THE UNIVERSITY OF MANITOBA

EVALUATION of REMOTE SENSING TECHNIQUES for BIO-PHYSICAL LAND CLASSIFICATION in the CHURCHILL AREA, MANITOBA

by

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"EVALUATION OF REMOTE SENSING TECHNIQUES FOR BIO-PHYSICAL LAND CLASSIFICATION IN THE CHURCHILL AREA, MANITOBA"

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ABSTRACT

The use of LANDSAT satellite and airborne remote-sensing imagery are evaluated in a sub-arctic and northern boreal environment near Churchill, Manitoba. Accuracy and cost-effectiveness of a number of interpretation methods are compared; they include visual and automated (supervised and unsupervised) techniques of LANDSAT data and air photo interpretation. Classification results of the different techniques are compared by using the overlay capabilities of the Canada Geographic Information Computer System. Conventional interpretation of aerial photographs enabled classification of about 50 different land types, and proved the best and most practical method for comprehensive bio-physical mapping. Satellite-based methods allowed the mapping of about 10 groups of land types, often, so broad that their practical value for resource management is limited. At present, visual satellite interpretations are more cost-effective than automated approaches for bio-physical mapping in this area.

ACKNOWLEDGEMENTS

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Analysis of the satellite data was carried out at the Canada Centre for Remote Sensing using their automated interpretation facilities. Valuable assistance was provided by Drs. Shlien and Goldberg and Mr. B. Dahms in applying various automatic interpretation techniques.

The Lands Directorate, Environment Canada, provided drafting and typing facilities and the use of the Canadian Geographic Information System for the overlay of different maps and analysis of classificaiton results.

Especially, I would like to express my appreciation and gratitude to my wife Marjolyn for her patience and encouragement, to my children for their patience, and to my supervisor C. Tarnocai of the Canada-Manitoba Soil Survey.

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INTRODUCTION

Development pressures for Canada's last frontier, the North, are increasing. For rational management of the resource base, planning and management agencies at the provincial and federal levels have found a serious lack of baseline data that allow an integrated or multi-disciplinary approach (Romaine, 1974). Hydro-electric development projects, arctic oil and gas pipelines and other developments require decisions and impacts assessments related to economic, social and ecological desirability for society. Biological-physiographical and socio-economic data are required.

Classification methods for mapping and description of the biological-physiographical characteristics of the earth's surface have evolved from single discipline oriented systems into integrated ones; from separate soil and vegetation classifications, forest inventories and geomorphological systems into ecologically-based ones such as the bio-physical land classification system (Lacate et al, 1969). This evolution was made possible largely by use of conventional airphoto interpretation techniques, through which the elements of ecosystems could be effectively integrated, related and mapped.

Besides the conventional aerial cameras and films the development of new sensors have provided a new and rapidly expanding technology: remote sensing. Remote sensing denotes the aerospace practices of surveying the ultra-violet, visible, infrared and microwave radiations emitted and reflected from the surface of the earth (Gregory, 1972). New remote sensors have added new dimensions to the survey of the environment. Multiband sensor packages aboard aircraft and satellite allow us to measure or map 'new' parameters such as surface temperatures, ice thickness, air pollutants, etc., and to discriminate better among objects of interest. Repetitive remote sensing adds a time dimension. The LANDSAT satellites, which orbit Canada four times daily and cover each part at least every 18 days, can play a significant role in realizing an ecologically-based environment inventory system integrating land, water, atmospheric and biological phenomena.

In Canada, development of a bio-physical classification system was started in 1967, under the auspices of the National Committee on Forest Land. The aim was to differentiate and classify at a small scale ecologically significant segments of the land surface (Lacate et al, 1969). It was recognized that this system should be ecologically based, that mapping and the description of land surfaces, and assessments, related to forestry, wildlife, recreation, agriculture etc., could be made rapidly and with little additional effort. The main levels of this classification: land region, land district, land system and land type, appear quite adequate and flexible for most resource planning and management requirements and for impact prediction. Mapping scales suggested are as follows:

Land Region	1:1,000,000 - 1:3,000,000
Land District	1:500,000 - 1:1,000,000
Land System	1:125,000 - 1:25,000
Land Type	1:10,000 - 1:20,000

The objective of this study is to compare and assess the usefulness of airborne and satellite remote sensing for biological-physiographical data gathering in northern areas. As low cost and rapidity are considered critical, most attention is concerned with the evaluation of LANDSAT data. Different interpretation methods are tested in an area, near Churchill, Manitoba, where boreal and arctic elements are present.

LITERATURE REVIEW

Air-photo interpretation has played a significant role in the development of environmental survey systems related to vegetation, surficial geology, soils, forestry and agriculture. In the early 1950s Hills recognized the value of aerial photographs for his forest site (physiographic site) classification. He stressed landform and surface geology as the integrating framework for vegetation, soils, local climate and 'site'. The value of landforms in delineating and describing site conditions was supported by Gimbarzevsky (1966) and Lacate (1966). Stereoscopic viewing of aerial photographs provides a three-dimensional image of terrain features. Relief and slope are important indicators of ecosystem parameters such as drainage, parent material, soil formation and vegetation succession (Thie, 1972). Good perception of depth in a stereo model and quick analysis of shapes and textures enables the human interpreter to separate readily significantly different units. Following field descriptions of selected sample areas results can be extrapolated to non-sampled similar areas by means of photo-interpretation. With this approach, the total number of field investigations is considerably less than in conventional surveys. The value of each field observation is much greater; therefore, both its choice and location, and its description and classification are more critical (Vink, 1964). Buringh (1960) and Goosen (1967) show that careful analysis of individual elements of the landscape (landform, relief and slope, drainage conditions and system, vegetation and parent material) permits inferences related to soil conditions with a high degree of confidence. Although made with limited sampling, the resulting soil maps are accurate.

The manual of photo interpretation, American Society of Photogrammetry (1960) provides a realistic picture of the state of the art of photo interpretation in the early 1960s, when most work was carried out with photographic sensors. The development of a new range of sensors besides the conventional airborne camera, introduced a new term 'remote sensing'. A wide range of sensors under development utilized the visible and non-visible parts of the electromagnetic spectrum for survey purposes (e.g. passive sensors such as multi-spectral line scanners, radiometers and active ones such as radar). MacDowall and Lapp (1973) described the Canadian sensor development program including: multi-spectral scanners, infra-red systems, spectrometers for the near IR, visible and UV wavebands, television systems, image intensifiers, lasers, radars, microwave radars and radiometers. A new range of potential application was introduced in such areas as water-depth measurements, ice-thickness, oil detection, heat detection and moisture measurements.

As a result of the development of new sensors, the interpretation methodology is changing rapidly. Much of the 'imagery' generated by sensors is now stored in an analogue or digital fashion on magnetic tape. Transforming these into visible images for human interpretation usually reduces significantly spectral information and spatial resolution. Computer interpretation of images should not entail loss of information (Shlien, 1973). Initial research in the field of automatic recognition of terrain features by multi-spectral scanner data and pattern recognition methods was performed at the University of Michigan, Willow Run laboratories (presently called ERIM), and the Laboratory for the Application of Remote Sensing (LARS) at Rurdue University. Their staff and research associates have published papers discussing methodology (Swain, Landgrebe, Wacker etc.) and applications (Kristoff, Baumgardner, Hoffer). They demonstrate that automated classification can be done successfully in a number of situations. However, these automated-pattern recognition techniques require much computation time. The ability to map and measure the soil-vegetation complex is important to bio-physical mapping. Kristoff (1972) showed that the use of multi-spectral sensing and automated interpretation has a potential for soil mapping. However, soil series are conventionally differentiated by surface and sub-surface properties, and so cannot be expected in all cases to have observable surface differences. Spectral variations within series can be greater than between series of bare soils (Kristoff and Zachary, 1972). Surface vegetation disturbed or managed by man considerably complicates the mapping of soils. Natural vegetation, without severe influence of man's activities, can indicate soil conditions in areas where relatively simple relationships exist between vegetation and soils. Care must be taken to check vegetation boundaries where they do not coincide with relief or drainage differences; frequently boundary changes are introduces by old forest fires (Thie, 1972). One of the problems, of remote sensing, in the study of the soil-vegetation complex is the quantification and precise location of ground observation site so that the data can be correlated with multispectral data acquired from aerospace platforms (Baumgardner, 1972).

The introduction of the airborne program of the Canada Centre for Remote Sensing and the launch of the Earth Resources Technology Satellite (ERTS, presently called LANDSAT) pushed the research and search for application of remote sensing in Canada rapidly ahead. Much of the work, at one time carried out in the U.S., now came within reach of Canadian researchers. These Canadian experimenters in remote sensing-assisted soil mapping and terrain studies (Beke, 1972; Mills, 1972: Tarnocai, 1972; Thie et al, 1974; Boydell, 1974) used visual and automated methods of analysis.

Because of the vast land resource of Canada, large areas covered by single satellite images and and its repetitive sequences, make LANDSAT satellites an important resource data-gathering instrument. Each area of Canada is covered at least once every 18 days; because of overlap in satellite passes, southern areas are covered in two consecutive days; this increases 5 to 6 consecutive days in northern latitudes. The multispectral scanner (MSS) on board the satellites measures radiation in 4 bands of the electro-magnetic spectrum, two of which are in the visible portion (bands 4 and 5 respectively of the 400-500nm and 500-600nm wavelength portions) and two of which are in the near infrared portion (band 6 and 7 respectively of the 700-800nm and 800-1100nm portions). Six sensors which scan a swath of six lines in one sweep generate an image in any one band. The spectral intensities are sampled 3200 times along each line and are digitized in 64 levels. The MSS data transmitted by both LANDSAT -1 and -2 satellites are received by the Prince Albert satellite station and recorded on magnetic tape. These tapes are used to produce photographic copies of the MSS data and computer compatible tapes (CCT's). Each CCT contains one LANDSAT frame composed of 2,400 lines, each with about 3,200 picture elements (pixels). Each picture element represents 77 m in the north-south and 58 m in the east-west direction (Goodenough et al, 1973).

Different approaches to satellite imagery interpretation can be used. Visual analysis of imagery for land classification was carried out by Thie et al (1974), Tarnocai and Thie (1974) and Gimbarzevsky (1974) based on conventional photo interpretation techniques, but using multi-date imagery and the different capabilities of four satellite bands. Combinations of winter and summer imagery interpretations appear to work well (Thie et al, 1974). Visual interpretation is aided by the use of special instruments such as a colour additive viewer, by which the interpreter can colour-combine four bands and change assignments of colours and brightness to enhance surface features. When two frames taken of the same area on different dates are placed in the viewer, change assessment is possible; however, geometric distortions cause complications. Analogue density slicers allow enhancement of density variations within a single band of an image. Although they work fast and are relatively low in cost, the value of the information extracted strongly depends on the quality of the original transparency and the proper calibration of the density slicer. Nielsen (1972) describes the use of photographic density slicing techniques using Agfacontour film. Taylor (1974) displayed the information on magnetic tapes to provide optimum perception by the human eye using the multi-spectral analyser display (MAD) at the Canada Centre for Remote Sensing. In the most common colour-combination of LANDSAT the MSS bands 4 and 5, which are highly correlated, are displayed in blue and green respectively, and band 3 is displayed in red. This result provides a picture which could be printed in red and blue-green. Rather than attempting to combine pictorially the information from different bands, Taylor extracts the information contained in the various bands as statistically uncorrelated images. These uncorrelated images are then mapped in three visual dimensions that are crudely described as 'red/green, blue/yellow' and 'brightness'.

Automated techniques are used to maximize the use of information contained on magnetic tape. Each of the four spectral bands of LANDSAT images is digitized in 64 levels, thus there is a possible total of 64^4 or about 16 million distinct observation vectors. Correlation between bands reduces this number to less than 10,000 and usually less than 5000; whereas, only a fraction occurs with any significant frequency (Shlien & Goodenough, 1974). Automated techniques for the interpretation of satellite imagery are based on statistical pattern recognition. The objective of any automated classification scheme is to partition the 4- or n- dimensional space into different regions corresponding to classes. Two well-established decision rules are the Maximum Likelihood Rule and the Minimum Distance Rule (Shlien & Goodenough, 1973). The most accurate classification scheme, the Maximum Likelihood Decision Rule, requires considerable amount of computation (Shlien & Smith, 1974). Despite the sophisticated classification schemes, many mis-classifications occur unless radiometric errors in the image are corrected. Errors are introduced because the MSS utilizes six sensors to generate an image in one band. These sensors are susceptible to drift owing to their sensitivity to operating temperatures. Most errors, however, can be compensated (Shlien & Goodenough 1974, Strome & Vishnubhatla, 1973).

There are basically two different approaches to automated classification: supervised and unsupervised classification. In the first, the observer selects training areas representative of the objects to be classified. The statistics of this sample are calculated, and those pixels which are close to the sample are, by some statistical measure, classified as members of the class (Shlien and Goodenough, 1973). Classes of interest must, of course, be spectrally separable. This cannot be ascertained readily beforehand and therefore a useful classification can be generated only by trial and error. With the unsupervised approach, the computer attempts to identify 'clusters'; for example, in the reflectance values of four LANDSAT bands, the computer assigns the individuals pixels to the appropriate clusters (Goldberg and Shlien, 1975).

Clusters or groups of clusters may then coincide with classes that are of interest to the user.

Spectral reflectance or signature is not the only source of information for classifying the earth's surface. Shape and relief are important elements in photo-interpretation of ecosystems and provide a means for inferring surface and subsurface conditions (Thie, 1972). Multispectral scanners do not provide relief information, but spatial features still can be analyzed. For example in areas where sufficient water bodies occur, shoreline configuration can be used to indicate physiographic conditions (Thie et al, 1974). It appears that in the visual photo interpretative process probably about 50% of the 'decision making' is based on shape and relief information; therefore, it can be expected that computer analysis of spatial features would help to improve spectral classifications. Wherever repetitive coverages are available temporal variation of spectral data can be used as input for the pattern recognition process and may improve classification results (Kalensky, 1974).

DESCRIPTION OF THE STUDY AREA

The area is located in northern Manitoba between 58° and 59° N and between 92° and 96° W, covering about 13,065 sq. km. or about 5,144 square miles, Area B, (Figure 1).

The climate is marked by long severe winters, and very short cool summers. The mean annual temperature in Churchill, the only location for which data are available, is -4.7°C; the mean minimum of the coldest month about -27°C. The mean annual precipitation is 353 mm, of which about 2/3 falls in the form of rain, the remainder about 143 mm as snow. The average number of degree-days (the accumulation of degrees of temperature above a

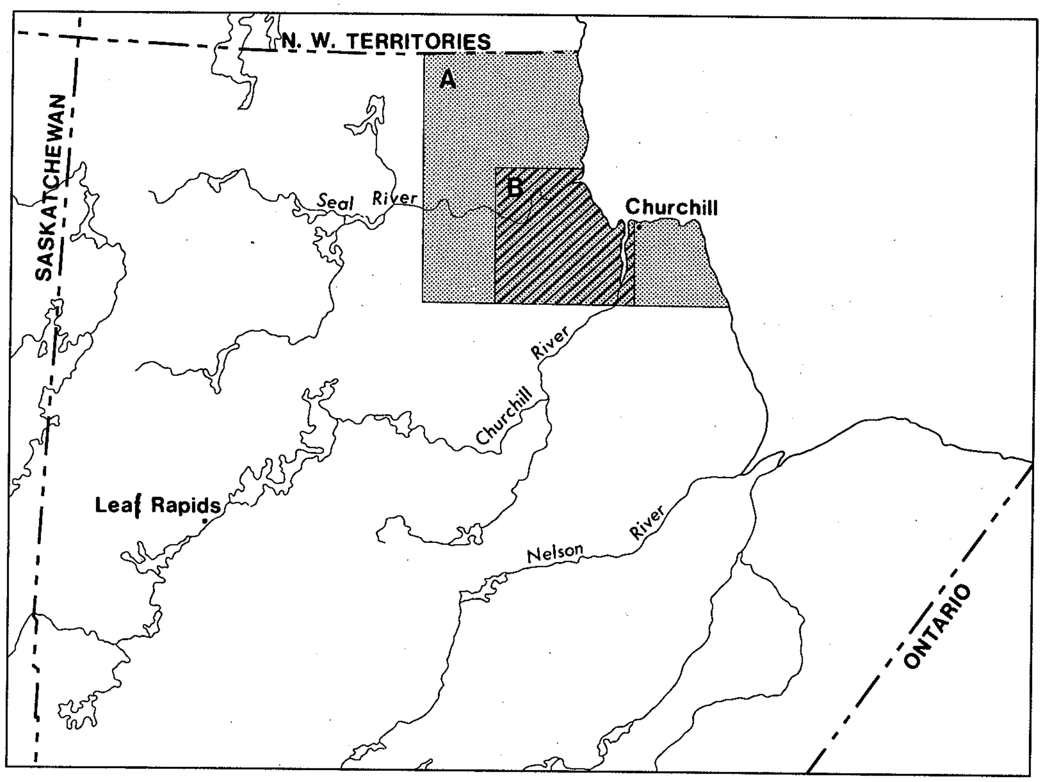


Figure 1: Location of the study area in northern Manitoba. A is the area where fieldwork and airborne sensing were carried out. B is the area covered by the 54L map-sheet where all methods were compared.

daily mean of $5^{o}C$) is about 400 in the northern part of the area and about 500 in the southern part (Economic Atlas of Manitoba, 1960). As the climate of the Churchill area is somewhat modified and more humid because of its proximity to Hudson Bay, inland areas may be colder and drier.

Relief varies from about 260 m above sea level (ASL) in the south-western corner of the area to sea level near Hudson Bay. The Seal River, North and South Knife Rivers and the Churchill River form the main drainage of the area. They follow the general relief trend in the area and flow into Hudson Bay.

Two main physiographic regions meet in this area: the Canadian Shield and the Hudson Bay Lowland. The Shield covers most of the western and northern parts of the area: ancient crystalline rocks which control relief are covered with thick layers of overburden providing for a gently undulating topography; few outcrops and relatively few lakes occur and these mainly in the northern part. The Hudson Bay Lowland is underlain by horizontally-bedded Ordovician and Silurian limestones that are covered with thick mantles of glacial and marine deposits (Coombs, 1954). The recent marine deposits along the coast have resulted from post-glacial emergence of the land. Numerous beaches, which parallel the present or past shorelines demonstrate the magnitude of this process. Marine deposits and marine modification of till and glacio-fluvial deposits are generally found below the 160 m contour.

The area lies within the widespread discontinuous and continuous permafrost zones (Brown, 1967). At Churchill, ice was found in cracks of bedrock at a bore depth of 45 m (Johnston, 1930). The presence or absence of permafrost determines the vegetation and soil type. Most of the perennially frozen soils are associated with patterned-ground types such as polygons, circles, nets and stripes, and with other permafrost landforms sampled for this study during field work are described in preliminary reports by Tarnocai (1973a, 1974) and Mills (personal communication). Soils in the area usually belong to the following orders: Brunisolic, Cryosolic, Organic, Gleysolic or Regosolic. Well-drained tills and glacio-fluvial deposits usually have Degraded or Orthic Dystric Brunisols.

In the northern part where patterned-ground and frost-heaving features become apparent, these soils become turbic, especially on the more imperfectly drained sites. In finer-textured tills and in areas where the permafrost table remains within the 1 m control section, Brunic or Gleyed Turbic Cryosols can be found. However, most Cryosols in the area are in organic materials e.g. Fibric or Mesic Organo Cryosols on peat plateaus and peat polygons. Non-frozen fen areas are usually Mesisols.

DESIGN OF INVESTIGATION

To evaluate airborne and satellite remote sensing for northern land classification an area was chosen in that part of northern Manitoba, where arctic and boreal elements meet (Fig. 1). Churchill, the only centre of population in this area, served as a base for field work. From this base aircraft of the Canada Centre for Remote Sensing covered the area with multi-band remote sensing imagery.

Acquisition of Remote Sensing Imagery

The area was flown during the summers of 1972 and 1973 with a Falcon fan jet. An area of about 16,000 sq. km. was covered from an altitude of about 10,700 m above sea level (ASL). Lower altitude coverage at 1,525 and 3,050 m.ASL.was obtained for selected areas on 1 June 1973 and 22 July 1973. Part of the Seal River Delta was flown on 22 August 1972. Detailed specifications of the flights, sensor packages and film-filter combinations are provided in Appendix A. Since earlier studies have shown the advantages of colour infrared film used in conjunction with yellow filters in contrast with other film-filter combinations (Thie, 1972; Tarnocai, 1972), this combination was chosen for the super-wide-angle survey camera to provide full coverage of the study area. The Kodak Ektachrome Infrared Aero film type 2443 is a false colour-reversal film. The film is sensitive to the visible and near-infrared portions of the electromagnetic spectrum respectively ranging from 400 to 700 nm and from 700 to 900 nm. A yellow filter, such as the Kodak Wratten No. 12, is always used on the camera lens to absorb blue radiation to which all three layers are sensitive. When the film is processed, the green sensitive layer is developed to a yellow-positive image; the red sensitive layer is developed to a magenta-positive image, and the infrared sensitive layer to a cyan-positive image. Based on suggestions by Worsfold (1972) who found colour compensating filters to improve interpretation quality colour compensatory filters CC20M and CC20B were added to a W-12 filter on some of the 70mm Vinten cameras. These filters modify the colour balance of the film material. The CC20M is a magenta filter with a peak density of 0.20; it introduces more yellow in the positive transparency by absorbing green light. The CC20B filter, also with a peak density of 0.20, is a blue filter; it provides more reds in the transparency by absorbing red and green. Both shift the respective characteristic curves of the film material towards the infrared curve. While the sensor package varied somewhat on the different altitudes and dates, the following combinations were used:

- 1RC-10 camera, 88 mm focal length, 2443 color IR film with 520 filter
- 4 Vinten 70 mm cameras, 3" and 6" focal length with color IR, color and panchromatic film, combined with filters like W12-CC20M, W12-CC20B, HF, W12, W25 and 89B.
- 1 RS-14 infrared scanner registering in the 8000-14000 nm range

In addition, a flight with side-looking radar was made by the Canadian Armed Forces Maritime Proving and Evaluating Unit at 2290 m above ground level (AGL).

LANDSAT-1 imagery was used in the form of transparencies, prints and enlargements; computer compatible tapes (CCT's) were obtained from the Canada Centre for Remote Sensing. For digital analysis special use was made of the following frames:

14 Aug. 1973 E-1387-17021 -TAPE No. RSØ198 (old format)
27 Jul. 1973 E-1369-17022 -TAPE No. RSØ351 (old format); RS2940 (new format)
30 Oct. 1972 E-1099-17025 -TAPE No. RSØØ31 (old format); RS2863 (new format)

For visual analysis of LANDSAT all available frames taken between July 1972 and July 1975 were used showing the area in most seasons.

Field Investigation

Fieldwork, for a total of about four weeks, was carried out during the 1971- and 1972-field seasons using a light, Beaver aircraft on floats. This mode of transportation permitted access to areas where lakes of sufficient depth and size occurred. About 25 landings were made and at each stop an average of 3 different sites were described and sampled according to bio-physical characteristics, including soil, vegetation, landform, relief and slope. The classification of soils and the chemical analysis of sampled profiles are described in preliminary reports by Tarnocai (1974) and G.F. Mills (personal communication).

laboratory Investigation

The objective is to compare the effectiveness of different remote sensing techniques, visual interpretation of airborne imagery and visual and automated (supervised, unsupervised, temporal) interpretation of LANDSAT satellite images. Therefore, it is important to proceed and partition the work so that the experience gained by the interpreter on one aspect of the study would not significantly bias later results.

This procedure was especially important since only one interpreter (the author) was involved; thus bias was reduced by working from small scale, low-resolution imagery towards the larger scale higher-resolution imagery, i.e. from the first step of visual interpretation of small scale satellite imagery to detailed interpretation of aerial photographs. Automated classification was carried out only after the visual analysis was completed. The order of interpretative work was as follows:

1. Study of airborne remote-sensing data for five representative, but relatively small areas, was undertaken to compare the usefulness of the different film-filter combinations at high and low altitudes. This part was considered important because it was thought that whatever type of classification was used, basic familiarization with vegetation, landform, soils and drainage etc. would be an essential first step for an understanding of the land types (ecosystem). This knowledge would not bias results for a comparison of methods since this step is a basic requirement for any type of classification whether visual or automated.
2. Satellite images for different dates were visually analyzed with and without aids such as colour-additive viewers, analogue density slicing devices and agfacountour film techniques. Based on the unaided analysis, land systems were outlined on

1:1,000,000 scale imagery and typed according to conventional air photo interpretation techniques. Results were mapped at scales of 1:250,000 and 1:500,000 (Map I, Appendix C).

3. Three representative areas (Plate 1) were selected: (A) The Seal River area, with bedrock-controlled, frost-heaved till and forest tundra; (B) The Mack Lake area with bedrock-controlled, deep till areas and a veneer of organic material, covered with sub-arctic forests; (C) The Lovett Lake area, one example of the poorly drained, peat-covered lowlands with peat polygons, sedge fens and numerous small lakes. For each of these areas enlarged colour images were produced (Plate 2 A,B) using computer compatible tapes displayed through the Multispectral Analyser Display (MAD) at the CCRS (Goodenough et al, 1974). 'Hard' copy images were produced by the CCRS using the Electron Beam Image Recorder (EBIR). Resulting 'digital blow ups' were interpreted and typed using conventional photo interpretaiton techniques (Plate 2A and Appendix D).

4. A supervised, automated classification using MAD, and the MICA classification package developed by Shlien, Goodenough, Smith and others at the CCRS was carried out on LANDSAT imagery. Tape data were radiometrically corrected and the Maximum Likelihood Decision rule was used (Shlien & Goodenough 1973). Training of the computer was done by means of a software cursor and ground-control data. Training data were selected from the most representative conditions across the whole image. A full image classification for a summer frame (1387-17021) was carried out on a pixel by pixel basis using a 10-class training set (Appendix E; Plate 2B). The three areas described under item 3 were treated with three different types of training data to assess the impact the number of classes would have on the classification results. Results were processed via the EBIR and photographically enlarged to 1:250,000. Success of the classification was measured in both quantitative and qualitative ways. This automated work was carried out after items 2 and 3 since results could influence the location of boundaries and typing estimates of these tasks.

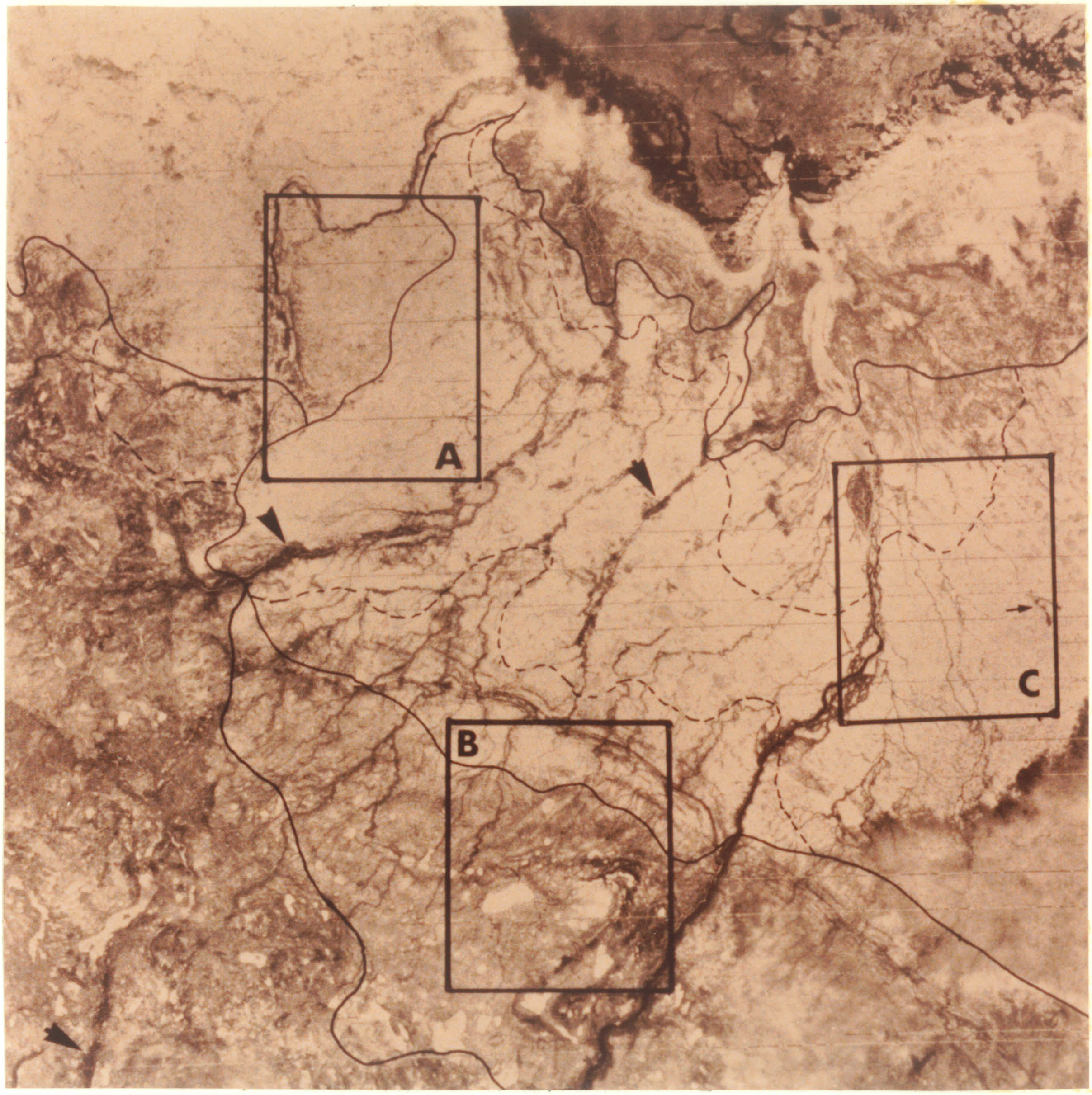
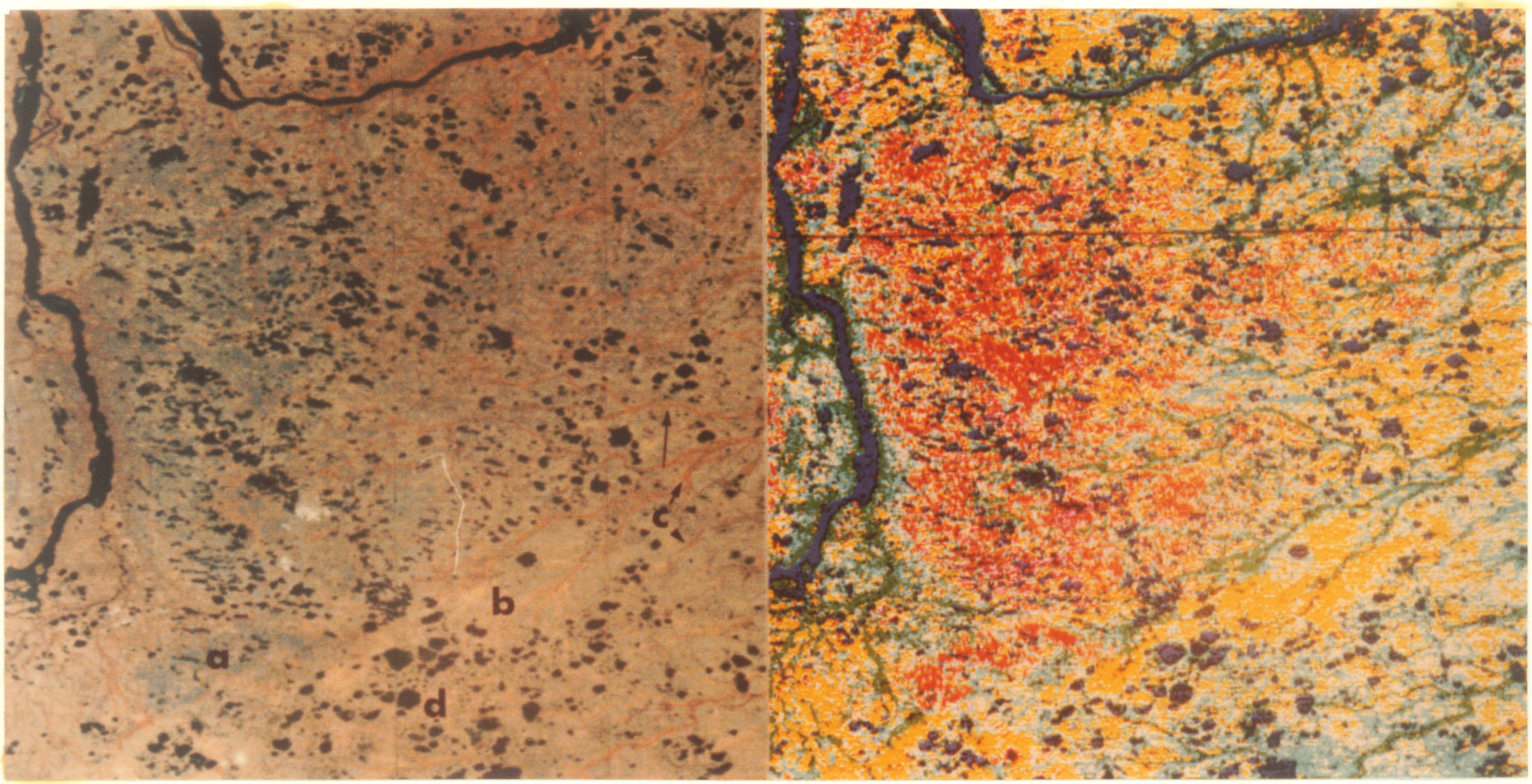


Plate 1: Location of the three Test areas: A, Seal River; B, Mack Lake; and C, Lovett Lake area. The background is a LANDSAT, winter image (30 Oct. 1972 - 1099 - 17025 - band 5) with boundary lines delineating land districts (see also plate 3). Snow has enhanced tree cover and allows easy identification of well drained glacio-fluvial deposits. (see arrows)

5. An unsupervised, clustering approach (Goldberg and Shlien, 1975) was used on the three representative areas. The results of this approach were compared with the results of supervised classification to learn whether more spectrally separable classes could be added to the classes already generated via the supervised approach. This aspect was carried out after item 4, since the results could influence the selection of training area.
6. A detailed photo interpretation and classification of a complete 1:250,000 scale topographic map (54L) was carried out using black and white aerial photography. The resulting biophysical map was used as a base against which all former steps were compared (Appendix F).

The legend, used for photo interpretation, was similar for all 6 items. Appendix B provides a detailed listing of all classes of the legend. Land types are briefly described by their characteristic components. A simple alpha-numerical system was used for annotation.

To allow easy comparison of the resulting interpretations, all resulting maps and associated classifications were stored in the Canada Geographic Information System (CGIS) of the Lands Directorate, Department of Environment, Ottawa. This system was designed to read, store, analyze, manipulate and compare maps. Using this system, all maps are overlaid on the detailed photo interpretation map (step 6, Appendix F). New classifications for each land system of each overlay were generated using the detailed base. These results were compared with the original classification of units.



A B

Plate 2 A, B: The Seal River Test area from computer compatible tape. (RSØ198 Aug. 14, 1973 - 1387 - 17021) magnified to about 1:250,000 scale and displayed on MAD. The left image is a colour combination of channels 4, 5 and 6, the right image is the result of a supervised automated classification. Frost-heaved stonefields (a) are devoid of vegetation. Some other land types in this area are: Peatpolygons (b), tamarack sedge in drainage channels (c) and patterned fens with some polygons (d).

DESCRIPTION OF BIO-PHYSICAL UNITS

The bio-physical classification system developed by the National Committee on Forest land and described by Lacate et al (1969) has 4 levels in its classification hierarchy. *Land region,* the first level, is defined as an area of land characterized by a distinctive regional climate as expressed by vegetation. The second level, the *Land district,* is basically a sub-division of the land region based primarily on the separation of major physiographic and/or geologic patterns that characterize the region as a whole. *Land system,* the third level, is defined as land areas throughout which there is a similar recurring pattern of land-forms, soils and vegetation. The fourth level, *Land type,* could also be called a land ecosystem. It has a fairly homogeneous combination of soil and chronosequence of vegetation.

The study area was mapped using these four levels (Appendix F); land regions and districts. Ritchie (1959, 1960, 1962) studied and mapped this region for prevalent categories of vegetation. He prepared also a landform map (Ritchie, 1962) at the 1:1,000,000 scale, which was later modified by Tarnocai (1974). Both sources and fieldwork by the author have provided part of the information in the following sections.

land Regions and land Districts

Using LANDSAT imagery, the area was sub-divided into two land regions and five land districts (Plate 3). Although the boundary of the land regions is actually based on a physiographic divide, the difference in the first place is climatic. This climatic difference is expressed in the distribution of vegetation and permafrost occurrence. *LAND REGION (1)* has continuous and widespread discontinuous permafrost (Brown, 1967), a prevalent forest-tundra type of vegetation (Ritchie, 1962) and an arctic climate. *LAND REGION (2)* is marked by widespread discontinuous permafrost, open coniferous forest and a north boreal and arctic climate.

The following is a description of each of the five land districts of this map-sheet.

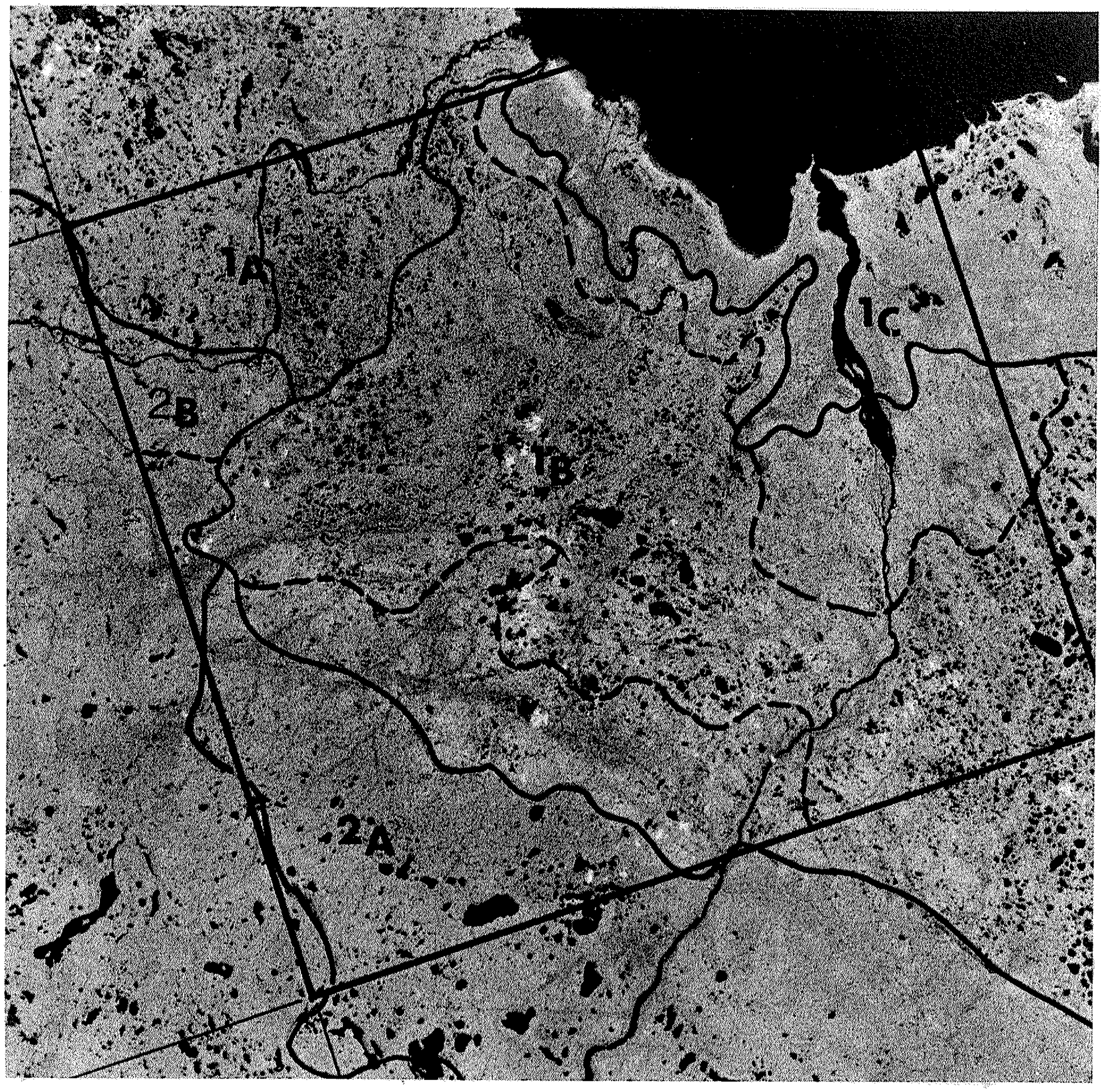


Plate 3: Land districts in the Churchill map-sheet (54L). The square area outlined in heavy lines represents the 54L sheet. Background is an image taken 14 Aug. 1973 (1387-17021-band 7-computer tape RS0198). Continuous lines delineate the land districts; broken, the 'transition' zones.

Mack Lake District, 2A. This district is controlled by Precambrian bedrock; it is overlain by a thick overburden of till which provides a gently undulating topography. Outcrops may occur near the shorelines of lakes or in river beds. Marine deposits may overlay the till; former marine beaches are found in the northeastern fringe of this district. More than 95% of the surface material is peat through which till or beach ridges sporadically dome up. Peat plateaus form the dominant landforms; they are covered by an open black spruce *(Picea mariana)*, *Sphagnum*, lichen, feathermoss vegetation with scattered low shrubs such as alder *(Alnus sp.)* and willow *(willow sp.)*. Permafrost occurs in the peat plateaus; the soils are usually Fibric or Mesic Organo Cryosols. Less than 10% of this district is covered by non-frozen saturated sedge fens, that form 'leads' between peat plateaus. They may have various mixtures of tamarack *(Larix laricina)* and dwarf birch *(Betula glandulosa)*; the associated soils are Mesisols.

Knife Rivers District, 2B. Till is the dominant surface material. Only about 20% of the area is covered by thick layers of peat, usually associated with peat plateaus (Organo Cryosols) and fens (Mesisols). The topography is more undulating and the associated well-to-imperfectly drained tills, with a coarse sandy loam texture, cover about 60% of the area. Glaciofluvial deposits, which may have been subject to wave action, and beaches cover less than 5% of the area. Well-drained sites on till have no real patterned-ground phenomena although permafrost exists. In wet-to-moist areas and in former drainage ways, frost heaving of stones and rocks in the till has resulted in rock and stone fields. On the well-drained sites black spruce forms semi-open stands which are occasionally mixed with tamarack; ground cover consists of lichens, feathermoss and ericaceous shrubs. Locally, fire may have introduced jack pine *(Pinus banksiana)*, white birch *(Betula papyrifera)*, trembling aspen *(Populus tremuloides)* on well- and imperfectly-drained sites. Soils of these sites are usually Dystric or Eutric Brunisols either Degraded, Orthid or Gleyed.

Seal River District, 1A. This area has relatively thin layers of stony till over Precambrian bedrock, again partly overlain by peat deposits. Sporadic outcrops occur more frequently here than in the rest of the map-sheet area, with the exception of the vicinity of the Churchill townsite. Water-modified glacio-fluvial deposits, till ridges and beaches occur throughout the area and demonstrate the impact of marine influence throughout most of the district. Continuous and widespread discontinuous permafrost occur in this district and patterned-ground features occur in peatland (i.e. peat polygons) and in till areas (unsorted circles). Peat polygons have a lichen-heath type of vegetation and Gleysolic Turbic or Gleysolic Static Cryosols and Organo Cryosols. *Carex-Eriophorum-Scirpus* fen areas occur intermixed with peat polygon areas. Till covers 30-40% of the area. Well-drained till and sandy glacio-fluvial deposits and beaches ridges have not necessarily been subject to strong cryoturbation and soils are often Orthic Dystric Brunisols. However, intermixed Turbic Dystric Brunisols or Turbic Degraded Dystric Brunisols occur. On poorly-drained till sites, former drainage courses and lake edges, strong frost heaving has resulted in extensive rock and stone fields. On imperfectly-drained till areas Brunic Turbic Cryosols occur; beaches and eskers that were exposed to wind erosion have Orthic and/or Turbic Regosols.

Lofthouse-Lovett Lakes District, 1B. This land district is the largest of the map-area. Organic deposits overlay marine sediments and till in 99% of the area. Occasional glacio-fluvial deposits can be found, usually associated with the river systems. Vegetation on these glacio-fluvial deposits is dominated by white spruce *(Picea glauca)* and lichens; soils are usually Degraded Cystric Brunisols. About 35-40% of the peat areas have peat polygons, often associated with patterned saturated sedge fens (30%). The former consist of a lichen-heath-tundra vegetation and associated Organo Cryosolic soils; the latter by *Carex-Eriophorum* vegetation and Mesisolic soils. The drainage system is poorly developed; internal drainage is usually by concentrated seepage. In these drainage courses, the vegetation is tamarack-sedge and occasionally scattered black spruce. In areas where water is richer in nutrients, willow, alder and dwarf birch may occur. Peat plateaus and polygonal-peat plateaus* are found in the northeastern and southern fringes of the district in transition zones near districts 2A and 1C (Plate 3). Their formation seems partly due to improved drainage conditions as a result of gentle slopes. Polygonal peat plateaus occur as a transition stage grading towards normal peat plateaus; in both soils are similar, i.e. Organo Cryosols. The plateaus have a lichen-heath type of vegetation in the centre, and a peat-plateau type of vegetation of black spruce, lichen, *Sphagnum spp.* with occasional tamarack along the edges. Continuous shrubs and white spruce forest may be found along the better-developed drainage channels.

Coastal District, 1C. This narrow strip along the coastline consists of extensive marine flats, alluvial deposits, numerous beach ridges parallel to the shoreline and thin layers of relatively recent organic deposits. Occasional bedrock outcrops (Churchill area) and glacio-fluvial deposits are found. About 50% of this zone has thin layers of organic material with vegetation such as sedges or sedge-tamarack somewhat patterned. Another 20% is dominated by tamarack-sedge vegetation mixed occasionally with black spruce. Mesisols are characteristic of these fens while Organo Cryosols are associated with minerotrophic palsas of the area. Mudflats and salt marshes cover about 5-10% of the area. About 10% of the district has peat plateaus and palsas with vegetation dominated by black spruce, lichen, *Ledum spp.*, *Sphagnum spp.* and ericaceous shrubs. Soils are usually Organo Cryosols. Beaches on water-worked till deposits cover 5-10% of the area. They have a lichen heath-type of vegetation and Degraded, Orthic or Gleyed Dystric Brunisols. White spruce forest occupies local glacio-fluvial deposits and near the estuaries of the Knife and Churchill rivers. On the younger alluvial sites, marsh, shrub and occasional scrub forest of tamarack and black spruce occur.

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*Definitions of peat plateaus, polygonal peat plateaus, polygonal plateaus and some other landforms as used in this study are described in the classification legend, Appendix B.

RESULTS AND ASSESSMENT

Airborne Remote Sensing

To test the value of different film-filter combinations (Plate 4), infrared scanning and radar, five areas chosen for detailed study represent most terrain types: 1) the Long Lake area (59° .25'N - 95° .25'W), 2) the Seal River area (A) (59°N, 95° .25'W), 3) the Seal River area (B) (58° .48'N, 95° .40'W), 4) the Lofthouse Lake area (58° .30'N, 95°W) and 5) the Alston Creek area (58° .25'N, 94° .10'W).

Plate 4 shows an example of the multi-band sensor coverage for the Long Lake area on two different dates. The strongest response in the infrared is on the 22 July imagery (Plate 4 A & B). 1 June imagery (Plate 4 C & F) is too early in the growing season to get such a response resulting in fewer red and magenta colours. Of the different July film-filter combinations the W12-CC20B filter (Plate 4, B) gives the best infrared content - an important feature where, because of bare surfaces of glacial till, stone fields and severe climate, vegetation cover is very sparse. The stone fields especially are prominent (Plate 4 B, a); whereas, on simultaneously taken colour imagery (Plate 4 E, a) they are not so clear.

The CC20M combination (22 July, Plàte 4, a) has a bluish overtone in this till area; water penetration is better, but infrared content is not as good. In areas where thicker and denser ground cover exists, the results with the CC20B filter becomes reddish on the July imagery, (Plates 5, A, D). The 20 M filter, which modifies the incoming green radiation, shows more detail in vegetation; for example, on Plate 5E (arrow), black spruce appears bluish against the reddish shrubs; on the 20B image (Plate 5D, arrow) both are reddish. In most test areas the W12-20B filter, which only modifies the green and the red, shows black spruce as reddish. This increase in vegetation discrimination makes the July CC20M results superior in subarctic forest and peat polygon areas (Plate 5, A, B & C). The Alston Creek area with sparsely wooded peat plateaus (Plateau 6) shows the same effect. Areas which are wet and areas where melting is taking place

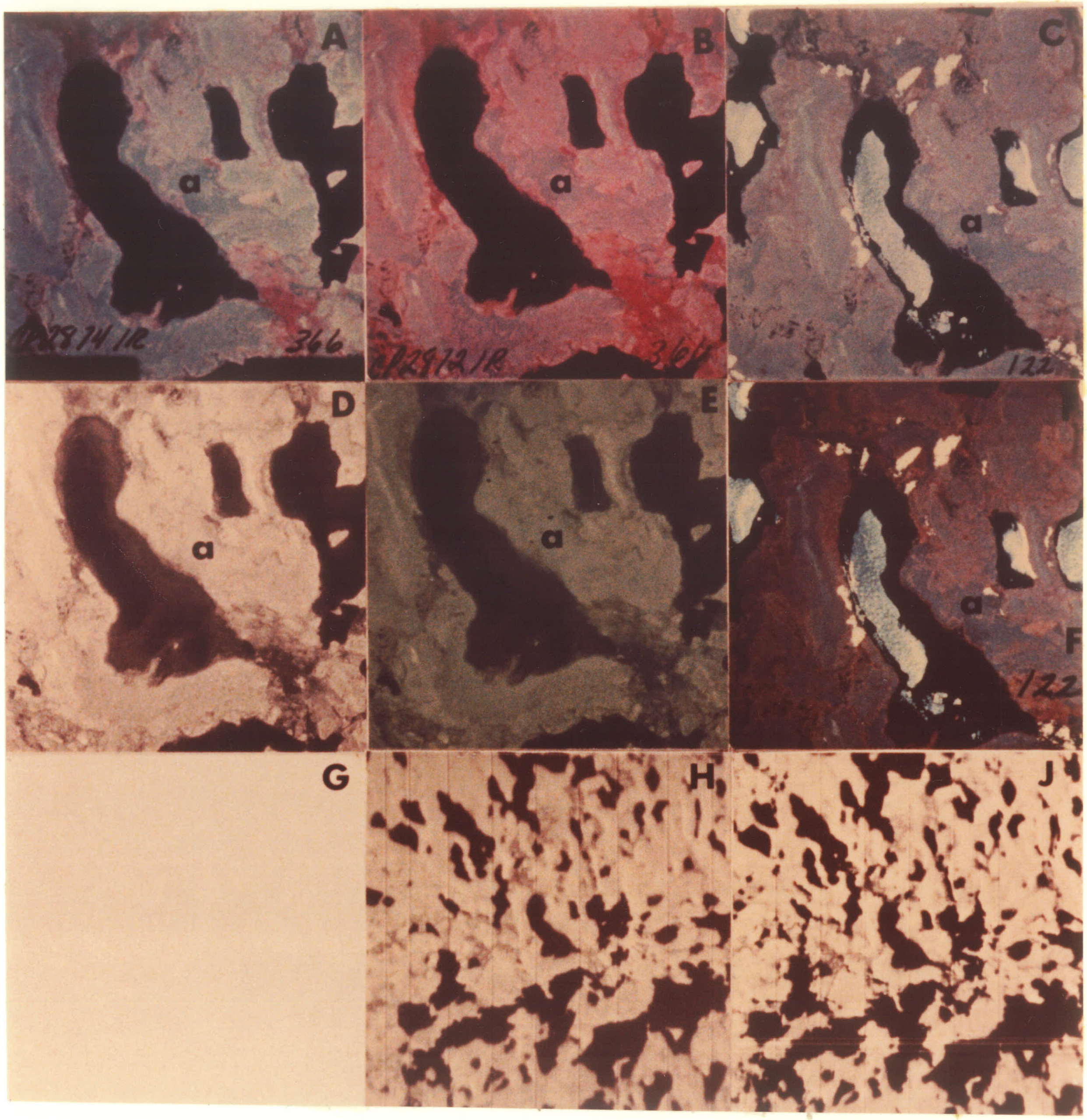

Plate 4: Airborne multi-band coverage of the Long Lake area. Two flights took place at an altitude of 3050 m. ASL. A, B, D, E and H 22 July 1973. C, F, G and I on 1 June 1973. (A) - CP 2874IR-366 is taken with a 2443 film with CC20M filter; (B) CP2872IR-366 is taken with a CC20B filter; (D) - Bn 2873-366 with a 2405 film with a W12 filter ('Red Band') and (e) C22875-366 a colour photo. (H) and (I) are thermal scanning images taken simultaneously with the 70 mm Vinten camera imagery. G is a part of the 9" x 9" small scale color infrared photo taken from 10.700 m. ASL. (RSPA-30665IR).

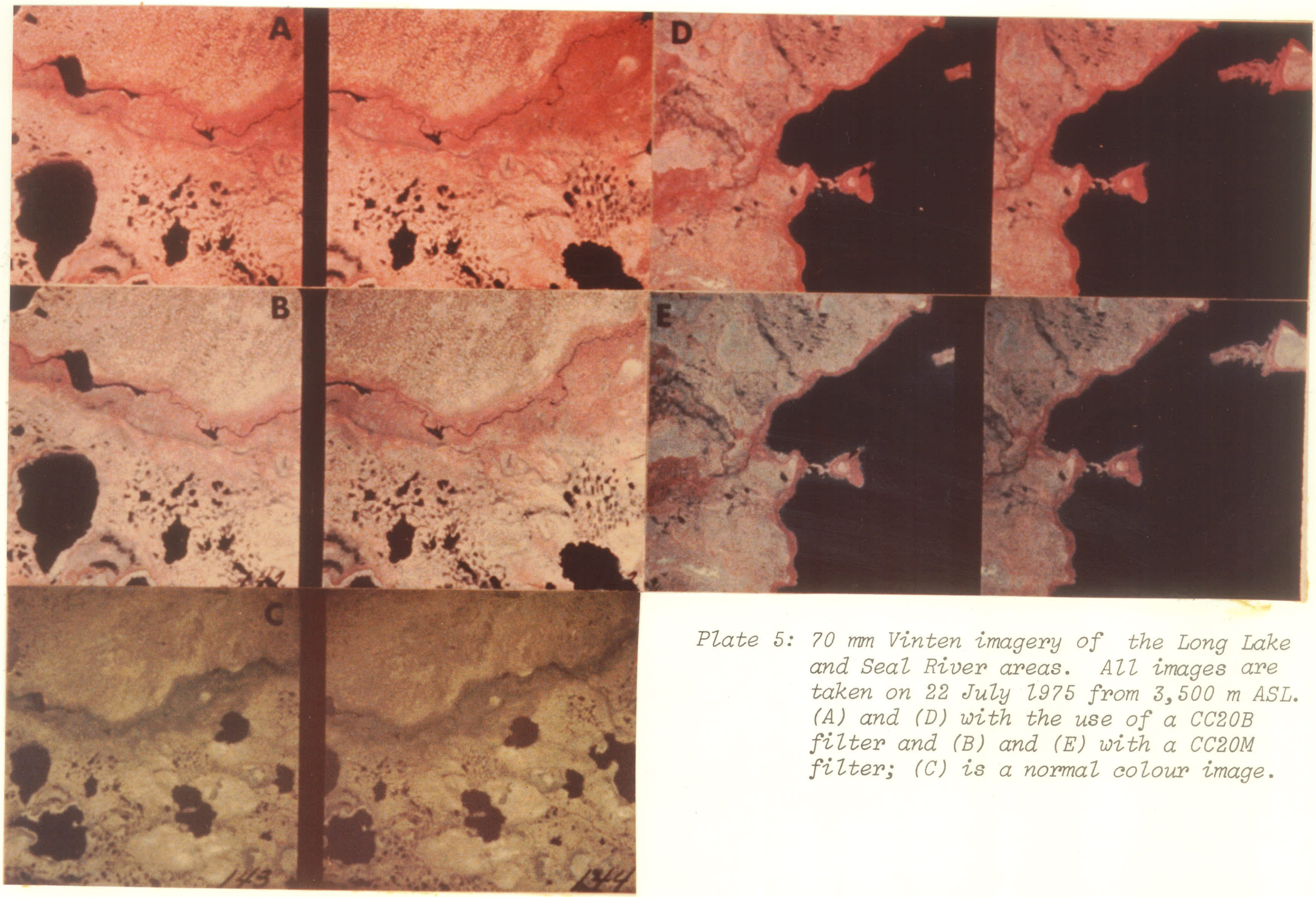

Plate 5: 70 mm Vinten imagery of the Long Lake and Seal River areas. All images are taken on 22 July 1975 from 3,500 m ASL. (A) and (D) with the use of a CC20B filter and (B) and (E) with a CC20M filter; (C) is a normal colour image.

(Plate 6 A, a) are most conspicuous on the CC20M results; burns show up best on CC20B. Peat polygons in the Long Lake, Seal River and Lofthouse Lake areas show well on both film-filter combinations (Plate 5). Ice wedge depressions, filled with water, are slightly more pronounced on the 20B image, but overall appearance of the CC20M is much better.

The high-altitude color infrared results (1:120,000) of the RC-10 camera with a 520 nm filter show strong vignetting in spite of the anti-vignetting filter. The material is, however, clearly superior to the existing black and white photography of a scale of about 1:100,000. It provides more vegetation detail and better separation between mineral and organic soils. Furthermore, peat polygons can be seen on the small scale color IR, whereas, they must be inferred from tone and site on the high-altitude black and white photography. In the Seal River area (B), peat polygons especially those with wide troughs and filled with water or sphagnum mosses can be distinguished on the small scale colour infrared photo. About 20-25% of the peat polygons can be positively identified; another 40-45% can be accurately inferred. In the Alston Lake area where palsas and peat plateaus are abundant, areas with melting permafrost stand out clearly on the 9" x 9" colour IR (Plate 6, E, I). One Vinten camera in the high-altitude sensor package carried 2443 film with a CC20B filter; although no vignetting occured, the results are not better than the 9" x 9" material.

Infrared scanning in the thermal range (8-14 μ) was carried out using a Reconovax scanner at 3050 and 10,400 m altitudes ASL. Simultaneous ground control was lacking to calibrate the temperatures. The main prupose was to test whether high- and low-altitude thermal scanning would assist in drawing boundaries for soil and ecosystem areas.

Plates 4, 6 and 7 show examples of high-altitude and low-altitude scan, black and white photography, and colour photography. It is believed that the 10,700 m altitude scan is of no real value for the delineation of boundaries though it appears to provide interesting information for lake classification. The 3,050 m scan is of considerably greater value. It demonstrates that surface temperature is mainly a function of the drainage condition of the area, and is only slightly modified by vegetation.

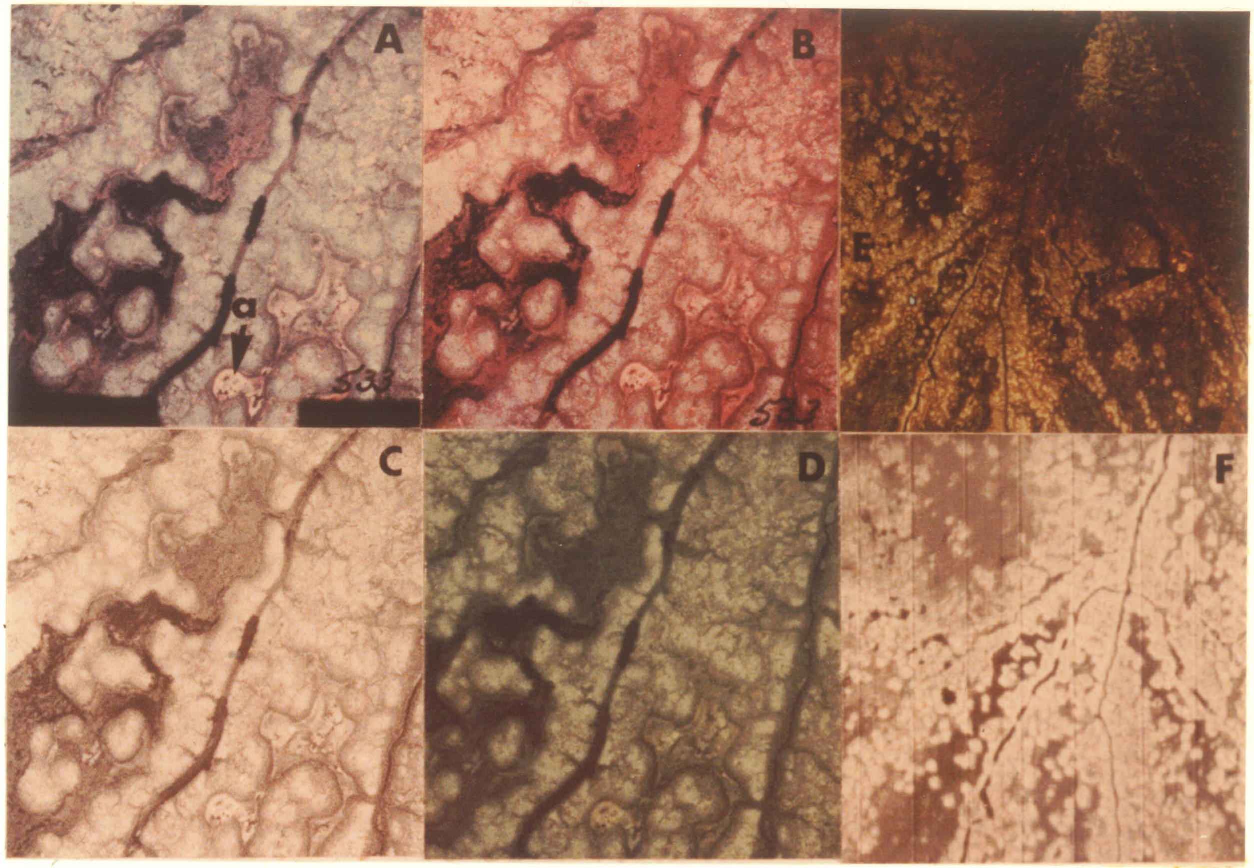

Plate 6: Multiband coverage of the Alston Creek area. All images are taken from 3,050 m ASL 22 July 1973, except (E) which is taken 1 June, from 10,700 m ASL. (A) shows a colour infrared film with W12-CC20M filter (CP2874IR-533);(B) the result with a W12-CC20B filter (CP2872IR-533);(C) is a red-band image (B2856-535) and (D) a normal colour photo. (F) is a thermal scan (8-14 u).

The difference between wet and dry areas is quite distinct. The till/rock-wetland interface is easier to delineate on the 1 June scan (when moisture is plentiful after snowmelt) than on the 22 July scan. It is difficult to separate well-drained peat polygons from till areas as they appear as warm or warmer than till.

A strip of radar imagery flown during 1972 (BN2157, 2288 m AGL) proved of little value in this area (Plate 8). Because of the extreme flatness of the terrain, radar failed to enhance physiographic differences. Vegetation and drainage conditions were considerably more difficult,

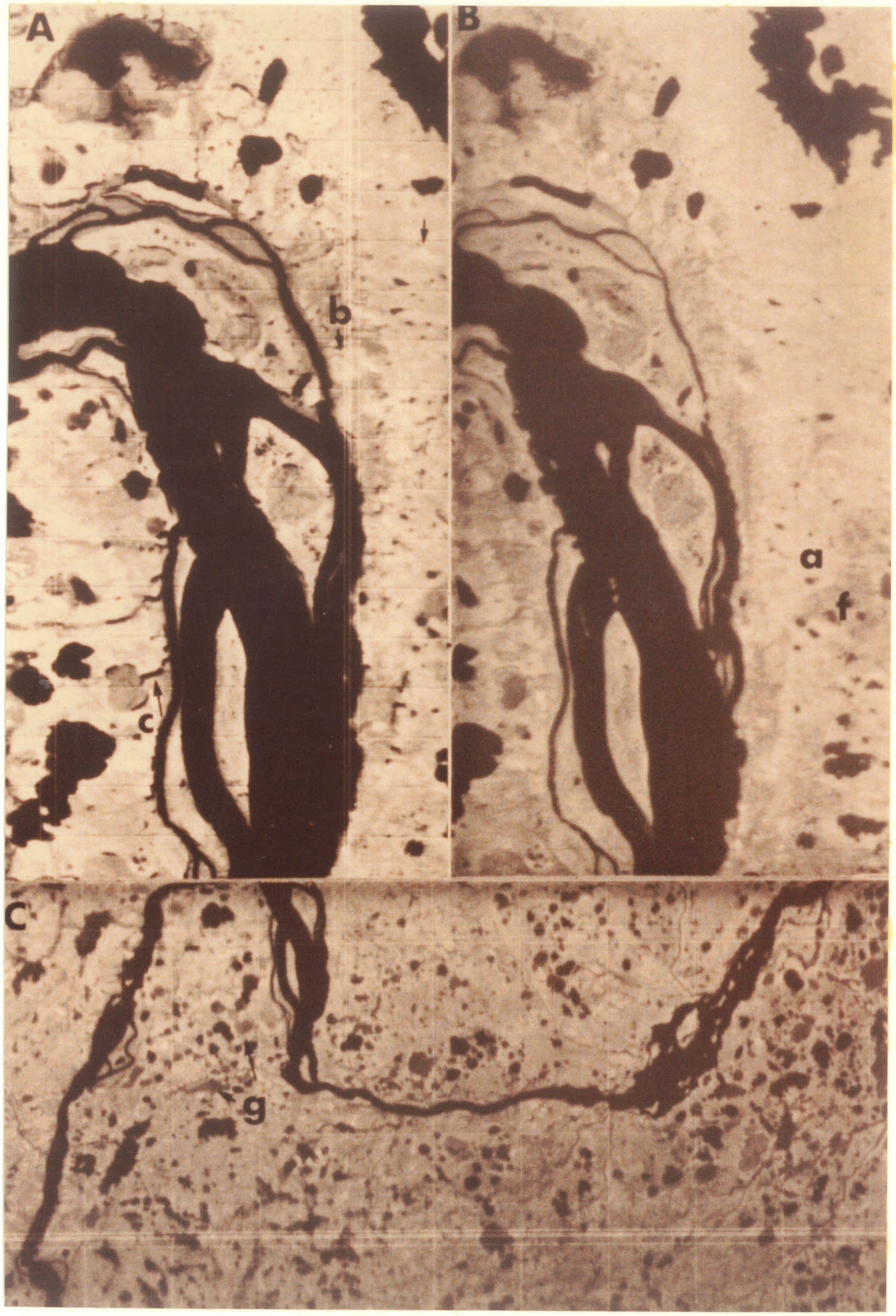

Plate 7: Thermal scanning in the Seal River area. (A) is taken on 1 June 1973 from 3050 ASL; B is the same area on the 22 July. C was taken on 1 June from 10.700 m. Note the stone fields (a), peat polygons (b), snow banks, fen areas (F) and the different tones of the lakes (g).

if not impossible, to interpret than on conventional black and white imagery.

Multi-band coverages such as those used in this study generate a large amount of material for interpretation. It is time consuming to interpret all data for a large study area. The best solution is to cover the entire area with a high-altitude sensor to carry out operational interpretation and to fly selected areas with low-level, multi-band packages. This procedure reduces the cost and the interpretation effort. The selection of the primary sensor for a study area is essential for the production of satisfactory maps. In the bio-physical type of survey, most elements of the ecosystem are mapped, studied and interrelated. Thus, it is difficult to select a sensor and a spectral band to provide optimum discrimination for most elements such as water, vegetation, soil, landform, relief, drainage etc. Photographic sensors, including black and white photography, appear best suited for bio-physical mapping as they cover the visible and near-infrared parts of the electromagnetic spectrum, and besides provide important relief informaiton. The results of this study, as well as earlier studies by Tarnocai (1972) and Thie (1972) in the boreal zone, show that colour infrared generally provides the best imagery for interpretation. Colour compensating filters may be added to modify the characteristic curves of the colour infrared film material. Results of the present study suggest that colour compensating film may be desirable to add to the normal W-12 filter. In areas where little reflection is expected in the infrared portion of the spectrum, such as in the Arctic, a blue filter, CC20B, can accentuate vegetation. In subarctic and boreal forested areas the shift of the characteristic curves towards the infrared should be minimized or avoided. A magenta coloured compensating filter may be considered or none should be used with a W12 filter.

The use of line scanners for bio-physical surveys has limitations. Basically they measure a narrow section of the electro-magnetic spectrum. One can almost design a scanner to measure the spectral characteristic of the parameter of interest. However, as it is necessary to register a multitude of parameters, multi-channel scanners would be required. To maximize the result of this multi-band data, computer analysis is required. Unfortunately, however, scanners do not provide the relief information so essential for delineating land types.

Results of this study indicate that when bio-physical surveys in northern areas are carried out by the photo-interpretation method, they benefit significantly from the use of colour infrared photography. The most essential element is a 2443 film in a 23 x 23 cm survey camera operated at high altitude. Selected parts of the area under survey may be covered at low altitude (about 3,050 m AGL) by a survey camera with at least two additional 70 mm cameras. One of the cameras should have a colour film to provide satisfactory water penetration, and a colour infrared film with a W12 filter supported by a colour-compensating filter. The selection of a colour-compensating filter should be based on the type of vegetation likely to be photographed. For areas with sparse vegetation, a CC-B filter is recommended; for areas with heavy vegetation, a CC-M filter or even no CC filter is recommended. Additional film-filter combinations can be used, but they do not appear as useful for differentiation of the land-vegetation complex. Thermal-scan support for the low-altitude flights is desirable, preferably with simultaneous groundcontrol and the support of a radiometer (e.g. PRT - 5).

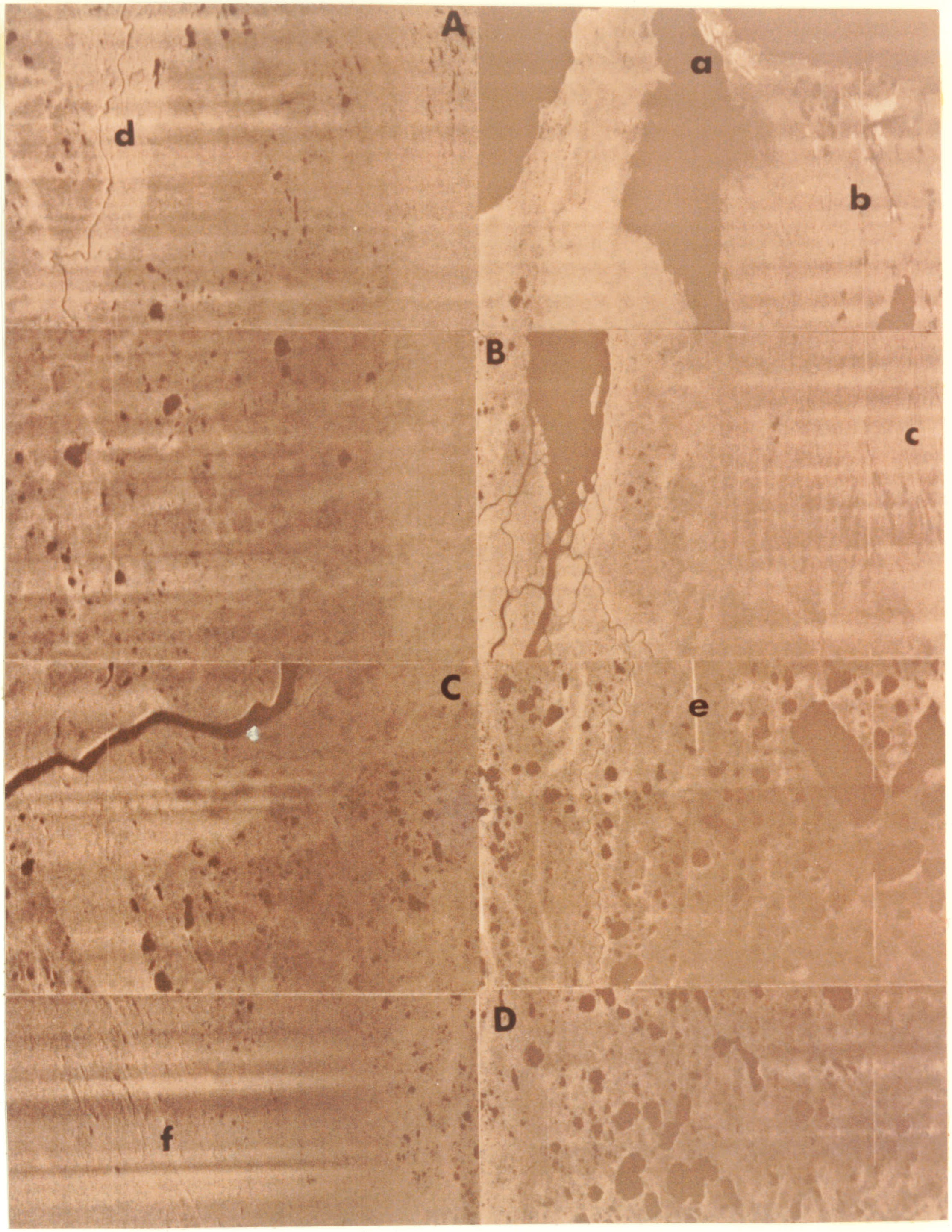

Plate 8: Side-looking Airborne Radar imagery in the Churchill area (3050 m AGL). (a) the harbor facilities of Churchill; (b) the runway of the airport; (c) peat plateaus just south of Churchill (see fig. 7); (e) the Hudson Bay Railway through wet-patterned fen areas near Lovett Lake; (f) the beach lines in the southern part of the map sheet. The left column is the left side scan; the right column is the right side scan.

Satellite Remote Sensing

By using the overlay capabilities of the Canada Geographic Information System (CGIS) of the Lands Directorate, Department of Environment, Ottawa, the interpretative results were compared as explained earlier (page 17). Four different maps and legends were put into the CGIS:

Map I:	1:1,000,000	LANDSAT visual interpretation. (Appendix C).
Map II:	1:250,000	LANDSAT visual interpretation of detailed test areas. (Appendix B).
Map III:	1:250,000	Land districts map (Plate 3).
Map IV:	1:250,000	Base information, based on detailed interpretation of aerial photographs and field sampling (Appendix E).

Maps I and II are compared with the base information. The results of these overlays are shown in Tables 1, 2, 3 and 4 and map V (Appendix G). A large amount of computer output is generated in the comparison of each land system on maps I and II and the base information map IV. A sample of the computer output of such comparison is given in Table 1.

The table lists for land system (543300003) the land types (classes), acreages and percentages that were used to describe the land system using visual interpretation of 1:1,000,000 LANDSAT imagery (Map I). Under Map IV the same information is provided, but now the same land system is described using the information provided by base map IV. The new listing is developed by overlaying the land-system boundary of Map I on top of Map IV; the computer then recalculates the classification by fractioning and summarizing the classes, acreages and percentages of the detailed Map IV units. The two right hand columns show respectively the differences in percentages for the individual classes and for the class groupings. The right hand columns are summarized and show that 53.5% of this land system is misclassified when individual classes are considered, and only 24.9% by class groupings. The summary also shows that in this land system most of the 53.5% results from confusion between closely related classes, mostly within class groups.

In table 2, the classification results for all land systems on Map I are summarized in the left series of columns, the results for all land systems on Map IV in the centre. The right hand columns display the difference. For example, 19% of the total study area is classified as A_3 (polygonal plateaus) using visual satellite interpretation (Map I). Using photo interpretation

Table l: Computer Generated Overlay Results

	MAP I			MAP IV			difference		
LANDSYSTEM 543300003	CLASS	AREA	%	CLASS	AREA	%	AREA	%	%
	A3	31593	60	A1	3888	7	3888	7	A 3.0
				A3	16629	32	-14964	-28	
				A31	12670	24	12670	24	
				B1	600	1	600	1	
	B2	10531	20				-10531	-20	B -18.9
				C2	4007	8	4007	8	C 7.6
				D1	104	0	104	0	D 6.3
				D2	174	0	174	0	
				D3	791	2	791	2	
				D5	2225	4	2225	4	
	E1	10531	20	E1	7354	14	-3176	-6	E -6.0
				G1	1501	3	1501	3	G 6.0
				G12	523	1	523	1	
				G2	1133	2	1133	2	
				O2	214	0	214	0	O 1.6
				O3	644	1	644	1	
				P1	196	0	196	0	P 0.4
				TOTAL	52655	100		53.5	24.9

In this example of computer generated overlay results, Map I and Map IV, the land system (no 543300124) is described by two columns with classes. The left one shows the method to be tested (Map I) right column shows the "true" classification based on (Map IV).

17% of the area was typed as A_3. The difference is -2% (IV-I) that is to say on Map I, A_3 is over-classified by 2%. Similar summary tables were prepared for each of the Land districts within the study area.

The number of map units identified by the different techniques can be used as an indication of the relative level of detail of each of the maps. For example, Map I has 149 land systems averaging 22,761 acres. Map IV has 700 land system units averaging 4,585 acres. The detailed satellite interpretation has 167 land systems for three areas covering about 25% of the total map-area with an average size of 5,928 acres. Thus, the detailed satellite interpretation (Map II) provides information of similar nature and detail as the detailed photo interpretation (Map IV).

Visual satellite interpretation.

1:1,000,000 LANDSAT Visual Interpretation. Map V (Appendix G) shows the classification results for each of the land systems as compared with the base. The percentages in the map units identify the amount of misclassification for each land system when Map I is compared (overlaid) with Map IV. The bottom number, gives the weighted sum (based on acreages) of the misclass-

Table 2: Summary Classification of Maps I and IV

OVERLAY (1)

TOTAL AREA	CLASS	AREA	# OCCUR	%
3211274				
	A1	62338	10	2
	A2	23334	5	1
	A3	617281	43	19
	A4	192191	19	6
	A5	22377	1	1
	B	1634	1	0
	B1	27320	9	1
	B2	96477	19	3
	B3	116349	23	4
	C1	2645	1	0
	C2	69390	17	2
	C3	49304	14	2
	D1	99160	29	3
	D2	158720	41	5
	D3	32441	8	1
	E	3997	1	0
	E1	274593	33	9
	F1	39362	8	1
	F2	36049	7	1
	G1	282914	31	9
	G2	394757	48	12
	G3	20470	4	1
	G4	185	1	0
	G5	889	1	0
	H1	1285	2	0
	H2	25876	13	1
	I	45805	5	1
	M1	39960	10	1
	M2	64917	9	2
	M3	616	1	0
	M4	719	1	0
	N1	22213	6	1
	N2	28351	8	1
	N3	2242	1	0
	O1	27013	12	1
	O2	52315	19	2
	O3	2027	2	0
	P1	46108	10	1
	P2	21359	5	1
	P3	7598	5	0
	R1	3696	4	0
	Z	194998	1	6
	TOTAL	3211274	488	100

OVERLAY (IV)

CLASS	AREA	# OCCUR	%
A1	150277	467	5
A2	35082	92	1
A3	544906	764	17
A31	185215	447	6
A4	13191	45	0
A5	1991	2	0
B1	76807	406	2
B2	8577	76	0
B3	39569	171	1
B5	10560	14	0
C1	72429	388	2
C2	125541	637	4
C3	20948	130	1
C4	3806	14	0
D1	34030	224	1
D2	61739	306	2
D3	73994	314	2
D5	86566	333	3
D12	1227	3	0
E1	334501	637	10
E12	45829	45	1
E2	14605	51	0
E3	11797	47	0
F4	11508	56	0
F1	27962	158	1
F2	15969	61	0
F3	3796	42	0
G	154	2	0
G1	261969	591	8
G12	18473	63	1
G2	362456	712	11
G22	21000	50	1
G3	523	3	0
H1	1891	16	0
H2	4368	37	0
H31	1264	1	0
I	4115	40	0
I2	2921	10	0
M1	62121	196	2
M2	22070	118	1
M3	2687	26	0
N1	268	2	0
N2	2717	20	0
O1	7193	68	0
O12	59680	187	2
O11	1318	5	0
O2	25519	154	1
O3	18863	154	1
O5	1025	2	0
P1	34662	255	1
P2	10628	109	0
P3	13070	77	0
R	81	1	0
R1	10736	53	0
Z	245445	56	8
***	161	2	0
TOTAL	3209800	8900	100

DIFFERENCE

AREA	# OCCUR	%
87939	457	3
11749	87	0
-72375	721	-2
185215	447	6
-179000	26	-6
-20386	1	-1
-1634	-1	-0
49486	397	2
-87900	57	-3
-76780	148	-2
10560	14	0
69785	387	2
56151	620	2
-28356	116	-1
3806	14	0
-65130	195	-2
-96981	265	-3
41553	306	1
86566	333	3
1227	3	0
-3997	-1	-0
59908	604	2
45829	45	1
14605	51	0
11797	47	0
11508	56	0
-11401	150	-0
-20080	54	-1
3796	42	0
154	2	0
-20945	560	-1
18473	63	1
-32301	664	-1
21000	50	1
-19947	-1	-1
-185	-1	-0
-889	-1	-0
606	14	0
-21507	24	-1
1264	1	0
-41690	35	-1
2921	10	0
22161	186	1
-42847	109	-1
2071	25	0
-719	-1	-0
-21945	-4	-1
-25634	12	-1
-2242	-1	-0
-19820	56	-1
59680	187	2
1318	5	0
-26796	135	-1
16835	152	1
1025	2	0
-11446	245	-0
-10731	104	-0
5473	72	0
81	1	0
7041	49	0
50447	55	2
161	2	0

This summary table of Map (I) and Map (IV) showing classification for total mapsheet and the difference.

ification for individual classes or land types (A_1, A_2, A_3, B_1, B_2 etc.*). The top number gives this weighted sum of misclassification for groupings of the individual classes (A, B, C, D etc.*) for that land system. Misclassification for each class or group of classes is based on the areas of omission per class or per group of classes by land system as a percentage

*Classes or land types A_1, A_2, A_3,.......B_1, B_2,.....etc. and groups of classes A, B, C, D,.........,Z are described in the classification legend, Appendix G.

of land system area, e.g.:

$$\frac{100 \times (\text{CLASS Y acreage (Map IV)} - \text{CLASS Y acreage Map (I)})}{(\text{land system acreage})} = \%\ \text{of omission for Y}$$

and

$$\text{Land system misclassification} = \frac{\Sigma\ |\%\ \text{of omission (A), (B), (C),...(Z)}|}{2}$$

As shown by the bottom numbers on Map V, Appendix G, the amount of misclassification arising from visual interpretation of individual land types of classes at the 1:1,000,000 scale of LANDSAT is excessive in most areas. The best land system has 21% misclassification. Only 11 of the 149 land systems have better than 35% misclassification. This indicates that the land type legend used for visual interpretation is too complicated for this method as it causes excessive classification errors. Simplifying the legend by joining land types into groups of classes (A,B,C, etc.) increases classification accuracy significantly (Top number Map V, Appendix G) to the extent that 58 of the 149 units have acceptable classification results. Map V shows that relatively large amounts of misclassification occur in the smaller and more complex land systems.

Before interpreting the results, consideration should be given to misclassification introduced as a result of generalizations during the delineation and classification of land systems. At least two types of generalizations may influence the results of this study:

(i) the area estimation of classes into 10% intervals

(ii) the usual desire in cartography and classification to keep the units and symbols as simple as possible.

The first type (i) may cause a maximum of 25% misclassification for a 10-class unit or 5% at most for a two-class symbol. However, land systems containing more than 5 classes seldomly occur and 2 - 4 are most common. Therefore, this generalization error may contribute 10% at most. The second type causes the deletion of classes with less than 5% areal extent and may cause the disappearance of slightly larger percentages, especially in smaller land systems in which cartographically only one or two land types can be labelled. The 'freed' percentages are usually added to the class that is ecologically closest to them. To test the importance of this 'generalization error' a random sample of 25 land systems was drawn from the total population of 149.

For each land system the 'true' classification based on Map IV (table 1) was generalized into 10% intervals. Small percentages were assigned to other classes or grouped, similar to the 1:1,000,000 visual LANDSAT interpretation. Then the land system data from Map I was compared with this generalized 'true' classification. The sample showed that the average misclassification error introduced as a result of these two types of generalizations is about 4.1% with a standard deviation of 3.9%.

Map V (Appendix G) lists the misclassification percentage for each land system and illustrates a relationship between physiographic complexity and the amount of misclassification. The greatest amount of misclassification is found in areas where mineral deposits occur. While peat-dominated areas, such as the peat plateaus in the southwestern part of the map area, have relatively good classification results (5-20% misclassification), till-dominated areas nearby in land region 2 are misclassified by as much as 90%. However, mineral soils in land region 1 are significantly better classified (about 30% misclassification). The condition could possibly arise from the relative lack of vegetation and the lack of vegetation disturbance in the area; therefore, it produces less confusion for interpretation. Map V also shows that higher amounts of misclassification are associated with the coastal zone and with some drainage and beach systems.

To study these physiographic aspects in more detail the computer comparison of Map I and IV for the land districts and the total map area is summarized in Table 3. Listed are:

(i) the omission per class group (A, B, C,...Z) as a percentage of the class group.
(ii) the omission per class group as a percentage of the district and map sheet.
(iii) the actual area of the class group as a percentage of the district.
(iv) the actual area of the class group as a percentage of the map-area.

The percentage of <u>misclassification (A)</u> is calculated by adding the absolute values of (ii) and dividing by two.

The classification results per land district and map area in this summary table are significantly lower than those identified for the separate land systems (Map V, Appendix G). Apparently errors are cancelled out in the summation process. For example in the Mack Lake District, misclassification (A) is 10.1%, while Map V shows that most land systems in this district have significantly higher amounts. To obtain a more accurate indicator, the classification performance for each land system was weighted according to acreage and summarized; it is called misclassification (B).

$$\text{misclassification } B = \frac{\Sigma[\text{misclass. (A) for each land system} \times \text{acreage}]}{\text{Land district acreage}}$$

To interpret this data the error introduced by generalization should be considered as discussed and *about 4% should be subtracted* from the misclassification (B) results. In addition, both types of misclassification were adjusted for the N-O difference. During interpretation of the LANDSAT imagery it was speculated that a distinction between N (loamy till) and O (sandy till) could be made. However, during the preparation of the photo-interpretation base map, this proved incorrect and N and O are grouped into one class: O. Therefore, for proper comparison N and O should be added in Tables 3 and 4.

Table 3 shows that the Coastal and Knife Rivers Districts have the poorest classification results, followed by the transition zones of Districts (2B-1A) and (1B-1C). All three areas are physiographically complex. The relatively simple 'Mack Lake' district has the best classification performance: misclassification (A) is 10.1% and misclassification (B), 18.8%. About 74% of this district is composed of peat plateaus. These are only 3.4% over-classified, mainly at the cost of sedge-dominated areas (class B) which as a result of generalization are consistently underclassified.

The Lofthouse-Lovett Lakes District and the Seal River District perform equally well on a land system basis, in spite of the fact that the Seal River area contains a significant proportion of mineral deposits (39% M and O). In both districts peat polygons represent a large part of the unit (between 30 and 50%) and are consistently well-classified. In the Seal River District the classification of patterned fens and stone fields is reasonably satisfactory (34% omission). In the latter, it is thought that the lack of vegetation on M has helped to identify the land types. Considerable confusion with O (till areas) is expected, as classes M_2 and M_3 include parts of O.

Peat plateaus (G) are well classified in all of, and D and E in part of, the Lofthouse-Lovett Lakes District. There appears to be confusion between B, E and C; all three groups contain overlapping land types. For example, B_2 is a sedge wetland with partly patterned features and B_1 is a sedge-tamarack fen, which can easily be confused with E_2 (patterned sedge fens) or E_4 (patterned sedge fens with tamarack). The Lofthouse-Lovett Lakes District is the largest in the map area, covering about 58.6%. It contains three distinct zones as shown in Table 3 and Plate 3. The average percentage of misclassification (B, N/O adjusted) is 36.6%. The transition zone in the southwest has the best results (misclassification B: 31.8%) and the coastal zone transition has the poorest (misclassification B: 39.2%).

The Knife Rivers District has the second highest rate of misclassification. About 54% of this area is comprised of mineral deposits or organic veneers covering mineral soils. Although the peat polygon and peat plateau classification is quite good, significant confusion occurs between O (till areas) and D (spruce dominated peat areas) and especially between moist-to-wet tills with a thin layer of organic (O_2) and bog veneer areas (D_5). In both land types, an open black spruce forest occurs with similar ground cover. In airphoto interpretation, the separation is based on relief conditions and the relative density of the tree cover. From satellite images, relief cannot be interpreted and only with great difficulty can such slight density changes be differentiated.

The Coastal District has the poorest results. Only peat polygons, (A), tills, (O) and peat plateaus (G) were identified reasonably accurately. Part of the poor performance is caused by the confusion between Z (water) and I (mud flats). Water was underestimated by 13% while (I) was overestimated by 10.6%. This situation is partly due to the mud flats being delineated from LANDSAT imagery at low tide.

By comparing the percentages of misclassification (A) with misclassification (B), an impression of the importance of the cancelling out of errors is obtained that is introduced by summarizing class acreages on a land district or map-sheet basis. The average cancelling out of errors is about 18.9% by district. Only an additional 5% is caused by summarizing the total

BY DISTRICTS

CLASS	TOTAL MAPSHEET			MACK LAKE DISTRICT (2A)				KNIFE RIVERS DISTRICT (2B)				TRANSITION DISTRICTS 2 and 1				SEAL RIVER DISTRICT			
	omission as % of class	omission as % of area	total of class as % of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map
A	1.4	0.4	29.0	-6	0.0	1	0.1	23	2.6	11	0.3	19	5.4	28	0.8	19	7.7	40	3.4
B	-78	-3.3	4.2	98	8.3	8	1.0	69	1.8	3	0.1	100	0.0	0	0.0	75	0.9	1	0.1
C	46	3.2	6.9	100	0.8	1	0.1	100	1.9	2	0.0	59	4.7	8	0.2	-74	-4.7	6	0.5
D	-13	-1.0	8.0	10	1.3	13	1.6	84	26.6	32	0.7	48	5.4	11	0.3	-144	-5.3	4	0.3
E	33	4.4	13.0	5	0.0	0	0.0	-51	-0.7	1	0.0	7	0.4	5	0.1	-34	-2.2	6	0.5
F	-139	-0.9	1.5	-	-	-	-	-	-	-	-	100	0.4	0	0.0	+100	0.1	0	0.0
G	-5	-1.1	20.7	-11	-8.4	74	8.6	8	2.3	29	0.6	-1685	-3.2	2	0.0	-	-	-	-
H	-261	-0.6	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
I	-551	-1.2	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	-22	-0.6	2.7	-	-	-	-	-42	-0.6	1	0.0	26	5.1	20	0.6	-34	-8.0	23	2.0
N	-1669	-1.6	0.1	-	-	-	-	*	-4.0	-	-	*	-37.9	-	0.0	*	-3.2	-	-
O	28	1.0	3.5	-9	-0.3	2	0.3	-119	-22.2	19	0.4	75	16.2	22	0.6	70	11.0	16	1.3
P	-29	-0.5	1.8	-199	-1.0	1	0.1	-427	-7.8	2	0.0	100	2.1	2	0.0	100	2.9	3	0.3
R	66	0.2	0.3	-	-	-	-	100	0.1	-	-	100	1.3	1	0.0	100	0.7	1	0.1
Z	21	1.5	7.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS			99.7			100	11.8			100	2.1			100	2.6			100	8.5
% misclassification (A)		10.8			10.1				35.3				41.1				23.4		
% misclass. A (n/o adjusted)		9.8			10.1				35.3				24.9				20.2		
% misclassification (B)		35.3			18.8				52				64.9				35.1		
% misclass. B (n/o adjusted)		34.0			18.8				52				46.2				32.2		

CLASS	LOFTHOUSE - LOVETT LAKES DISTRICT												COASTAL DISTRICTS			
	TRANSITION 1B and 2A&B				DISTRICT 1B				TRANSITION (2) and 1C							
	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map	omission % of class	omission % of district	% of district	% of map
A	11	3.4	30	3.6	-4	-2.0	49	18.2	-6	-1.5	27	2.6	22	0.3	1	0.1
B	-188	-3.0	2	0.2	-336	-8.5	2	0.9	-21	-1.8	8	0.8	-59	-6.9	12	1.2
C	100	4.3	4	0.5	61	5.2	8	3.2	30	+3.5	11	1.1	.41	5.3	13	1.3
D	-63	-8.3	13	1.6	0	0.0	7	2.5	-25	-1.2	5	0.5	-57	-3.3	6	0.6
E	85	5.1	6	0.7	26	6.5	25	9.7	65	11.6	18	1.7	91	4.0	4	0.5
F	-	-			75	0.1	0	0.0	-123	-2.1	2	0.2	-57	-7.1	12	1.3
G	-0.6	-0.3	39	4.7	-3	-0.1	4	1.7	-40	-9.8	24	2.3	35	9.5	27	2.7
H	100	0.3	0	0.0	94	0.0	0	0.0	-109	-0.9	1	0.1	-549	-5.6	1	0.1
I	-	-	-	-	-	-	-	-	-	-	-	-	493	-10.6	2	0.2
M	-	-	-	-	-100	-0.2	0	0.1	-100	0.3	0	0.0	100	0.0	0	0
N	-	-	-	-	68	0.2	0	0.1	*	-0.7	-	-	*	-1.3	-	-
O	85	1.0	1	0.1	-9	-0.1	2	0.6	44	0.4	1	0.1	19	0.2	1	0.1
P	-55	-2.4	4	0.5	-81	-1.3	2	0.6	100	0.9	1	0.1	70	1.5	2	0.2
R	-	-	-	-	100	0.0	0	0.0	100	0	0	0.0	5.6	1.5	2	0.2
Z	-	-	-	-	-	-	-	-	100	1.3	1	0.1	81	13.0	16	1.6
TOTALS			100	11.9			100	37.2			100	9.5			100	10.2
% misclassification (A)		14.1				12.1				18.6				35.3		
% misclass. A (n/o adjusted)		14.1				12.0				18.2				35.1		
% misclassification (B)		31.8				37.4				39.2				59.1		
% misclass. B (n/o adjusted)		31.8				37.4				39.2				59.1		

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Table 3: Summary of misclassification (A) and misclassification (B) per land district and for the total map area based on the results of the visual interpretation of 1:1,000,000 Landsat imagery.

map-area, and it may indicate that detailed description and classification using satellite data gives more accurate results showing more promise for land district than for land system mapping. Because of the cancelling out of errors the land district results in areas physiographically similar to the study area may range from 8-25% better than land-system classification by satellite. This hypothesis, however, has not been tested adequately in this study.

The summary column in Table 3 shows that the misclassification (B, N/O adjusted) for the total map-area is 34.0%. Considering a generalization error of about 4%, the misclassification for the total map sheet is 30%. Thus, on a map-sheet basis visual interpretation of 1:1,000,000 LANDSAT may be of practical value for areas which have a similar or simpler physiographic and ecologic complexity. Table 3 shows that classes A, D, G, M, O, P, Z and, to a lesser extent, E perform well. Of these, only A (peat polygons) and G (peat plateaus) perform consistently well throughout all districts. Of the land types, A_3, E_1, G_1 and G_2 gave the best classification results on a map sheet and district basis.

The above comparison of the 1:1,000,000 map and classification with the base information does not provide an adequate assessment of the accuracy of the mapping lines of the land system. For this purpose a visual analysis was made of a colour-coded base map and the satellite interpretation map (I) enlarged to 1:250,000 scale (Appendix C). It was found that about 10-15% of the land system lines corresponded relatively closely to the base. About 30% differed significantly from the base data. About 20-30% of the lines could have been improved to provide a closer match with the base data. The subjective visual analysis showed results similar to the computer overlay on land type and system performance.

1:250,000 scale LANDSAT Visual Interpretation. Table 4, showing the classification results for the Mack Lake, Seal River and Lovett Lake test areas, is similar in composition to Table 3. From the results of misclassifications (A) and (B), the detailed interpretation clearly does not compare well with the results of Map I based on 1:1,000,000 LANDSAT interpretation. In the Mack Lake test area, misclassification (A) is more than double that of the total Mack Lake land district. Only class G (peat plateaus) and P (beaches) are well classified. B, D, A and O perform considerably less well. The increase in accuracy for (P) can be explained that at the more detailed level, narrow beachlines and irregular glacio-fluvial deposits can be delineated more accurately. In the Seal River test area, the overall classification performance is 18% poorer than for the land district of the same name, though classes A, C, D and M are well classified. In fact, these classes perform better than on Map I, but difficulties associated with B, E and O lower test-area results. B and E especially appear to be confused.

In the Lovett Lake test area, classes B and E are also confused. B is 36.3% overclassified and E is 34.4% underclassified. The reason for this confusion was explained earlier: i.e. the overlap between the sedge-fen land types (B) with patterns (B_2) and tamarack (B_1) which can readily be confused with E_2 or E_4. This confusion increases misclassification by 21% in the Seal River area and 34.4% in the Lovett Lake Area. In fact, E is not used on Map II. The reason may be a change in the application of the legend resulting from a long-time interval between the interpretations of Maps I, II and IV. Also, the 1:250,000 scale satellite interpretation provided more detail than the base Map IV in the E-dominated areas although for all other classes the reverse is true. As both Map I and Map IV show the successful use of E, and, as the interpretation for Map II is carried out between Maps I and IV, it is logical to assume that adjustments should be made while interpreting the results. With adjustments for B and E (i.e. joining the two classes) the misclassification figures change significantly (Table 4).

If we incorporate the B/E adjustment into the results for Map I, the 1:1,000,000 satellite interpretation, the results are close for the Seal River and Lovett Lake test areas and their respective districts: 18.9% versus 19.3% and 7.1% versus 5.5%.

By comparing Map II (detailed) and Map I (small scale results), the Map I results are clearly equal or better than Map II results. Although delineation of a land system at the detailed scale is more accurate, it is not matched by a similar increase in classification accuracy. The interpretation time involved for Map II is only slightly less than that required for interpretation of aerial photographs. The satellite interpretation at the 1:1,000,000 scale takes considerably less time: about 15-20 hours for the total map sheet;

CLASS	MACK LAKE			SEAL RIVER			LOVETT LAKE		
	omission as % of class	omission as % of area	total of class as % of area	omission as % of class	omission as % of area	total of class as % of area	omission as % of class	omission as % of area	total of class as % of area
A	-408	-16.0	3.9	25	9.5	38.0	16	6.6	41.8
B	-43	-2.2	5.3	-1592	-33.5	2.1	-520	-36.3	7.0
C	-371	-5.4	1.4	19	2.0	10.7	-157	-4.4	2.8
D	54	6.2	11.5	7	0.2	3.4	9	0.1	8.5
E	100	0.5	0.5	100	21.0	21.0	100	34.4	34.4
F	-	-	-	-292	0.2	0.1	31	0.3	0.9
G	+20	14.8	73	-8756	-2.8	0.0	-14	-0.5	3.8
H	-	-	-	-	-	-	-	-	-
I	-	-	-	-	-	-	-	- 0.2	-
M	-	-	-	-11.0	-1.6	15.0	-	-	-
N	-	-	-	-1126	-3.9	0.3	-	-1.3	-
O	70	1.1	1.5	100	8.0	8.0	100	0.5	0.5
P	3.5	1.0	2.9	100	0.7	0.7	100	0.0	0.0
R	-	-	-	100	0.5	0.5	-	-	-
Z	-	-	-	-	-	-	100	0.3	0.3
Total	na		100	na		99.8	na		100.0
% misclassification (A)		23.6			41.8			42.6	
% misclass (A-n/o adj)		23.6			37.9			42.1	
% misclass (A-n/o- B/E adj)		23.1			16.9			7.1	
% misclass (B-n/o adj)		38.2			49.8			54.5	
% misclass (B-n/o- B/E adj)		38.2			33.4			26.2	

Table 4: Summary of classification results for the three test areas based on the results of 1:250,000 scale visual satellite interpretation.

photo interpretation for the same area took between 75 and 90 hours. This time-factor makes the land-system analysis from detailed satellite photographs ineffective compared with conventional airphoto interpretation. The small scale satellite interpretation may be a realistic alternative for physiographically similar areas, when no adequate photo-interpretation time is available. This situation could usually exist if large areas, e.g. in the order of 10,000-100,000 sq. miles required a preliminary inventory within a period of a year. A land system analysis at the 1:250,000 to 1:500,000 scale is possible from satellite imagery providing the area involved is ecologically and physiographically simple. Thus, most of Canada would be eliminated with applications restricted mainly to arctic and subarctic areas, and the large wetlands of the boreal zone. Possibly, land district description can successfully be done in a wider range of physiographic conditions in Canada, while delineation of land districts, not including accurate description, can be done for all of Canada.

Automated Satellite Classification. There are two different approaches to automated classification: supervised and unsupervised. Each was applied to single- as well as multi-date satellite imagery. LANDSAT I tapes RSØ198 and RSØ35 were used; moreover, summer and winter data are combined using band 7 or RS2863 (30 October, 1972) and bands 5, 6, 7 or RS2940 (27 July, 1972).

Supervised automated classification: In supervised classification the interpreter selects the objects to classify, and identifies training areas for the computer. In this study the objective was to identify as many land types of the legend described in Appendix B as possible. Training areas were selected across the whole image by available ground control and photo-interpretation. This procedure allows the selection of relatively large, pure and representative sites for the respective land types. Classification was carried out using the CCRS computer, MAD (Multi-spectral Analyser Display) and the MICA interpretation package, developed by scientists at the Canada Centre for Remote Sensing. Training areas were delineated with a software cursor. The computer then analysed reflectance intensity values in the four spectral bands and calculated statistics of the sample. The computer compatible satellite tapes used for the automated classification were corrected radiometrically.

Fig. 2 shows the correlation between the intensities of bands 6 and 5 for a number of land types, and the overlap existing between the reflection intensities of these land types. To reduce the overlap and increase the success of the classification, training data were modified using confusion, divergence and other class statistics as guides (Table 5). For the classification, the Maximum Likelihood Decision Rule was used in all evaluations, as implemented on the CCRS computer. After about 15 iterations of training, displaying, classifying and analyzing training statistics, a final trianing set evolved. This set, inlcuding water, represents 10 different class groups. It was not possible to produce class groups identical to the groupings identified in the classification legend of Appendix B.

Table 6 shows the divergence and confusion matrix for the class statistics, and the final set. An increase in the number of classes was

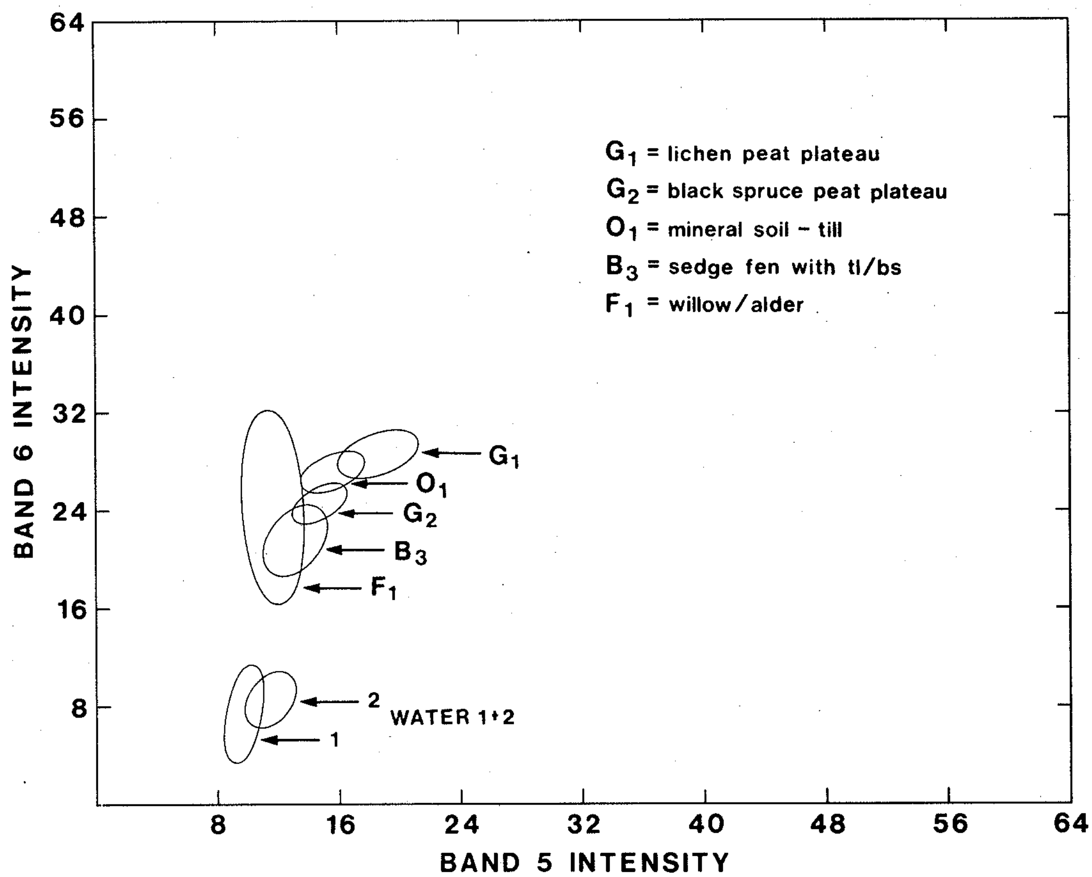


Figure 2: Correlation between the intensities of band 6 and band 5 for five land types and water.

found to increase confusion and to give less satisfactory results. Initially, in the training process, an attempt to show land types (A_1, B_1, B_2, C_3, etc.) was tested, but confusion between land types made it impossible at that level of detail. For the final classification the following groups of classes were used:

Class 1 - sedge, with tamarack and occasional black spruce, includes B (B_1, B_2, B_3) and possibly C_1; colour - light blue.

Class 2 - open black spruce, includes all D, C_1, C_2, G_2, G_3, G_4, O_1, O_2, O_3, P_2 and N; colour - green.

Class 3 - stonefields, includes M_1, M_2, M_3 and possible O, N and R; colour - red.

Class 4 - willow-alder-birch, includes F_1 and C_3; colour - orange.

Class 5 - water, colour - blue; also most black (unclassified) would fit in water class.

Class 6 - peat plateaus, includes G_1 and H_1; colour - brown.

Class 7 - peat polygons, includes A_1, A_2, A_3, A_{31}, A_4, A_5, A_6 and partly E_1; colour - yellow.

Class 8 - lichen-covered sands, includes P_1, P_2, O_1 and N_1; colour - pink.

Class 9 - patterned fens, includes all E's and possibly B_2 and C_1; colour - grey.

Through continuing 'trial and error' training it may be possible to add one or two more classes to this list. However, the number of classes that can be separated does not approach the 43 that are identified using interpretation of 1:100,000 scale, black and white aerial photographs.

The confusion matrix (Table 5) shows that within the training areas class separability is quite satisfactory. Sedge fens and patterned fens are most confused (10%) and peat plateaus are mixed with lichen-covered sands and stone fields as the M_2 (stone fields) may have inclusions of till with a lichen cover. While all classes, particularly class 2, include a wide range of land types, 'open black spruce' combines land types which are significantly different. Because of similarity in tree cover, class groups such as D, G, C (organic areas), O (till areas) and P (glacio-fluvial and marine deposits) are included in this class. Unsupervised classification (discussed later), shows that only C could be separated from the other components.

Table 6 shows the divergence and confusion matrix for the same set of classes when 'bedrock' is added. This new class is confused with stone fields, lichen-covered sands, and slightly with patterned fens. Although this new class covers only 0.3% of the total area, misclassification because of the introduciton of this class is probably 0.8% of the total area. This latter percentage was obtained by multiplying the confusion increase in percentages with the total acreage of the class (Table 2). Fewer classes improved the matrix (Table 7); the patterned fen class is deleted.

The three training sets discussed above were used to classify some

DIVERGENCE MATRIX

CLASS	1	2	3	4	5	6	7	8	9
1	0.00								
2	15.78	0.00							
3	29.71	80.78	0.00						
4	69.29	24.64	105.96	0.00					
5	255.62	343.49	305.87	776.03	0.00				
6	51.28	77.46	30.56	130.40	612.99	0.00			
7	64.68	90.33	45.13	160.84	809.39	18.54	0.00		
8	54.83	130.89	32.09	267.86	531.33	8.68	37.20	0.00	
9	6.56	42.06	17.60	122.87	311.42	32.30	33.39	38.17	0.00

CONFUSION MATRIX

Chosen Class / True Class	1	2	3	4	5	6	7	8	9
0	0	0	0	0	0	0	0	1	0
1	89	3	0	0	0	0	0	0	10
2	1	96	0	0	0	0	0	0	0
3	0	0	94	0	0	0	0	5	2
4	0	1	0	100	0	0	0	0	0
5	0	0	0	0	100	0	0	0	0
6	0	0	0	0	0	89	5	5	0
7	0	0	0	0	0	3	95	2	1
8	0	0	1	0	0	8	0	86	0
9	10	0	5	0	0	0	0	1	87

MEAN SPECTRAL INTENSITIES

Class	Band 4	5	6	7
1 - sedge-bs/th	15.4	13.0	19.6	11.7
2 - open black spruce	14.8	11.1	21.9	12.9
3 - stonefields	18.3	16.2	21.1	11.1
4 - willow - alder-birch	14.9	10.5	27.5	18.3
5 - water	13.2	9.2	7.1	0.9
6 - peat plateaus	19.1	18.4	27.9	17.7
7 - peat polygons	17.5	17.4	25.7	17.3
8 - lichen/sand-till	20.5	19.5	27.7	16.8
9 - patterned fens	16.7	14.7	21.2	12.6

Table 5: Divergence and Confusion matrix and means statistics for the "final" training set.

of the test areas. Plate 9 shows examples of the classification results for the Seal River test area. C is the best; it represents the results of the final training set. B relates to Table 7; here the deletion of the patterned fen class has changed the results for the sedge areas (light blue), but it has increased the area classified as stone fields (red) and thereby caused overclassification. *Although the confusion matrix has not changed for the other classes, the actual classification has.* The original patterned fen pixels are added to the stone fields, to the peat polygons (yellow) and to the sedge areas (light blue). These changes can easily be seen when images B and C of Plate 9 are viewed simultaneously with a pocket stereoscope.

Most of the satellite images were classified with the final training set. Eighteen areas, each with a size of 500 pixels by 500 lines, were classified and the results reproduced in a hard colour copy using the EBIR at the Canada Centre for Remote Sensing and made into a mosaic (Appendix E). These results were compared with the base map (Map IV; Appendix F). However, this was done visually as it is not yet possible to overlay the geometrically-distorted digital classification data on the base map using the CGIS . Also, the classification program at the CCRS does not permit the use of test areas to calculate the classification results quantitatively. Assessment of the results on a pixel by pixel basis or by the use of transects was rejected because of the difficulty in exactly locating the pixel on the ground and the complex nature of most pixels in natural areas. Instead, a subjective evaluation was chosen that examined the automated classification results in the different land districts and assessed the amount and nature of the misclassification. The mosaic with digital classification results was compared carefully with the base map (IV) and available aerial photographs. Each class was evaluated on a land district basis and classification results expressed as follows:

(1) very poor
(2) poor
(3) imperfect
(4) satisfactory
(5) good
(6) very good

Table 8 shows the results of this evaluation. The ratings only identify the classification accuracy of the different classes in the training set. Whether the particular class itself is satisfactory is not considered. Table 8 shows that the overall performance of the classifier is satisfactory. Best results (70%) are achieved in the Mack Lake, Knife Rivers and Seal River districts, possibly because these districts have seven or fewer classes. The Lofthouse-Lake district and its transition zones perform uniformly with about 65% classification accuracy. The Coastal Zone has the poorest showing: none of the classes except 'water' and 'willow/alder/birch' perform well.

Table 6

DIVERGENCE MATRIX

CLASS	1	2	3	4	5	6	7	8	9	10
1	0.00									
2	15.78	0.00								
3	29.71	80.78	0.00							
4	69.29	24.64	105.96	0.00						
5	255.62	343.49	305.87	776.03	0.00					
6	51.28	77.46	30.56	130.40	612.99	0.00				
7	64.68	92.33	45.13	160.84	809.39	18.54	0.00			
8	54.83	130.89	32.09	267.86	531.33	8.68	37.20	0.00		
9	6.56	42.06	17.60	122.87	311.42	32.30	33.39	38.17	0.00	
10	31.71	85.42	3.83	148.61	400.07	19.59	23.08	17.70	14.03	0.00

CONFUSION MATRIX

CHOSEN CLASS/TRUE CLASS	1	2	3	4	5	6	7	8	9	10
0	0	0	0	0	0	0	0	1	0	0
1	89	3	0	0	0	0	0	0	10	0
2	1	96	0	0	0	0	0	0	0	0
3	0	0	73	0	0	0	0	0	1	17
4	0	1	0	100	0	0	0	0	0	0
5	0	0	0	0	100	0	0	0	0	0
6	0	0	0	0	0	89	5	5	0	0
7	0	0	0	0	0	3	95	2	1	0
8	0	0	0	0	0	8	0	80	0	3
9	10	0	5	0	0	0	0	1	86	1
10	0	0	22	0	0	0	0	11	2	79

LEGEND:

0 - none
1 - sedge with some bs/th
2 - open black spruce
3 - stone fields
4 - willow - alder-birch
5 - water
6 - peat plateaus
7 - peat polygons
8 - lichen covered sand/till
9 - patterned fens
10 - bedrock

Table 6: Divergence and confusion matrices for the 'final' set plus bedrock.

Table 7

DIVERGENCE MATRIX

CLASS	1	2	3	4	5	6	7	8
1	0.00							
2	15.78	0.00						
3	29.71	80.78	0.00					
4	69.29	24.64	105.96	0.00				
5	255.62	343.49	305.87	776.03	0.00			
6	51.28	77.46	30.56	130.40	612.99	0.00		
7	64.68	90.33	45.13	160.84	809.39	18.54	0.00	
8	54.83	130.89	32.09	267.86	531.33	8.68	37.20	0.00

CONFUSION MATRIX

CHOSEN CLASS/TRUE CLASS	1	2	3	4	5	6	7	8
0	0	0	0	0	0	0	0	1
1	99	3	0	0	0	0	0	0
2	1	96	0	0	0	0	0	0
3	0	0	99	0	0	0	0	5
4	0	1	0	100	0	0	0	0
5	0	0	0	0	100	0	0	0
6	0	0	0	0	0	89	5	5
7	0	0	0	0	0	3	95	3
8	0	0	1	0	0	8	0	86

LEGEND:

0 - none
1 - sedge with some bs/th
2 - open black spruce
3 - stonefields
4 - willow - alder-birch
5 - water
6 - peat plateaus
7 - peat polygons
8 - lichen covered sand/till

Table 7: Divergence and confusion matrices for the 'final' set minus patterned fens.

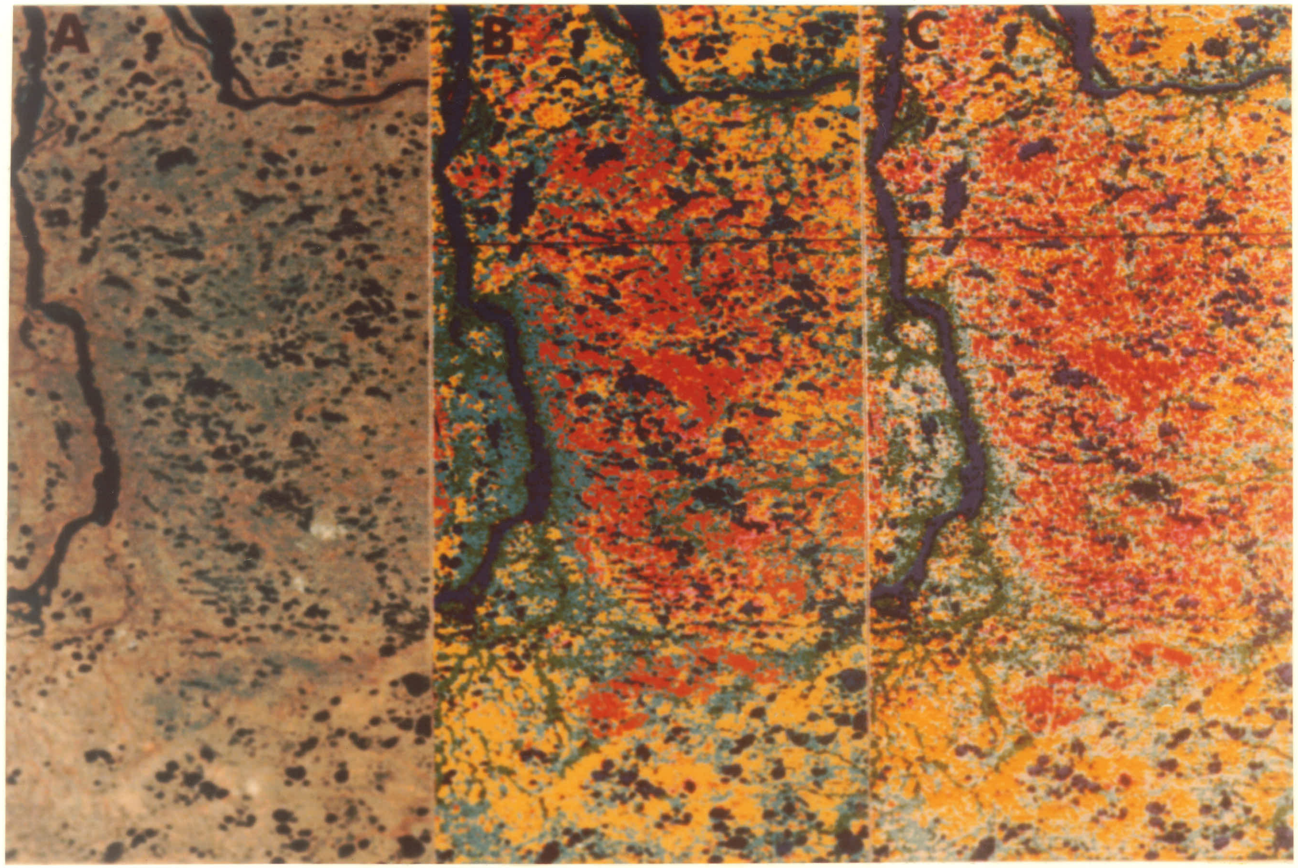


Plate 9: Supervised automated classification in the Seal River area: A is a colour composite satellite image showing a combination of channels 4, 5 and 7; B is the result of a classification using the training set described in Table 6. C is the result of the 'final' set. Blue represents water, red - stone fields, yellow - peat polygons, green - open black spruce, pink - lichen-covered till areas, light blue - sedge-dominated areas and light grey - patterned fens.

On a total map-sheet basis, water is classified well in all areas. This result can be expected as water is seldom confused with any other class (see Fig. 2). Sedge areas (light blue) and patterned fens (light grey) are consistently poorly classified. Sedge areas in the Knife Rivers District are confused with D_5 (bog veneers) and treed phases of O (till). The light blue often occurs as a transition to lichen-covered till areas (Fig. 12 -C1), depressional peat plateaus and tamarack-sedge wetlands. Similar misclassification occurs in the Mack Lake district, but is less obvious. The Lofthouse-Lovett Lakes District is slightly better, but considerable confusion exists with D (spruce peatlands), E (patterned fens) and C (tamarack fens) (Plate 10 -D_2). Peat plateaus, with an open black spruce-lichen cover, are classified well in the area of training (Plate 10-A - brown). Confusion with peat polygons (yellow) is apparent in the same plate. The polygons are much confused with lichen-covered till areas (Plate 10 A, D - pink): the pink is highly over-estimated in the peatlands around D_2 and A_3. The latter covers such a large continuous area that perhaps a thin haze has modified the signatures sufficiently to move the area into the next brighter class. Class 8 (lichen-till/sand) is quite well classified, but it is not useful. The class identifies vegetation accurately, but it correlates very poorly with soil and landform; the pink occurs in peatlands, in polygonal areas and peat plateaus (Plate 10). Stone fields (Plate 10 -E, Red) are classified accurately in areas where they occur, but red also identifies bedrock, muddy lakeshores and dried-up lakes. The 'open black spruce' class performs well, but is not practical as it comprises too wide a variety of conditions; moreover, it can be confused with 'alder/willow', 'sedge-tamarack' and 'tamarack-black spruce' (Plate 10).

As another check on accuracy, the percentages of the different colours generated by the automated classification were estimated and compared with the base data (IV). Comparison was possible by grouping the land-type results (Table 2) into classes as identified on pages 45 and 46. This comparison indicated that about 20% of the total area is misclassified.

Although the classification results cna be described as satisfactory for the total map area, they do not indicate that automated classification

Table 8

CLASS	KNIFE RIVERS DISTRICT (2B)	MACK LAKE DISTR. (2A)	SEAL RIVER DISTR. 1A	LOFTHOUSE-LOVETT LAKES DISTR.			COASTAL DISTR. 1C	TOTAL MAPSHEET
				TRANSITION 1B-2B	1B	TRANSITION 1B-1C		
1 Sedge-bs-tl	1	3	2	3	2	3	1	3-
2 Open black spruce	4*	5	4-	4-	4-	3	3	4-
3 Stonefields	5*	6*	4+	5*	6*	5*	4*	4+
4 Willow/ald/birch	6*	6*	6*	6*	6*	6*	4+	4+
5 Water	5	5	6	5	5	5	5	5+
6 Peat plateaus	4	4+	5*	4	3-4	4+	1	4
7 Peat polygones	5*	2	4	3	4	2-3	2	4-
8 Lichen-sand-till	4-	4	4+	4-	3	2	3	3+
9 Patterned fens	6*	6*	2	3	2	3	1	3-
10 Unclassified	5	3	5	2	3	5	4	4
All Classes	4	4+	4	4	4	4	2	4

Table 8: Evaluation of supervised automated classification results for total map-area and for each land district: (1) - very poor; (2) - poor; (3) - imperfect; (4) - satisfactory; (5) - good and (6) - very good. Asterisk (*) indicates that the particular class does not occur in appreciable quantity.

can generate useful results. The nine-class final legend is too broad and too simple to be of much value. As a vegetation classification the results could be considered successful; however, as a bio-physical classification, the method performs poorly. As there is a relation between classification results of land districts and distribution of classes, automated classification may be improved by classifying on a land district basis.

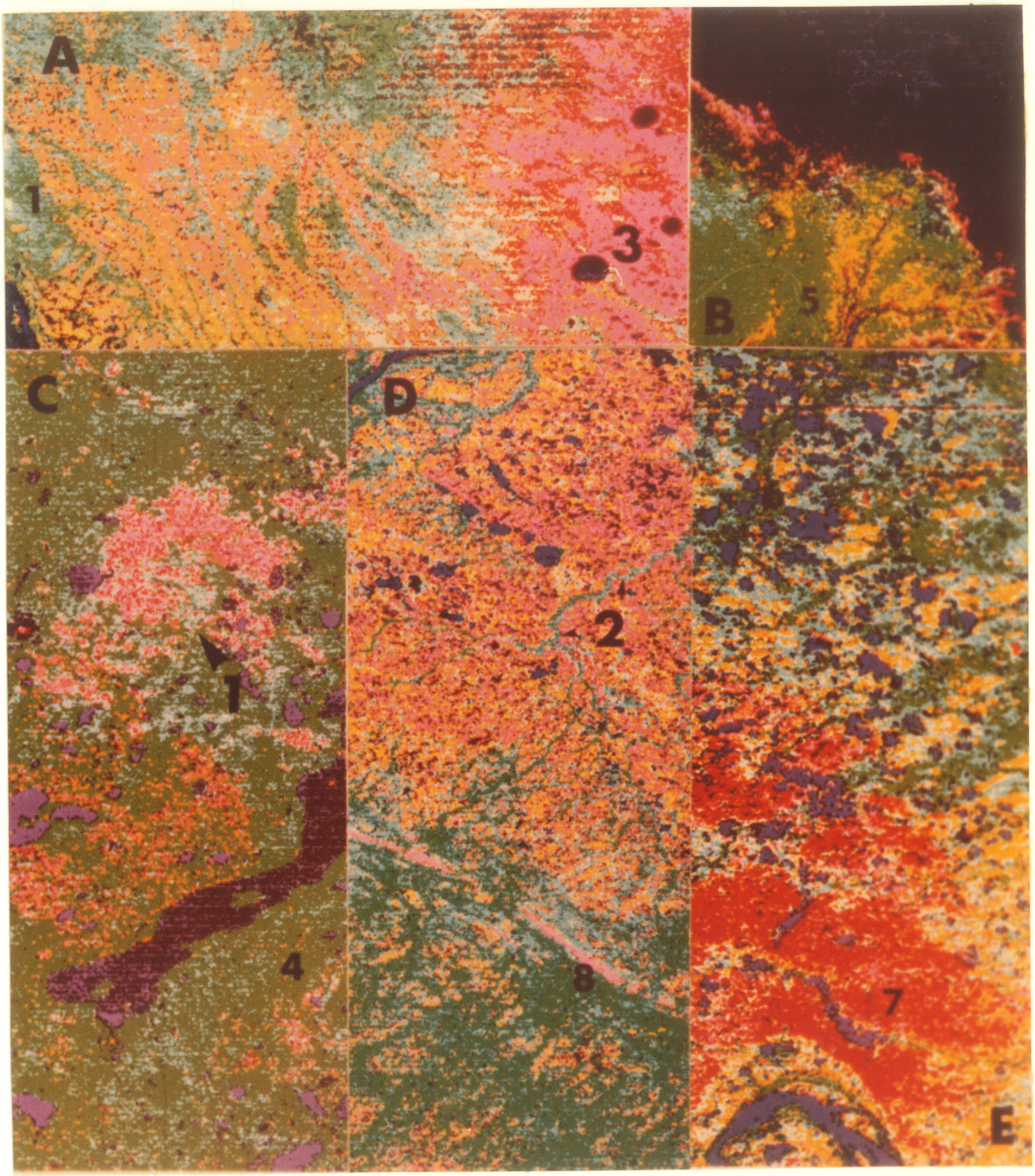


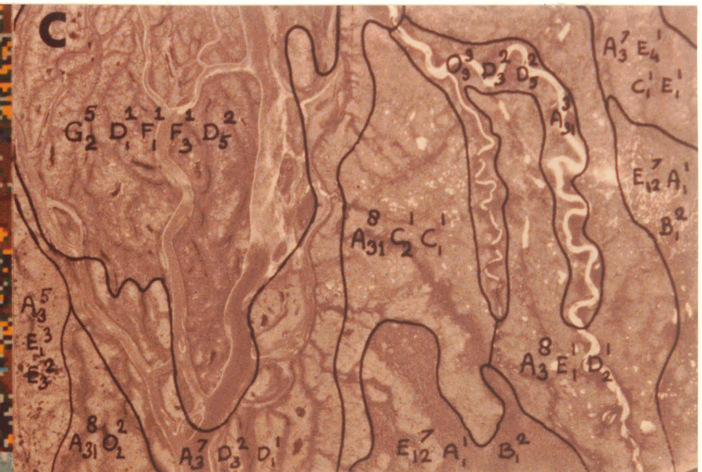
Plate 10: Supervised automated classification results in the land districts: A - Lofthouse-Lovett Lake transition to coastal zone with peat plateaus (brown) and sedge areas (light blue); B - Knife River delta in Coastal zone; C - Knife Rivers district with misclassified sedge areas (1); D - Lofthouse Lake district with beaches (8) and misclassified peat plateaus (2); E - Seal River area with stone fields (7).

This procedure implies training takes place within a district, is repeated for each district and that legends would vary according to districts. For example, the pink in the Mack Lake area would remain as 'lichen-till', but could be interpreted as, or added to, a polygonal or peat-plateau class in the Lofthouse Lake area. Confusion would be reduced considerably. 'Green', the broadest class, could be successfully split up in this manner. However, it would also increase the required time for training and classification of a satellite frame 5 to 20 times, assuming that about 5 to 20 land districts are likely to occur in one satellite frame. Although this procedure would not drastically increase computer time required, it would imply a number of days of interactive supervised training, with probable result of a 20 or fewer class legend, varying according to land district and heavily biased towards vegetation.

Unsupervised Automated Classification: In the three test areas (Seal River, Mack Lake and Lovett Lake), unsupervised classification was carried out using a multi-dimensional histogram approach (Goldberg and Shlien, 1975). In this method, the image to be classified is scanned and a four-dimensional histogram of intensity vectors is created. By choosing a threshold, the intensity vectors can be grouped into clusters. The interpreter chooses the threshold value. This procedure makes the approach interactive; the interpreter can break up specific clusters by raising the threshold value and treating only the vectors belonging to that cluster (Goldberg and Shlien, 1975). Plate II, showing the Long Island area and part of the Lovett Lake test area, permits the comparison of an unsupervised clustering (A), a supervised classification (B) and interpretation (C) of a 1:100,000 scale black and white photograph. C shows typical biophysical land systems as complexes of land types, with each primary land type identified by a class and percentage of occurrence. The unsupervised classification provides the most detailed map themes. A is the result of about 16 clusters, only 10 of which occur in considerable quantity; whereas, B maps only 9 classes. The primary clusters are described in Table 9 and related to the colours of the supervised classification. The table indicates that some of the supervised classes may successfully be split and, therefore, a more detailed classification would be possible. For example, green (Plate 11 -B) is represented by light brown, blue and light yellow. Also sedge wetlands (light blue on B) can be divided into light brown, dark brown and some green. However, both have light brown in common, and a further split would increase confusion in some classes. Assessing the thematic value of cluster 'classes', it appears that only one or two classes could be added to the supervised classification in this area. The unsupervised clusters are not better classes or land types than the ones derived from supervised classification; they do not fit the legend (Appendix B) any better. In fact, the results of the supervised classification are closer to a desirable split than the unsupervised results. Unsupervised classification in the Seal River and the Mack Lake test areas give similar results; there is no significant improvement over the supervised technique and only the 'open black spruce class' could be broken up locally.

The advantage then of the unsupervised technique is that the computer, with little user inter-action and time, gives an impression of what objects are separable. However, relating clusters to practical classes and themes, and grouping them, is usually not a simple task. It can be time consuming and still not provide the most desirable classification. In addition the 'editing' process requires as much, or more ground control, than is needed for supervised classification. *In other words, unsupervised classification shows quickly what is spectrally separable, but classes may not be useful. The supervised classification attempts to provide directly what is needed, but this may prove to be spectrally unseparable.*

Use of Multi-date Imagery for Automated Classification: The visual interpretation of satellite images has demonstrated the value of using multi-date satellite imagery for classification purposes. Also Kalensky (1974) reported an increase in classification accuracy for vegetation mapping using multi-date information. Winter imagery especially contains information that is complementary to the summer data. Figure 3 shows land system boundaries of the visual satellite interpretation that are derived from summer and winter imagery. At the more detialed level of automated



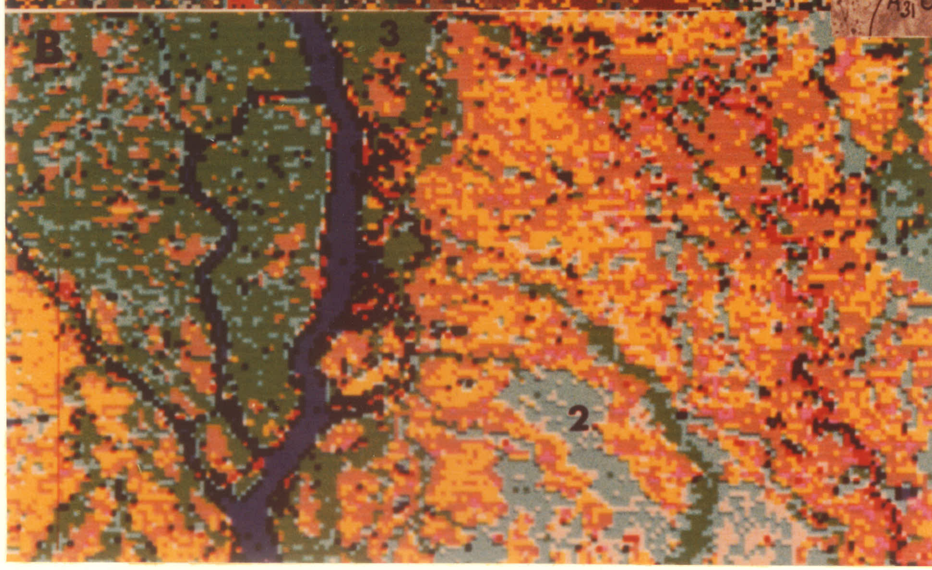


Plate 11: Comparison of unsupervised (A), supervised (B) and interpretation of black and white aerial photographs (1:100,000). Colour scheme of (A) is explained in Table (9), and of (B) on pages 45 & 46 (C) shows land system with percentages of land types (Appendix B). Note the break up of the green around B_3 on A, also note the difference between A_2 and B_2.

SUPERVISED	UNSUPERVISED CLASSIFICATION	
green, light brown, red ,	light brown	- area with fairly open black spruce (bs), tamarack(tl) vegetation: dense as well as fairly open, abundance of lichen, cover on ground, also includes tamarack fen, patterned fen, wetlands and tamarack, black spruce drainage ways.
light blue, grey, red	dark brown	- patterned fens with tamarack, little surface water.
light blue, brown, red	green	- open and semi open lichen, black spruce, peatplateaus.
green	blue	- dense black spruce peatplateaus and dense bs/tl.
brown	grey blue	- drainage ways in polygonal areas or polygonal fen areas with few trees,
yellow	yellow	- polygonal peatplateau area with very small ponds and low centred polygones intermixed.
pink, yellow, brown	grey	- relatively well-drained polygones and open lichen peatplateaus.
green	light yellow	- possibly alder, spruce, birch, and willow in small gullies and on riverbanks.
yellow, brown	dark blue	- peat polygones similar to yellow.
blue	red	- water
black	light blue	- small channels and riverbanks.

Table 9: Description of major unsupervised clusters for the Long Island area, part of the Lovett Lake test area.

classification the influence may be more significant. As a result of the very special associations among vegetation, soils and permafrost in this subarctic area, winter imagery enhances, for example, the distribution of well-drained glacio-fluvial and beach deposits (Plate 1, arrows).

To assess the value of multi-date, automated-image classification, one channel of a winter image was added to three channels of a summer image. The correlation between the four winter channels is so strong that addition of two winter channels is not expected to improve classification. The deletion of one of the summer channels was not expected to reduce classification accuracy significantly as compared with a 4-channel summer image. These assumptions were found to be correct during the course of the study (Fig. 4, 6, 7 and 8). Channel 5 of a 30 October, 1972, image was combined with channels 5, 6 and 7 of an image taken on 27 July, 1973. This winter image was chosen

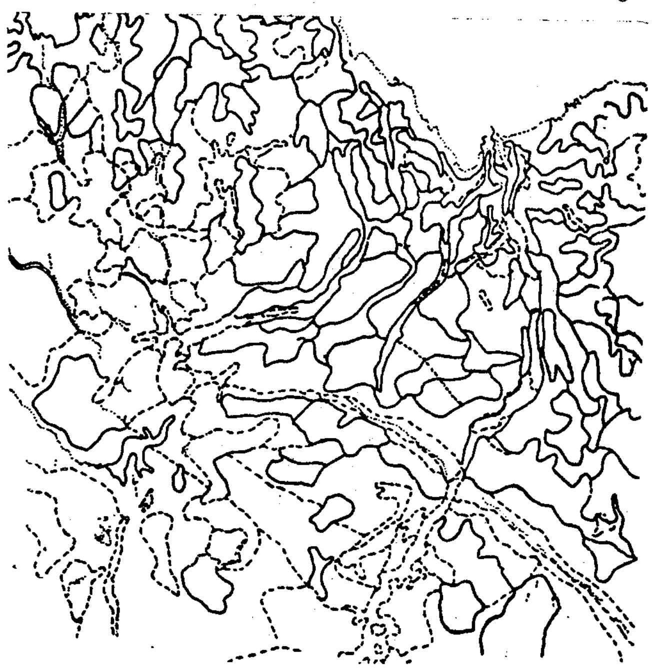


Figure 3: Land system boundaries derived from summer (closed lines) and winter (broken lines) satellite imagery through visual interpretation.

as it had a continuous snow cover, while some lakes were still partly open. These dark waterbodies allowed the selection of control points for the geometric corrections carried out on the Image 100 system of the CCRS. In total, nine control points were used.

The Seal River test area (Plate 1, A) was used for the multi-date evaluation as it has suitable representation of mineral and organic soils, and vegetation is not visibly disturbed. Both supervised and unsupervised classifications were applied to the composite tape. Figure 4 shows one-dimensional histogram displays of the intensities of the composite tape for pixels within the same clustering training area. A gives the histograms for the summer data and B, the composite summer-winter data. The intensities of reflection have a far wider distribution on the winter channel than on the summer ones. Moreover, the peak frequency is in the high reflectance range which can be expected on a winter image. Supervised classification was carried out on the summer-winter combination. Training areas were saved and applied to each of the following combination of channels:

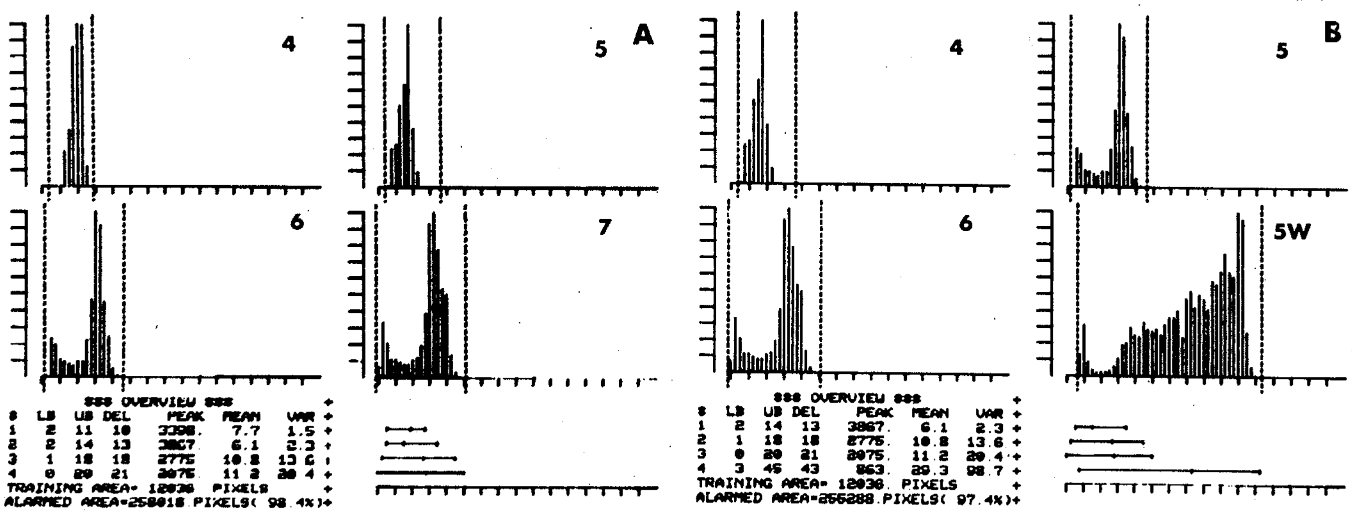


Figure 4: *One-dimensional histogram displays of the intensities of the composite summer-winter image B (summer channels 4, 5, 6; winter channel 5W) and the summer image A (summer channels 4, 5, 6 and 7) for the same clustering training area. The horizontal axis displays the reflectance values (from 1-63) and the vertical axis, the frequency of pixels with those values. Note the wide range of distribution and the skew towards light reflectance values of (5W).*

1) 5, 6, 7 summer - 5 winter
2) 5, 7 summer - 5 winter
3) 4, 5, 6, 7 summer
4) 5, 6, 7 summer

Figure 5 shows the one-dimensional histogram for 'stone fields' (A,B) and 'tamarack-sedge (bs) drainage' (C,D) for the winter (A,C) and the summer combination (B,D). In each, the winter channel differs considerably from the others. The effect of this difference is shown in Figure 7. Based on four-channels summer classification, the statistics for stone fields are displayed on B; whereas A shows the same data for the summer-winter combination. The difference, 2.9% of the area, is quite significant; the area identified as stone fields on the summer image is reduced by almost 40% with the addition of a winter channel.

Figure 6 displays this difference pictorally. The distribution of the pixels classified as stone fields is given; it is based on classification of the summer image (A), summer-winter composite (B) and the difference (C). Comparison of A and B with the base map (IV) and aerial photograph showed that the theme on A (summer) is clearly superior to the theme on B (summer-winter). The amount of misclassification (almost 40% of A) introduced by the addition of the winter channel is shown on C.

The opposite situation was noticed for the tamarack-sedge (bs) class. The winter channel permits the separation of the black spruce element that had caused confusion with black spruce occurring on till. The moving of the lower bound (Fig. 5, C-W5) on the winter channel eliminated the black spruce pixels from the theme; these usually had values of less than 25 for the 4th channel. The lower reflectance values coincided with the denser forest stands. Snow cover on the ground increases the reflectance values of the sedge-dominated areas with sparse tree cover. The addition of the winter image reduced and improved the classification of the four summer channels by about 45%, i.e. the classified area was reduced from 17.1% to 9.2% of the test area. These results appear to indicate that snow-covered images enhance differences within forest stands and shrub lands in which the vegetation is sufficiently high and dense to lower the reflectance values of snow. However, in areas either devoid of vegetation or containing low vegetation completely covered by a snow mantle, the addition of a winter channel will not be beneficial and, in fact, may lower classification accuracy.

The impact of the winter channel is considerable and is mainly beneficial where vegetation, because of its lack of disturbance, is a good indicator of land types. The deletion of one summer channel from the 4-channel summer and from the 4-channel summer-winter image has little effect on the respective classification results. Figure 7 gives an example for a sedge-patterned fen class; the (B-C) image shows the difference in classified areas between a 4-channel summer-image classification and a 4-channel summer-winter image classification. If one channel (channel 4) is deleted from the summer image this difference does not change appreciably (B-A, Fig. 7). B-D in the same figure shows the difference between a 4-channel summer-winter and a 3-channel summer-winter classification when band 4 (summer) is deleted;

however, compared to B-C and B-A (Fig. 7) the difference is minimal. A-C shows the pixels that are added to the theme by adding channel 4 to the 3-channel summer classification. Again the amount of pixels is comparatively small to the total theme areas. These results demonstrate that the addition

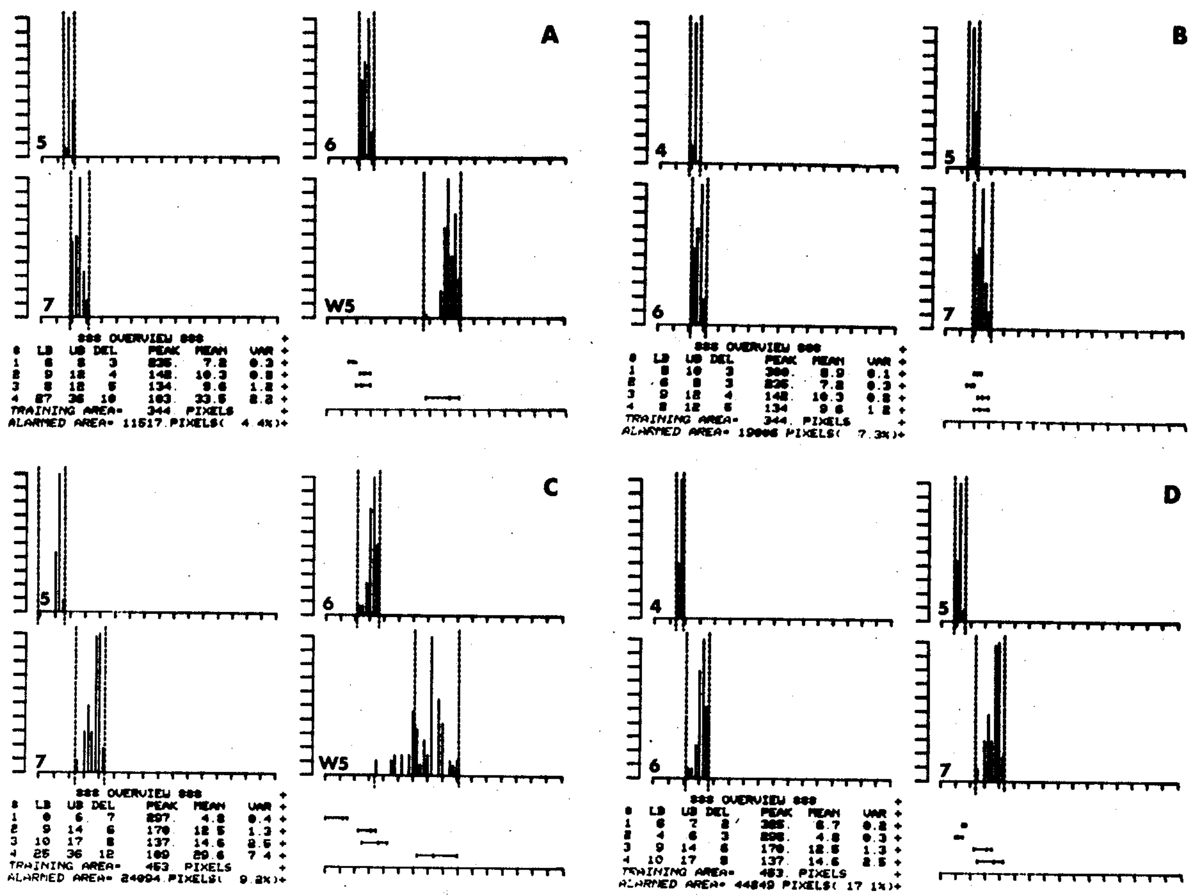


Figure 5: One-dimensional histograms displaying frequencies for stone fields (A summer-winter image, B summer image) and tamarack sedge (bs) (D summer-winter; D summer). Note the wide reflection range for the winter channel (W5).

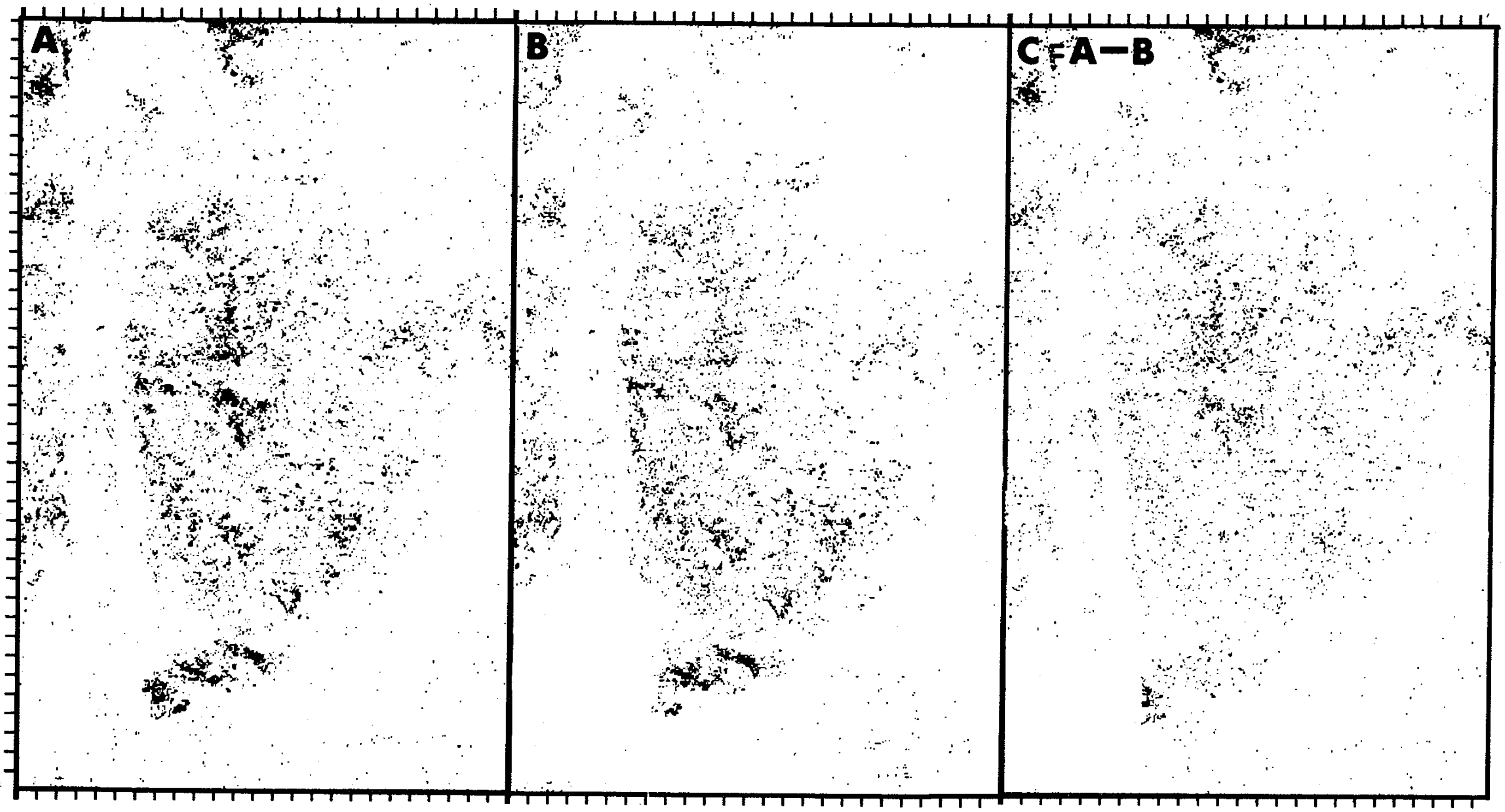


Figure 6: *Comparison of stone fields classification on summer (A) and summer-winter (B) imagery in the Seal River area. C displays the difference when theme B is subtracted from theme A.*

of a winter channel has a considerable effect on the classification of the sedge-patterned fen class; the deletion of a summer channel does not change the theme appreciably.

Satellite Resolution, Signatures and Classification Success

The success of automated classification is dependent on the characteristic differences in signatures between objects of interest. Intensity vectors in a multi-dimensional space must be statistically separable before they can be accurately grouped into useful classes. As well, the resolution of the scanner or other sensor should enable the registration of the object of interest. Objects should be spectrally separable; however, spectral signatures are strongly dependent on the size and location of the resolution element on the ground, i.e. the source of its radiation. The size of the LANDSAT resolution element, 1 pixel, is about 57 x 80 m, and the measured radiation is an average of the different conditions that occur within this area and in the immediate surroundings. This averaged radiation value may or may not be representative for the various conditions within the pixel. It is likely to be so, if the composition of the pixel is simple. Patterned fens for example may have communities dominated by any combination of water and sedge, sphagnum, birch and tamarack within one pixel. The spectral signature of each of these communities is quite different. A slight change in the water surface may change the pixel value as measured by satellite. This may cause considerable difficulty in the 'signature' classification of these wetlands. In this study, the sedge-dominated areas and patterned fen areas are consistently poorly classified; whereas the more homogeneous areas such as peat polygons and stone fields performed considerably better. But even relatively simple landforms such as peat plateaus cause problems for the automated classifier. On peat plateaus in this area there is a vegetative gradient from lichen-dominated communities in the centre to spruce-dominated communities along the edge. In this study they were, inescapably, classified as green (spruce) along the edge, pink or yellow (lichen-dominated) in the middle position and brown (lichen, black spruce, peat plateaus) in the transition (A, Plate 10).

Our objective is to map bio-physical land units at various scales which entails the mapping and description of ecosystems or 'land' systems,

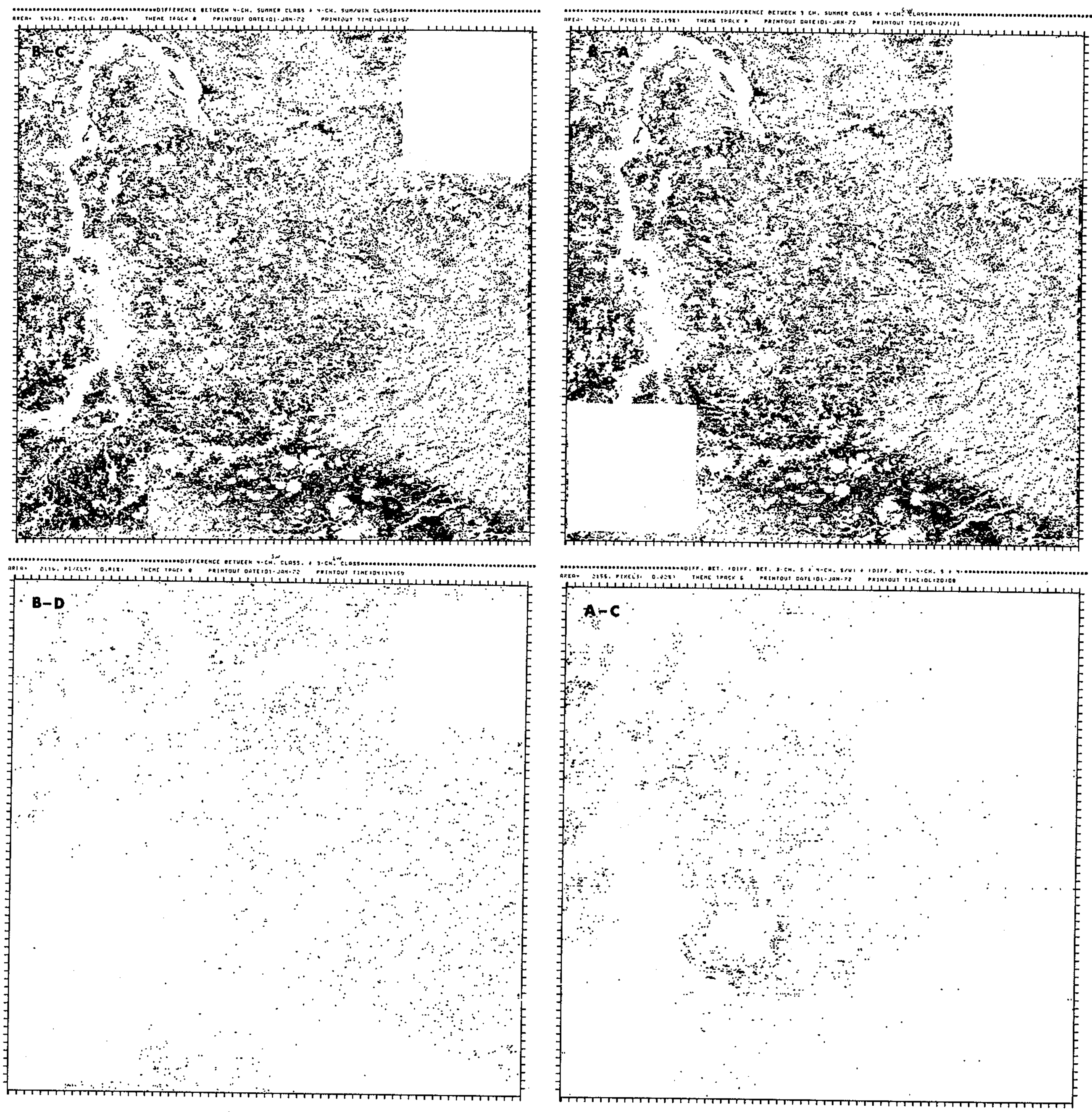


Figure 7: Effect of the deletion of a summer image channel (band 4) on the patterned fen theme. (B) is the classification based on a 4 channel and (D) on a 3 channel summer-winter image; A is a 3 channel summer classification and C a 4 channel one. (B-C) shows the difference between B and C; in fact the part of the theme due to the winter channel. (B-D) and (A-C) show the difference between B and D and A and C respectively; in fact the impact of the deletion of a summer channel.

and includes soil, drainage, vegetation, landform and wildlife aspects. Remote sensing, through the registration of reflected and emitted radiation, measures only the surface of the earth. Through the use of surface 'signatures', important sub-surface conditions must be identified, for example, soil and drainage, before the land system can be characterized. As the earth's land surface is either bare or covered with vegetation, this requirement limits the use of spectral discrimination to areas where vegetation and bare surfaces can be considered an indicator of the total ecosystem. Thus, changes in relief, drainage, soils, climate, etc. should be reflected in vegetation signature differences that are separable in a multi-dimensional space. Although this assumption may be true for lands that are covered with a climax vegetation, or vegetation which is in the same stage of succession, in practice it does not hold for large tracts of land.

Man has made his imprint on the environment in many ways through logging, farming and other resource uses. More important, natural events such as fires and diseases have caused a very complex vegetation mosaic in large areas of Canada. Such disturbances make the separation of a land system or an ecosystem on the basis of vegetation signature impossible unless only the conditions of uniform stage of succession or disturbance are considered. These complications eliminate most of Canada's lands except arctic and subarctic areas, and large wetlands in the boreal zone for potential signature-based, automated mapping. Moreover, it is essential that within relatively uniform vegetation types differentiation can be made to indicate changes; for example, in soil conditions. Again, this procedure appears only possible in the relatively simple ecosystems of the northern boreal, subarctic and arctic zones. Kalensky and Wilson (1975) showed that identical tree species can have different reflectance spectra on different sites and this resulted in confusion with other species. They advise partitioning a survey area into sectors with homogeneous site conditions. Such an approach however, seems somewhat impractical for bio-physical mapping at reconnaissance scales since most species may occur on a wide variety of sites.

Thus, it can be concluded that, although automatic classification of satellite imagery may show promise for vegetation mapping, it is unsuited for mapping landforms in most parts of Canada. As landform is the basis for most ecosystem mapping and for bio-physical classification in particular, automated classification does not appear promising. As landform identification is largely based on the analysis of spatial features in a photo-interpretation process, it can be expected that the use of automated-spatial feature analysis and spatial filtering techniques may improve classification. This may be particularly true for patterned fen and similarly complex areas. For practical and ecological purposes, such areas should be grouped into one land type. This sort of grouping would be impossible using automated classification unless shape information can be analysed by a computer.

COMPARISON OF INTERPRETIVE METHODS, CONCLUSIONS

The present state of the art of automated-interpretation methodology suggests conventional interpretation of aerial photographs should be considered the most practical and effective method of obtaining a detailed and reconnaissance type of bio-physical land classification. Airphoto-interpretation enables the interpreter to delineate landform accurately and infer site, soil and vegetation conditions, particularly when selected airborne sensors, adapted to the work objectives provide support. Colour infrared film, used with or without colour compensating filters, is especially valuable in reducing the optimum photo scale for interpretation and reducing the cost of the survey. At the same time, photo-interpretation increases the interpreter's knowledge of the area, induces hypothesis-making related to ecosystem characteristics and allows more selective and lower cost ground sampling.

The author, after assessing different satellite interpretation methods, was amazed how his understanding of the area increased through carrying out the conventional airphoto-interpretation. In this study, time involved in the interpretation of about 5,000 square miles of land for bio-physical mapping at the 1:125,000 scale was from 10 to 15 man-days; the amount of time would increase with larger photo scales and for physiographically more complex areas; the cost for reconnaissance-type of bio-physical surveys would vary between \$5 and \$20 a square mile (Thie et al, 1974). It is estimated that about 10% of the cost can be attributed only to photo-interpretation, if it is assumed that small scale black and white photography is available. Therefore, the cost of the photo-interpretation part cannot be considered prohibitive, or a weak link in present bio-physical methodology. Fieldwork form the most significant expense, especially in northern areas.

Based on this study and earlier studies by the author (Thie, 1972; Thie et al, 1974), it is suggested that the quality of bio-physical surveys can be improved by the use of high-altitude, colour infrared photography, supported by selected low-level coverage. For this coverage (e.g. 3000 m AGL), at least two 70 mm cameras with a colour film for water penetration and colour infrared film are preferable. If small scale black and white photography is already available, a new, high-altitude colour infrared coverage for large areas may not be cost-effective because of the high cost of airborne remote sensing in remote areas, unless other uses can be made of remote sensing imagery. Low-altitude remote sensing can be an attractive complement to black and white photography, but again it would increase interpretation costs. However, if no aerial photographs at suitable scales are available, it is strongly recommended that colour infrared coverage should be taken from a high altitude.

Visual satellite interpretation at the land system and land district levels appear to be practical methods only for bio-physical classification in special circumstances. For instance, when within a very short period of time a preliminary mapping and description is required of a large area, the visual interpretation approach is suitable. Its success however, will be dependent on the ecologic and physiographic simplicity of the area. In areas, such as sub-arctic peatlands, land system mapping and characterization can be carried out from satellite imagery at 1:1,000,000 scale and mapped on 1:500,000 scale with reasonable success. About 30% of the area may be misclassified, compared with a generalized photo-interpretation assessment. The description of the land system would remain simple, i.e. in the order of 10 or 12 classes which may be successfully distinguishable, using multi-date satellite imagery. Combining summer and winter imagery is especially valuable with such an approach. About 15 to 20 hours would be required to complete the total map sheet, including some airphoto-interpretation in sample areas.

Visual interpretation of photographic or digitally enlarged imagery did not provide better classification accuracy than the interpretation of 1:1,000,000 scale LANDSAT imagery. Land system delineation may have been better, but the combination of mapping and classification did not perform well. Furthermore, detailed analysis of magnified satellite images seems to defeat the purpose of rapid analysis. In this study, visual interpretation of satellite imagery at the 1:250,000 scale required almost as much time as the interpretation of aerial photographs for the same area. Classification success was again related to the physiographic and ecological simplicity of the area.

In both methods of visual interpretation, simple land districts showed the best performance in land systems and land district classifications. The most complex districts, with mixtures of mineral and organic deposits and distrubed vegetation, showed the poorest results and often, unsatisfactory classifications. Therefore, successful visual interpretation of land systems from satellites may succeed only in the relatively simple parts of the arctic and sub-arctic zones and in the large wetlands of the boreal zone. However, summarization of class results on a land district basis, improved classification results due to cancelling out of error. This condition may indicate that a land district classification using the visual method can be carried out in a wider range of physiographic conditions in Canada than is suggested for land systems.

Automated supervised classification generated a satisfactory map for 9-class groups including water; however, the classes are too general to provide a practical alternative for photo-interpretation. As a comparison, the airphoto-interpretation method generated about 43 different mappable land types. The success of automated classification is comparable to the visual satellite analysis, though it is still considered less attractive for practical applications due to time and cost considerations. Visual analysis is cheaper; it can be carried out independently of computer systems, and can readily assess multi-date imagery. Apparently, because of the use of spatial and time information, maps derived through visual analysis appeared superior in practical usefulness to the digital results. Locally, however, automated classification and unsupervised clustering provided more detailed information. With an automated approach, classification results are also dependent on physiography and classification performance differs according to land districts: the simpler ones yield the best results. The addition of a winter channel appears to improve classification of classes having strong vegetation links, but may decrease the results of classes in which vegetation does not play a significant role (e.g. stone fields). The deletion of a summer channel for automated classification does not change significantly classification results of the summer tapes and the summer-winter combination.

Clearly, at present, automated classification techniques fall considerably short of providing bio-physical data for practical use. The spectral signature alone appears inadequate for mapping the building blocks of the environment, i.e. ecosystems and landforms. The development of automated spatial-feature analysis techniques may change the future outlook of application of automated techniques.

Although the principal conclusion of the study is that interpretation of small scale aerial photographs is the most effective method for bio-physical classification, the author considers LANDSAT imagery a most important tool for bio-physical surveys. Its chief benefit is the unique repetitive nature of the data. It allows, for the first time, a study description and mapping of dynamic environmental phenomena, and the selection of natural models for environmental impact prediction (Thie and Wachman, 1975). Considering that a bio-physical classification aims to characterize the ecological relationships among land, water, flora, fauna and climate and, that these elements and their inter-actions are dynamic, earth resources satellites are expected to revolutionize inventory and monitoring techniques and the understanding of the global ecosystem. LANDSAT imagery is an important technological achievement in this development.

SUMMARY

This study was carried out to evaluate the practical usefulness of various methods of remote sensing interpretation for ecologically-based land inventories of northern areas. Visual interpretation methods of airborne and satellite images, and automated (supervised, unsupervised and temporal) data, are compared.

The study area of about 13,000 sq. km is located in northern Manitoba, south and west of the town of Churchill. This area contains representative elements of subarctic and northern boreal ecoregions. Physiographically the area is relatively simple; surficial materials are mainly organic deposits (with and without permafrost) and till, bedrock and glacio-fluvial deposits. In the recent past, few fires have disturbed vegetation; therefore, present vegetation can be considered a suitable indicator for the mapping and description of ecosystems.

Fieldwork was carried out during the summers of 1973 and 1974. It entailed an aircraft survey and the sampling of landform-soil-vegetation-permafrost complex in about 100 locations.

Remote sensing photography, including high altitude coverage for the complete study area and low altitude and radar coverage for selected parts of the area, was obtained during different dates in the summer of 1973. The standard sensor package included colour infrared, colour, and black and white photography combined with various filters and thermal infrared scanning. Moreover, various LANDSAT images in the form of prints, transparencies and digital tapes were used in the satellite evaluation.

Based on field sampling and different interpretative methods five bio-physical maps, classifying land systems and describing land types, were prepared:

MAP I :	1:1,000,000	LANDSAT visual interpretation.
MAP II :	1:250,000	LANDSAT visual interpretation.
MAP III:	1:250,000	LANDSAT supervised automated interpretation.
MAP IV :	1:250,000	Detailed bio-physical base map, derived from 1:100,000 B&W aerial photographic interpretation.
MAP VI :	1:250,000	Land District map.

All maps, except Map III were compared with the bio-physical base Map IV, using the overlaying capabilities of the Canadian Geographic Information System. The amount of misclassification was calculated as the difference between the base map (for each class and groups of classes of a land system and land district) and total mapsheet basis. Because of geometric distortions, Map III was visually compared with Map IV and detailed aerial photographs.

Results of this study indicate that bio-physical mapping in northern areas, carried out by photo interpretation, can benefit from the use of colour infrared photography from high and low altitudes. For areas of sparse vegetation a CC-B colour compensating filter is recommended in addition to a W-12 filter; for more vegetative areas a CC-M filter may increase interpretation quality. Thermal scanning and radar imagery proved of little value for mapping land types.

Based on fieldwork and aerial photo interpretation 43 land types were identified and mapped on the bio-physical base Map IV. The land types fell into 14 groups or classes.

Using visual analysis of 1:1,000,000 multi-date LANDSAT imagery 149 land types were delineated and classified. Of these only 11 had less than 35% misclassification using the land-type legend. Grouping the land types into broader class groups improved classification results. The amount of misclassification appeared to be dependent on the physiographic and ecologic complexity of the land system; it varied considerably by land districts. The simplest district (Mack Lake) had only 14.8% misclassification; the most complex district (coastal) had 54.1%. Peat plateaus and peat polygons were well classified throughout the study area, but picea-dominated peatlands, stonefields, till, glacio-fluvial deposits and beaches were classified reasonably accurately throughout most districts. Magnification of LANDSAT imagery to 1:250,000 for interpretation did not increase classification accuracy, though the land systems delineated were comparable in size to those mapped on 1:100,000 aerial photographs.

Supervised automated classification of a complete LANDSAT frame using the multi-spectral image analysis programs of the CCRS allowed the mapping of 10-class groups, including water, with a misclassification estimated between 20 and 30% of the area. Increase in the number of class groups reduced accuracy of classification. Furthermore, results of the automated classification varied according to physiographic and ecologic complexity: the Mack Lake district showed the best results and the coastal district the poorest.

Unsupervised automated classification did not perform better than the supervised approach. Of the cluster classes that were separable only about 10 occurred in significant quantities.

The combination of summer and winter digital data for automated classification proved beneficial in areas where vegetation can be considered a suitable indicator of land types and, where it penetrates sufficiently through the snow mantle (e.g. closed, open and scrub forest and shrub areas). In areas where no vegetation or close ground cover existed, the added winter channel lowered classification accuracy.

Considering the time, cost and usefulness of the information generated by the different methods, it is concluded that conventional photo-interpretation of aerial photographs is clearly the most efficient and practical method for bio-physical classification at present.

Visual analysis of multi-date satellite imagery appears to be of practical use when large tracts of land - in order of 50,000 sq. km per man-year must be inventoried in a short period of time. This assessment applies, however, only to areas of relatively simple physiographic and/or ecologic complexity, such as the arctic and subarctic regions.

Automated methods do provide a satisfactory map of 9-class groups, but results appear, in fact, inferior to those derived from the visual methods from a users viewpoint. An automated approach is considered of little practical value presently because of the time and cost requirements. Spectral signatures alone appear inadequate for the mapping of ecosystems and landforms - the building blocks of an environmental inventory.

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APPENDICES

APPENDIX A

AIRBORNE REMOTE SENSING IMAGERY IN THE STUDY AREA

Coverage I: Black and white photography.

Flown 31 July, 1961 with a RC-9 camera (#471' MAG 48; focal length 88.28 mm; lens #SAG 32; P2X-filter). Photographs no. A17406, 1-114. Altitude 9150 m ASL; scale 1:1,000,000.

Coverage II: Recent Remote Sensing Imagery.

-1 June, 1973. Task 73/147 (CCRS); Alt. 10.700 m ASL.
- 1 RC-10: 9"x9"; 3.47" lens; Roll RSPA 30665IR (1-136) 2443 film with a 520 nm filter;
  4 Vintens, 70 mm; 3" f.l.;

  Roll CP2381 IR,1-463; 2442 - 12-CC20B filter
  BN2382 1-463; 2405 - W25 filter
  BN2383 IR,1-463; 2424 - 89B filter
- RS-14, 5" scanner (thermal range) BN2384 IRsc (8-14μ range)

-1 June, 1973. Task 73/147 (CCRS) - 3050 m ASL
- RC-10 - 9"x9"; 88 mm f.l.; Roll RSPA30664, 1-116; 2448 film - NAF
- 4 Vinten's, 70 mm:

  3" f.l. Roll BN2379-1-656; 2405 film - W25
  6" f.l. Roll CP2377 IR-1-643; 2443 film - W12-CC20B
  6" f.l. Roll CP2378 IR-1-643; 2443 film - W12-CC20M

- RS-14, 5" scanner (9-14μ), Roll BN2380 IRsc

-22 July, 1973. Task 73/147 (CCRS); Altitude 3050 m ASL
- 1 RC-10; focal length 88 mm; RSPA30821, 1-123, 2448 film - 520 nm - AV3.34
- 2 Vinten 70 mm;

  6" f.l. Roll CP2872 IR, (1-611); 2443 film; 12-CC20B
  6" f.l. Roll CP2874 IR, (1-611); 2443 film; 12-CC20M
  3" f.l. Roll BN2873 IR, (1-611); 2405 film; W12
  Not simultaneous: CP2875, (1-512); 2448 - Hf.

- IR scanner BN2855 IRsc simultaneous to RSPA 30821; 8-14μ range.

-RADAR - side looking radar, provided by the Maritimes proving Evaluation Unit, Canadian Armed Forces taken during late summer of 1973. Roll BN2157; Tract 359^{o}T. Run 5 Gillam - Churchill; 2290 m AGL.

APPENDIX B

CLASSIFICATION LEGEND

The following legend is used in all parts of the study unless otherwise indicated. It provides detailed descriptions for the land types used in the classification of maps I, II, III and IV and the classes and class groupings used for automated satellite classification.

A: Peat Polygonal Areas:

A1 : relatively well-drained polygons, usually with a high centre, or horizontal, with a lichen-heath type of vegetation and *Sphagnum spp.* in and along trenches. Associated soils are (fibric and mesic) Organo Crysols; turbic near trenches. Significant percentages of low centred polygones with *Carex spp.* and water may be included in units.

A2 : Relatively poorly drained polygons, usually low centred with *Sphagnum spp.* and lichen heath near trenches and *Carex, Eriophorum spp.* in saturated low centre areas, often with small ponds. Associated soils are (turbic) Organo Cryosols near trenches and mesic or fibric Organo Cryosols in sedge areas. Significant amounts of ribbed sedge fens, with numerous water bodies may be included.

A3 : Polygonal plateaus; these are extensive plateau like peat polygon areas, slightly domed and usually surrounded by fen areas or leads; may contain portions of both A1 and A2. Vegetation and soils are similar to A1 and A2 (no occurance of *Picea Mariana*).

A31: Polygonal peat plateaus; these resemble peat plateaus as they are elevated slightly above the surrounding fen area, they have usually a characteristics edge of *Picea Mariana* towards the fen but are otherwise covered by a lichen-heath type of vegetation and show polygonal patterns as results of ice wedges. Soils are Organo Cryosols.

A4 : Combination of A1 and A2.

A5 : Combination of A1 and A3.

A6 : Combination of A1, A2 and A3.

B: Carex Fens:

B1 : Sedge wetlands dominated by Carex spp., Eriophorum and Scirpus spp. Fens are saturated and do not show distinctive patterns. Small inclusions of other peat landforms as well as Larix, willow, alder etc. may occur as result of local differences in nutrient supply and drainage regime. Soils are primarily Mesisols.

B2 : As B1, but characteristic pattern in fens are noticeable in a part of the unit expressed by vegetation, peat landform and permafrost differences.

B3 : *Carex-Larix* fens; sedges form the dominant type of vegetation, but Larix Laricina occurs dispersed throughout much of the unit. Soils are usually Mesisols.

C: Larix Fens:

C1 : *Larix-Carex* fens. Open tamarack occurs throughout the unit;sedges form the dominant type of ground cover of this water saturated wetland. Soils are Mesisols and there is no occurance of permafrost.

C2 : *Larix-Picea* wetlands. In some portion of wetlands *Sphagnum spp.* occur possibly resulting in the formation of palsas with associated *Picea Mariana.* In some parts of the area *Larix* and *Picea M.* may occur side-by-side in drainage ways especially at the edge of peat plateaus. Permafrost may be found under Sphagnum hummocks. Soils are usually Mesisols, with pockets of Organo Cryosols.

C3 : *Larix-Betula-Salix-Alnus* wetlands. In drainage ways various percentages of *Betula, Salix, Alnus spp.* may occur as result of locally different nutrient and drainage regimes. Tamarack and sedges are dominant in most of the unit. Soils are mainly Mesisols.

C4 : Combination of C1 and C2.

D: Picea dominated Peatlands:

D1 : *Picea mariana* and/or *Picea glauca* along drainage channels, rivers, lakes, etc., on relatively well to imperfectly drained shallow or deep organics. Trees are stunted but form, considering the climate of the area, relatively closed stands or fringes. *Ledum spp., Sphagnum spp.,* feather mosses etc. may form the ground cover. Usually, permafrost occurs. Soils and Organic Cryosols or Peaty Gleysols. Also classified by this symbol are recent alluvial deposits covered by *Picea glauca.*

D2 : *Picea-Larix* drainage ways: these units are wet and saturated, are similar to C2, but *Picea Mariana* is dominant. Soils are usually Mesisols with inclusions of Organo Cryosols.

D3 : As D1, but spruce is fairly high along waterways, mainly areas with milder regional or micro-climate.

D4 : Combination of D1 and D2.

D5 : Bog Veneer, usually *Picea Mariana*, open or semi-open, with *Sphagnum spp.* Thin layer of organic material over mineral soil. Areas are usually sloping, which results in an improved drainage and prohibited the formation of peat plateaus. Surface and close to surface drainage patterns (Runnels) are often clearly visible and enhanced by past fire history. Soils are usually Organo Cryosols, or Peaty Gleysols. Permafrost is almost continuous.

E. Patterned Fen areas:

E1 : Patterned fen-peat polygon areas: these units are a combination of *Carex-Eriophorum* dominated patterned wetlands with frequent occurrance of ridges with peat polygons and small open water areas. Soils are usually Mesisols, with Organo Cryosols in the ridges.

E1.2:As E1 but with limited occurrance of peat polygons.

E2 : *Carex* patterned fen without ponds and peat polygons.

E3 : *Carex* patterned fen with palsas.

E4 : Patterned fens with tamarack.

F. Marshes and Swamps:

F1 : *Salix-Alnus-Betula* wetlands. These are dominated by any of the named species or by mixture of these. They usually occur on recent alluvial deposits, eroding banks along rivers and in nutrient rich drainage systems. Soils may be Peaty Gleysols, or Regosols.

F2 : Salt marshes; these wetlands are under the influence of tidal action and saline water penetration.

F3 : A combination of F2 and I (mudflats).

G. Peat Plateaus:

G1 : Lichen-Black Spruce-Sphagnum peat plateaus. These units have a characteristic lichen cover with only few stunted conifers. Polygonal cracks are not visible. Soils are usually Organo Cryosols. Black spruce occurrance increases towards the edge of the peat plateau.

G1.1:As G1, but level.

G1.2:As G1, but sloping.

G2 : Black spruce - Sphagnum-Lichen peat plateau. These have a more continuous cover of open black spruce than G1. Soils are mesic or fibric Organo Cryosols.

G2.1:As G2, but level.

G2.2:As G2, but sloping.

G3 :Black spruce-Sphagnum plateaus. Compared to G2, trees are denser and lichen portions have decreased.

G4 :Black spruce - feathermoss plateaus. A dense stand of *Picea Mariana* with ground cover of feather mosses like *Pleurozium, Hylocomium and Hypnum spp*. Soils are fibric or mesic Organo Cryosols.

H. Palsas:

H1 : Bare, usually Sphagnum-lichen-heath covered palsas.

H2 : Treed palsas, usually with *Picea Mariana, Sphagnum spp.* and, *Ledum spp.*

I. Mudflats:

M. Stone fields:

M1 : Till areas that as result of frost heaving, have become fields of large rocks. They usually are associated with former depressional areas or poorly drained tills, in which frost heaving because of the availability of water, could work effectively. Stones are mainly covered by rock lichens, otherwise area is void of vegetation though in some areas rocks are covered by vegetated organic material.

M2 : Combination of M1 and stoney tills that have not resulted in continuous rock covers, usually as result of better drainage (well-drained sites). Vegetation is usually a lichen heath tundra or forest tundra and occasional *Picea Mariana* or *Larix Laricina* may occur. Soils are usually Dystric Brunisols (orthic or degraded) and sometimes turbic as result of cryoturbation.

M3 : Combination of M1 and M2.

N. Glacial Till: stoney, moderately coarse texture, loamy till.

N1 : Well-drained phase of the till, usually associated with a lichen-heath, or forest tundra. Limited cryoturbation. Soils are usually degraded or orthic Dystric Brunisols, often turbic.

N2 : Imperfectly drained phase of the till, with possibly gleyed orthic Dystric Brunisols or Peaty Gleysols.

N3 : Combined of N1 and N2.

O. Glacial Till: moderately coarse, sandy till.

O1 : Well to rapidly drained phase with usually (degraded or orthic) Dystric or Eutric Brunisols. Though permafrost occurs often, signs may be absent due to good drainage. Vegetation may vary considerably, from open and semi-open black spruce-lichen-heath, with occasional tamarack to Jack pine and White spruce.

O2 : Moist to wet tills which may have a thin layer of accumulated organic material in lower areas. Soil may vary as result of drainage condition, like Degraded Dystric Brunisols, Orthic Brunisols, Gleyed Brunisols etc. and occasionally Peaty Gleysols.

O3 : Combination of O1 and O2.

P. <u>Sandy Beach and Glacio-fluvial deposits</u>:

P1 : Well to rapidly drained. Vegetation is a *Picea Glauca*- lichen-heath type. Parent material may show signs of wave action and deposition (beaches). Wind erosion may have bared surfaces of vegetation. Regosols, Degraded and Orthic Dystric Brunisols are common. Permafrost, if occurring may be more than 1.5 meters deep.

P2 : Imperfectly to poorly drained sands, usually with shallow layer of organic material. (Peaty Gleysols, Gleyed Brunisols, Brunic Turbic Cryosols).

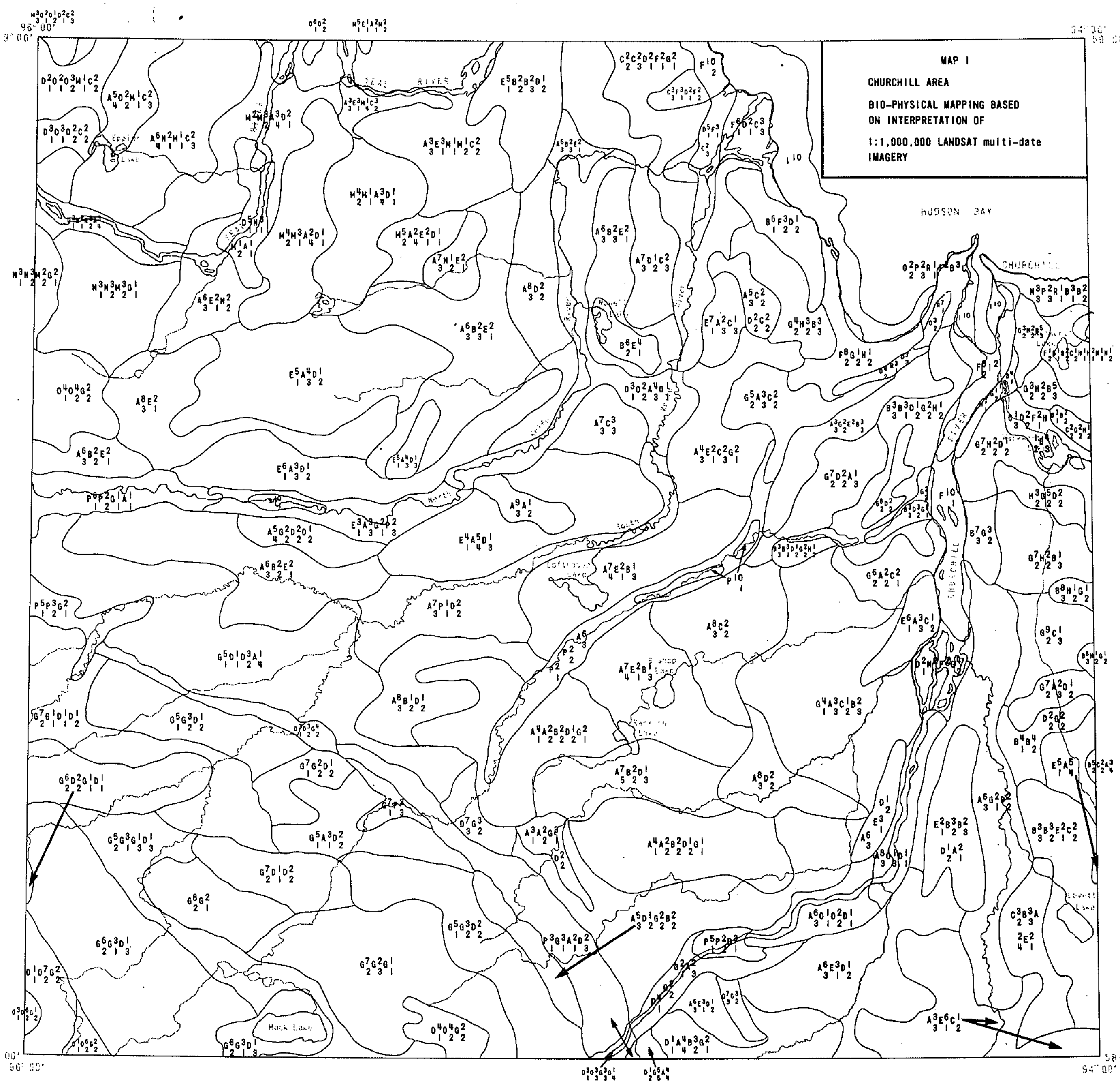
R. <u>Bedrock Outcrop:</u>

R1 : Precambrian

R2 : Paleozoic.

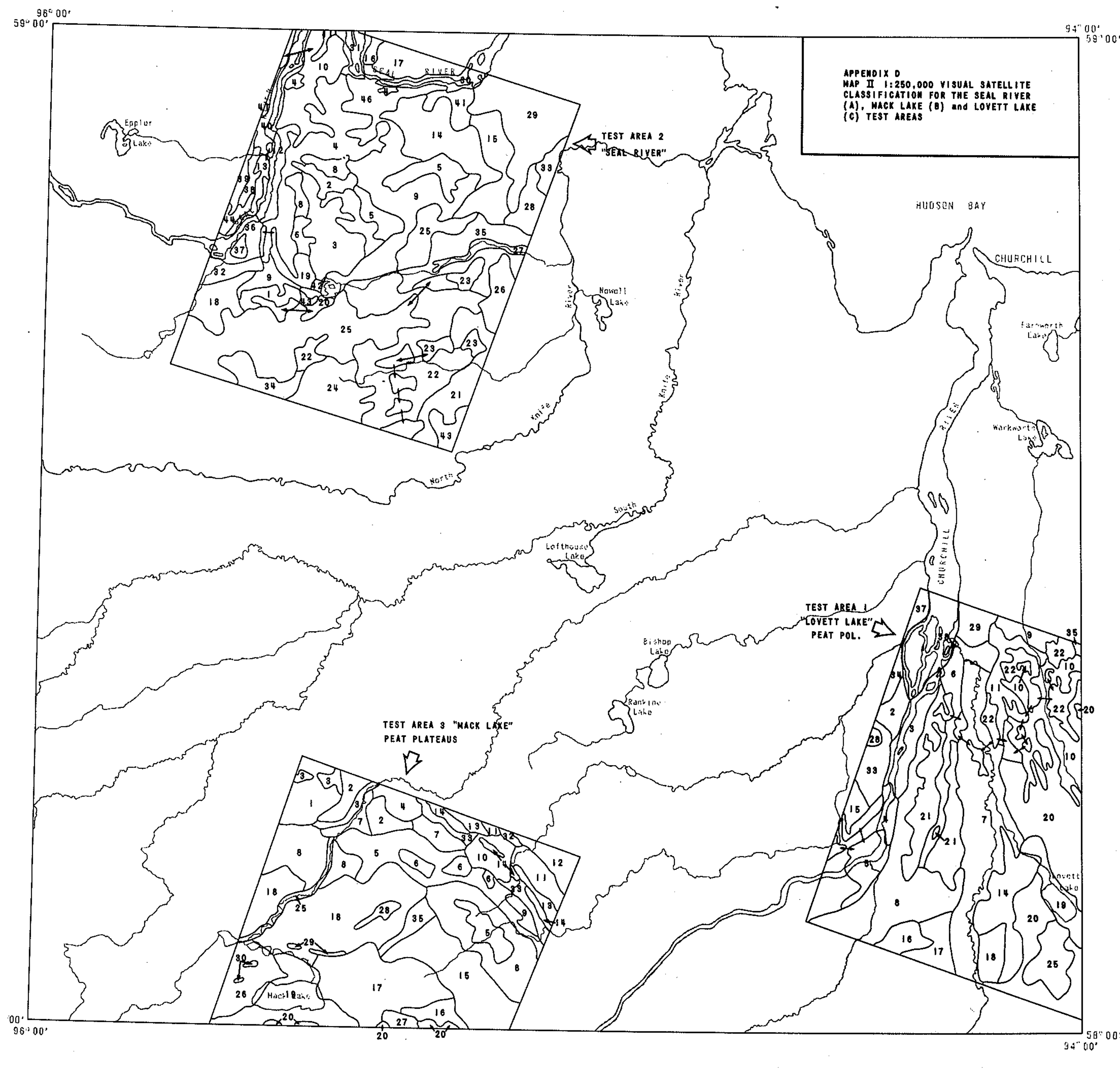
APPENDIX C

MAP I: A bio-physical classification of the Churchill mapsheet (54L) based on visual interpretation of 1:1,000,000 LANDSAT multi-date imagery. 149 land systems are mapped averaging 9211 ha (22,761 acres). Scale of the map is 1:750,000.



APPENDIX D

MAP II: A bio-physical classification of three test areas (Seal River, Mack Lake and Lovett Lake) in the Churchill mapsheet (54L) based on the visual interpretation of single date LANDSAT imagery, enlarged about 4 times to a scale of about 1:250,000. A total of 167 land systems are mapped in the three test areas with an average size of about 2399 ha (5928 acres). On page 86, the classification symbols are listed for each of these systems. Original map is at the scale 1:250,000, displayed for convenience at the scale of 1:750,000.



SEAL RIVER AREA (A)

1) $M_1^9A_4^1$
2) $M_1^8A_4^2$
3) $M_1^3M_2^3N_1^2A_4^1B_1^1$
4) $M_1^4M_2^3N_1^1A_4^1B_1^1$
5) 3
6) $M_1^7D_1^1C_1^1C_2^1$
7) $M_1^2M_2^1N_2^2C_1^1C_2^2A_4^2$
8) $A_4^3C_1^2C_2^2M_2^3$
9) $A_4^3M_1^1M_2^1N_2^1C_2^1B_1^2B_2^1$
10) $M_3^3N_2^1A_4^3C_1^1B_1^1B_2^1$
11) $M_1^2M_2^2N_2^2A_4^2B_1^1B_2^1$
12) $D_1^2G_2^1M_1^3M_2^2A_1^2$
13) $M_3^7D_1^2A_1^1$
14) $D_2^3B_1^{2.5}A_1^1A_2^1C_1^1G_2^1N_2^{0.5}$
15) $A_1^2A_2^2B_2^2B_1^2C_1^1G_2^1$
16) $N_2^1B_2^2B_1^1A_4^3M_3^3$
17) $B_2^4B_1^4A_1^1A_2^1$
18) $A_1^2A_2^2B_2^2B_1^2C_1^1G_2^1$
19) $M_3^5A_1^1A_2^1B_1^1B_2^1C_2^1$
20) $A_1^7M_2^1B_1^1C_1^1$
21) $A_1^2A_2^2C_1^1G_2^{0.5}B_1^2B_2^{2.5}$
22) $A_1^4A_2^2B_1^2B_2^{0.5}D_1^{0.5}C_2^1$
23) $B_1^4B_2^4A_1^1A_2^1$
24) $B_1^5B_2^4A_4^1$
25) $A_4^3B_2^3B_1^2C_2^1M_2^{0.5}N_2^{0.5}$
26) $B_1^4B_2^4A_4^{1.5}C_1^{0.5}$
27) $D_1^6G_2^2A_1^2$
28) $B_1^4B_2^2C_1^1G_2^1A_4^2$
29) $B_1^3B_2^4C_1^1G_2^1A_4^1$
30) $D_1^7A_1^2F_1^1$
31) $A_1^3D_1^3F_1^1B_2^3$
32) $A_1^4B_2^5C_1^1$
33) $C_2^2C_1^3B_2^2A_4^2B_1^1$
34) $C_2^2B_2^3A_2^3A_1^2$
35) $A_1^3A_2^1B_1^1B_2^3C_1^2$
36) $D_1^2G_2^3C_1^1A_1^1A_2^1F_1^1M_1^1$
37) $A_1^4A_2^2B_1^2C_1^2$
38) $G_2^4A_1^3C_2^1M_3^2$
39) $M_1^4M_2^3A_4^2C_2^1$
40) $D_1^3M_2^2A_1^3G_2^2$
41) 39
42) $B_1^3C_2^2C_1^2A_4^3$
43) $C_2^1A_1^3A_2^2B_2^3B_3^1$
44) $M_1^2M_2^2A_1^2A_2^2C_2^1B_1^1$
45) $M_2^4M_1^2C_2^2C_1^1B_2^1$
46) 9
47) 35

MACK LAKE AREA (B)

1) $A_1^3A_2^2B_2^4C_2^1$
2) $A_1^2A_2^2B_2^6$
3) $G_2^3D_1^1C_1^2A_4^2B_2^2$
4) $A_1^6A_2^1B_2^2C_2^1$
5) $A_1^5A_2^1C_2^1D_1^1B_2^2$
6) $C_2^1G_2^4A_1^3G_1^2$
7) $A_1^4A_2^2B_2^3C_2^1$
8) $C_2^2G_2^4G_1^2A_1^2$
9) 7
10) $D_3^3G_2^4C_1^1A_2^2$
11) $G_2^6C_1^1A_1^3$
12) 7
13) 7
14) P^{10}
15) $G_2^7G_3^3$
16) $D_3^4G_3^2G_2^1O_1^2O_2^2$
17) $D_3^2G_2^7G_1^1$
18) 15
19) $G_2^4G_1^2G_3^3C_1^1$
20) $G_2^6G_3^2G_1^2$
21) $B_3^3G_3^3G_2^4$
22) $D_3^8G_3^2$
23) $G_3^7D_3^3$
24) 27
25) D_3^{10}
26) $G_2^6G_1^4$
27) $A_3^8G_2^2$
28) $A_1^6G_1^2G_2^2$
29) 28
30) 28
31) 23
32) $A_3^7A_2^2C_2^1$
33) $C_1^2A_1^3G_1^2G_3^2C_2^1$
34) $D_3^4G_4^2G_3^2G_2^2$

LOVETT LAKE AREA (C)

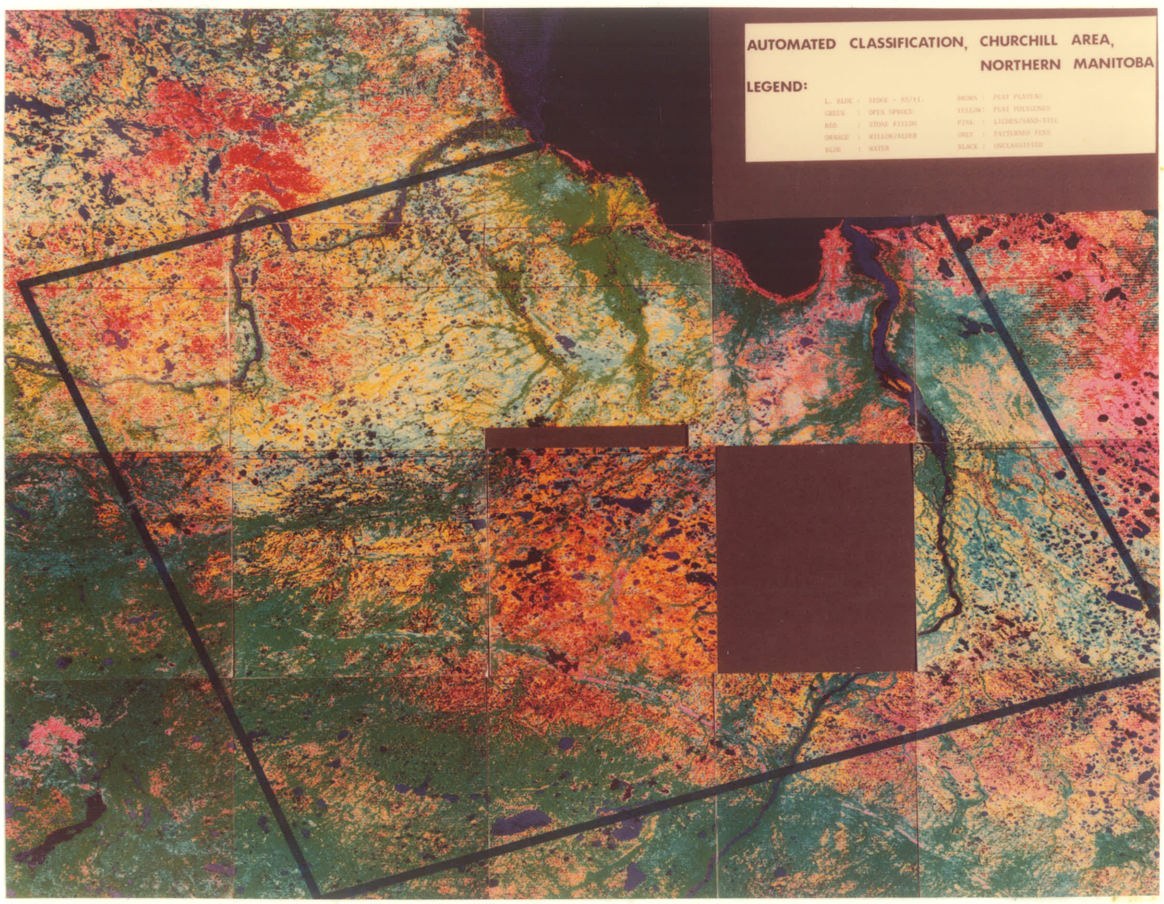
1) $D_1^6A_1^2F_1^1G_2^1$
2) $A_1^8D_1^2$
3) $A_1^6D_1^2B_1^1N_2^{.5}I^{.5}$
4) $A_1^4D_1^4B_1^{.5}F_1^{.5}B_2^1$
5) $A_1^4A_2^2B_2^3D_1^1$
6) $A_1^3A_2^3D_1^{1.5}N_2^{0.5}G_1^2$
7) $A_1^3A_2^2B_1^1B_2^2C_2^{1.5}N_2^{0.5}$
8) $A_1^1A_2^3B_1^2B_2^3D_2^1$
9) $G_1^7D_1^1D_2^1A_1^1$
10) $A_1^3G_1^1A_2^2C_2^1N_2^{0.5}B_2^{2.5}$
11) $G_1^2G_2^2C_1^2B_1^3A_1^1$
12) $A_1^2A_2^1G_1^2N_2^3C_1^2$
13) $A_3^4B_2^2B_1^2C_1^2$
14) $A_1^2A_2^1C_1^2B_2^4B_1^1$
15) $A_1^3G_1^1A_2^2D_2^1B_2^3$
16) $A_3^4A_2^1D_2^2B_2^3$
17) $A_3^4A_2^1D_2^2B_2^4$
18) $A_1^2A_2^1C_1^1B_2^6$
19) $A_1^3A_2^2B_2^5$
20) $B_2^7C_1^1A_1^1B_1^1$
21) $B_1^5B_2^2A_3^2C_2^1$
22) $B_1^7C_1^1G_2^1A_3^1$
23) $B_2^6B_1^1A_3^1F_1^1C_2^1$
24) $B_2^8A_1^1C_2^1$
25) $B_2^8A_1^1C_1^1$
26) $F_1^4A_1^2B_2^2A_2^2$
27) $A_1^3A_2^1B_2^5C_2^1$
28) 21
29) $B_2^6A_1^3A_2^1$
30) $P_1^8P_2^2$
31) $P_2^2A_1^2C_1^1G_2^1G_1^4$
32) $A_1^4A_2^2B_2^4$
33) $A_3^6B_2^3C_2^1$
34) $A_3^8B_2^2$
35) $B_2^4B_3^4C_2^2G_1^2$
36) $A_1^5A_2^2B_1^3$
37) 34
38) N_1^{10}

APPENDIX D: Classification symbols for the land systems derived from visual interpretation of 1:250,000 scale LANDSAT imagery for the Seal River (A), Mack Lake (B) and Lovett Lake (C) test areas. Land system are mapped on page 84.

APPENDIX E

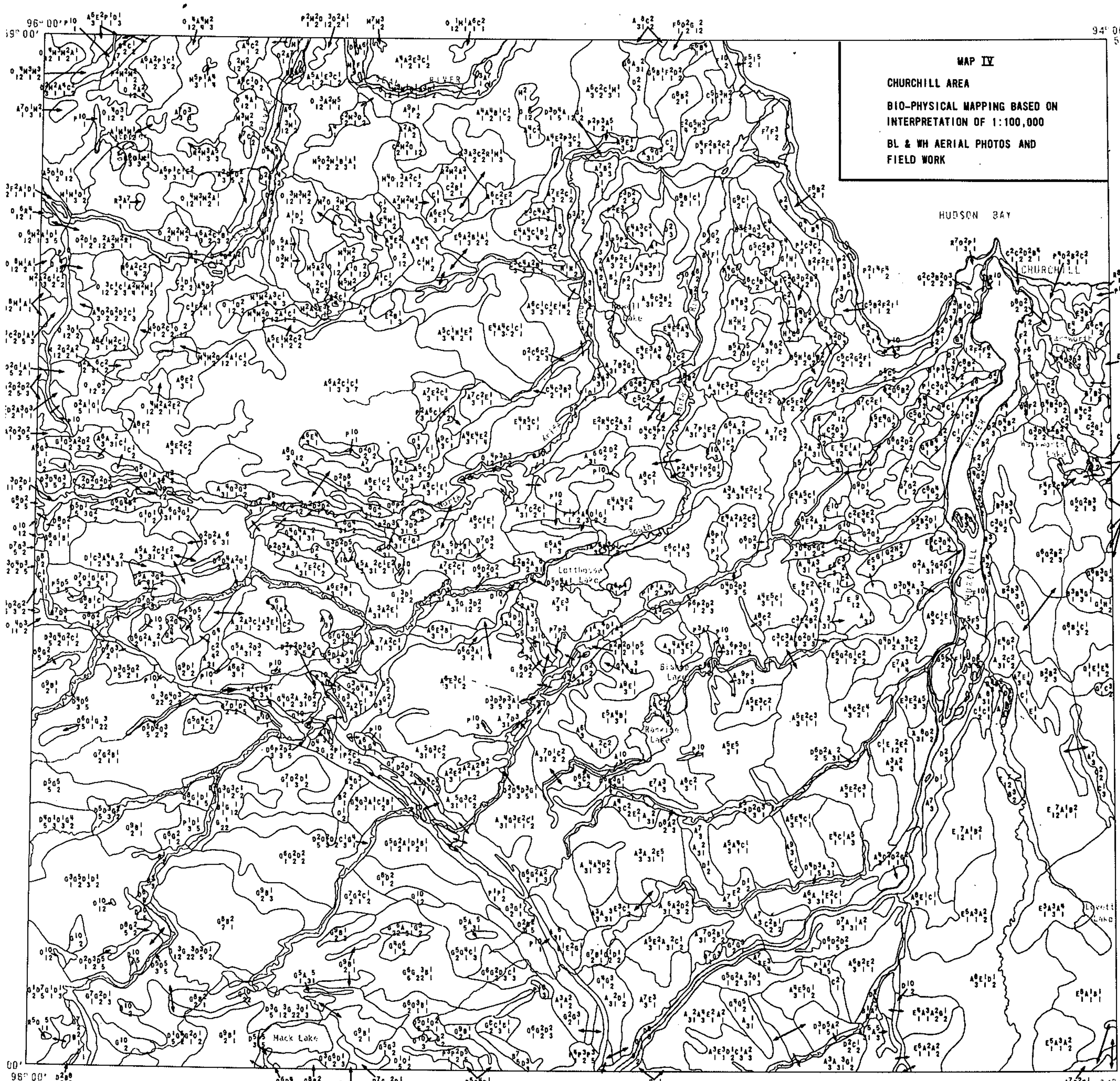
MAP III: A supervised automated classification of the Churchill area. Mapsheet 54L is identified by thick line. Colour themes were generated through the use of the CCRS multispectral analyser display (MAD).

Dark blue	— water	Brown	— peat plateaus
light blue	— sedge - bs/tl	yellow	— peat polygons
green	— open spruce	pink	— lichen/sand - till
red	— stone fields	grey	— patterned fens
orange	— willow/alder	black	— unclassified



APPENDIX F

MAP IV: Bio-physical base map for the Churchill area (54L) based on fieldwork and interpretation of 1:100,000 scale black and white aerial photographs. A total of 700 land systems are delineated with an average size of 1855 ha (4585 acres). Scale of the original map is 1:250,000, displayed here at 1:750,000.



APPENDIX G

MAP V: A comparison of classification results. MAP I was overlaid on the bio-physical base map (MAP IV) and misclassification of MAP I calculated for each land system using the Canadian Geographic Information Computer System. The top number gives the misclassification per land system when the various land types are grouped into broader class groups (A, B, C.....Z), while the bottom number lists the misclassification per land system when individual land types are compared (A_1, A_2, A_3,... B_1, B_2,.....,C_1, etc.). Scale of map is 1:750,000.