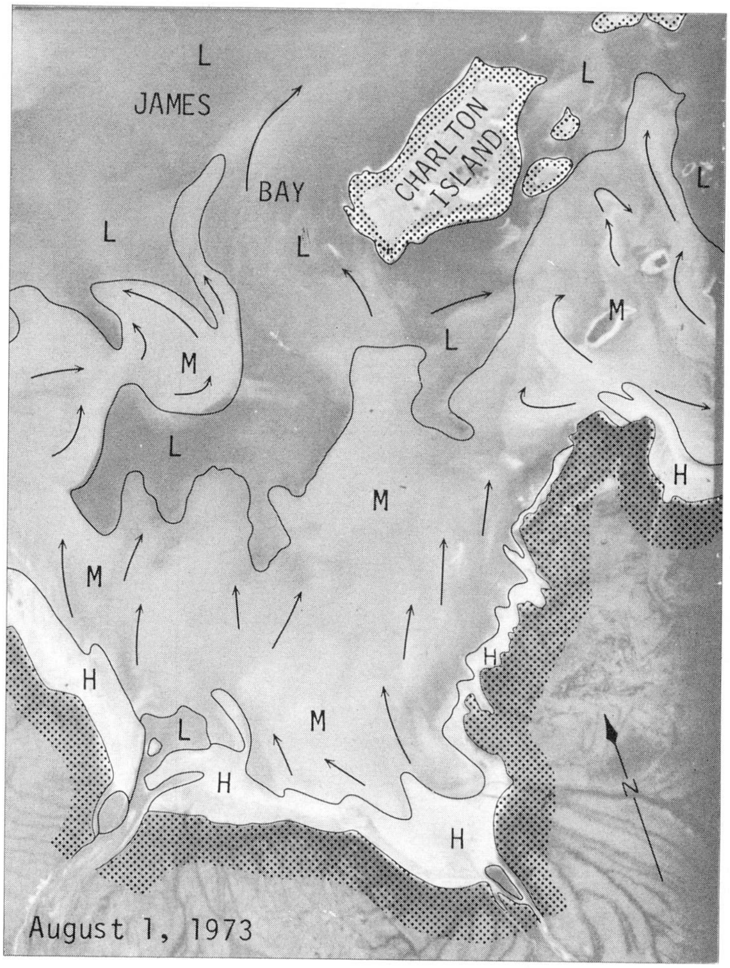


Figure 3.2A

GSC

Heavily silted water....................H
Moderately silty water..................M
Least silty water.......................L
Flow trends.......................
Approximate levels
of silt in water..............


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Figure 3.2B

3.3

TORONTO

B.A. Liberty[1]

The Lake Simcoe image (Fig. 3.3) embraces the southern edge of the Canadian Shield and onlapping Ordovician sedimentary strata. Four areas of distinct tonal character are visible. Area 1 displays structural grain typical of the Precambrian Grenville Province, with intrusive bodies surrounded by deformed sedimentary features. Lakes are abundant. Area 2 is underlain by jointed, generally porous, Middle Ordovician limestone units. Modern and relict pre-Pleistocene drainage patterns are present. The area is subdivided into a southerly zone underlain by the relatively impermeable Lindsay Formation on which surface drainage is visible. Area 3 is characterized by the presence of Upper Ordovician shale and Quaternary morainic material, and is therefore darker in tone. This area is covered in part by the Oak Ridge (Pleistocene) Interlobate Moraine, which in the northeastern part of the area attains considerable thickness and relief. Drainage is impeded and predominantly northward into Area 2. Area 4, of light tone along the western edge of the image, Silurian strata bounded to the east by the Niagara Escarpment. Items of specific interest include the following: 1) the Kawartha Lineament (Liberty, 1969) is clearly delimited by the Kawartha Lakes, Lake Simcoe and Nottawasaga Bay; 2) pre-glacial drainage is visible in the Rice Lake, Stony-Pigeon-Scugog Lakes, and Coutchiching-Simcoe-Cook Bay linears; 3) the west arm of Lake Simcoe extends toward Nottawasaga Bay along the northern edge of the buried Barrie Island (Deane, 1950); 4) the Simcoe Escarpment (Liberty, 1969) which arises from the bifurcation of the Niagara Escarpment, south of Alliston, is traceable eastward to the Cook Bay extension; and 5) possible Precambrian structural control of the Paleozoic rocks can be seen as grain in the area north of the Paleozoics in Area 1.

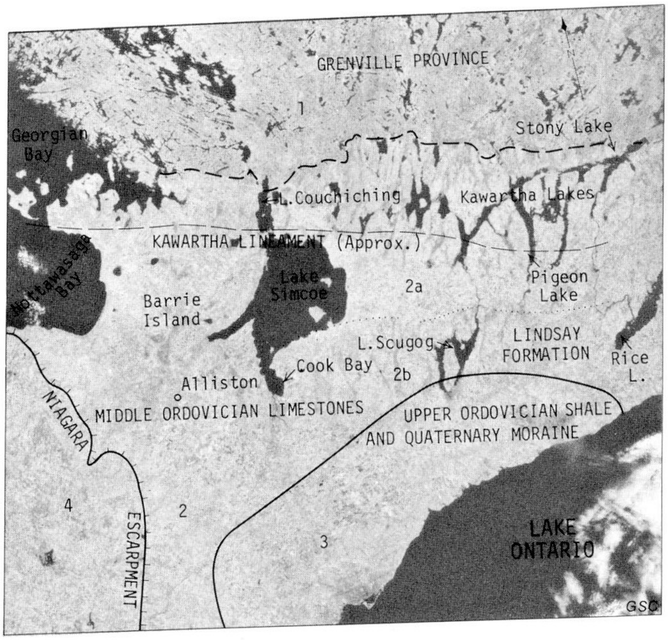

Figure 3.3

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[1] Department of Geological Science, Brock University, St. Catharines, Ontario.


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N 44 00
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Figure 3.3 A

THE ARCTIC REGION

Section 4

4.1 Bathurst Island, N.W.T.
J.Wm. Kerr

4.2 Brodeur Peninsula, Baffin Island
G.D. Jackson

4.3 Bylot Island, N.W.T.
G.D. Jackson

4.4 Frobisher Bay, South Baffin Island
W.W. Heywood

4.1

BATHURST ISLAND, N.W.T.

J.Wm. Kerr

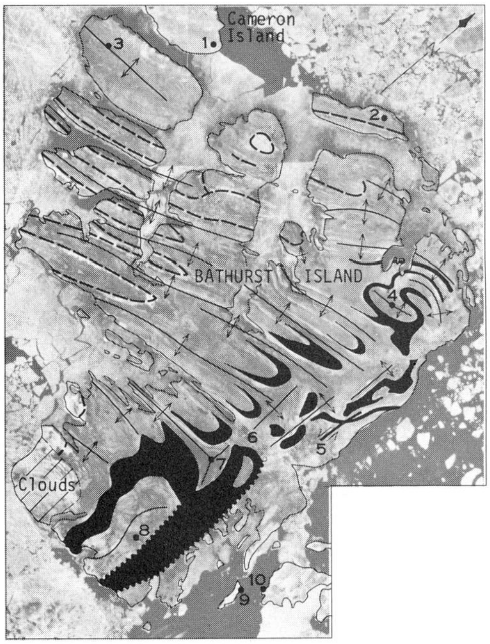
The principal feature to be seen on the Landsat mosaic of Bathurst Island is the pattern of folds in Paleozoic bedrock (Fig. 4.1). Two prominent light coloured units delineate this pattern, which occurs also on a published geological map (Kerr, 1974). The older is a resistant carbonate unit, made up principally of the Lower to Middle Devonian Disappointment Bay and Blue Fiord formations. These grade out westward into formations that do not show the light colour. The younger unit is a soft, friable Upper Devonian sandstone of the Hecla Bay Formation. A very small exposure of the Hecla Bay Formation is visible on the image where it outcrops along a fault on Cameron Island (Fig. 4.1A). A very small outlier of the Belcher Channel Formation, the basal unit of the Sverdrup Basin, is visible on Helena Island (2).

The mosaic of Bathurst Island displays the right angled intersection of the east-trending Parry Islands Fold Belt with the north-trending Cornwallis Fold Belt. The Cornwallis Fold Belt developed first and occurs only in the east; the folds are deep seated and were produced by vertical movement of underlying basement blocks. The Parry Islands Fold Belt is younger and was formed by southward transport on a décollement. Southward relative movement produced left lateral faults along the western edge of and within the Cornwallis Fold Belt, one such fault being shown (5).

A rectilinear pattern of inlets is visible on the Landsat image, having segments that trend roughly parallel to each of the fold directions. These inlets were controlled by bedrock structures and were sculptured by erosional processes, including glaciation. Bathurst Island lacks prominent glacial landforms such as eskers and drumlins (Blake, 1964). It bears evidence of glaciation in the form of till, erratics, and meltwater channels, but these are not visible on the Landsat image.

The prominent east-west valley through Bathurst Island is Polar Bear Pass (6). It can be seen that in the pass long arms of the sea nearly bisect the Island and also that the valley is anticlinal. The valley was ice-filled until about 8500 years ago and from that data until about 4500 years ago it was occupied by an arm of the sea that separated Bathurst Island into two islands (Blake, 1974). It is not possible to see evidence of this glaciation or of the more extensive former seas on the Landsat images.

Four unsuccessful oil wells have been drilled in the area (3, 4, 7, and 8). No evidence of them is visible on the image. Two lead-zinc occurrences are within the area (Kerr, 1975). At Truro Island (9) there is a showing, but little work has been done; however, at Polaris (10) there has been some underground mining. Neither site is visible on the images.



1. Hecla Bay Formation
2. Belcher Channel Formation
3. Vanier Island well
4. Young Inlet well
5. Left lateral fault
6. Polar Bear Pass
7. Caledonian River well
8. Allison River well
9. Truro Island Pb-Zn showing
10. Polaris Pb.Zn mine

Hecla Bay Formation........................... — — — — —

Disappointment Bay and Blue Fiord Formations... ━━━

Fault zone...................................... 〰〰〰

Figure 4.1

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SCALE
1:1 333 333

Figure 4.1A

BRODEUR PENINSULA, BAFFIN ISLAND

R.G. Blackadar

Brodeur Peninsula is primarily underlain by Ordovician-Silurian carbonate rocks. However faults have exposed Precambrian granitic gneisses in places.

Two physiographic divisions occur: Lancaster Plateau to the north and Boothia Plain to the south. Elevations in the plain do not exceed 500 feet whereas the plateau surface is characterized by steep, near vertical cliffs that rise 1000 feet or more above the sea. Above these cliffs the topography rises more gradually to reach maximum elevations of just under 1700 feet.

The well-developed drainage is dendritic in character. Rivers are deeply incised except at their headwaters. Westward draining rivers head within 15 miles of the east coast. The lake-studded area in the south indicates the presence of thick ground moraine. Vegetation is sparse and the undulating land surface has a barren, desolate appearance.

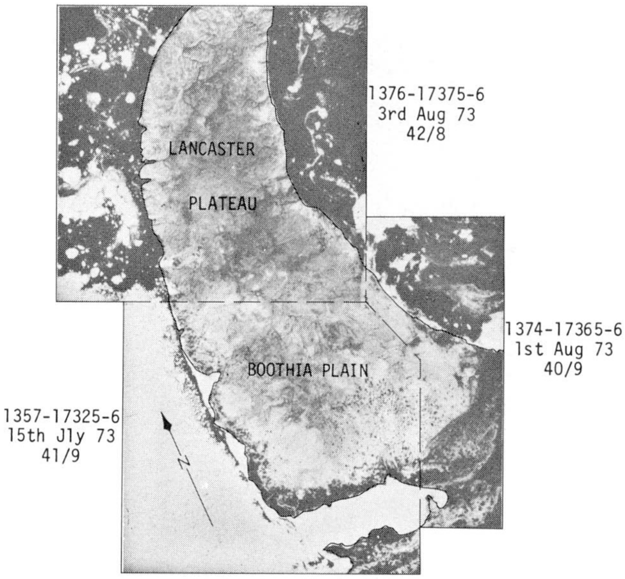

Figure 4.2

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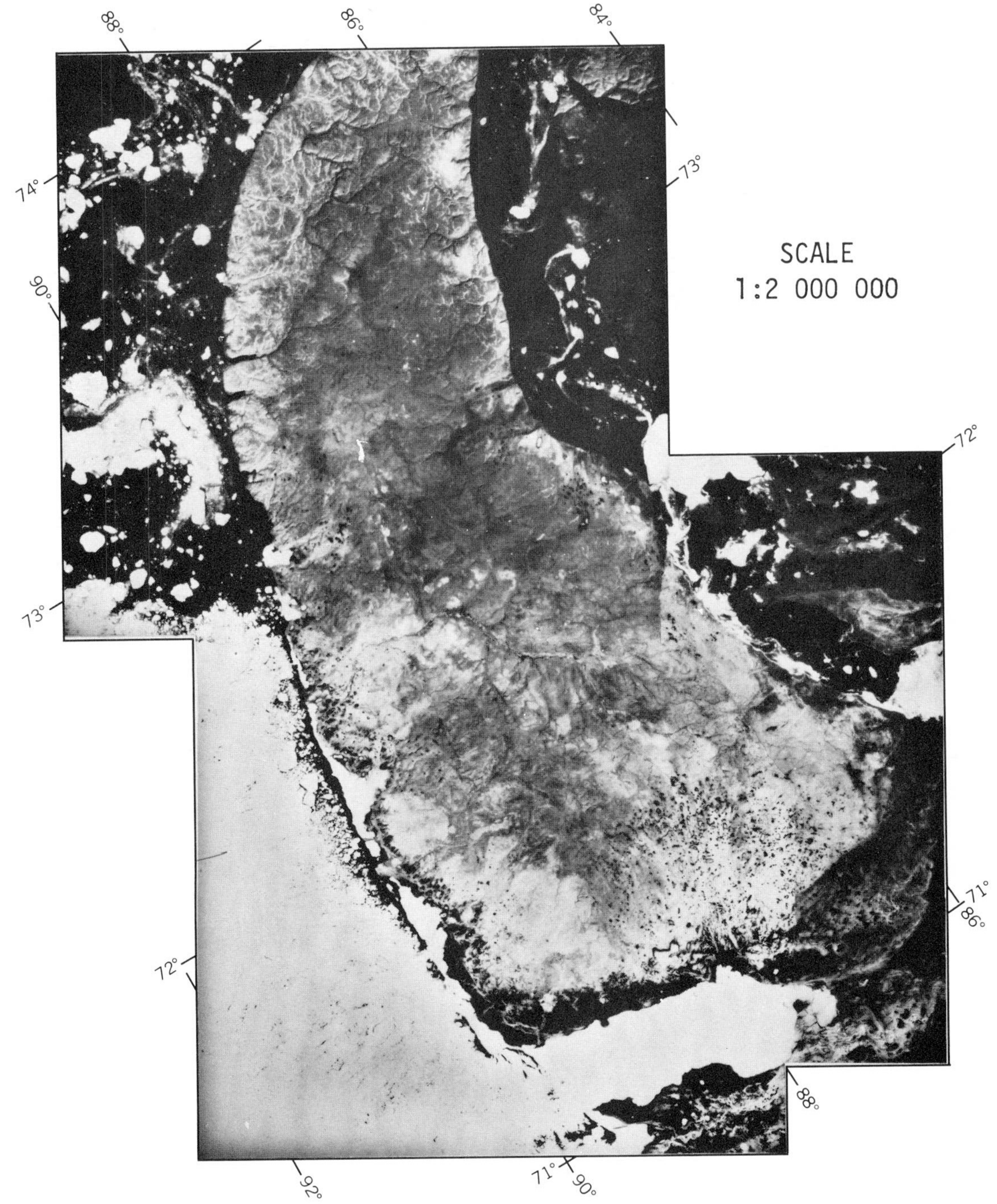


Figure 4.2 A

4.3

BYLOT ISLAND, N.W.T.

G.D. Jackson

The Navy-Board Inlet – Eclipse Sound region, which is shown in this image, is dominated by the snow and ice-covered Byam Martin Mountains (Fig. 4.3) that rise abruptly out of the sea to a maximum elevation of over 6000 feet (1900 m). These mountains are the accumulation centre for innumerable classic valley glaciers, complete with associated moraines, that flow outward toward the coast. Some of these glaciers have coalesced near the base of the mountains to form piedmont glaciers. Elevations in excess of 4500 feet (1400 m) are attained east of Pond Inlet and over 3000 feet (900 m) along the White Bay Fault Zone. The cloud cover shown is characteristic for this region in the port-breakup season when fog and clouds persist out to sea, stream around northern Bylot Island and dissipate in Navy Board Inlet and the vicinity of Mt. Herodier so that sunny weather persists in Eclipse Sound and the town of Pond Inlet.

Geologically, the area is part of the Churchill Structural Province and the most rugged terrain is underlain by units 1 and 2 (Fig. 4.3A). Much of the area is underlain by a metamorphic complex of Archean and Aphebian gneisses (1), most of which is layered migmatite of various types. Bodies of metasediments, metavolcanics, foliated and nebulitic granitoid rocks, and ultrabasic rocks occur within the complex. Pegmatites and granitoid dykes intrude all the rocks within the complex.

The Bylot Batholith (2) is mostly feldsparphyric monzocharnockite (hypersthene-bearing quartz monzonite) with minor associated anorthosite, mangerite-jotunite, and foliated granodiorite.

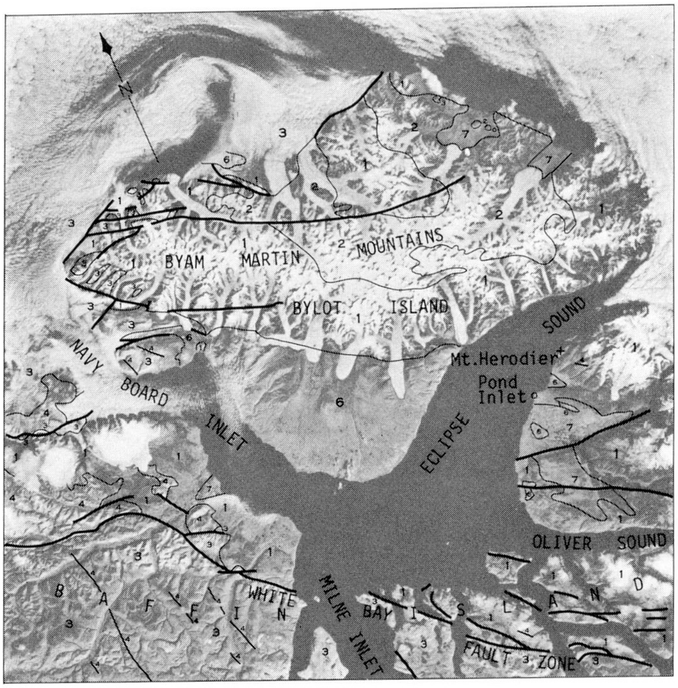
A profound unconformity separates units 1 and 2 from overlying sedimentary groups of several ages. Gently folded Neohelikian strata (3) occupy fairly rugged areas of intermediate relief and occur mostly south of the White Bay Fault Zone, and in relatively low flat to hilly ridge and valley terrain on northwestern and northern Bylot Island. Total thickness of these strata, which include some basalt near the base, may be in excess of 6000 m.

Hadrynian tholeiitic dykes (4), intrude all of the other Precambrian rocks in the region. Most of the dykes trend northwest, but several, particularly west of Navy Board Inlet trend north by west. It is not yet known whether or not the two trends represent dyke swarms of two different ages.

A slight angular unconformity separates lower Paleozoic strata (5) from the Neohelikian strata. Except for a small area of shale and limestone of dubious age on northern Bylot Island all of the Paleozoic strata lie west of Navy Board Inlet.

Cretaceous-Eocene strata (6) are flat to gently dipping, poorly consolidated, and poorly exposed. They underlie relatively low-lying flat to hilly areas and are best displayed on southwest Bylot Island. A thin veneer of these strata may underlie some of the drift-covered area (7) south of Pond Inlet.

Steep, northwest-trending faulting initiated in Helikian time (mid-Proterozoic) and continuing up to recent time, has divided Bylot and northern Baffin islands into alternating horsts and grabens (North Baffin Rift Zone). In addition to the faults shown, the contact between Cretaceous-Eocene strata and the basement gneisses on southwest Bylot Island is probably a fault scarp or a fault-line scarp. The 700 Ma old Franklin dykes were emplaced along and parallel to these faults.



PLEISTOCENE - RECENT

7 Unconsolidated glacial, freshwater, and marine deposits.

CRETACEOUS - EOCENE
ECLIPSE GROUP

6 Sandstone, siltstone, mudstone, conglomerate, coal.

CAMBRIAN - SILURIAN
ADMIRALTY TO BRODEUR GROUPS INCLUSIVE

5 Sandstone, dolomite, limestone, conglomerate.

HADRYNIAN
FRANKLIN INTRUSIONS

4 Diabase

NEOHELIKIAN
EQALULIK AND ULUKSON GROUPS

3 Sandstone, shale, dolomite, limestone, conglomerate, minor gypsum, basalt.

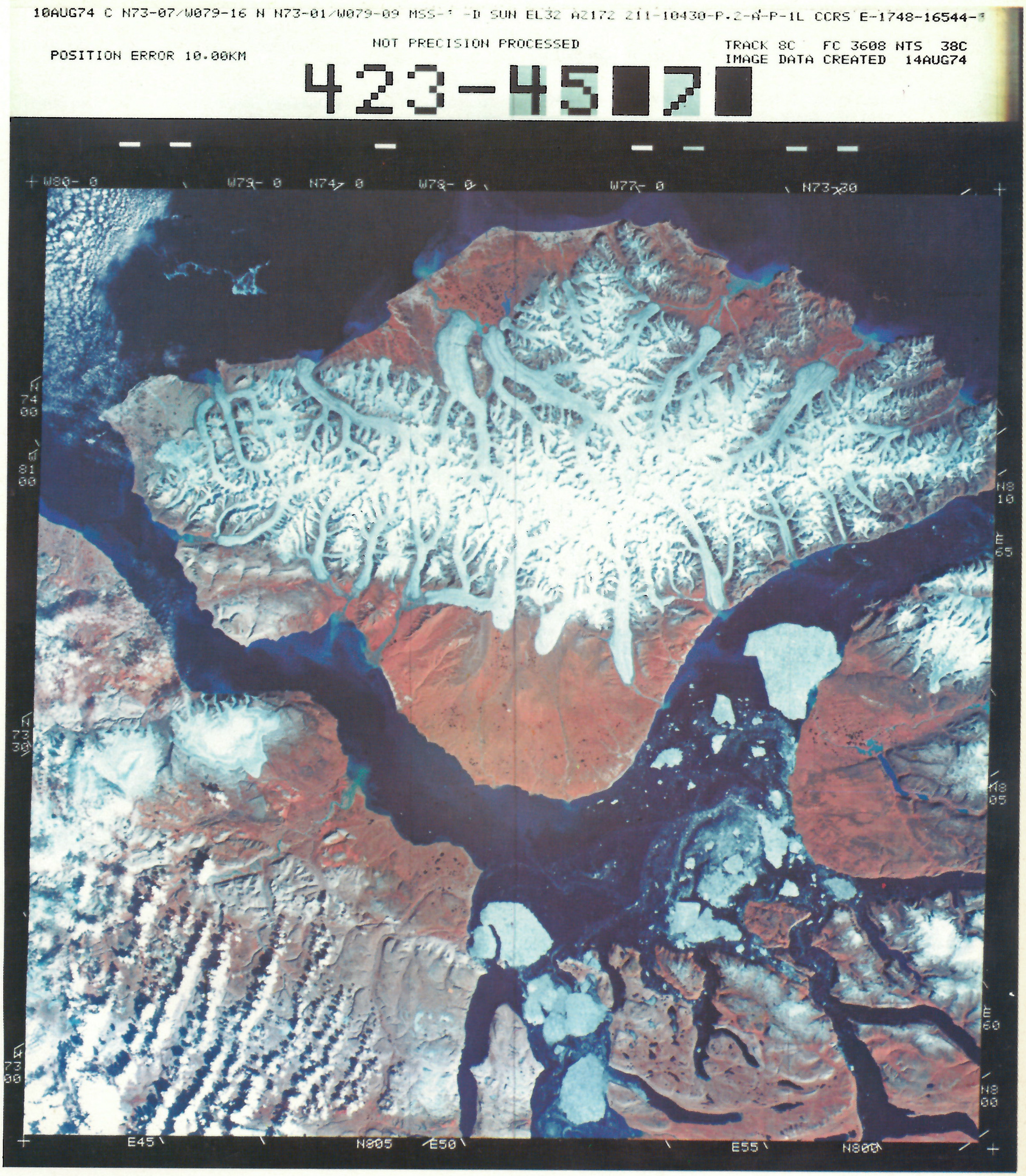
ARCHEAN - APHEBIAN

2 Monzocharnockite

1 Migmatite, metasediments, metavolcanics, granitic rocks, minor ultrabasic rocks.

Fault ———— Dyke ————

Figure 4.3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E50
E55
N800

Figure 4.3 A

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4.4

FROBISHER BAY, SOUTH BAFFIN ISLAND

W.W. Heywood

This image (Fig. 4.4, 4.4A) is composed mainly of Precambrian metamorphic rocks belonging to the Churchill Structural Province.

A series of northwest-trending faults cross Baffin Island. The blocks of land separated by these faults are tilted to the southwest. Thus the south shore of the bay has steep cliffs rising more than 300 m 1000 feet above sea level, and the north shore is relatively low.

Southwest of the fault-line, the metamorphic rocks are varied and have a complex structure. This is well displayed around Markham Bay, an area composed of schistose, rusty paragneiss, well-foliated garnet-biotite-quartz-feldspar gneiss and migmatite.

The pond-dotted area east of Amadjuak Lake is underlain by a highly fractured, massive, reddish biotite granite. East of this (in higher terrain) hypersthene granite with little lineation or foliation, predominates.

The light coloured patches extending east from Amadjuak Lake reflect thin Paleozoic limestone outcrop but the similar light toned patch to the northeast is glacial drift which marks the southeastern margin of a moraine system that can be traced at least 525 km from Hudson Strait. The linear textures seen here reflect ice movement from northwest to southeast.

Frobisher Bay airstrip is clearly visible at the head of the bay.

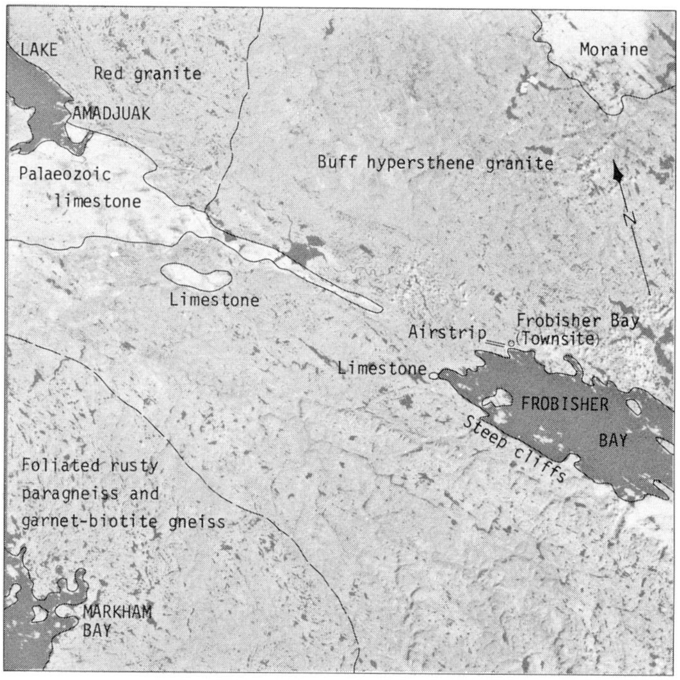

Figure 4.4

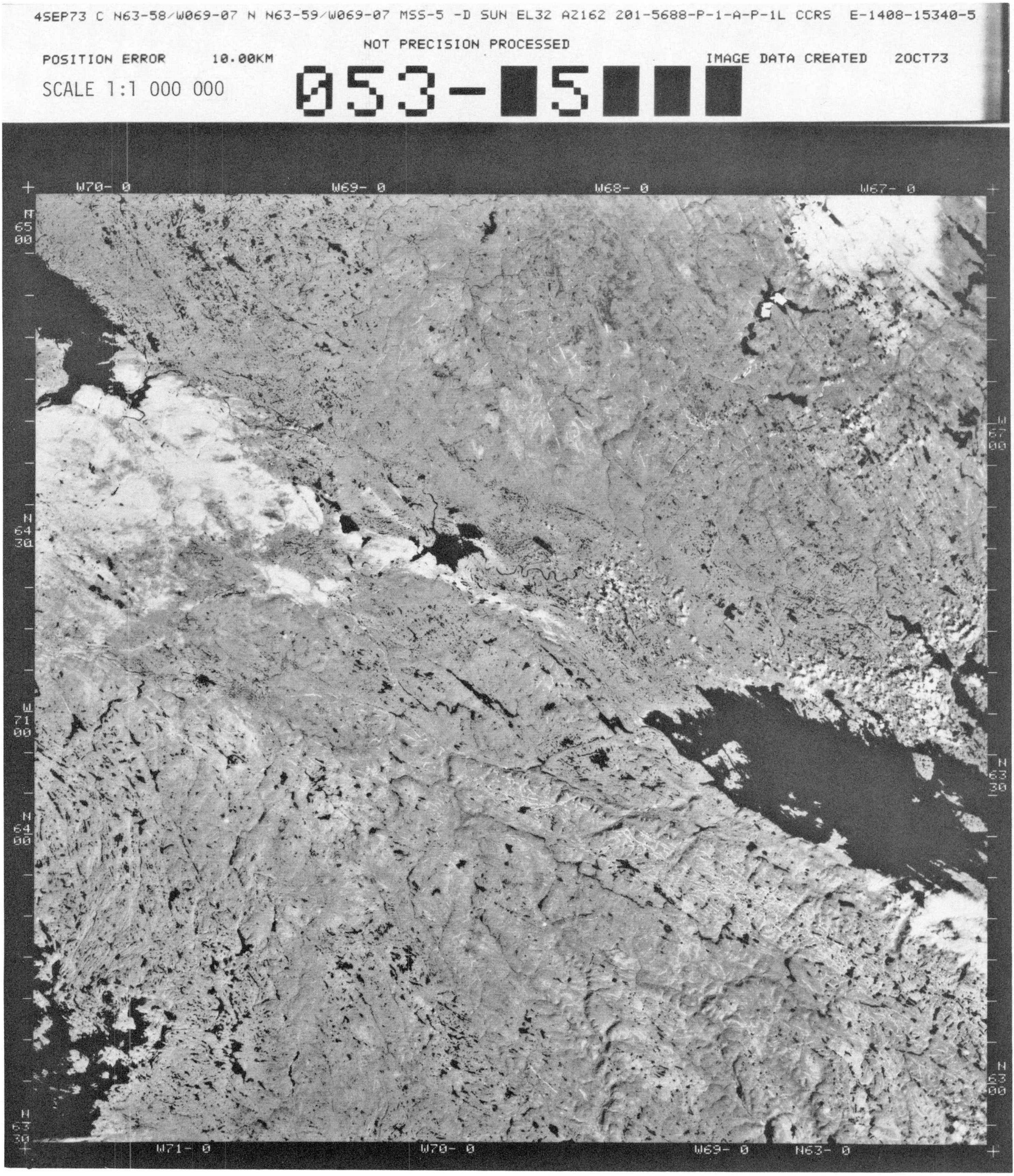
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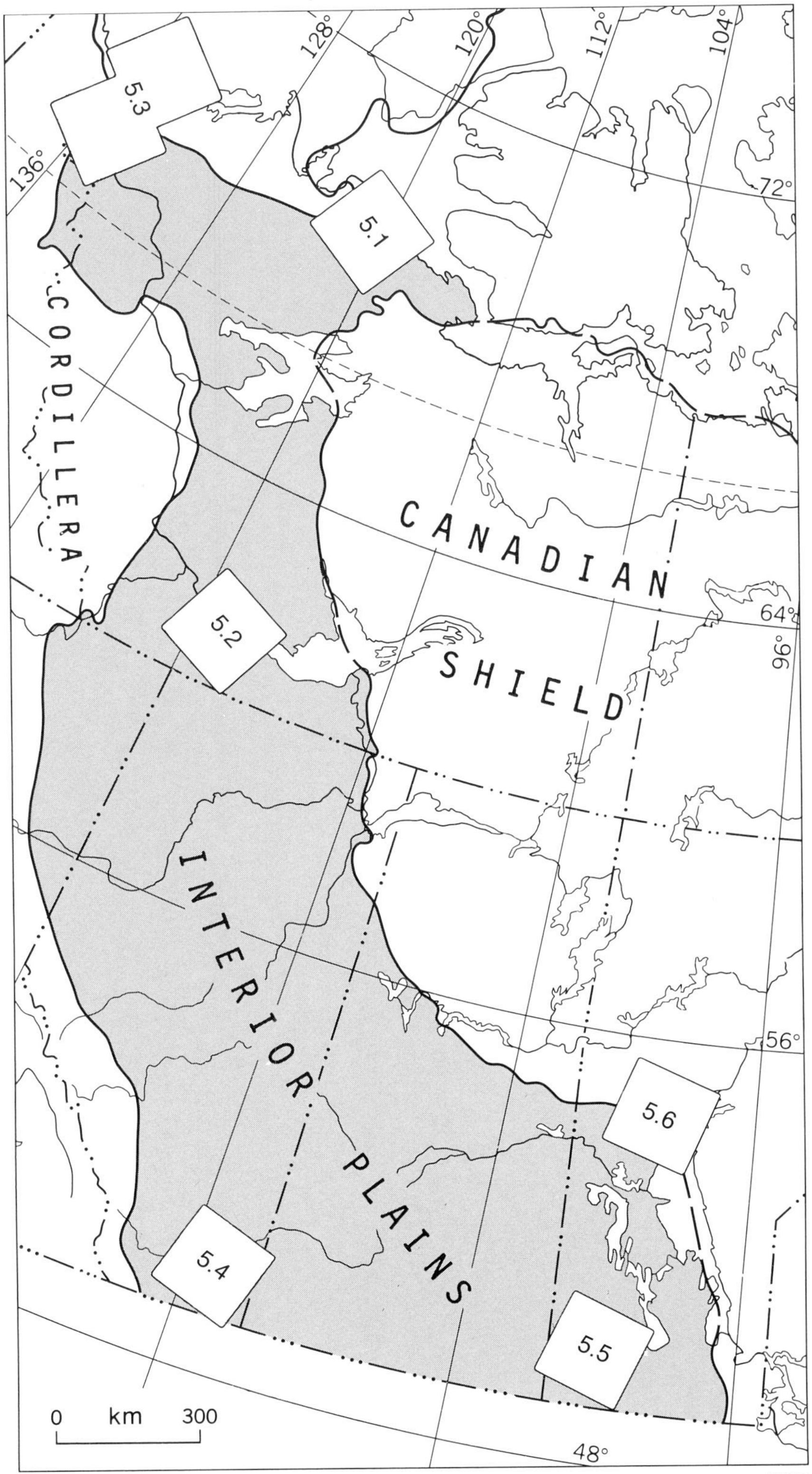
Figure 4.4 A

THE INTERIOR PLAINS

Section 5



5.1	Dolphin and Union Strait **R.J. Fulton**	5.4	Medicine Hat **D.A. St. Onge**
5.2	Fort Profidence, N.W.T. **N.W. Rutter**	5.5	Neepawa, Manitoba **R.W. Klassen**
5.3	Mackenzie Delta **V. Rampton**	5.6	Wekusko Lake **R.W. Klassen**

DOLPHIN AND UNION STRAIT

R.J. Fulton

This image (Fig. 5.1) is of particular interest because it represents an area that probably was not covered by the last Wisconsin ice advance. Many of the features seen on conventional air photos are visible here.

The area in the central part of the image (mainly terrain type II) appears to have stood out as a nunatak above the ice flows that passed from east to west along Dolphin and Union Strait, and northwards from the Great Bear Lake Basin (Fig. 5.1A). Drumlins and drumlinoid ridges are plainly visible paralleling Dolphin and Union Strait. Morainal ridges are known from aerial photographs to flank most of the central upland area. Some of these ridges are visible on the image and the presence of others can be inferred from the pattern of melt water channels.

Nine major terrain types can be recognized, sufficient to make a preliminary classification.

Type I	consists mainly of bare rock with a local colluvial or felsenmeer cover giving a distinctive light tone to the image.
Type II	is thought to consist mainly of rock with a vegetated, colluvial-residual mantle. Outcrops are limited to steep valley walls.
Type III	areas are largely underlain by till which probably varies in thickness. Small lakes and linear, hummocky features that appear to be of glacial origin are typical of this terrain.
Type IV	is thought to be predominantly thick till with low relief hummocky moraine interspersed with numerous lakes.
Type V	is characterized by relatively thin till containing few lakes but with striking linear features resulting from ice movement.
Type VI	consists largely of thick till marked by linear and hummocky features and many small lakes and abandoned channels.
Type VII	terrain is probably underlain by thick till which has been molded into roughly parallel drumlinoid ridges and includes numerous small lakes.
Type VIII	areas are vegetated floodplain, terrace, delta or fan deposit.
Type IX	areas are thought to be unvegetated (possibly deflated) fan terrace and floodplain deposits occurring at the mouths of or along streams.

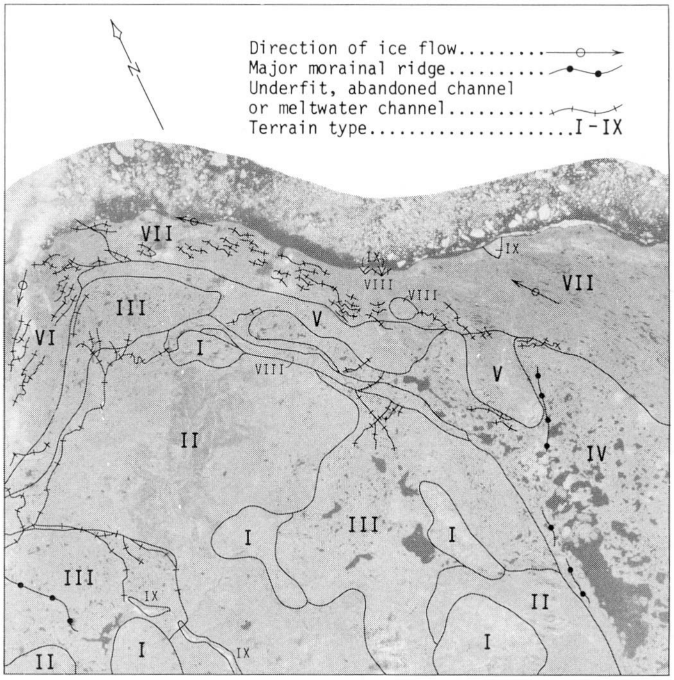


Figure 5.1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E 70
N7 65
N7 60
E 65
E50
N760
E60

Figure 5.1A

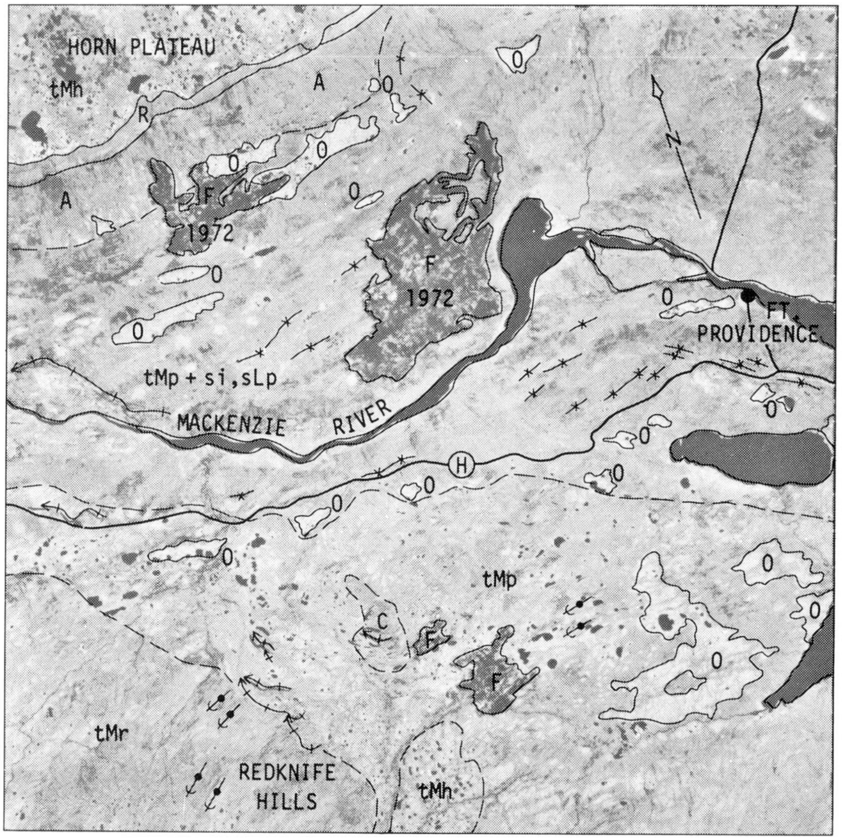
FORT PROVIDENCE, N.W.T.

N.W. Rutter[1]

The image (Fig. 5.2) includes the southern margin of the Horn Plateau, a section of the Mackenzie River, and the northern part of the Redknife Hills. The upland areas consist of Lower Cretaceous shale whereas the Mackenzie River valley is underlain by Upper Devonian carbonate and shale (Fig. 5.2A). The flutings and drumlinoid features, flowing in southwesterly direction, are clearly visible on parts of the image. These represent the last continental ice sheet which covered the entire area. During deglaciation, the ice retreated toward the northeast leaving a blanket of till and associated deposits on, and about the upland areas. Hummocky moraine, a result of stagnant ice, can be recognized by hundreds of small lakes in the summit area of the Horn plateau and east of the Redknife Hills. Till, with less local relief, forms a moraine plain south of the Mackenzie River. In the southwest part of the area there is ridged moraine, consisting mainly of till with parallel flutings and drumlinoid features. Abandoned meltwater channels that developed near the ice front as deglaciation took place are clearly visible, as are 'swarms' or parallel series of less extensive channels.

Towards the final stages of deglaciation, Glacial Lake McConnell formed in the lower part of the Mackenzie River valley. The presence of the former lake is suggested by a number of parallel beach ridges both north and south of the Mackenzie River. The highest beaches, about 850 feet in elevation, are in the vicinity of the Mackenzie Highway and mark the southern limit of the lake. On the north side of the river, beaches are less distinct, but the general configuration of the former lake can be detected by beaches that strike parallel to the river and then shift northward. In addition, the distribution of beaches at various elevations suggest that lake levels fluctuated. Deposits located in the area of beaches include beach gravel and sand, lacustrine silt and sand, and till.

A number of permanently frozen peat bogs are indicated by the light tones of Cladonia moss. Post-glacial alluvium can also be recognized near the Horn plateau by its drainage patterns. A fire in the summer of 1972 produced the dark toned areas north of Mackenzie River (F).



tMh	Till:	hummocky moraine	A	Alluvium: mostly reworked till
tMr	Till:	ridged moraine, flutings and drumlinoid features	R	Colluvium and bedrock
tMp	Till:	ground moraine plain, rolling	C	Area of abondoned meltwater channels
tMp + si,sLp		Undifferentiated till moraine plain and lacustrine silt and sand plain	O	Frozen peat palsas

Beach ridges.................................—x—x—
Abandoned meltwater channel.................—+—+→
Flutings and drumlinoid features indicating
assumed ice flow directions.................—●—)—
Mackenzie Highway...........................—(H)—
Moraine unit boundary.......................— — —

Figure 5.2

Reference

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[1] Present Address:

Department of Geology
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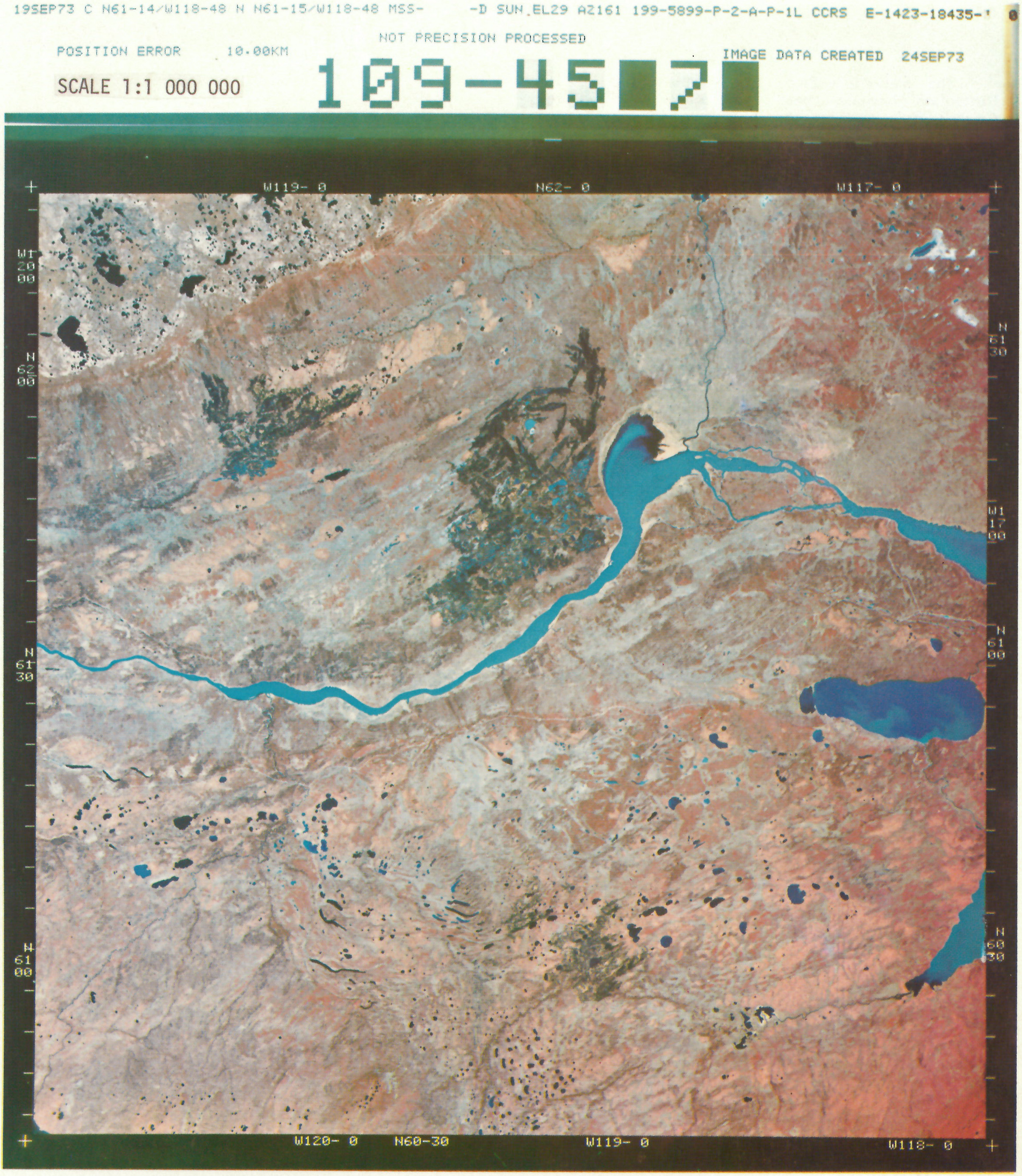
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Figure 5.2 A

5.3

MACKENZIE DELTA

V. Rampton[1]

The Mackenzie Delta, the northern end of the Richardson Mountains, west of the Mackenzie River, the Caribou Hills east of the Mackenzie River, and the Pleistocene Coastal Plain consisting of Richards Island and Tuktoyaktuk Peninsula are the outstanding physiographic features of this mosaic (Fig. 5.3). The very different morphologies of these units are quite obvious: sharp crested ridges and mountains in the Richardson Mountains; smooth slopes of the Caribou Hills; the channel and lake covered surface of the Mackenzie Delta; and the Pleistocene Coastal Plain with its large number of lakes, many of which are oriented.

This imagery presents a pleasant overview of the physiographic units, but adds nothing that cannot be obtained from a study of conventional airphoto mosaics or topographic maps.

The clear outline of the Mackenzie River sediment plume in Mackenzie Bay, and the striking difference in the zone of sediment-laden water flowing through the Mackenzie Delta and of water in lakes and channels having no in-flow are obvious on the mosaic and indicates the usefulness of Landsat imagery for studies of modern hydrology and sedimentary processes in the fluvial deltaic, marine, and lacustrine environments. With Landsat, comparisons of the Mackenzie River sediment plume can be made both at different times throughout the year and from year to year and the number of lakes subjected to in-flow on the delta can be compared over the years. The image is also of some value in tracing breakup and freeze-over of different water bodies.

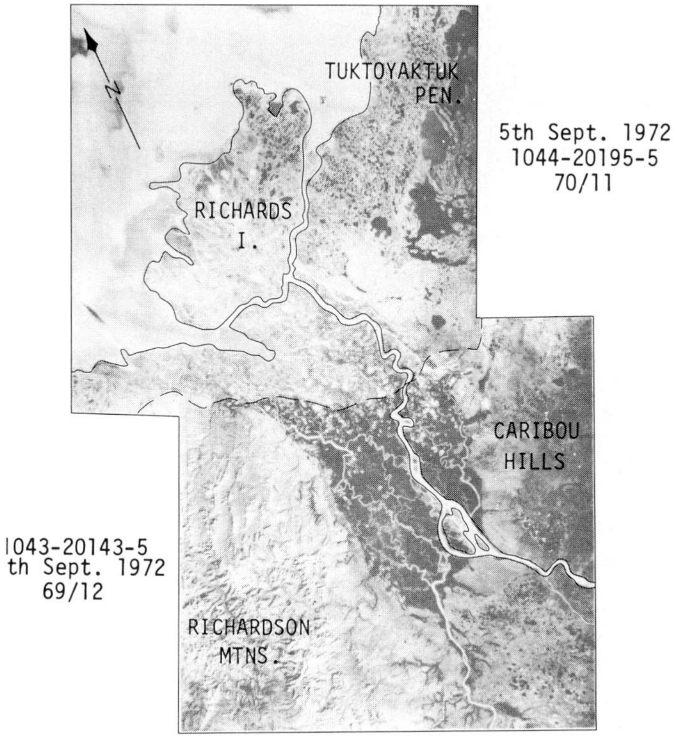

Figure 5.3

Reference

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[1] Present Address:

President, Terrain Mapping Services Ltd.
P.O. Box 756
106 Carp Road
Stittsville, Ontario

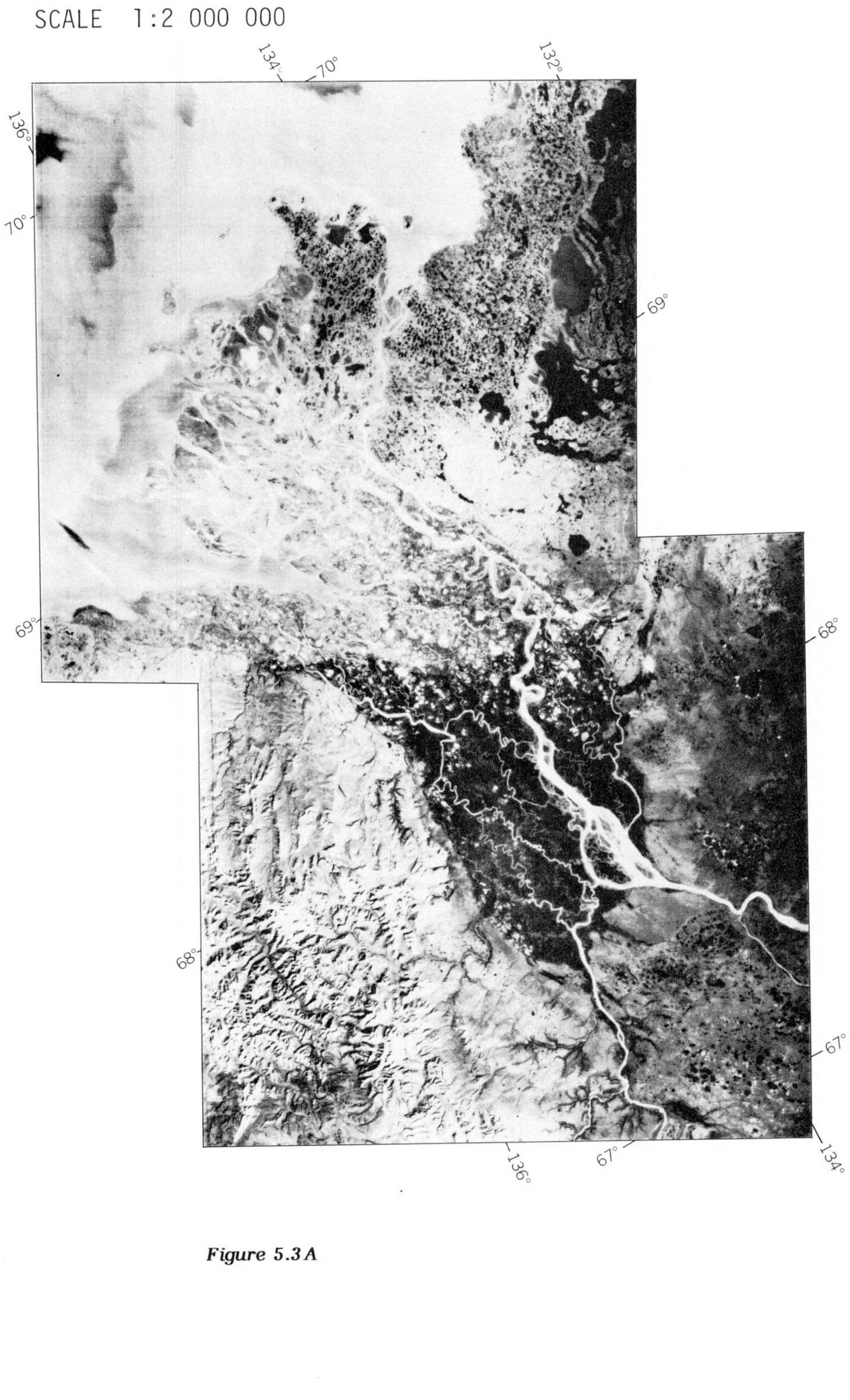

Figure 5.3 A

5.4

MEDICINE HAT

D.A. St. Onge[1]

This image (Fig. 5.4) is a typical example of the semi-arid Interior Plain of central Canada. The area represented by the image is underlain by gently dipping sandstone, clay and shale of Cretaceous age. The wooded Cypress Hills which barely extend into the southeastern quadrant of the image, are composed of Quaternary sands and gravels, and rise 500 m above the general level of the plain. Two major rivers cross the plain: in the northwest, the Red Deer River, and in the centre of the image, the South Saskatchewan River (Fig. 5.4A). The many pale blue lakes, often with white fringes, are salt encrusted alkali flats.

Two types of land use dominate the region. Ranching is the major activity in the light soils along the South Saskatchewan River north of Medicine Hat, in areas of thin drift and in areas of pronounced morainic topography around the Cypress Hills. Most of the rest of the region is a classic example of strip farming with north-south elongated fields. Wheat is the main crop usually alternating with periods of fallow, which explains the contrasting tones within the field pattern. In the upper centre of the image the Suffield military training camp introduces a land use type quite unrelated to the rest of the region.

Hummocky moraine is a typical feature of the landscape that does not stand out on the image, presumably because of its moderate (20-40 m) relief, and the relatively high (35°) sun angle.

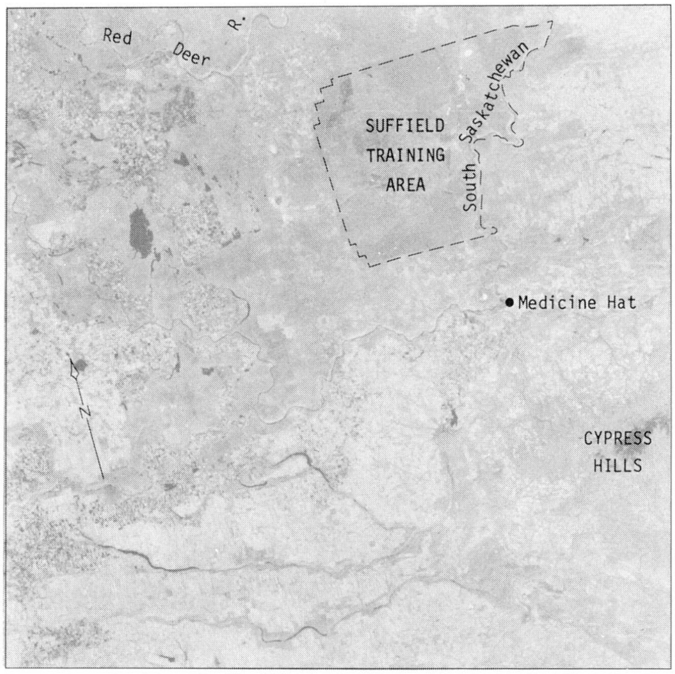

Figure 5.4

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Williams, M.Y. and Dyers, W.S.
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[1] Present Address:

Department of Geography and Regional Planning
University of Ottawa
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K1N 6N5

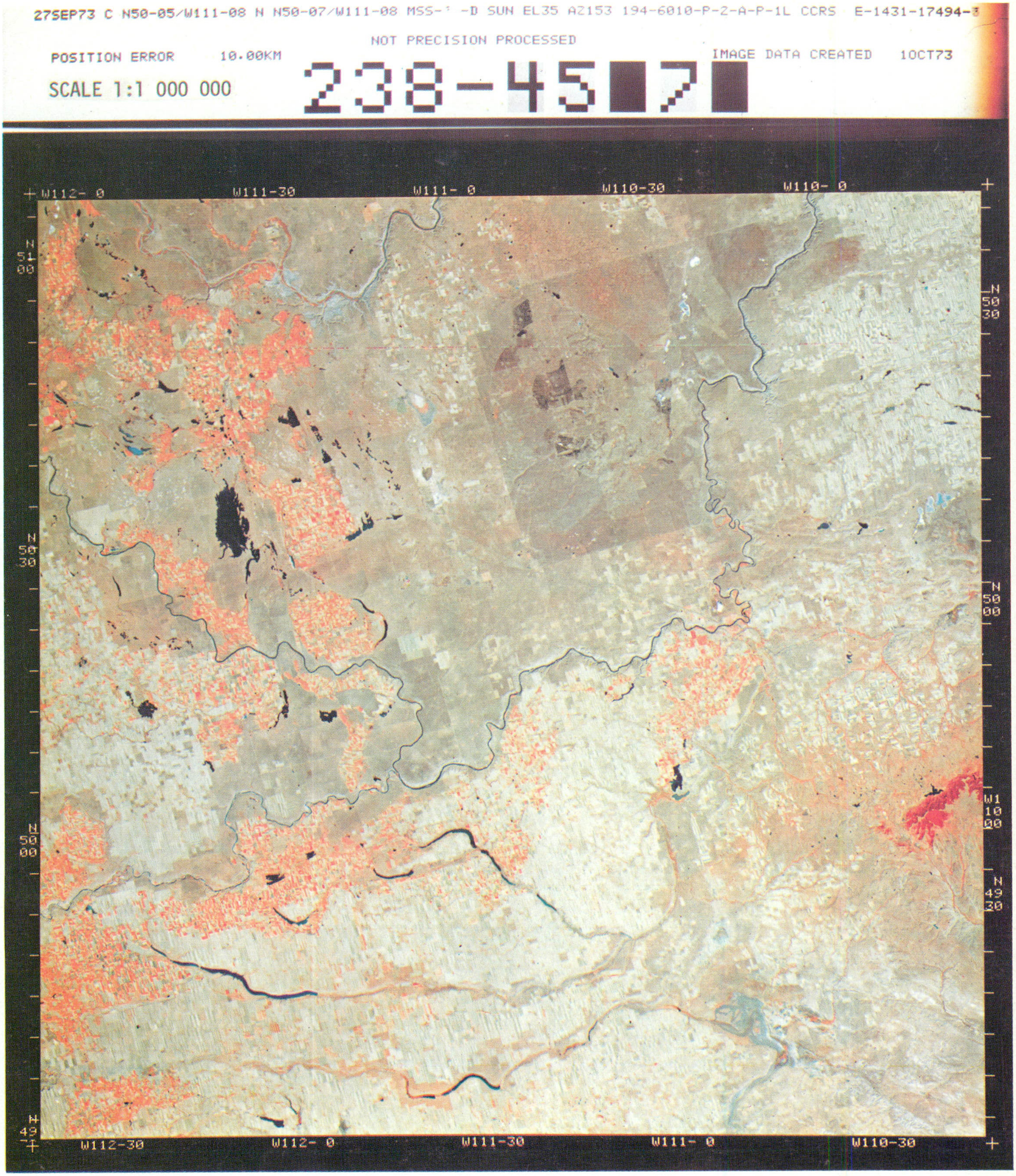
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Figure 5.4A

5.5

NEEPAWA, MANITOBA

R.W. Klassen

The image (Fig. 5.5) covers part of the Manitoba Plain (area 1) and the Saskatchewan Plain (areas 2 to 5, Fig. 5.5A). These are major physiographic divisions within the southern Interior Plains Region. The boundary between these divisions, marked by the Manitoba Escarpment, is coincident in part with an abandoned beach.

Area 1 is a low relief, water-eroded plain consisting of thin till over carbonate bedrock. Northwest-southeast-trending broad glacial grooves characterize most of the area. Much of the northeastern part is poorly drained. Organic deposits are represented by very dark grey to black elongated patches. The light toned areas separating these patches represent better drained till ridges. The cultivation pattern (1a) is a free-draining veneer of clay and sand over till.

Area 2 includes extensive, low relief till plains with a distinctive cultivation pattern. The prominent drainage network consists mainly of trench-shaped valleys that formed as glacial lake spillways and meltwater channels.

Area 3 is an upland characterized by widespread, uniformly textured, light grey to grey tones and numerous, small, irregular lakes in the southern part. Except for the southern margin, the area is cultivated and covered by a mixed wood forest. The surficial deposits are mainly thick till with extensive patches and belts of clay, silt, sand, and gravel. The underlying shale bedrock is frequently exposed along the escarpment. In the southern half of the area, the terrain is hummocky and lakes occupy the depressions.

Area 4, an ancient delta of the Assiniboine River, is roughly outlined on this image by mottled light grey tones representing the combined effects of vegetation (mainly a parkland type tree cover) and surficial deposits (silt and sand). A cultivation pattern is lacking. Glacial Lake Agassiz, in which the delta formed, also left numerous beaches along the delta front and beyond it.

Area 5 is Lake Souris, a glacial lake basin, that can be identified on the basis of the same criteria as area 4. Small light-toned patches with subdued cultivation patterns are areas of water-eroded till (5a) and outwash sand and gravel (5b).

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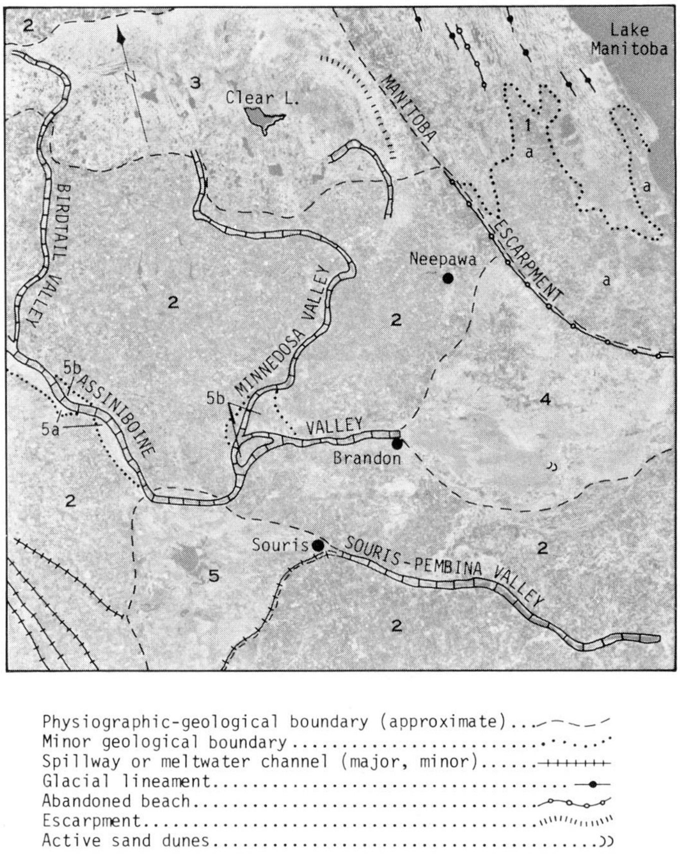

Figure 5.5

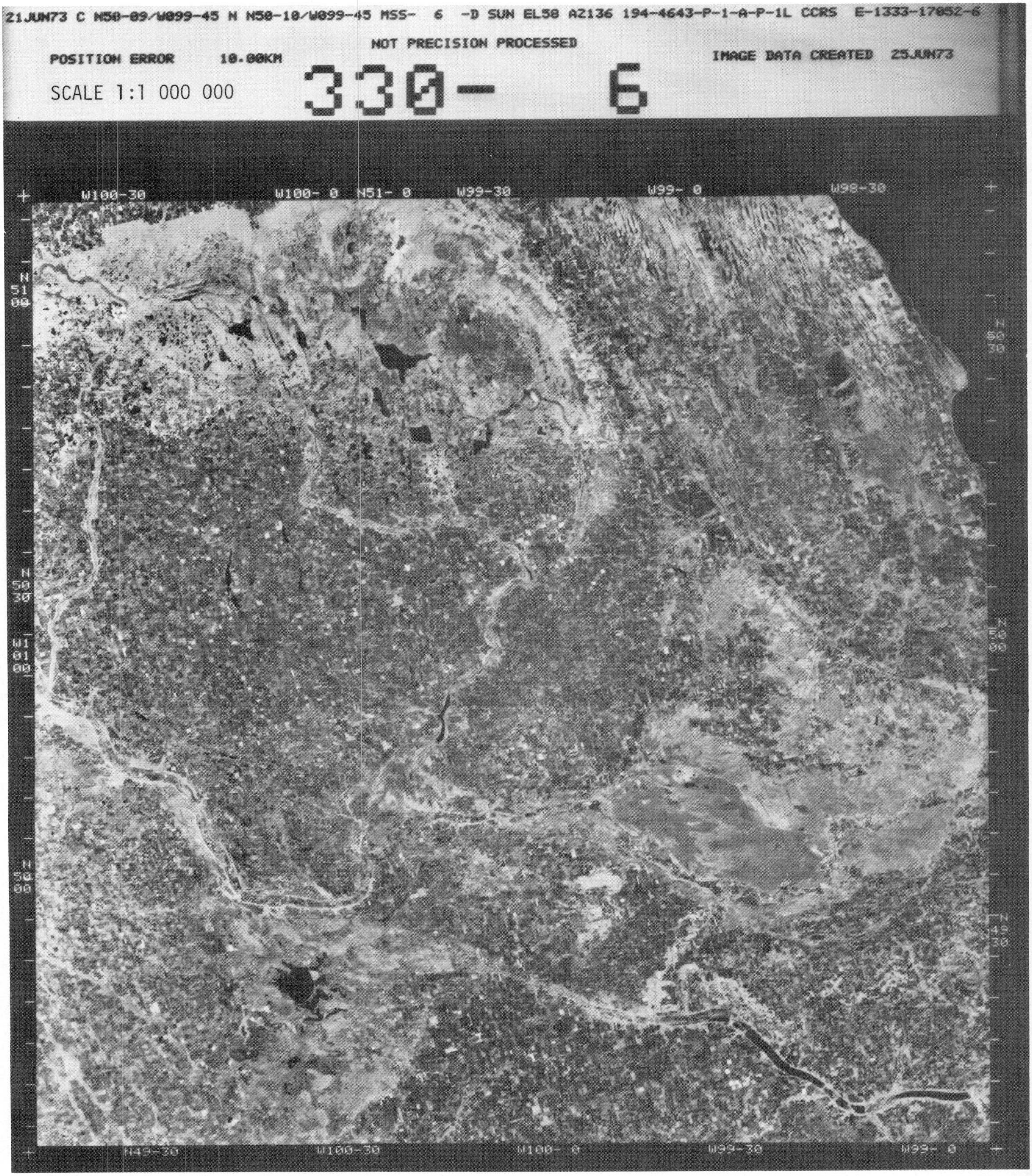
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Figure 5.5A

5.6

WEKUSKO LAKE

R.W. Klassen

The image area is located at the northern end of Lake Winnipeg, Manitoba (Fig. 5.6). The edge of the Precambrian Shield crosses the centre of the image. The junction of the Churchill and Superior structural provinces also lies in this area although it is obscured by surficial material. The region can be separated into four areas that reflect the geology, physiology and vegetation (Fig. 5.6A).

In Area 1, Precambrian Shield rocks of the Churchill Structural Province form knolls, ridges and depressions with some 50 feet or less local relief. The structural trend of the rocks is strongly marked by numerous parallel linears and by the elongate form of the many lakes. Drift (clay and till) is thin and patchy and mainly restricted to depressions. Dark patches on the image indicate a closed tree cover and the lighter tones a scattered tree cover on knolls and ridges or grassy fens in the depressions.

Area 2, in the northeastern part of the image, is underlain by Precambrian rocks of the Superior Structural Province. The drift cover of lacustrine clay with some till and sand is thicker and more extensive than in area 1. Knolls and ridges of bedrock occur but the rock surfaces are not as extensively exposed and the local relief is somewhat lower. Linear features are very sparse except at the margins of lakes.

Area 3 is flat to rolling countryside underlain by carbonate rocks of Paleozoic age. The carbonate rocks have a thin cover of rubble, clay and till. The dark toned areas in the southern part of area 3 indicate a heavy tree cover. The mosaic of light and dark tones in the northwestern part of area 3 shows that the tree cover here is broken, possibly because the topography forms an irregular series of broad ridges. The carbonate rock terrane terminates in discontinuous low bluffs along its eastern boundary. Morainic ridges oriented in a northeast-southwest direction are faintly discernible in the northern portion of area 3.

Area 4 represents a zone of lacustrine clay – evidently a former extension of Lake Winnipeg – overlain by bog (dark tones) and fen (light tones). Abandoned beaches associated with local sandy areas appear as dark lines in the southeast near Lake Winnipeg.

Lighter toned areas (a-e), commonly with flame-like boundaries crossing regional structures, are the result of forest fires. The most recent of these is area 'a' located on the low relief carbonate terrain.

Most minor landforms of glacial origin that are readily identified on photomosaics (1:125 000) do not appear on this image.

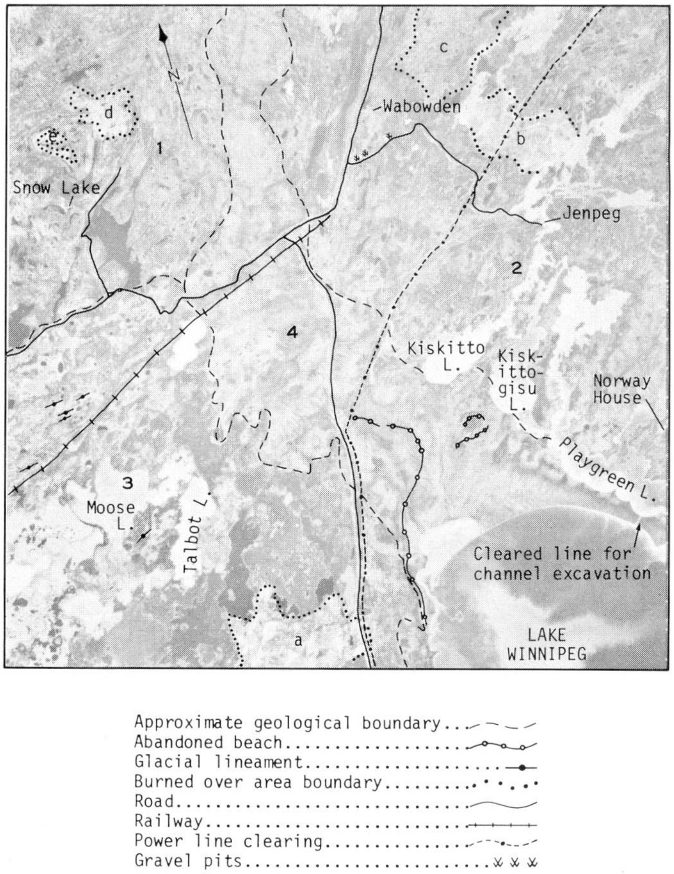

Figure 5.6

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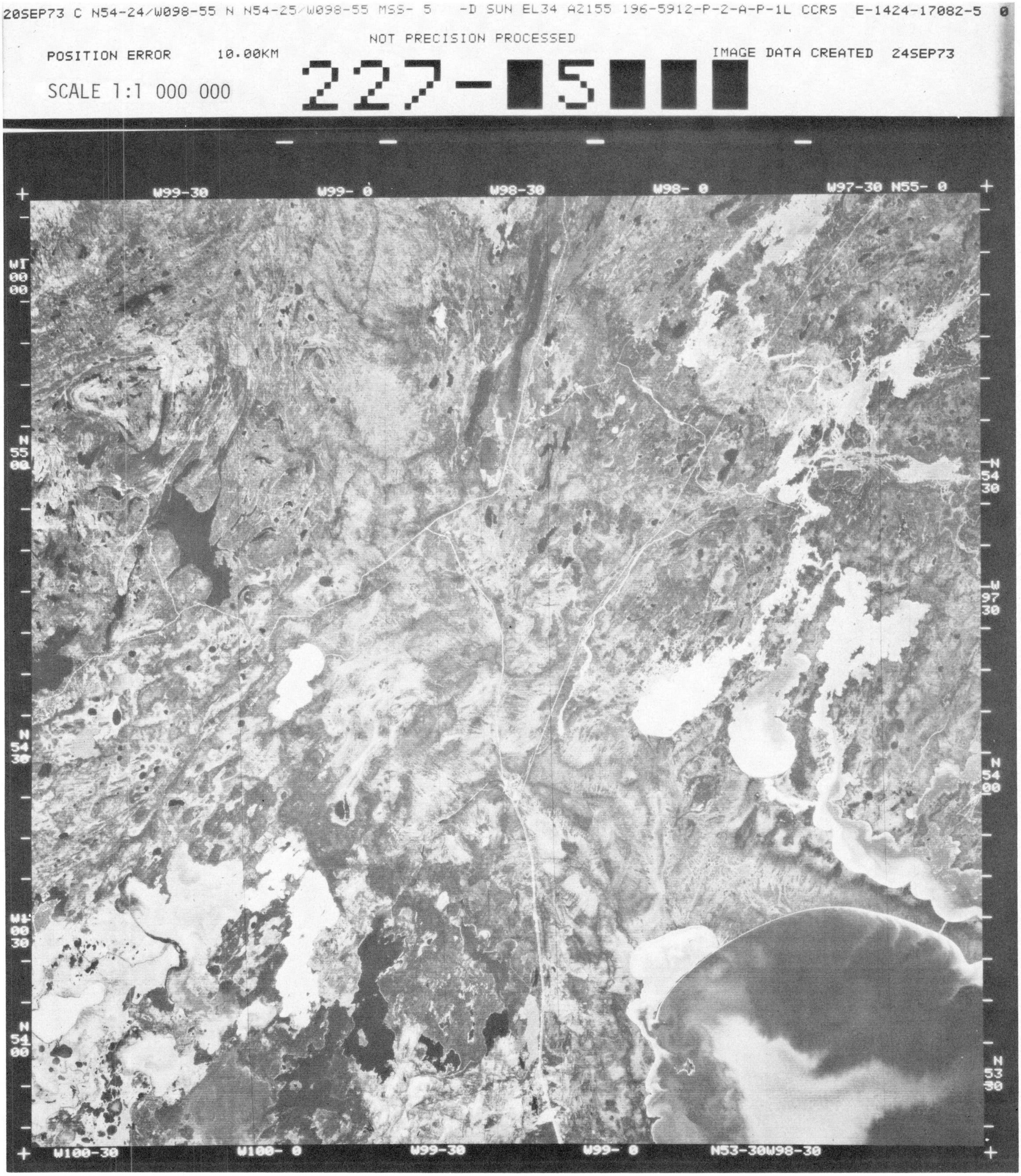
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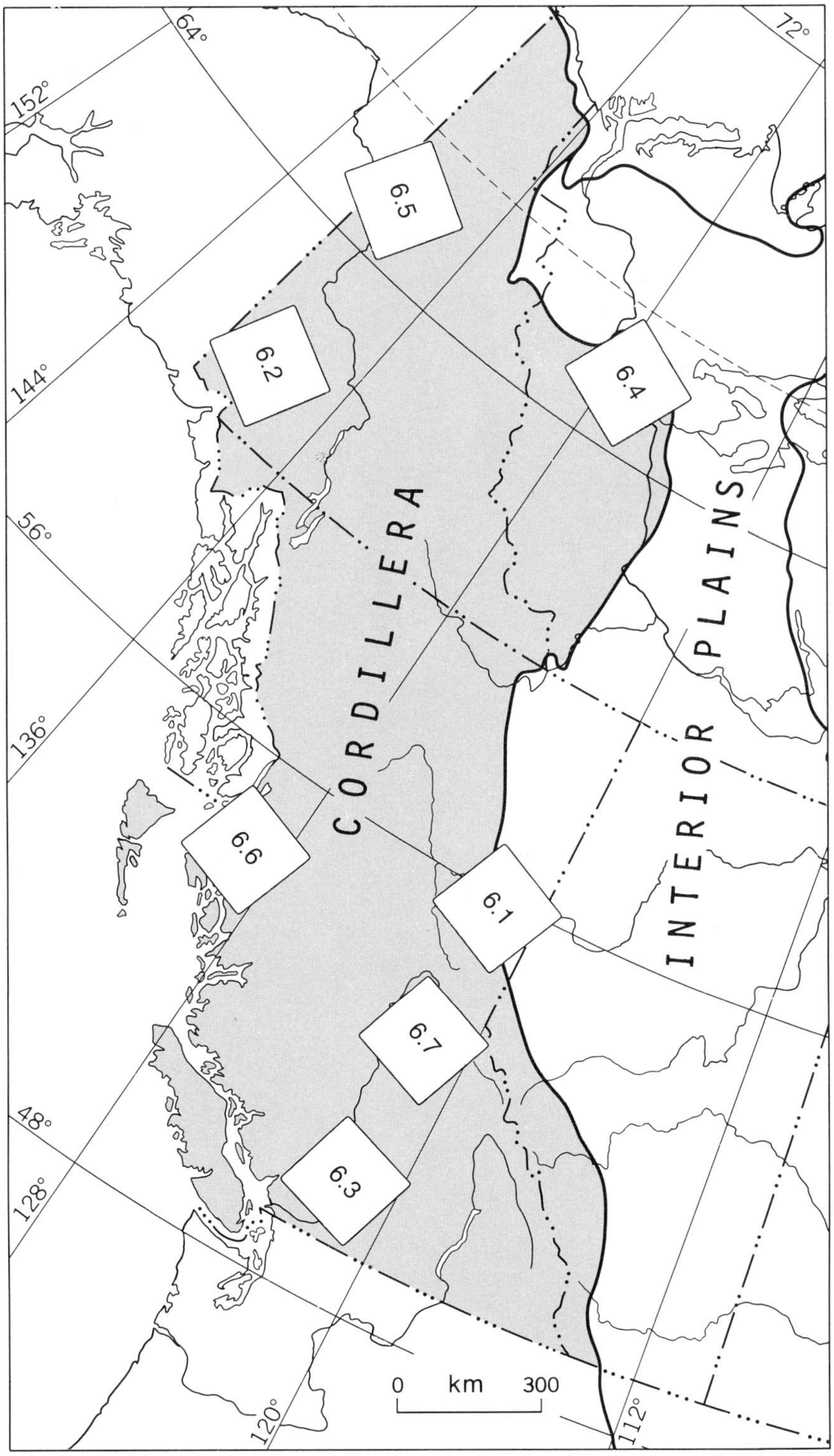
Figure 5.6 A

THE CORDILLERAN REGION

Section 6



6.1 Fort St. John
G.C. Taylor

6.2 Kluane Lake, Yukon
R.B. Campbell

6.3 Lytton
J.W.H. Monger

6.4 Part of Northern Mackenzie and Franklin Mountains, District of Mackenzie
D.G. Cook

6.5 Ogilvie River
D.K. Norris

6.6 Prince Rupert – Terrace
J.A. Roddick

6.7 Quesnel Lake
R.B. Campbell

6.1

FORT ST. JOHN

G.C. Taylor

This remarkable image (Fig. 6.1) spans the complete width of the Rocky Mountains and Foothills at the narrowest point of that lengthy mountain system. The prominent Murray fault is clearly visible separating the Main Ranges from Front Ranges (Fig. 6.1A). Underlying structural control of the topography is obvious. The prominent scarp bounding the Foothills and Great Plains is an expression of the upper Cretaceous sandstone of the Smoky Group.

Much of the fine structural detail is identifiable to the geologist experienced in the area, although little is immediately obvious to the casual or uninformed observer. The eye may catch a peculiar crudely circular drainage pattern in the south-southwest portion of the image near the Foothills – Front Ranges boundary. This appears to be an accident of drainage as the local geology has no specific expression reflecting the circular pattern.

Two cultural features are evident on the west side of the image: Wollaston Lake formed behind the Bennett Dam, and the transmission power-line right-of-way extending from the dam-site through the Pine Pass en route to Vancouver.

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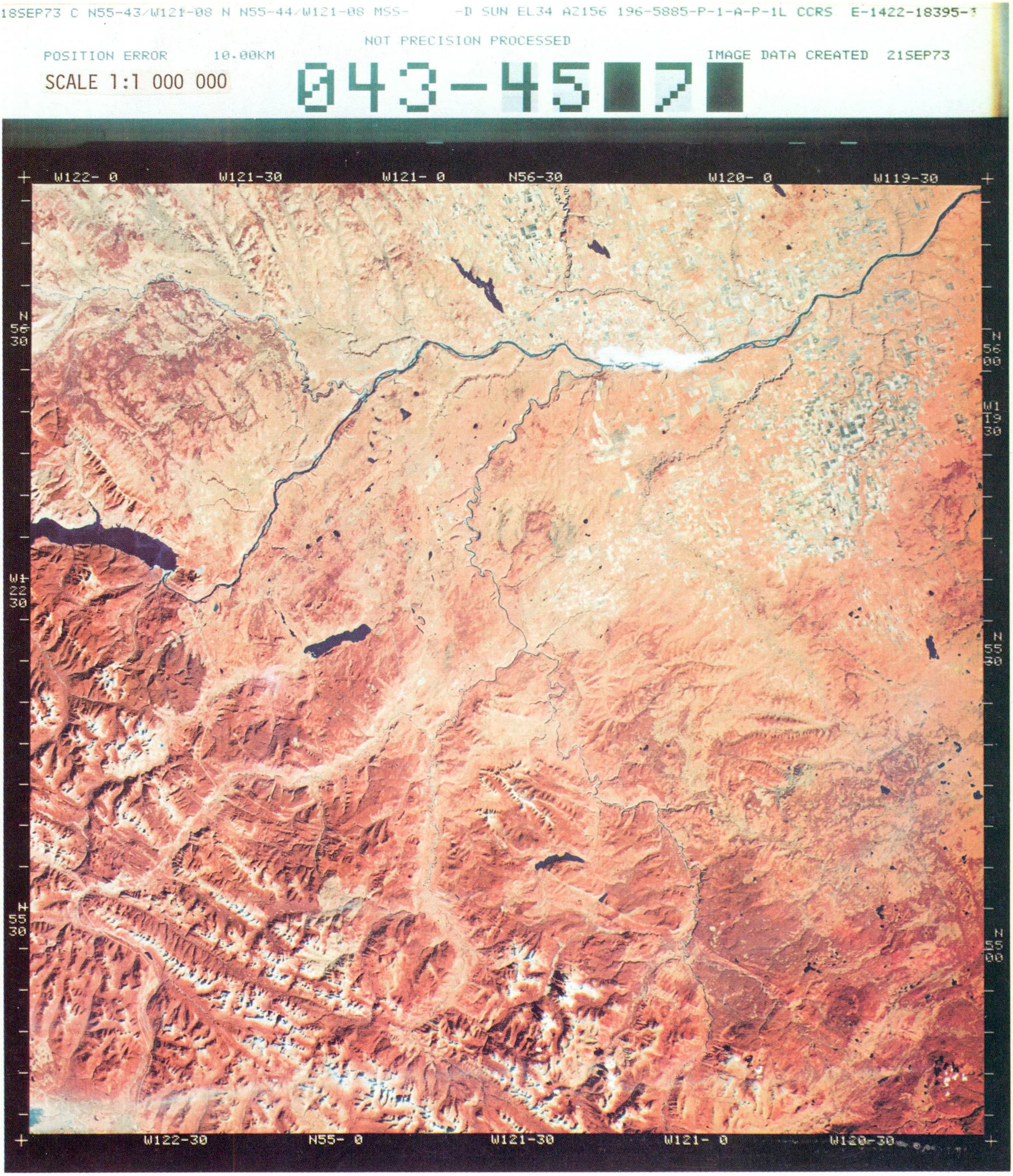
Figure 6.1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W120-30

Figure 6.1A

6.2

KLUANE LAKE, YUKON

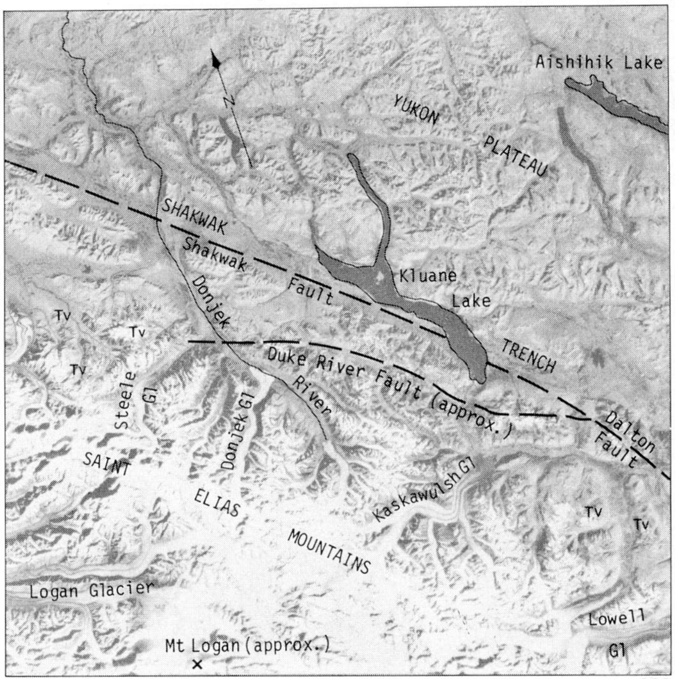
R.B. Campbell

Kluane Lake, prominent in the centre of the image, lies partly in a segment of the Shakwak Trench (Fig. 6.2). This northwesterly trending trench separates the Saint Elias Mountains with its great ice fields and distributary glaciers to the southwest, from the more topographically subdued and partly unglaciated, dissected Yukon Plateau to the northeast. Ice of the last Pleistocene glaciation flowed out of the main valley of the mountains into the trench but did not reach far into the plateau. The glacial limit is not readily apparent in the image.

Northwest from the southern end of Kluane Lake the trench marks the site of the Shakwak Fault, a segment of the Denali fault system (Fig. 6.2A). South of the lake, the fault diverges from the trench and can be traced for about 100 km to the southeast through the Saint Elias Mountains, where it is called the Dalton Fault. The trace of the Dalton Fault is not obvious on this or other images, although it is marked locally by short, straight valleys. Equally obscure is the trace of the Duke River Fault in the mountains between Kluane Lake and Donjek River.

Prominently layered, flat lying, tertiary volcanic rocks (Tv) cannot be distinguished from older sedimentary, volcanic and plutonic rocks in the Saint Elias Mountains or from metamorphic and plutonic rocks in the Yukon Plateau.

The Alaska Highway is barely visible in a few places in the Shakwak Trench.



GSC

Figure 6.2

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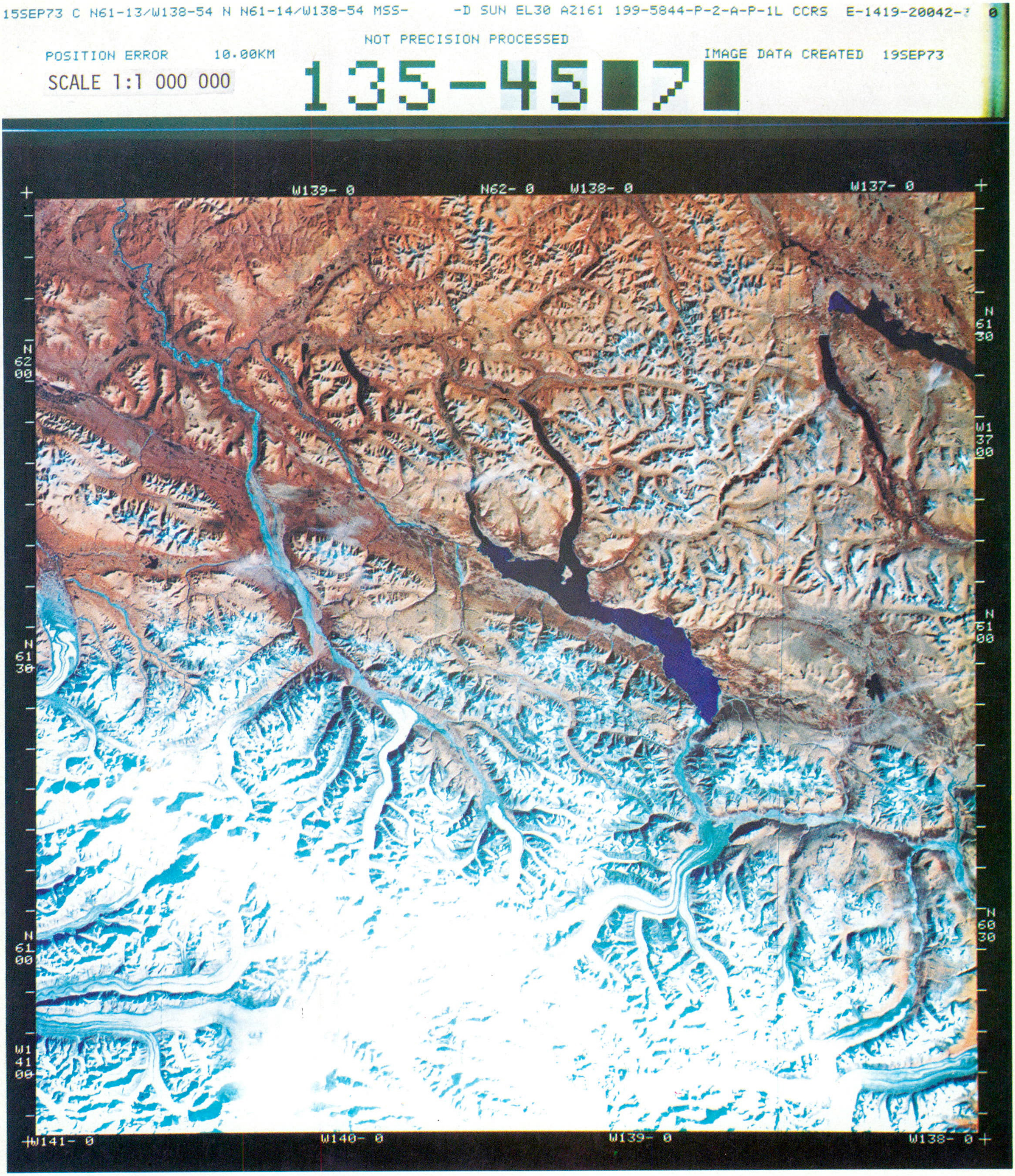
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W138- 0

Figure 6.2 A

6.3

LYTTON

J.W.H. Monger

The image spans two of the major geological and physiographic features of the Canadian Cordillera (Fig. 6.3, 6.3A). The southwestern half is underlain by the rugged terrain of the predominantly granitic and high-grade metamorphic Coast and Cascade Mountains, whereas the more subdued topography of the Interior Plateau in the northeastern half is underlain by Mesozoic and lower Tertiary volcanic and sedimentary rocks cut by granitic plutons.

A major feature is the largely fault-controlled Fraser River valley, that runs north-northeasterly across the image. In the north, this feature forms the geological and physiographic boundary between the Coast Mountains and the Interior Plateau. South of the confluence of the Thompson and Fraser rivers, it is the somewhat arbitrary boundary between Coast and Cascade mountains. The fault-lines of the Fraser fault system are visible on both sides of the valley near the southern margin of the image.

In the Coast Mountains the deep glacially formed valleys are apparent. Most of these seem to show little relationship to bedrock, the exceptions being the northwesterly trending valley containing Harrison Lake, which is a fault zone, and possibly the subparallel valley branching north-northwest from Harrison Lake, to Duffy Lake that is approximately on trend with the fault zone passing through Bralorne gold camp.

Little bedrock control is apparent in the Interior Plateau. An exception is the northerly to north-northeasterly trending grain south of Nicola Lake produced by partly faulted, Lower Tertiary sedimentary basins on Upper Triassic volcanic rocks.

Traces of several important open-pit copper mines can be seen in the Highland Valley, located northwest of Nicola Lake.

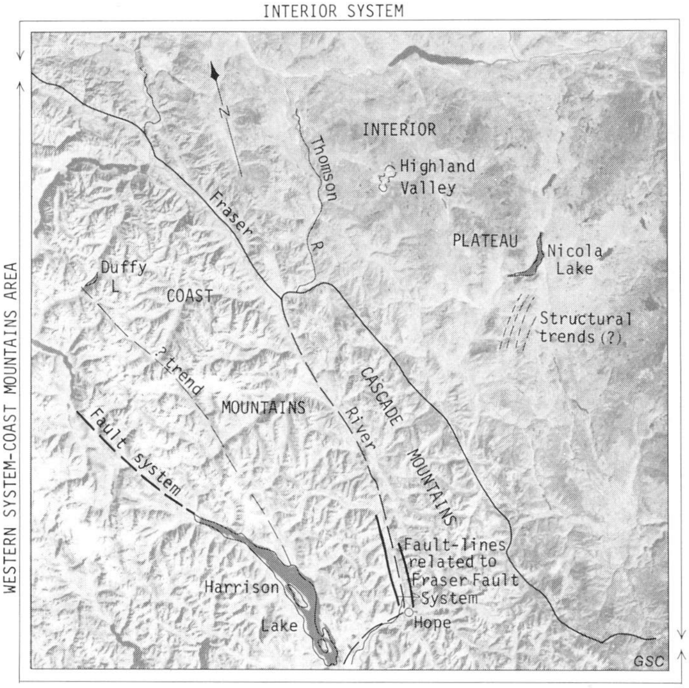

Figure 6.3

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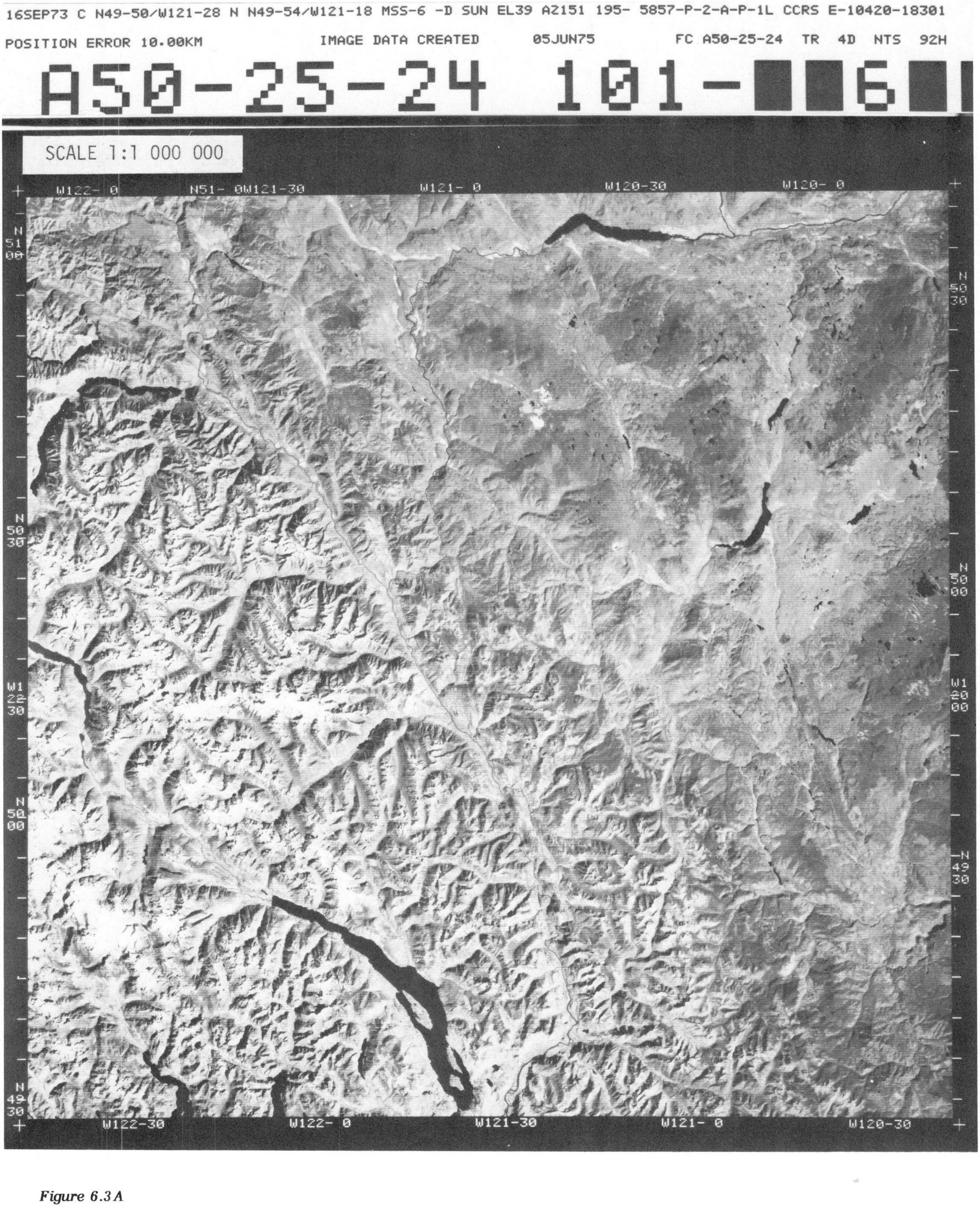
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Figure 6.3A

6.4

PART OF NORTHERN MACKENZIE AND FRANKLIN MOUNTAINS, DISTRICT OF MACKENZIE, NORTHWEST TERRITORIES

D.G. Cook

This image (Fig. 6.4) shows part of the northern Mackenzie Mountains and a large part of the northern Franklin Mountains. The annotated reduced image will aid in locating features discussed below.

The most striking geologic feature identifiable is a sharp contact between Proterozoic quartzite (which appears black on band 7) and Paleozoic carbonate and shale (which appear light grey). This excellent structural marker outlines the broad anticlines and relatively tight synclines characteristic of the northern Mackenzie Mountains (Aitken and Cook, 1974). Aitken and Cook (ibid.) have mapped, in part of the area shown, seven subdivisions of the Proterozoic rocks and sixteen subdivisions of Paleozoic and Mesozoic rocks. Although upper units in the Proterozoic rocks can locally be seen, no meaningful subdivision can be made on the Landsat image. Similarly, no differentiation of Paleozoic or Mesozoic units is possible on the Landsat image.

Other prominent features identifiable on the photo are the Mackenzie Mountain Front, and structural trends in the Franklin Mountains. Identifiable steep escarpments reveal the monoclinal nature of most ridges in the Franklins.

A small doubly plunging syncline is detectable just north of the Mackenzie Mountain Front whereas, surprisingly, a larger adjacent structure, Imperial Anticline has virtually no expression.

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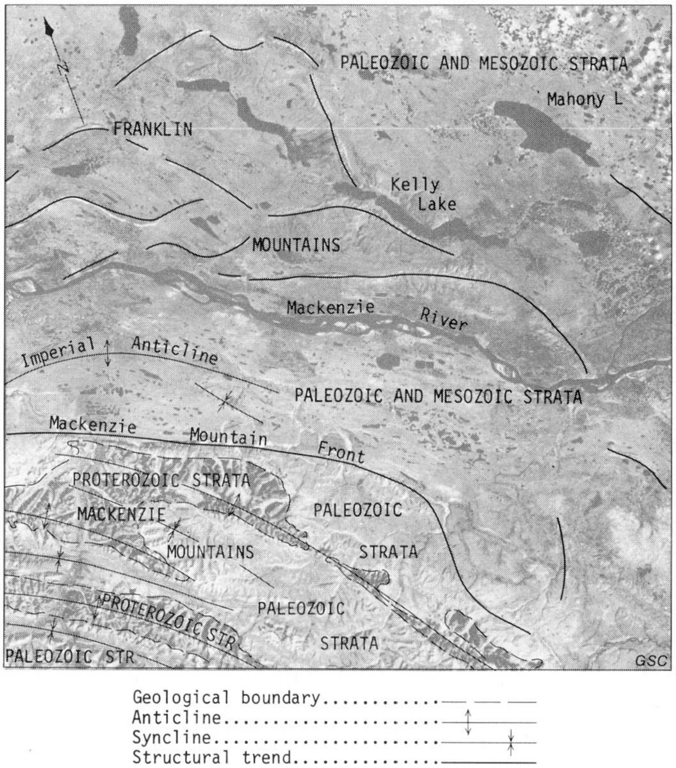
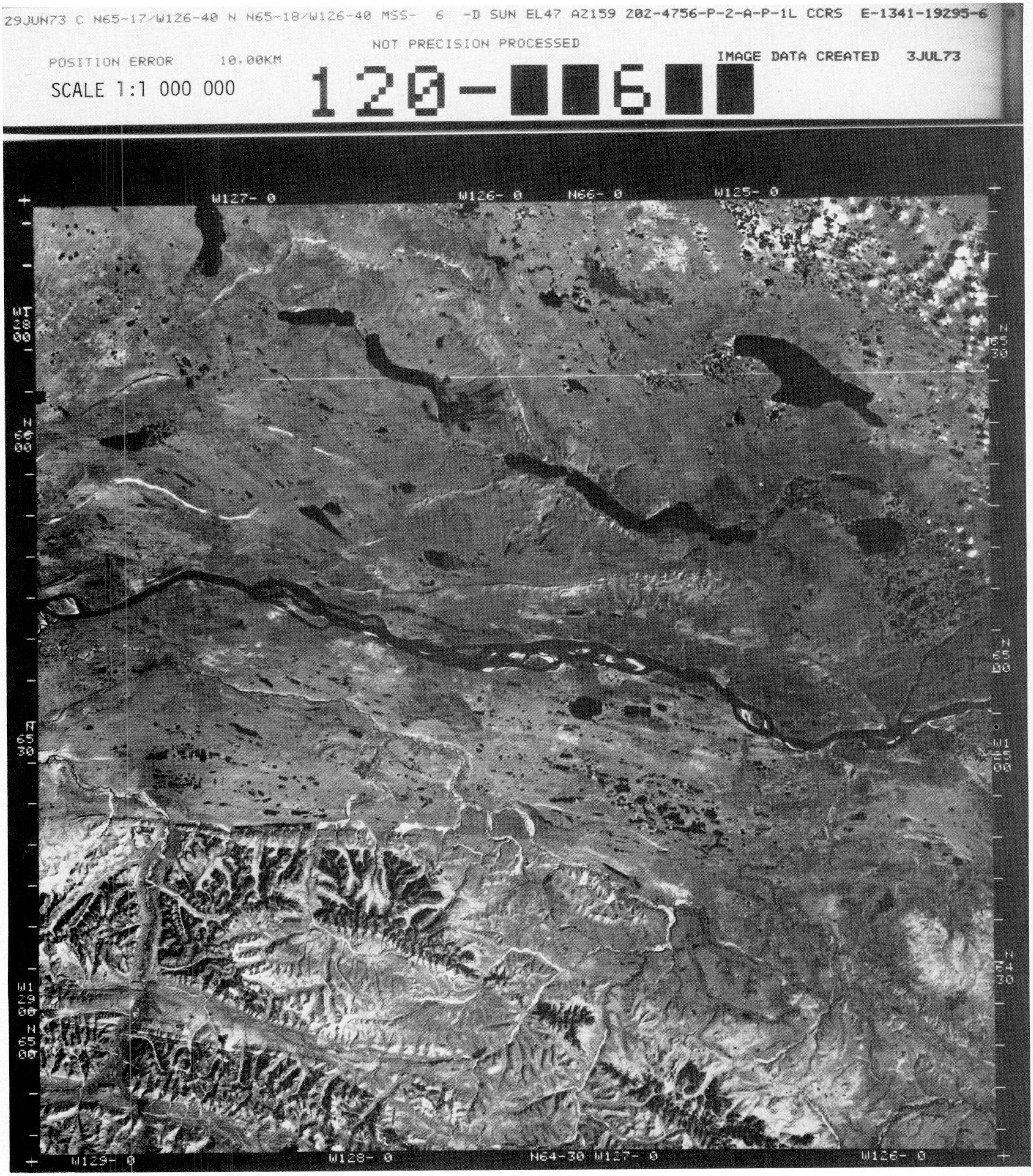


Figure 6.4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W126- 0

Figure 6.4A

6.5

OGILVIE RIVER

D.K. Norris

This image (Fig. 6.5) covers part of the Cordilleran Orogenic System between Yukon Territory and Alaska. Within it are two principal subdivisions of the Columbian Orogen, separated by the Tintina Trench (Fig. 6.5A). Northeast of the Trench is part of the Northern Yukon Tectonic Complex, a miogeoclinal, layered sedimentary sequence at the headwaters of the Ogilvie River. Southwest of the Trench is the Yukon Crystalline Platform.

The Northern Yukon Tectonic Complex contains four elements; Eagle Depression, Taiga-Nahoni Fold Belt, Ogilvie Fold Belt, and Kandik Basin. The structural grain of the orogenic system changes abruptly from west to north around the re-entrant called the Ogilvie Deflection. Eagle Depression lies at the nose of the deflection and is characterized by north-trending folds in the Upper Cretaceous clastic rocks. Flanking it on both sides is the Taiga-Nahoni Fold Belt comprising Proterozoic through Lower Cretaceous clastics and carbonates. The left-hand en echelon fold system plunging westward into the axis of the Ogilvie Deflection is revealed by resistant Middle Devonian limestone of the Taiga Ranges. This west-trending structural grain persists in the clastics and carbonates of the Ogilvie Fold Belt but, like the arcuate grain of the Lower Cretaceous and older rocks of the Kandik Basin, it is truncated against the Tintina Trench.

The Trench marks a major, northwest-trending fault zone, intermittently active at least since Early Paleozoic time and with a net right-lateral displacement estimated to be between 220 and 260 miles. Southwest of it are the metamorphic and igneous rocks of the Yukon Crystalline Platform in the core of the Columbian Orogen.

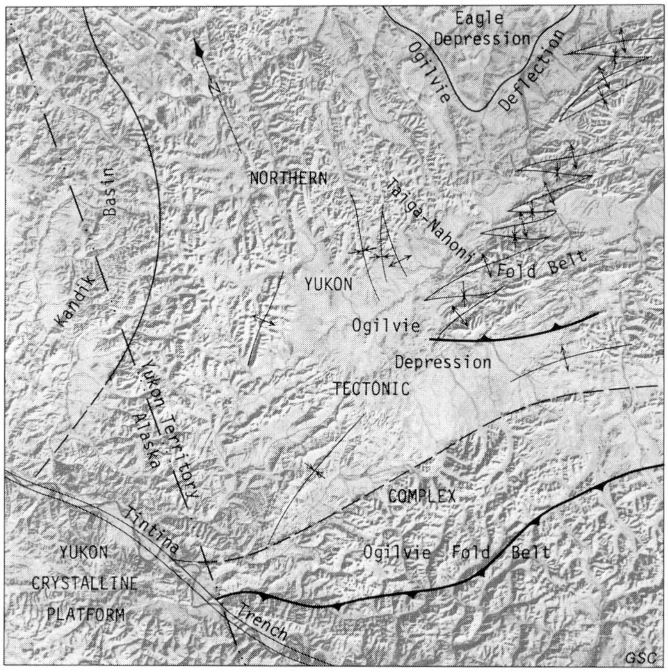

Figure 6.5

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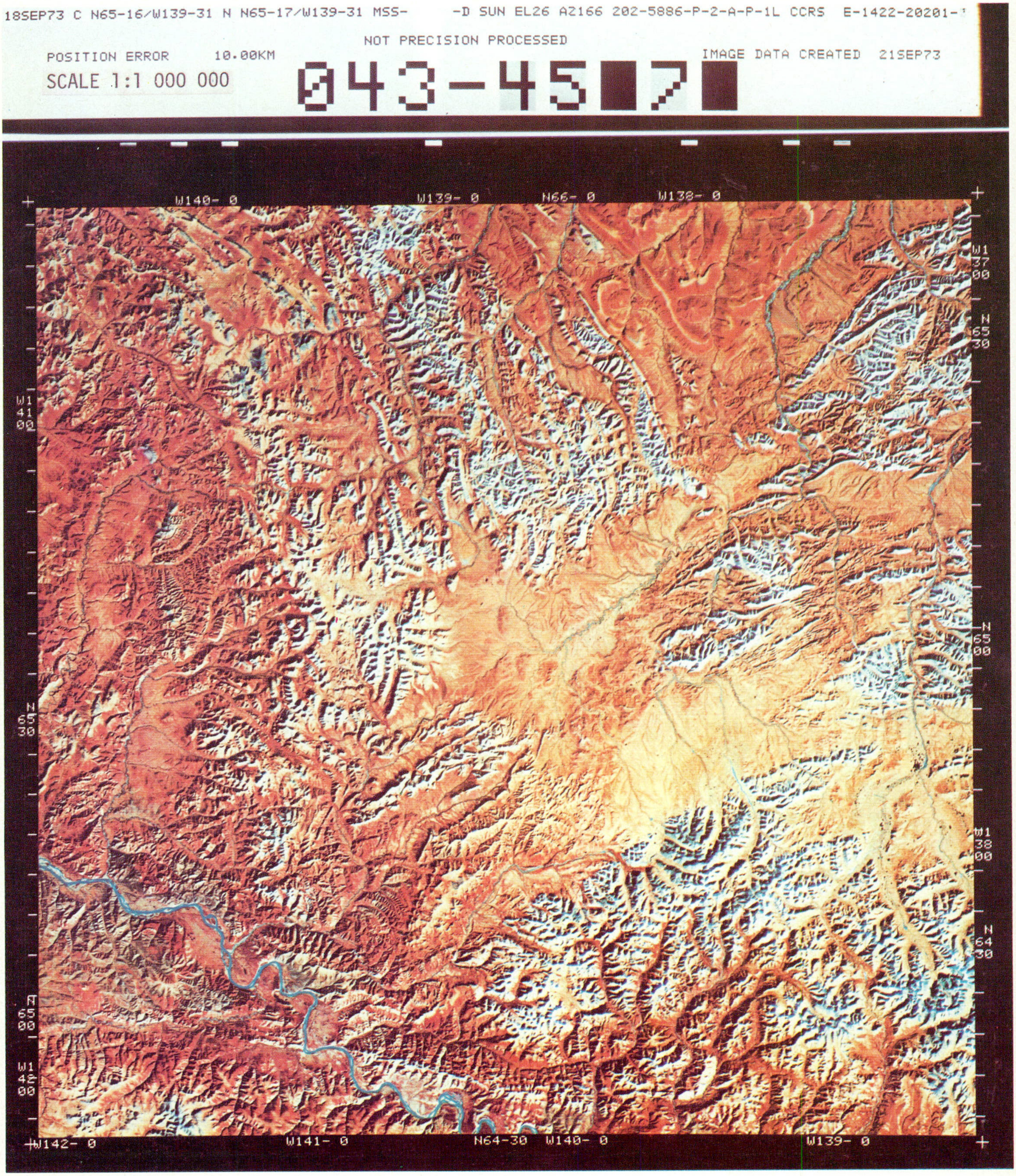
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Figure 6.5A

6.6

PRINCE RUPERT – TERRACE

J.A. Roddick

The image (Fig. 6.6) spans practically the entire width of the Coast Mountains in the region of latitude 55°N. The broad valley extending north from Kitimat at the upper end of Douglas Channel to beyond Kitsumkalum Lake contains Pleistocene marine clays which show that it was formerly an extension of Douglas Channel (Fig. 6.6A). This deeply penetrating fiord was probably intersected by another which occupied the present valley of Skeena River, and thus formed a large triangular island bounded on the southwest by Grenville Channel or possibly by another fiord along the line of Ecstall River.

Shearing along Grenville and Work channels indicates that they mark the loci of major faults. Hummocky lowland on the coast south of Port Simpson, on Digby, McCauley and Banks islands forms part of an old erosion surface, possibly wave-cut, which appears in many places along the Insular Trough (the 'Inland Passage' route of coastal freighters).

The lower part of Nass River Valley is flooded with basalt lava flows only a few hundred years old, which account for the subdued topography there. Between Nass River and Portland Canal, the terrain exhibits a strong northeast regional trend. The present erosional level does not expose geological structures concordant with this trend. The grain was apparently superposed from overlying strata which have since been removed by erosion. The northeast trend has been emphasized by the sculpting of southwest-moving glaciers.

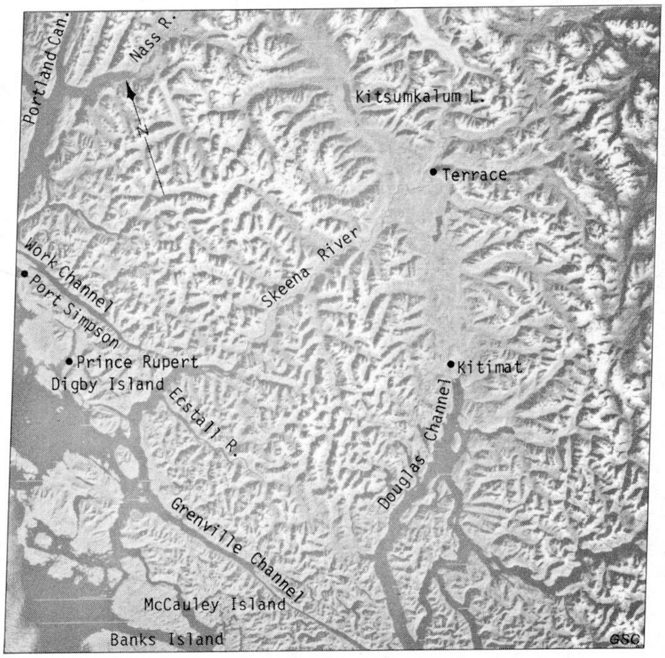

Figure 6.6

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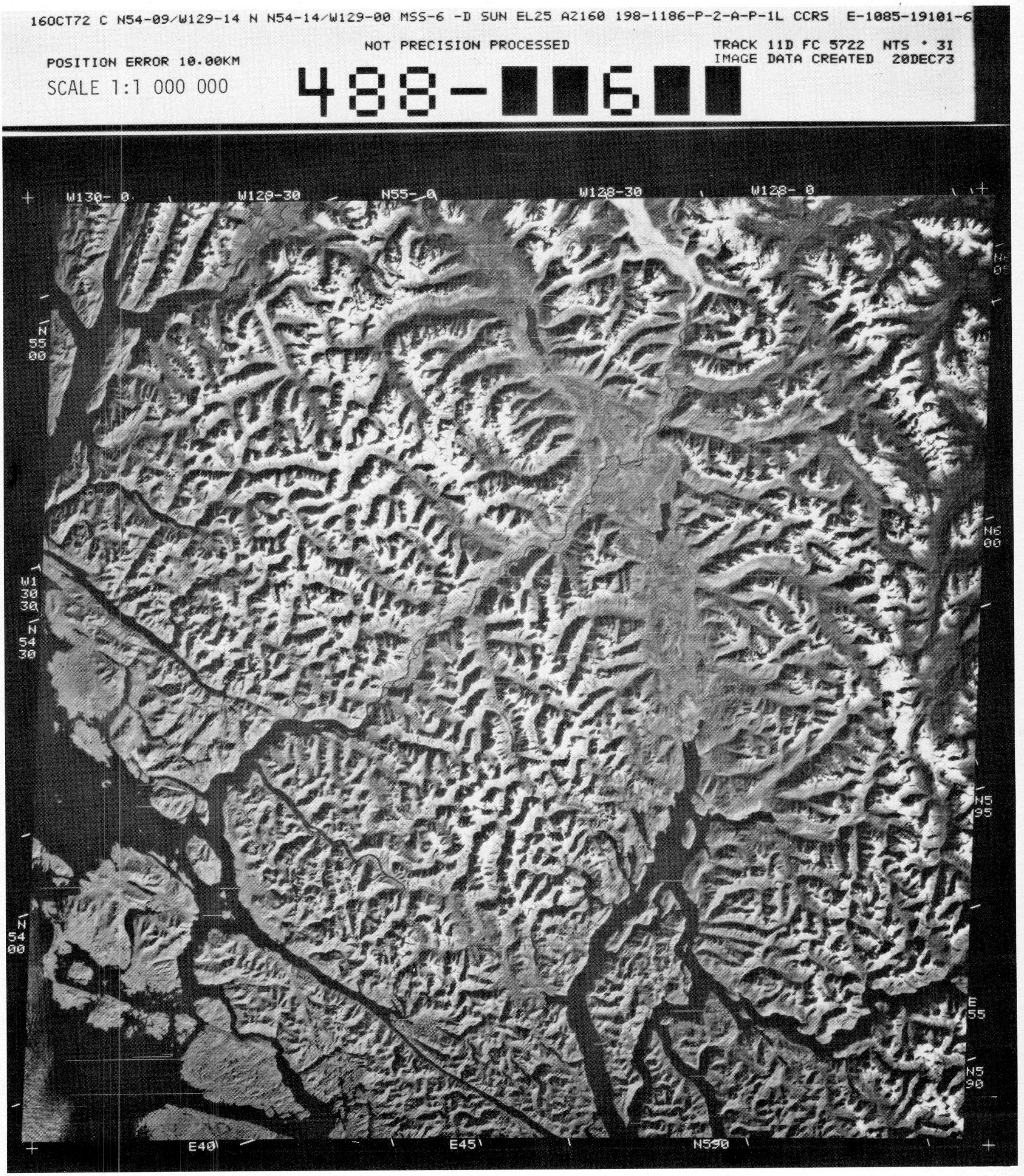
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N590

Figure 6.6 A

6.7

QUESNEL LAKE

R.B. Campbell

The image (Fig. 6.7, 6.7A) clearly shows the major physiographic divisions of the east-central Canadian Cordillera. The northern end of the southern Rocky Mountain Trench separates the Rocky Mountains from the Cariboo Mountains and clearly merges with the Interior Plateau. Although the boundaries between mountains, highland and plateau are not obvious in all places, each division displays distinctive characteristics. The mountains rise well above timber line and are light coloured in the image. The most visible small-scale features are avalanche chutes. The lower, highly-dissected highland is mainly timbered, but has substantial relief whereas little relief is apparent in the Fraser Plateau. Patterns resulting from cultivation and from logging are most obvious in the plateau and trench. Highways, power-line and pipeline rights-of-way and other cultural features are barely visible or cannot be detected.

The Fraser Plateau exhibits prominent glacial flow features which are not visible in the image.

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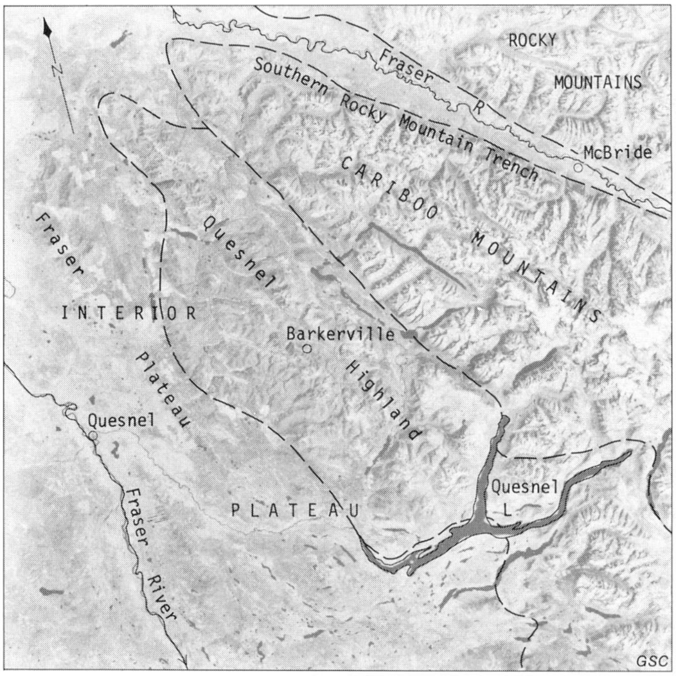

Figure 6.7

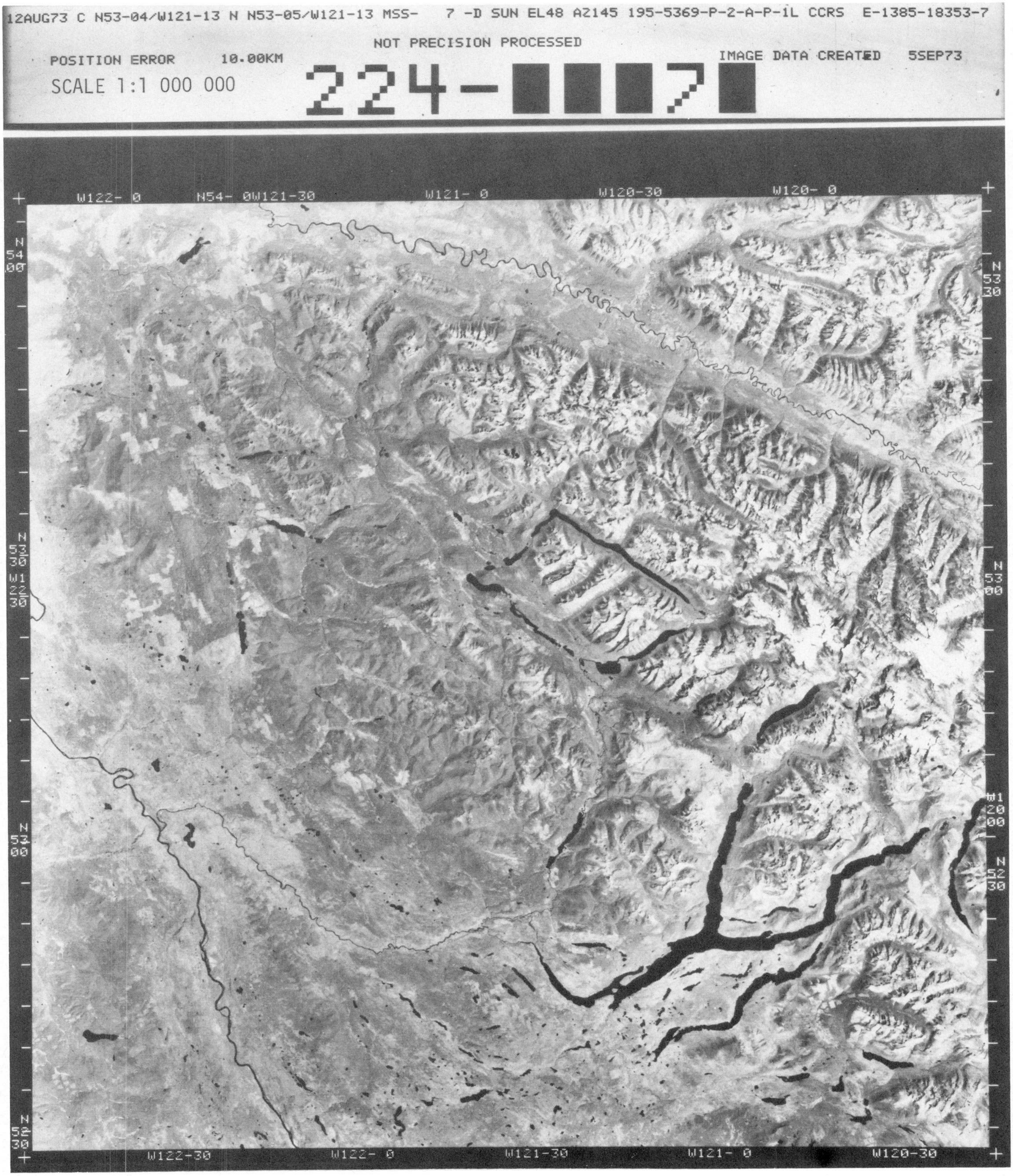
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Figure 6.7 A

AUTHOR INDEX