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PERMAFROST AND REMOTE SENSING

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ABSTRACT

Permafrost features can be effectively mapped and described by means of airborne remote sensing techniques. Work in the discontinuous and continuous permafrost zone with a wide range of remote sensing imagery showed that aerial photography, especially colour infrared with W12 and CC 20M or 20B filters allows accurate delineation of permafrost especially in organic terrain. Dynamic phenomena like melting can be studied and related to environmental conditions using repetitive sensing. On mineral terrain, it was also found to be effective for separating unvegetated, from heaved stone fields from other mineral areas and identifying active flow slides and aggradating permafrost in alluvial deposits. ERTS satellite imagery allowed typing of permafrost in arctic and sub arctic environments. In the boreal part of the discontinuous zone peatplateaus greater than 100 meters in diameter could be identified visually in large peatlands. High and low altitude thermal scanning (3-5 μm and 8-14 μm ranges) and SLAR imagery showed little promise of the detection of permafrost.

INTRODUCTION

During the last decade an increasing number of terrain studies have been carried out in northern Canada. Because of the inaccessible nature of the terrain and the lack of scientific information, most of these studies have relied heavily on remotely sensed data. In the earlier stages this was mainly black and white aerial photography. Multi-band photography, multispectral scanning and microwave sensors have added other dimensions to permafrost studies. Satellite platforms provide us with an effective

tool to monitor environmental changes that may affect the permafrost. This approach not only reduces the cost but also provides a great deal of additional information about the permafrost environment.

To evaluate the different remote sensing techniques and imagery for mapping and describing permafrost phenomena four study areas were selected in the localized, discontinuous and continuous permafrost zones. The study areas are located in Northern Manitoba and The MacKenzie Valley (N.W.T.). In this paper the approach to the interpretation of remotely sensed data for permafrost mapping is discussed based on the results with a wide variety of airborne imagery and ERTS satellite imagery.

MATERIALS

Remote sensing data used in this study are based on airborne and satellite information supplied by the Canada Centre for Remote Sensing during the last three years. The colour, infrared and black and white imagery used were obtained by use of Vinten and RC-10 cameras, at altitude varying between 5000 and 30,000 A.G.L. In most cases thermal scanning in the 3-5 Mm and 8-14 Mm was part of the airborne platform.

SLAR imagery was flown by the Maritime Proving and Evaluation unit for the Manitoba Test Sites. The satellite data from the Earth Resources Technology Satellite was used in the form of images and computer compatible tapes.

PHOTO ANALYSIS

The most important pattern elements of the natural landscape for image interpretation are macro and micro landforms, vegetation, and drainage.

The present operationally available remote sensors do not significantly penetrate the surface of the soil. Most of them register, in one way or another, radiation reflected or emitted from the surface of the land or vegetation canopy. The signatures of the surface are a function of the particular environmental conditions which influence the reflection or emission from this surface.

Since permafrost is a subsurface phenomenon, it does not appear directly on remote sensing data. However, it has long been recognized that permafrost greatly influences the geomorphic, vegetational, drainage and soil patterns of northern terrain (Hopkins, 1959; Tedrow and Harries, 1960). Understanding the relationships and dynamics of ecosystems is the key to the interpretation of permafrost as subsurface phenomena. If the relationships between permafrost and landform, relief, vegetation, drainage condition and drainage flow, soil and possibly climate and microclimate are known, all or most of these ecosystem elements can be used as indicators. The results of this interpretation will in most cases only provide information about the presence or absence of permafrost and its nature to a depth of approximately 1.5 to 2 meters.

In general, permafrost phenomena that are presently in balance with climate or that have been in balance during the last 600 years can be interpreted and described using the ecosystem approach. This includes much of the permafrost in the discontinuous zone and the upperpart of the permafrost in the continuous zone.

It is not presently possible to use remote sensing data to provide a quantitative value for the ice content of the near-surface zone. It is possible, however, to make an estimate of the ice content (e.g. low, medium or high) by applying knowledge concerning the landform, soil and vegetation.

RESULTS

Three areas were studied in detail during the last five years (Figure 1). These were: the area north of Lake

Winnipeg, Manitoba, at the southern limit of the discontinuous permafrost zone; the Churchill area, Manitoba, in the northern portion of the widespread discontinuous and southern portion of continuous zones; and the MacKenzie River area around Norman Wells and Inuvik in the widespread discontinuous and continuous zones, respectively. The results of these studies are given below.

Area North of Lake Winnipeg

In this area permafrost occurs only in peat deposits in the form of palsas and peatplateaus. Here, the main objective is to delineate permafrost in the largely unfrozen organic complexes. This can be easily and accurately accomplished on most types of aerial photography with large and small scales. Successful interpretation is possible by using the characteristic landform, vegetation and drainage patterns as well as by noting frequent association with collapse scars. (Figure 2.5). While colour and black and white imagery at various altitudes are effective tools for interpretation of permafrost bodies, the best results were obtained with colour infrared film with a W12 + CC 20M or CC 20B filters. This combination of filters proved more successful than any others tried in delineating small melting pockets in black spruce stands on permafrost, as well as the older collapse scars (Figure 2.5).

The ERTS imagery of this area was found to be useful for delineating larger permafrost bodies. Using visual techniques, perennially frozen peatlands (peatplateaus) with a diameter of about 100 meters could be identified (Figure 2.1 and 2.2). Identification of collapse scars from satellite was virtually impossible. Density slicing of the winter image of band 5 showed a highly contrasting pattern between snow covered fens (unfrozen) and black spruce covered peat plateaus (perennially frozen). As it is shown on Figure 2.3 the ERTS image was also interpreted by using Agfa contour slicing (Nielsen, 1973). Using these later techniques, fens and mineral terrain (both unfrozen) were separated from perennially frozen land. The frozen land was further separated according to large bodies with various amounts of collapse scars and other unfrozen peatlands and

isolated permafrost bodies surrounded by fens.

Using the above techniques detailed mapping of permafrost in this area was carried out in selected areas and yielded a great deal of accurate information concerning not only the occurrence of permafrost but also the associated landform, vegetation, drainage, peat material and soil (Tarnocai, 1972; Thie, 1972). The rate of degradation of permafrost was measured using aerial photographs with a 20 and 10 year time interval and related to other environmental factors. The melting was found to be approximately 1 per cent per year on an areal basis (Tarnocai, 1972), representing an annual rate of 1 meter melting per year in actively collapsing areas. As well different types of melting could be recognized: a peripheral collapse around very small small permafrost bodies and central collapse for larger ones (Thie, 1972). Thermal IR and radar data taken in this area contain very little information about permafrost and all of it was available on the photographic data in a much more detailed way.

Churchill Area

Permafrost occurs in almost all materials in this area. Small unfrozen areas are present surrounded by frozen terrain. The main objective in this area was to identify these unfrozen areas as well as the different kinds of permafrost types.

Most of the peatlands are frozen; only small parts are unfrozen or have permafrost at greater depths. The landforms associated with permafrost in this area are palsas, peatplateaus, peat polygons and frozen ribbed fens. Evaluation of the images indicated that the colour infrared film with a W12 + CC 20M or 20B filter produced the best results. The W12 + CC 20M combination provided more information about the vegetation cover of the wet and collapse areas.

On mineral terrain colour infrared film, also with a W12 + CC 20M and CC 20B filters, were very effective. Using this type of data, frost-heaved stone fields were easily separated from till and peat covered areas (Figure 4) even at very small scales (1:120 000).

Computer compatible ERTS tapes were interpreted and classified in an automated using program developed by Shlien and Goodenough (1973) at the Canada Centre for Remote Sensing. A separation between peat polygone areas, peatplateau areas, frost-heaved stone fields and frozen ribbed fens was obtained (Figure 4). Here again, thermal scanning (8-14 μ m range) provided very little or no information for the interpretation of permafrost.

MacKenzie River Area

The multispectral imagery taken in the Mountain River area (west of Normal Wells) was examined to evaluate its usefulness in detecting flow slide disturbance. The most common manifestation of disturbance in the MacKenzie Valley is the development of flow slides (disturbance of active layer starts the melting of high ice content permafrost, triggering slide development). These flow slides are active for quite a long period of time and then, due to revegetation and other processes, they become inactive. These inactive or partly active flow slides are slowly revegetated mainly with willows and other shrubs.

The MacKenzie Delta area represents a continuous aggradation and degradation of permafrost due to shifting of river channels, inundation and alluvium deposition and peat buildup. Areas where permafrost is close to the surface (less than 1 m deep) are covered with spruce forest (dark reddish) (see Figure 5); areas which are inundated and the permafrost nonexistent or just starting to develop have willows (red) as the dominant vegetation; and the active, unvegetated sand bars, where no permafrost is found, are identified by a whitish pattern on the colour infrared photograph.

Forest fires are very common in the boreal and subarctic boreal forest regions. Fires remove vegetation and the surface peaty layer. The active layer increases two-fold and ice-rich surface permafrost melts and triggers flow slide development and other erosion.

The area around Sitidgi Lake near Inuvik was burned excessively. Density slicing techniques were used to separate unburned and burned areas. The results were promising. Density slicing of ERTS channel 7 provided information about the unburned area where permafrost is close to the surface, burned areas where active layer increased, and finally the unburned tundra areas.

DISCUSSION

Results in the discontinuous and continuous permafrost zones of northern Manitoba showed that airborne multiband data, especially colour infrared photography used with a W12 colour compensating filter (such as CC 20M or CC 20B), are extremely useful for identifying permafrost. These film and filter combinations provided great accuracy and detail in work on peatlands. The W12 CC 20B combination is best suited for enhancement of the infrared and the W12 CC 20M is best for sharpness and good infrared return combined. (Worsfold 1972). In addition to macro and micro relief features, vegetation is one of the most important factors for the mapping of permafrost. Especially in organic terrain and sub-arctic and arctic where vegetation accurately reflects drainage conditions e.g. minerotrophic sedge fens, ombrotrophic sphagnum black spruce communities. Based on vegetation, provided one "eliminates" the effect of fires, one can delineate permafrost, assess degradation or aggradation and map presently unproven areas that would likely develop permafrost with a slight climatic deterioration. Normal colour and panchromatic photography also lends themselves to much of this, but with lesser accuracy. Colour IR allow the effective use of small scale imagery to 1:100 000, therefore reducing survey cost.

Comparison of photographs taken during the past ten and twenty years enabled determination of the rate of melting or degradation of perennially frozen peat landforms as a function of time and environmental parameters like climate, fires, drainage, etc. Repetitive sensing can therefore assist in approximating natural dynamic features and sensitivity to change can be inferred. This will help to

predict environmental impact on man's activities. One could expect that forest fires on peatplateaus in the sensitive southernmost fringe of the discontinuous permafrost zone would increase the rate of melting, however, comparison of 1947 and 1967 photography that the rate remains unchanged in old and recent burn areas.

In the continuous permafrost zone separating permafrost types is obviously more important than detection. Colour infrared photography lends itself to such typing as it enhances vegetation differences which, in the sub-arctic and arctic are significant indicators. It is relatively simple to map areas of palsas, peat polygons, peatplateaus, ribbed fens, stone fields and patterned ground phenomena. For frozen ground phenomena under shallow water colour images with their sensitivity in the blue and green parts of the electromagnetic spectrum are superior. In the arctic a multi-band camera package should preferably include colour and colour infrared. Inferences about the type of permafrost can only be made for the firm 1-2 meters of the surface layer, as this is the part that is influenced by climatic and other environmental conditions at present or in the past. Relict types of permafrost cannot be mapped unless they have a near surface contact, nor can their depth be estimated.

Satellite imagery obtained from the Earth Resources Technology Satellite (ERTS) provides only very general information about permafrost. The small scale of the ERTS data (1:1,000,000) makes it extremely difficult to recognize landform, vegetation or drainage features in any detail through the use of conventional interpretation techniques.

ERTS imagery allowed permafrost interpretation (using human and automated methods) in areas that had relatively simple permafrost ecosystems, especially simple vegetation-permafrost relationships. For example, in the southern zone detection and mapping of peatplateaus with diameters as small as 100 meters was possible in large organic complexes. In these large peatland areas the shapes and pattern of these permafrost landforms provided the key for successful identification rather than

signature. The more broken landforms of the Precambrian Shield proved to be too complex for successful permafrost mapping as shape and pattern were too much controlled by bedrock.

In sub-arctic and arctic environments where relatively simple relationships exist between vegetation surface reflection and permafrost type ERTS imagery interpretation for permafrost can be successful. Surface signatures become more significant indicators and the success of automated classification increases considerably. Optimum use can be made from the detail provided by the ERTS computer compatible tapes. The smallest resolution element if one pixel (250'-250' feet on the ground) enables thematic mapping at scales as large as 1:50 000. It should be realized that ERTS is of very limited value for the description of permafrost landforms. This has to be done on the ground and from aerial photographs. For this reason it is considered more effective to use airborne images if work at scales from 1:50 000-1:100 000 is required. ERTS becomes particularly attractive if mapping at 1:250 000 - 1:2 000 000 is attempted.

Features resulting from the melting of permafrost are good indicators of the presence of high ice content, perennially frozen materials. Using colour infrared photography, the active and inactive flow slides can be identified using human interpretation methods. In the MacKenzie Delta area, where permafrost is generally close to the surface, permafrost found at greater depths or unvegetated shorelines and sandbars without permafrost can be identified on colour infrared photography.

High and low altitude thermal infrared scanning in the 3-5 μm and the 8-15 μm ranges showed very little promise for detection of permafrost. This scanning was carried out in the daytime and permafrost bodies appeared as warm areas as they have a dry organic surface cover which warms up to approximately the temperature of the air (Tarnocai, 1972). Best results are obtained when repetitive day and night flights are made. Information of this nature appears to be of significance for understanding the dynamics of the active layer. The disadvantage of

scanner data is that it does not provide information about relief, while many permafrost landforms are relief-related. In addition the resolution of aerial photographs is considerably better at present. It is therefore suggested that any thermal scanning be accompanied by regular aerial or multispectral photography.

SLAR imagery, flown at an altitude of 7,5000 feet was of no value for the detection or delineation of permafrost.

REFERENCES

- Hopkins, D.M., 1959. Some characteristics of the climate in forest and tundra regions in Alaska. *Arctic* V:12, pp. 215-220.
- Nielsen, U., 1972. Agfacontour film for interpretation. *Journal of the American Society of Photogrammetry*, Vol. 38, No. 11, pp. 1099-1105.
- Shlien, S., and Goodenough, D., 1973. Automated interpretation of ERTS-A imagery using the maximum likelihood decision rule. Technical Report 73-2, Canada Centre for Remote Sensing, Ottawa, Canada.
- Tarnocai, C., 1972. The use of remote sensing techniques to study peatland and vegetation types, organic soils and permafrost in the boreal region of Manitoba. *Proceedings of the First Canadian Symposium on Remote Sensing*, V:1, pp. 323-335.
- Tedrow, J.C.F., and H. Harries, 1960. Tundra soil in relation to vegetation, permafrost and glaciation. *Oikos* V:11, pp. 237-249.
- Thie, J., 1972. Application of remote sensing techniques for description and mapping of forest ecosystems. *Proceedings of the First Canadian Symposium on Remote Sensing*, V:1, pp. 149-169.
- Worsfold, R.D., A qualitative study of Kodack Aerochrome infrared film, type 2443 and the effect produced by Kodak colour compensating filters at high altitude, *Proc. 1st Canadian Symposium on Remote Sensing*, V:2, pp. 417-427.

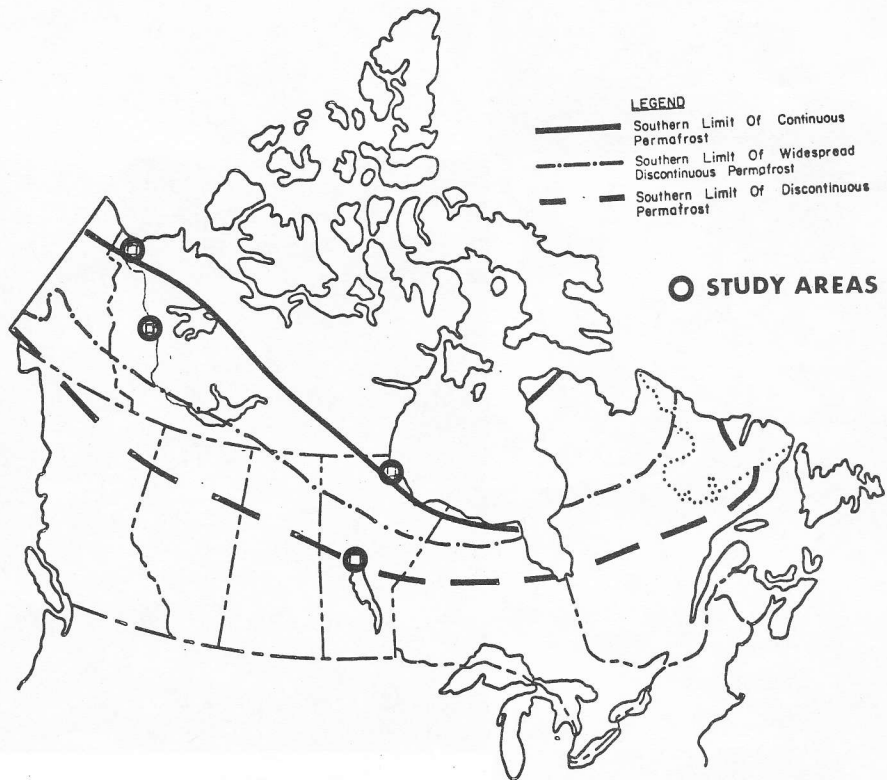


Figure 1

Location of study areas and permafrost zones.

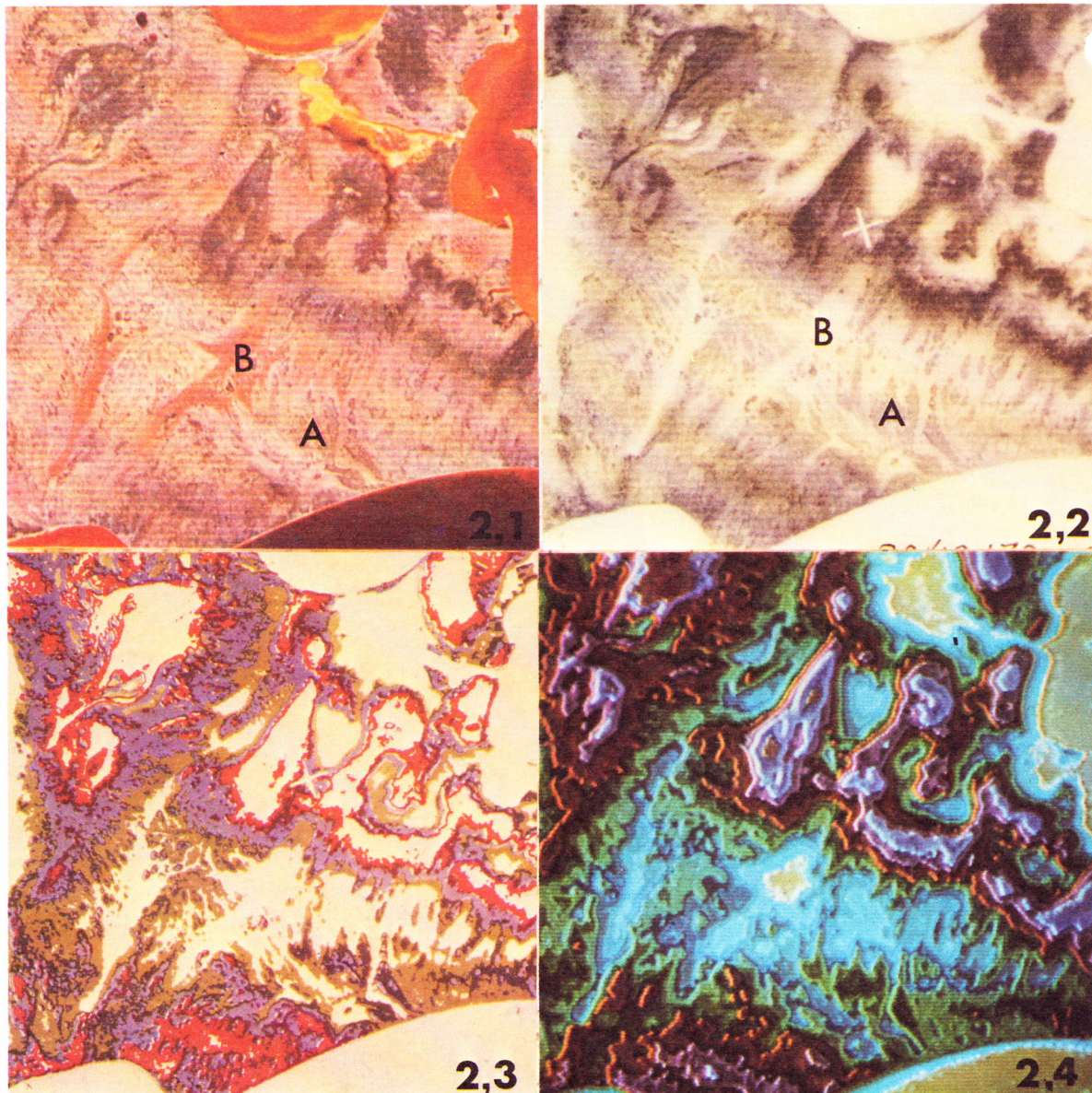
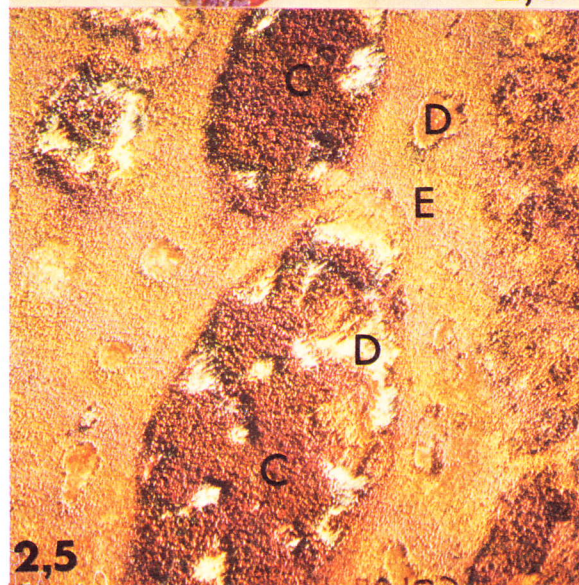


Figure 2

ERTS colorcomposite (photo 1) and a black and white winter image (photo 2) of the north shore of Lake Winnipeg showing perennially frozen peatlands (A) and unfrozen fen areas (B). The winter image was sliced using an analogue colour density slicer (photo 4) and Agfa contour techniques (photo 3). The latter was superior: the white areas are unfrozen wetlands or uplands, the red, blue and green areas contain various percentages of permafrost. Photo 5 is a colour infrared photograph taken from 5000 ft. ASL with a W12 + CC 20B filter. Note the frozen peatplateaus (C), collapse scars (D) and unfrozen tamarack fen areas (E). F identifies areas that recently melted; the grey tone is caused by recently killed trees.



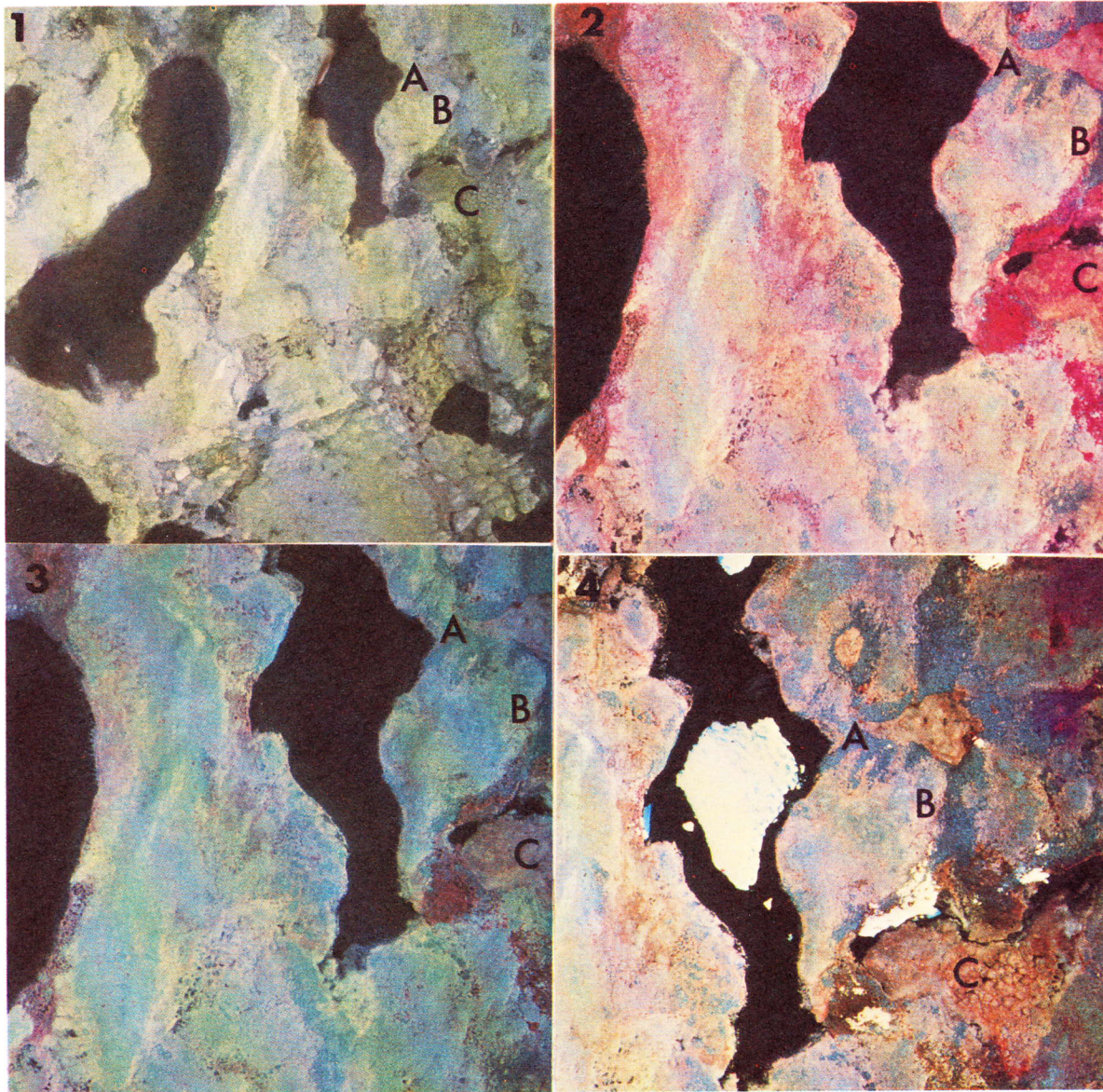


Figure 3

Colour and colour infrared photographs taken from 10,000 feet (a.s.l.). Photo's 1,2 and 3 were taken on July 22 and no. 4 on June 1, 1973. Wratten 12 filter with CC20M(2) and CC20B(3 and 4) were used. The frost-heaved stone fields (A) are easily separated from the till (B) and peatlands (C) areas on photo's 2,3 and 4. On the colour photograph this separation is more difficult to make.

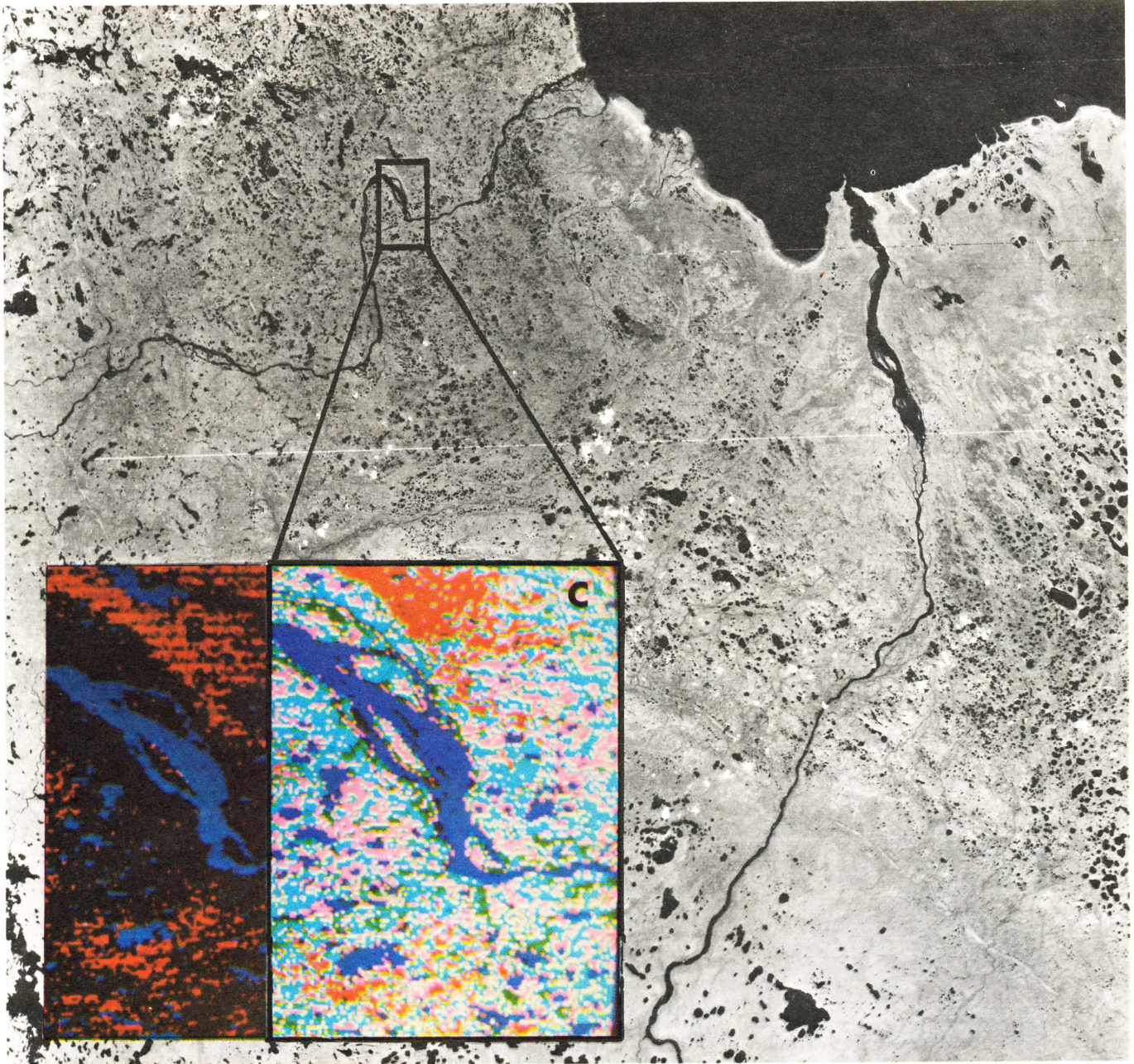


Figure 4

A computer classification of a part of the Churchill area displayed on the Multispectral Analyser Display at the CCRS. Water is blue, well drained peat polygons light blue, stonefields red, black spruce fringes green, ribbed fen areas are pink.

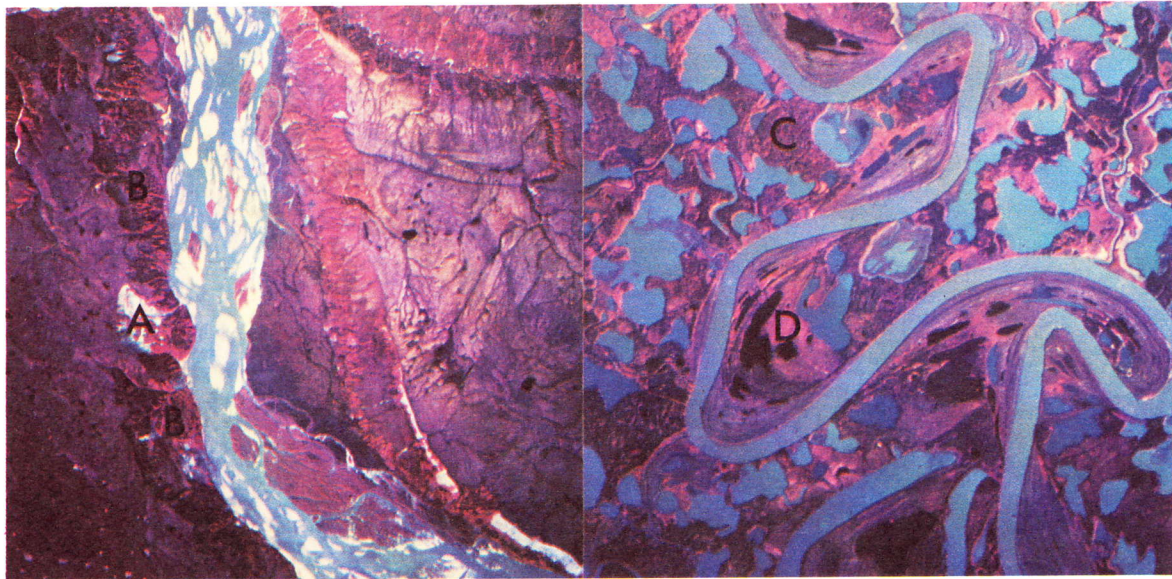


Figure 5

Active (A) and partly active (E) flow slides in the Mountain River area are shown on photo 1. On photo 2, the MacKenzie Delta area, can be seen forested areas (C) where permafrost is close to surface and willow covered areas (D) where there is either no permafrost or aggrading permafrost.