REMOTE SENSING

AND

THE ATHABASCA TAR SANDS

AN OVERVIEW

ENVIRONMENTAL RESEARCH MONOGRAPH 1974-1
Published as a public service by
Syncrude CANADA LTD.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF FIGURES

SYNCRUDE CANADA LTD.

ENVIRONMENTAL POLICY STATEMENT

Syncrude Canada Ltd. works with the conviction that human use of the environment need not be destructive. With careful planning, based upon good information, man-altered and natural ecosystems can exist in harmony. In order to accomplish this planning, Syncrude considers resource development from a total-systems point of view. This comprehensive approach corrects the frequent tendency to attempt resolution of problems on a single purpose basis. The total-systems analysis approach leads to a plan of operations using the best practicable technology, both in resource development and in environmental protection. An ecosystem approach to resource development, an integral part of our approach, implies an understanding of and respect for the potential of natural systems and the use of the economy of nature, wherever possible.

Through a comprehensive program of surveillance of the effects of our technology and careful application of that technology, we aim to prevent accidental damage to the environment. Total effects will be examined by professional ecologists and study results provided to public representatives.

FOREWORD

This report is a survey of remote sensing technology and its applicability to the environmental study needs of the tar sands area. The report includes examples of surveys of this nature that have already been completed by Syncrude Canada Ltd. No attempt is made here to provide detailed analysis of the many habitat types within the area of the tar sands. The intentions are to suggest the appropriate use of remote sensing technology in future studies and to illuminate the value of existing data for environmental surveys.

This monograph, based on work done by L.G.L. Limited -- Environmental Research Associates and prepared by Dr. Allan Falconer and James Nalbach, includes remote sensing imagery prepared by Machair Limited of Calgary, interpreted by the Sibbald Group and Dr. Falconer.

The Management of Syncrude Canada Ltd. feel that scientific information which results from its studies should be made available to the public. We feel a responsibility to contribute to the body of knowledge necessary for orderly development of the tar sands in order to minimize damage and maintain the ecological integrity of the area. We hope that the research information will be helpful to the scientific community and to the citizens of Alberta who are concerned with the management of resources on a sound ecological basis.

I. REMOTE SENSING

A. Definition of Remote Sensing

Any discussion of remote sensing requires definition of the process itself:

> "For the purpose of this report, 'remote sensing' is defined as being the measurement of environmental conditions at or near the surface of the earth that is performed primarily with sensors on airborne and space vehicles." (Ottawa 1970)

The definition is pertinent to the purposes of this report because it embodies aspects of environmental conditions and flexibility of sensor platforms that are important in the development of the Athabasca tar sands. The environment must be protected from destructive forces, and these forces must be monitored at the specific site and on the regional scale. These scales of monitoring can be realized through use of aircraft of various capabilities and through spacecraft equipped with remote sensing devices.

B. Relevance to the Athabasca Tar Sands

The development of any major resource has become a cause of concern to industry and agencies of government. What justifies concern is the significant deterioration that has been observed in many areas where natural resources have been exploited in the past. Often such deterioration has resulted from a lack of knowledge of the environmental setting and from an inability to view the whole area in which deterioration was taking place. Frequently deterioration has advanced to a crisis point before the full extent of the environmental damage has been appreciated.

In recent years greater effort has been devoted to studies of the interaction of all aspects of our "natural" environment, and this effort has increased our level of understanding of ecological principles. This state of awareness of ecological principles in turn means that there is presently less likelihood of unexpected secondary effects of our actions. We have more experience on which to base our predictions of these effects and a greater chance of avoiding the adverse effects in particular through careful planning.

The keys to such integrated planning are the abilities to measure environmental conditions and to understand the significance of any changes that may be recorded. We must be able to monitor environmental conditions in a way that will permit a rapid diagnosis of all symptoms and that will enable us to identify and correct any tendency toward deterioration. Remote sensing, as defined above, measures environmental conditions at or near the surface of the earth. Because such remote sensing measurements are conducted from aircraft and space vehicles, the vehicles can be used to monitor environmental conditions by obtaining repetitive measurements.

The Athabasca Tar Sands cover an area of 11,340 square miles (Anonymous, 1973, p. 11). Such an area would not be difficult to monitor in a more densely settled and well-serviced area of the province; but in the region that surrounds Fort McMurray and Fort Mackay there is comparatively little access to many areas (helicopters or light aircraft would be the most satisfactory method of transportation). The environment, mostly a mosaic of muskeg, wooded areas, and sand dunes, is in many senses a wild environment (Anonymous, 1973 p. 39). Presently within the tar sands area are unpolluted streams supporting populations of fish; also within the area are many species of small mammals and game animals. At the appropriate seasons, waterfowl and other birds use this area as a stopover on their migration to and from the arctic and sub-arctic regions.

International agreements concerning the protection of migrating birds must be honoured. The activities of the World Wildlife Fund and similar organizations with international significance are focusing their attention on the need for better conservation practices and management of wild lands. The influence of these organizations creates a situation that requires development to proceed in harmony with the management of the natural resource of wildlife and the habitats that this resource depends upon.

Following from this requirement for management of the environment is the need to obtain measurements of environmental conditions over an area of 11,000 square miles or more. The use of remote sensing techniques efficiently satisfies this need. Provided below is a summary of the major techniques that would aid in the monitoring of the environment of the Athabasca tar sands area.

C. Remote Sensing Data

In the definition of remote sensing, reference is made to "sensors on airborne and space vehicles". It is the aim of this section to briefly describe the nature of the sensors commonly employed and to discuss the appropriate use of various types of airborne and space vehicles. The sensors employed in remote sensing operations all make use of reflected or radiated electromagnetic energy that returns to space as radiation from the earth. Energy in the visible spectrum provides the information that we can see. Energy in the radiated infrared part of the spectrum provides information that we can feel as heat. In simple situations, remote sensing, as the conventional air-photo, is the recording of visible light on film. In such situations the sensor is a camera. A more sophisticated sensor is the radiation thermometer, which records the heat energy as a temperature reading and which can (if suitably equipped) provide us with a temperature map or "heat picture" of an area. The radiation thermometer uses electronic systems, and not the optical system used in the conventional camera, to record temperatures. Because the more sophisticated sensors also use electronic systems to record light energy, the term "sensor" cannot be used interchangeably with "camera". An aerial camera is only one type of sensor, and in many ways it provides us with an elementary form of data.

C1. Photographic Data (b & w photographs)

Panchromatic film used in aerial camera provides black and white photographs of the ground area. Such photographs have been available for several decades, and there is now a sophisticated industry capable of collecting high quality photographs and of producing accurate site plans from these photographs. Examples of this use of air photographs are numerous. The whole subject of photogrammetry is based upon the stereoscopic effects that can be created by collecting photographs with overlap between frames. Detailed measurements of height, volume, and area can be obtained from appropriate survey photography, and such photography often forms the basis of much of the work produced by soil surveys, land use studies, geological work, forest inventories, and vegetation surveys. The scale of these photographs may vary greatly. Scales of 1:5,000 to 1:40,000 are commonly used, and such photographs provide sufficient detail for identification of many tree species, shrubland, crops, soil types, stream characteristics, and the condition of ponds and lakes. A skilled photo interpreter can use this type of information to great advantage.

Air-photos of this type will be invaluable for detailed work pertinent to the Athabasca tar sands. Site investigation and engineering work on the Syncrude Project used this type of data for the preparation of the initial plans. This type of data is typically used in the inspection of river bank conditions and the extent of tree canopies and in the mapping of small areas of specific cover type. Identification from this type of information of habitat suitable for various associations of mammals and birds is a routine matter. Surveys of areas on this level of detail are capable of complementing studies undertaken on a broader scale. It is useful to undertake this type of detailed analysis in conjunction with broader scale studies because such analysis provides excellent definition of variability within a larger region. Judicious use of such detailed studies of sample areas efficiently provides a wealth of information.

C2. Photographic data (colour photographs)

The use of colour film permits a greater range of information to be recorded. Differentiation of vegetation types becomes an easier task when colour photographs are employed (Heller, 1970; American Society of Photogrammetry, 1968). The use of natural colour film in comparison with panchromatic film generally enhances recording of information. Best results are obtained when the film is used with a filter combination that eliminates haze. This combination effectively introduces selectivity into the camera system; hence, only a portion of the light in the visible spectrum is recorded. Colour aerial photography is a great asset in the compilation of habitat maps and in vegetation and soils studies and similar work.

Even more detail can be extracted from colour aerial photographs when false-colour (colour-infrared) film is used. This type of film includes energy in the range beyond the visible spectrum. This film is, in fact, sensitive to both visible light and to the reflected infrared energy. Film of this type is also referred to as "camouflage detection film" and is used with a yellow filter (Wratten, No. 12). The filter prevents blue light from recording on the film giving excellent haze penetration. Characteristically, colour infrared film shows healthy vegetation in a bright red and magenta colour. This appearance serves to record the facts that healthy vegetation is highly infrared reflective and that the combination of dyes used in the film records this sensitivity in red and magenta tones (for detailed discussion see Heller, 1970, p. 47). Dead vegetation or plants suffering stress show colours other than the typical red colour of healthy vegetation. Colour infrared photography is therefore extremely useful in studies of vegetation stress resulting from changes in drainage, application of chemicals, the effects of air pollution, or disease, or insect infestation. The degree of stress can be determined from the colours recorded for stressed vegetation (see Heller, 1970, p. 48). This film is useful in monitoring sites where changes in drainage characteristics are expected, and it also provides information on the relative abundance of chlorophyll in lakes and ponds with chlorophyll concentrations of medium and high values.

C3. Photographic Data (multi-spectral camera systems)

The most sophisticated of the camera systems is the multi-spectral camera system. As its name suggests, this system records the energy from multiple portions of the spectrum. This recording is achieved by sighting several cameras on the same scene. Each camera carries a film and filter combination that allows it to record only the information that is contained in a limited part of the spectrum. The typical system has either three or four such cameras trained on the scene and hence records information in three or four areas of the spectrum. Multispectral information of this type can be used to discriminate between features that may appear similar on panchromatic photography--between such features, for instance, as idle or abandoned farmland and young forest cover or burnt areas of forest and bedrock outcrops. In land use mapping and identification of habitats, this type of imagery is particularly useful on small scales (1:60,000, 1:120,000) because it provides regional data that can be easily manipulated.

C4. Scanner Data

The scanner is a more sophisticated sensor system than the multi-spectral camera system. Usually referred to as the multi-spectral scanner (abbreviated as MSS), this sensor is an electronic recorder than scans a scene in a manner resembling that of a conventional television camera. Such scanning produces a signal that is the record of the electromagnetic energy. This signal can be split into very narrow wavebands permitting a wide portion of the electromagnetic spectrum to be recorded as a series of narrow wavebands. Because these records are electronic, these data can be easily manipulated by computer. Multi-spectral scanners currently in use are capable of recording ten or more divisions of the spectrum. Detailed work with data of this type has shown that use of ratios of certain bands can reveal many features. Successful work with MSS data includes the mapping of silicon-rich areas (ERIM, 1973), the effective discrimination of crop types and vegetation types, the mapping of effluent in streams, the determination of soil moisture, the detection of plant disease, and many other applications relevant to the monitoring of environmental conditions (Krumpe, 1973; Myers, 1970). A scanner system of this type that records data in four spectral bands is the operational sensor on the earth resources technology satellite (ERTS).

C5. Radar Sensors

Many applications of radar sensors are in the process of development (Holter, *et al* , 1970). Effectively used in areas where cloud or vegetation cover is extreme, radar provides information concerning the interrelated subjects of geology, geomorphology, and terrain type. Radar is not at present an appropriate sensing system for the Athabasca tar sands area, although applications of radar systems for timber volume assessments are operational and would be effective in studies for forestry purposes.

C6. Microwave Sensors

Microwave sensors are useful in the detection of soil moisture and the mapping of ice conditions on lakes and oceans. Because these sensors can penetrate cloud cover (Holter, *et al.*, 1970), they are of particular value in regions that have a high percentage of cloud cover. Although the data gathered appear to have a variety of useful applications, much of the work with these sensors is still in the experimental stage.

C7. Other Sensing Systems

Experimental sensors using laser beams and variants of the radar and microwave systems are in the developmental stages. Some of these sensors will become operational during the next decade, but they are not presently viable as environmental monitoring systems.

D. Data Products

Remote sensing can produce many different types of data. Because data in a photographic form is commonly produced, a tendency exists to equate all such products with a photograph. This equation is not always a valid one. Computerized data records are very flexible and can be put out on a line printer, as a cathode-ray tube display, on a computer-plotter, or in photographic form. The versatility of such systems is an inverse function of their availability; the most readily available systems (cameras) offer least and the more specialized systems (scanners) greatest flexibility. The following notes indicate the nature of the various data products.

D1. Photographs

Both black and white and colour air photographs are useful forms of data. Such photographs do have certain distortions contained in the data; these distortions are a function of the lens properties of the camera. The angle of view, moreover, can also create difficulties of interpretation. The typical air photograph covers a relatively small area, usually less than 81 square miles when viewed in a 9" x 9" photograph. In order, therefore, to create a regional overview, several individual photographs must be assembled into a mosaic. Mosaics of large areas become an expensive undertaking, and in the creation of these mosaics the balancing of tones and the "fitting" of the constituent prints destroy the absolute measurements of image density. Because of these distortions, it is difficult to use air photographs to record measurements of reflected light. Hence, the information concerning aerial extent and location of the features noted by an interpreter constitutes the major data content of such photographs.

The photographs produced from the multi-spectral camera system are subject to the same distortions, but this system is more flexible because each spectral band can be displayed in any chosen colour. Superimposition of two such images (each displaying information from different parts of the spectrum) can create a false colour image that clearly displays the features of interest. Scanner data may also be displayed in this manner. In this case, the record of energy in each band would not be distorted by a camera lens, but the positional accuracy of these measurements would be more difficult to determine than in a photograph. In short, the conventional photographic systems provide information about areas and position, and the scanner provides an accurate record of the energy in selected portions of the electromagnetic spectrum.

D2. Maps and Digital Data

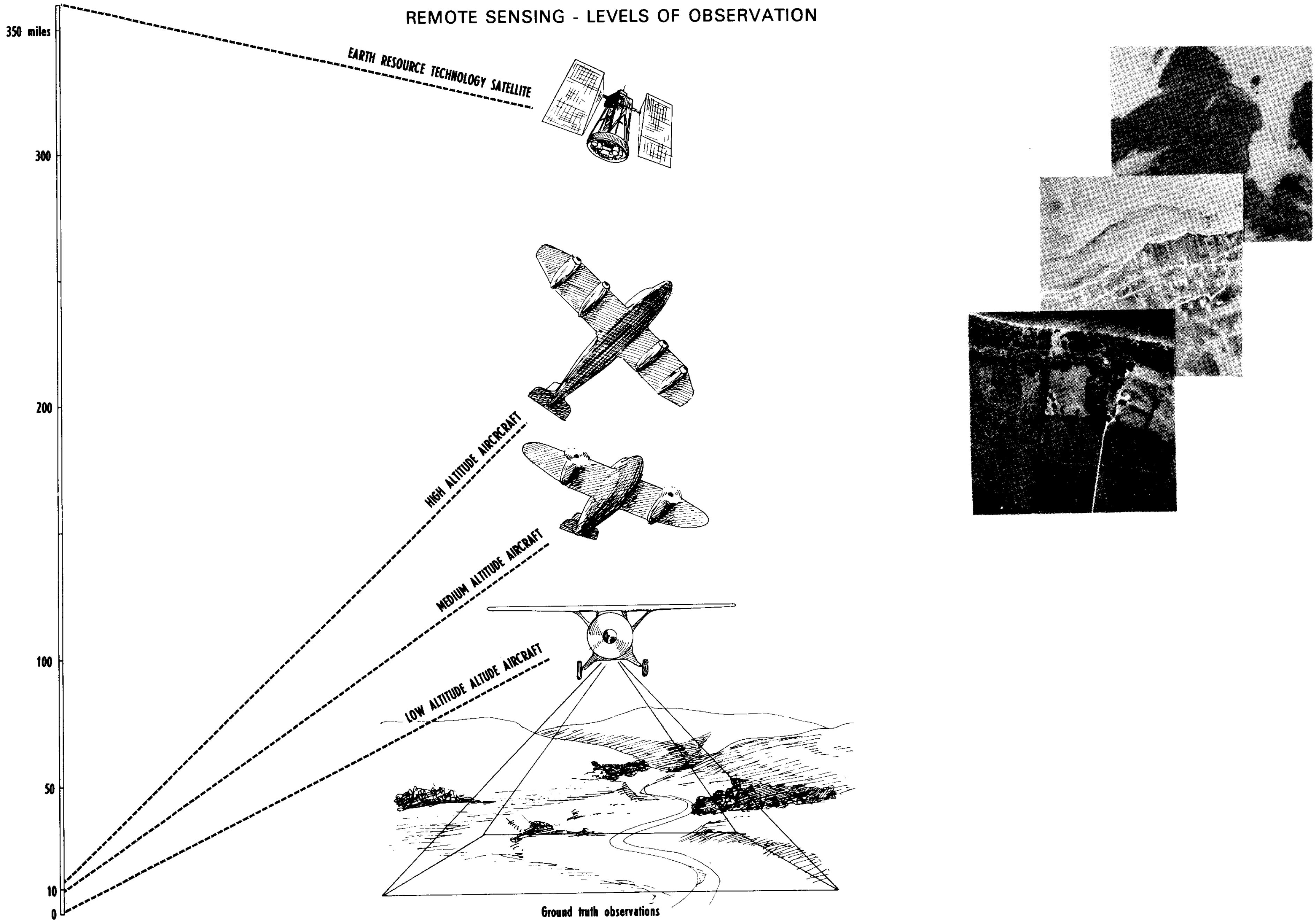
Studies have shown that a plot of energy against wavelength for various items produces curves that define the items very closely. These curves are referred to as "spectral signatures", and the spectral signature of muskeg differs from that of coniferous woodland. Spectral signatures can be used for example to distinguish crop types, soil types, and open water and land. The rapid comparison of spectral signatures is best accomplished by a computer, and multi-spectral data can be rapidly processed by computer systems in order to identify chosen features. These multi-spectral data, once gathered from an area, can be rapidly processed in a way that will, for instance, identify open water. These data can then be printed out by the computer as a "map" of open water; the map can moreover be displayed on a cathode-ray tube as a colour television picture in which open water may be displayed in any chosen colour. Several such features may also be identified; hence, the display may show open water, coniferous forest, swamp, and rangeland for the whole study area. The speed and capacity of computerized systems ideally qualifies them for analysis of large volumes of data. These systems are capable of much finer divisions of data and of more precise definition of detail than would be possible through use of any visual system of interpretation. The application of such systems is discussed in Sections IV, V, and VI below.

E. Sensor Platforms (Vehicles)

The sensors discussed above must be carried over the study area in order for them to record the required information. Each type of sensor may be carried in an aircraft, in a spacecraft (or satellite), or each may be suspended from a crane or "cherry-picker" and conveyed over the study area through use of different methods. The effects of the use of the different vehicles (or sensor platforms) are considerable (see Figure 1). Major consequences

Figure 1

REMOTE SENSING - LEVELS OF OBSERVATION



of the choice of vehicle are discussed below.

E1. Crane or "Cherry-picker"

The use of a remote sensing system suspended from a mobile crane or installed in a "cherry-picker" has proved to be an extremely efficient method in detailed small-area studies. The mobile crane and the "cherry-picker" maintain the lowest possible altitude for observation of the environment by remote sensing techniques and consequently produce data on a large scale. Such systems could be used to study the behaviour patterns of fish in small ponds or of beaver around their dams; or they could be used to study the detailed sequence of events as parts of a new tailing pond or of an effluent holding area are established.

E2. Aircraft

Remote sensing is usually conducted from an airborne platform. The significant effects on data are related to the size and capability of the aircraft chosen for use. The larger the aircraft is the more equipment it can carry. A full complement of remote sensing devices can be carried by a DC-3 or similar-sized aircraft. Individual sensors (such as radiation thermometers and single cameras) can be carried by suitably equipped aircraft. Low flying aircraft necessarily have a more restricted field of view than those with a greater operational altitude.* Thus the type of aircraft limits the scale size on which data can be gathered.

* With a 6" focal length camera, an aircraft flying up to 10,000 feet can produce imagery on a scale of 1:20,000. This gives an area of about 9 square miles per 9" x 9" frame. To obtain a regional overview of an area of 324 square miles per 9" x 9" frame (scale 1:120,000 approximately), the same camera would have to be carried to an altitude of 60,000 feet. Cost also becomes an important consideration in these calculations.

The avilability of suitable aircraft and the onset of weather conditions that allow data collection are also important considerations. Any attempt to monitor environmental conditions on a seasonal or annual basis requires a large budget and such favourable circumstances as aircraft availability and suitable weather conditions.

E3. Space Platforms (Satellites)

At the present time the systems of space platforms that carry remote sensing devices consist of satellites that orbit the globe with varying frequencies and purposes. The largest systems of satellites are the weather satellites that provide daily a total view of global weather. These systems do not provide a great deal of information concerning the earth's surface. In the absence of cloud cover, however, these systems do provide a small-scale view of portions of the globe. The latest series of these satellites launched by the National Oceanographic Atmospheric Administration of the U.S.A. (NOAA) provide more detailed information than previous weather satellites. NOAA-2, with a thermal sensor on board, provides images of the earth's surface on very small scale every 12 hours. On this small scale much detail is obscured, but major regional patterns can nevertheless be observed.

The primary source of data concerning the earth's surface is the Earth Resources Technology Satellite (ERTS-1). This satellite, which currently orbits the earth every 103 minutes, observes each point on the earth's surface between 82^{O}N and 82^{O}S at least once every 18 days (when cloud cover permits). The data from ERTS-1 are gathered by a multi-spectral scanner system that records information for four areas of the spectrum. These areas are identified as follows:

Channel 4 -- 500-600 micrometers (wavelength);
Channel 5 -- 600-700 micrometers
Channel 6 -- 700-800 micrometers
Channel 7 -- 800-1100 micrometers

As it orbits the globe, the scanner system views a swath 100 nautical miles (185 km) in width. Data from the satellite are available in photographic form on a scale of 1:1,000,000 or 1:250,000 and may be obtained as black and white prints, as transparencies of each band, or on colour composites through use of information from 3 of the 4 bands recorded. The data are also available in computer-compatible tapes, which may be processed to yield information at the smallest resolution element level. The smallest resolution element for ERTS is approximately 80 m x 80 m (about 1.5 acres).

ERTS is an experimental satellite the capabilities of which are still being evaluated. It is, however, a substantial improvement over other existing remote sensing systems because it permits monitoring of environmental conditions over large areas at a comparatively small cost. ERTS has provided the first clear views of seasonal conditions over the whole of Canada and continues to gather additional data each day.

Canada's unique "quicklook" system enables users who wish to obtain data immediately to have data transmitted to them within minutes of the satellite pass. For monitoring purposes, the "quicklook" data can be mailed to the user within 3 or 4 days of the satellite pass. This capability of the "quicklook" system is a great asset in any study of environmental conditions over a large area.

II. THE ATHABASCA TAR SANDS

Within the past two years, numerous reports and studies have been prepared by governmental agencies and private industry concerning the environment of the Athabasca tar sands. Most of these reports and studies have consisted of overviews or "screening studies" that were conducted in order to illuminate some specific area of concern, but some of the major environmental issues also become apparent. The theme underlying these general observations is one of environmental protection on a regional scale.

Where issues of regional development are of primary importance, the need exists for data for the planning process on this scale. Primary concern is, clearly, for planned development of a region that will ensure minimal environmental impact. Because the environment totally integrates factors in the region, it cannot be studied effectively on any single disciplinary basis. Both this integration and the regional planning that is recommended are aspects of the geography of this region.

Emphasis of geography in this way serves to highlight the integrated nature of the studies that will be required. Rock type, vegetation cover, climatic condition, and hydrologic characteristics of an area are interrelated. The planner must be continuously aware of this interrelationship and must be careful not to accept conclusions of any single specialist in any single discipline without first referring thoroughly to the other constituents of the environment. Remote sensing data provide this integrated view of the environment and when used as a planning base serve as a constant reminder of the variability and interaction of the components of the environment.

Within the tar sands area there now exists the opportunity to exploit the regional scale data supplied by the Earth Resources Technology Satellite (ERTS-1). For the first time, these data (discussed below) provide a total integration of environmental factors in one scene and remove the need for subjective elimination of data that has previously been used by cartographers designing maps on small scales for regional use. This new data source should be exploited by all concerned government and industrial management agencies in their formulation of plans for the development in the tar sands region.

III. REMOTE SENSING USED BY SYNCRUDE CANADA LTD.

On August 17, 1972, a series of colour and infrared aerial photographs were taken by Machair Surveys Ltd. in the area of Syncrude Lease #17. Interpretation based on these photographs was prepared by the Sibbald Group. On September 5 and 6, 1973, more photographs were taken. With the exception that some of the deciduous foliage had changed colour, the interpretation was similar to that of 1972. The leases under study cover about 45 square miles and include the Syncrude extraction and bitumen upgrading area, the initial mining area, and the Beaver Creek water diversion area. The areas consist of natural forest and sedge meadows containing mixed coniferous and deciduous timber stands,shrubs, native grasses, peat bogs, and lakes. Numerous seismic lines, on which trees have been periodically cleared, criss-cross the area. Generally, the native grasses along these cut lines show healthy growth; in a few areas, however, the topsoil had been disturbed to the extent that the vegetation has not recovered.

Tree stress was most noticeable along water routes where the high water level had caused trees to drown. Stress from frost, recently defoliated trees, and old exfoliated trees with the bark peeled off is also evident.

Syncrude intends to continue and expand photographic monitoring during the construction phase and the opening of the mining area. It should be noted that some of the remote sensing work described here took place previous to the major construction thrust and was used as baseline data against which to monitor changes in the environment resulting from development.

Syncrude now uses photographic data in studies of medium and large scale features within their own lease areas. The study completed by the Sibbald Group (Sibbald, 1973) provides many clear examples of the use of this type of data. The series of photographs taken by Machair Surveys were analysed by the Sibbald Group, and a small number of these have been selected to illustrate the uses of colour infrared photography (see Figure 2). The use of black and white air photographs on a medium scale (1:31,680) for overviews of portions of lease areas is also demonstrated.

An example of such use is provided in Figure 3, which is a view of the Athabasca River in the Mildred Lake area. This scene, originally photographed on a scale of 1:31,680 on August 31, 1967, has been included to illustrate the use of black and white air photographs on a medium scale (approximately 2" - 1 mile) for use in planning and monitoring operations within the area of a lease. In this scene the environmental complex is well illustrated. The topography is of the sag and swell type, and the swells (elongated ridges) are generally underlain by gravel covered by a veneer of soil. These areas are generally well drained and have healthy coniferous stands (dark tones) established on them.

The sag areas have discontinuous deciduous tree cover and grass and/or sedge growth, and these areas show as bright tones in the photograph. Mildred Lake is a depression in a sag area, and organic mats formed on the lake surface are visible. A smaller pond in the centre of the scene shows advanced stages of bog development covered with a growth of moss. Sags are probably areas of limited access during all seasons but winter, when they are frozen. These low-lying areas have only low tree cover (less than 10' in height) and probably include species of willow and birch. The scene clearly shows the network of tracks cut in the region for drilling over the area. Although these tracks are very

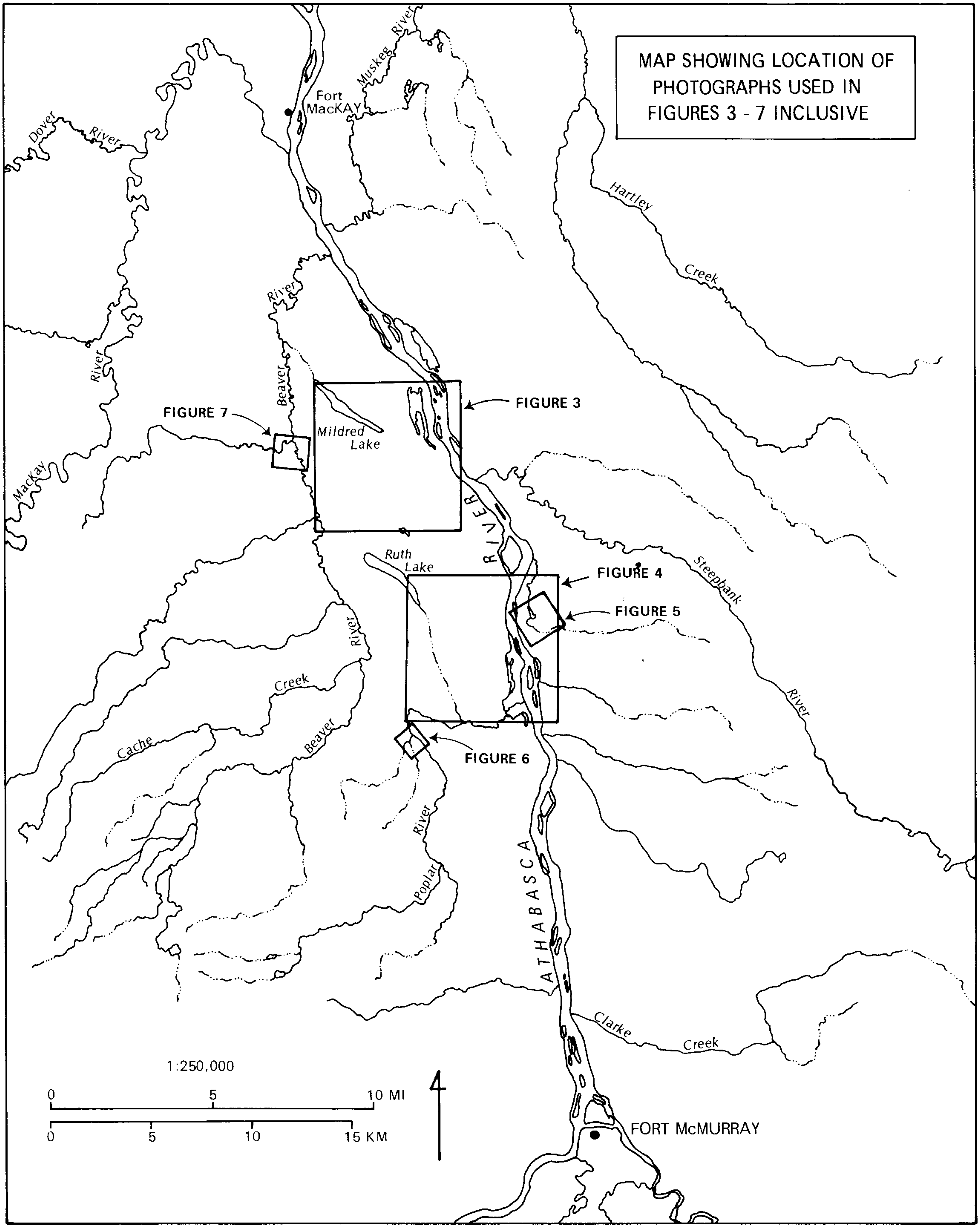

MAP SHOWING LOCATION OF
PHOTOGRAPHS USED IN
FIGURES 3 - 7 INCLUSIVE
Fort
MacKAY
Muskeg River
Dover River
Hartley Creek
River
Beaver
River
MacKay
FIGURE 7
FIGURE 3
Mildred
Lake
RIVER
Ruth
Lake
FIGURE 4
FIGURE 5
Steepbank
River
Creek
Cache
Beaver
River
FIGURE 6
River
Poplar
ATHABASCA
Clarke
Creek
FORT McMURRAY
1:250,000
0
5
10 MI
0
5
10
15 KM

Figure 2

Figure 3

BLACK AND WHITE VERTICAL AIR PHOTOGRAPH OF THE MILDRED LAKE AREA, AUGUST 31, 1967 apparent, no terrain damage other than the aesthetic result of tree removal over a grid pattern is detectable. Examination of the imagery gathered in 1972 and 1973 shows that there has been no noticeable effect on the terrain in subsequent years. Figure 4 provides a further example of this use of black and white air photographs that shows the variability in the type and amount of vegetation over the southern reaches of Ruth Lake.

Of particular interest in Figure 4 are the large sediment loads carried by the river and the islands, sand banks, and small spits deposited by the river. Increase in the sediment load of the river from bank collapse, or other input of material, would be reflected in greater water turbidity, and in this stretch, probably an increase in depositional features. Such relationships between open water and vegetation on Ruth Lake and between river turbidity and depositional features are clearly revealed in this type of imagery. The associations of muskeg, lakes, and coniferous vegetation are again clearly revealed; coniferous stands showing as a dark tone and the open deciduous areas (muskeg) as a lighter tone.

The use of false colour (colour infrared) film is of great advantage in the interpretation of such areas. In Figure 5 a classic example of muskeg is shown; the lake pictured is in the process of being filled in by vegetation growth. When completely covered in vegetation the lake is known as a quaking bog. The underlying decaying vegetation forms a shallow spongy area that was formerly occupied by the lake. The mauve-purple tones of vegetation around the marsh indicate excess water and anaerobic conditions, which contrast markedly with the magenta tone of the healthy vegetation to the south.

Natural processes, for example, cause vegetation stress, which is easily detected on colour-infrared photography. In Figure 6 an example of stress produced by a small beaver dam

Figure 4

BLACK AND WHITE VERTICAL AIR PHOTOGRAPH OF THE SOUTHERN TIP OF RUTH LAKE AND A REACH OF THE ATHABASCA RIVER AUGUST 31, 1967

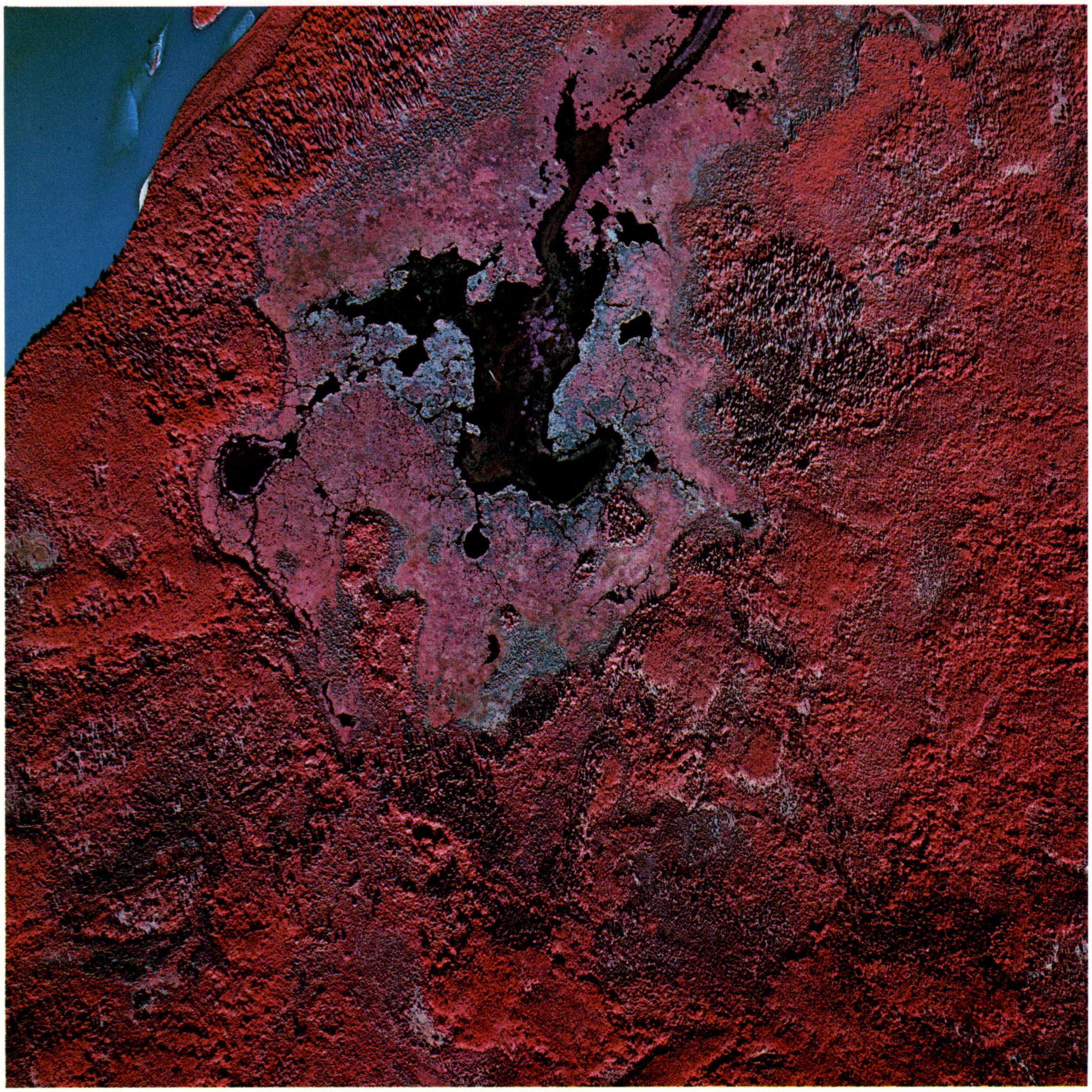


Figure 5

COLOUR INFRARED PHOTOGRAPH SHOWING MUSKEG GROWTH ADJACENT TO THE ATHABASCA RIVER

Figure 6

COLOUR INFRARED PHOTOGRAPH SHOWING VEGETATION STRESS CAUSED BY BEAVER DAM (CIRCLED) AND AREA OF POOR TOPSOIL (WHITE TONES) is circled in the NE quadrant of the photograph. The light tones of the central area reveal sandy soils with sparse tree cover and many fallen trees, where the overall situation is one of poor topsoil conditions. Routes and vehicle movement in this area do not appear to have created any major vegetation stress.

The examples used thus far indicate the uses of remote sensing in the collection of a record of environmental conditions in which human disturbance has occurred. The regionalisation of muskeg and conifers, for instance, can easily be done from this type of photographic data. The final example used in this section is a colour infrared photograph of a development in the Syncrude test-pit programme (Figure 7). A total lack of red and magenta tones throughout the development area attests to the absence of vegetation, and the layout of holding ponds, roads, tracks, dragline operations, and drainage ditches is clearly revealed. Trees drowned by the restriction of flow in a small stream can be seen in the northwest quadrant of the photograph (circled), and the overall impact on the natural environment is clear. Such data are of great value in the determination of the effects of development. The consequences of disrupting drainage, of overburden removal, or of removing natural cover types can easily be recorded.

Syncrude has used data of this type in all stages of its planning of lease 17. Similar systems of survey, if used by all companies involved in development of the tar sands, would rapidly produce a total environmental record of the original conditions and a record of the impact of each stage of development. Major damage could, then, be detected rapidly and remedial action taken when necessary.

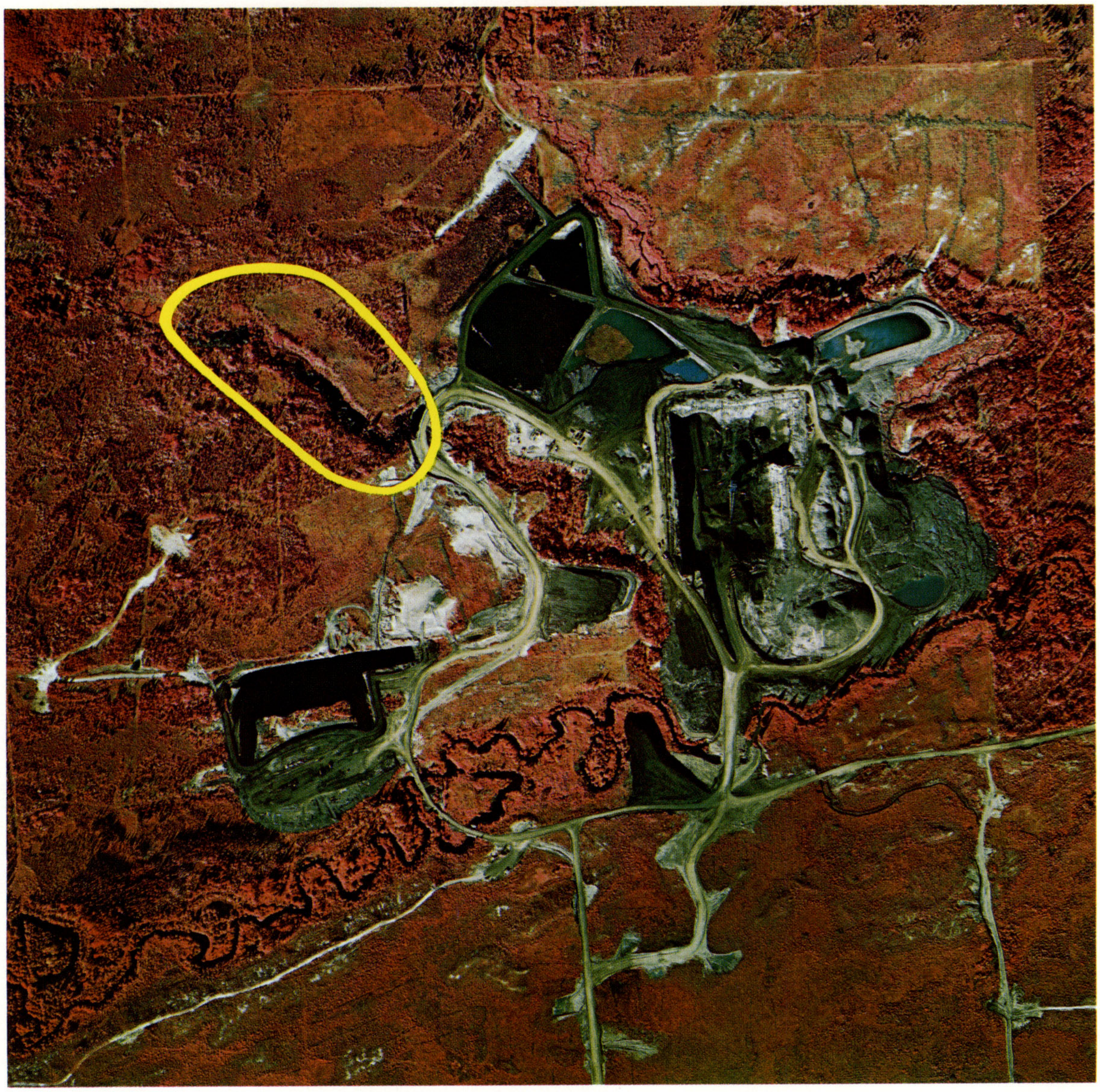


Figure 7

COLOUR INFRARED PHOTOGRAPH OF THE SYNCRUDE TEST PIT. Note the great detail, position of vehicles, holding ponds, total site layout. Minor damage to vegetation (circled) caused by damming of small stream. Damage is otherwise restricted to the development site.

IV. ERTS DATA AS A REGIONAL MAP

Environmental conditions over the area of the tar sands have not been mapped in detail. The reports mentioned above contain only partial assessments of environmental conditions and lack summary maps of the whole region that integrate the information provided on an individual disciplinary basis. The studies are valuable, however, in the detailed treatment of specific problems or of areas of concern.

Remote sensing offers a great deal of information concerning the variability of habitat and the major regions of the tar sands. Data gathered by ERTS (Earth Resources Technology Satellite) are produced on a 1:1,000,000 scale, and each photographic print of the data covers approximately 10,000 square miles. Moreover, the entire tar sands area extends over 11,340 square miles (Anon., 1973); this is to say, then, that one image from ERTS covers almost the entire area of interest. Because the satellite's sensors record not only forest and water but also the whole integrated complex of phenomena present in the field of view, ERTS is able to provide fully integrated regional data.

The regional extent of major cover types, the relationships of land-units to each other, and the identification of terrain types are clearly displayed by ERTS imagery. ERTS data provide a powerful method of conveying integrated information about the region (Colvocorresses, 1973). Presently there is no system more capable of efficiently conveying such information. Figure 8 provides an example of such integration of information; the figure includes the geographic regionalization of the area and a series of marginal notes on the features displayed. The geographic regionalization and marginal notes constitute the information, and Figure 8 has been compiled only for demonstration purposes. Detailed analysis reveals far more information. The use of all four spectral bands instead of band 7 alone (used in Figure 8) permits an extremely detailed analysis of the study region. However, Figure 8 suffers a loss of detail that results from reduction to a scale less than 1:2,000,000.

The same image, but with a slightly more detailed annotation and less marginal comment, is used in Figure 9. Figure 9 more clearly illustrates the wealth of detail contained in an ERTS image. The power of this image is especially surprising when one considers that 10,000 square miles of Alberta are reliably represented in this one scene. It is important to realize that the scene is presented through use of only 25% of the available data. Bands 4, 5, and 6 also contain an equivalent amount of information. Through the combination of these bands by use of different colours, it is possible to display a much greater level of detail. Computer processing of the scene permits even more detail to be mapped. It must be stressed that Figures 8 and 9 represent an illustration of ERTS data for general purposes only. Detailed analysis of the area can produce maps that show either all forested areas or muskegs individually or maps that show both areas. Analysis of the image in each case requires a clear definition of the aims of the analyst. Accurate maps of any selected features can, then, usually be produced with relative ease.

The regional approach to the general observations clearly receives support from the regional data supplied by ERTS. More detailed ecological information for the planning process can be obtained from ERTS data at the regional scale, and the repetitive coverage conducted by ERTS (again on the regional scale) provides a system of monitoring the effects

Figure 8

THE ATHABASCA TAR SANDS AS SHOWN BY EARTH RESOURCE TECHNOLOGY SATELLITE IMAGERY

Altitude: 560 miles Time: 9.06 hr.
Date: January 3, 1973 Sun angle: 10°

GEOGRAPHICAL REGIONS

A Deeply dissected moraine with complex of lakes and muskeg, coniferous forest on slopes.

B North facing slopes supporting coniferous forest.

C Level plain of lake deposits overlying limestone, mostly freely drained, with coniferous forest.

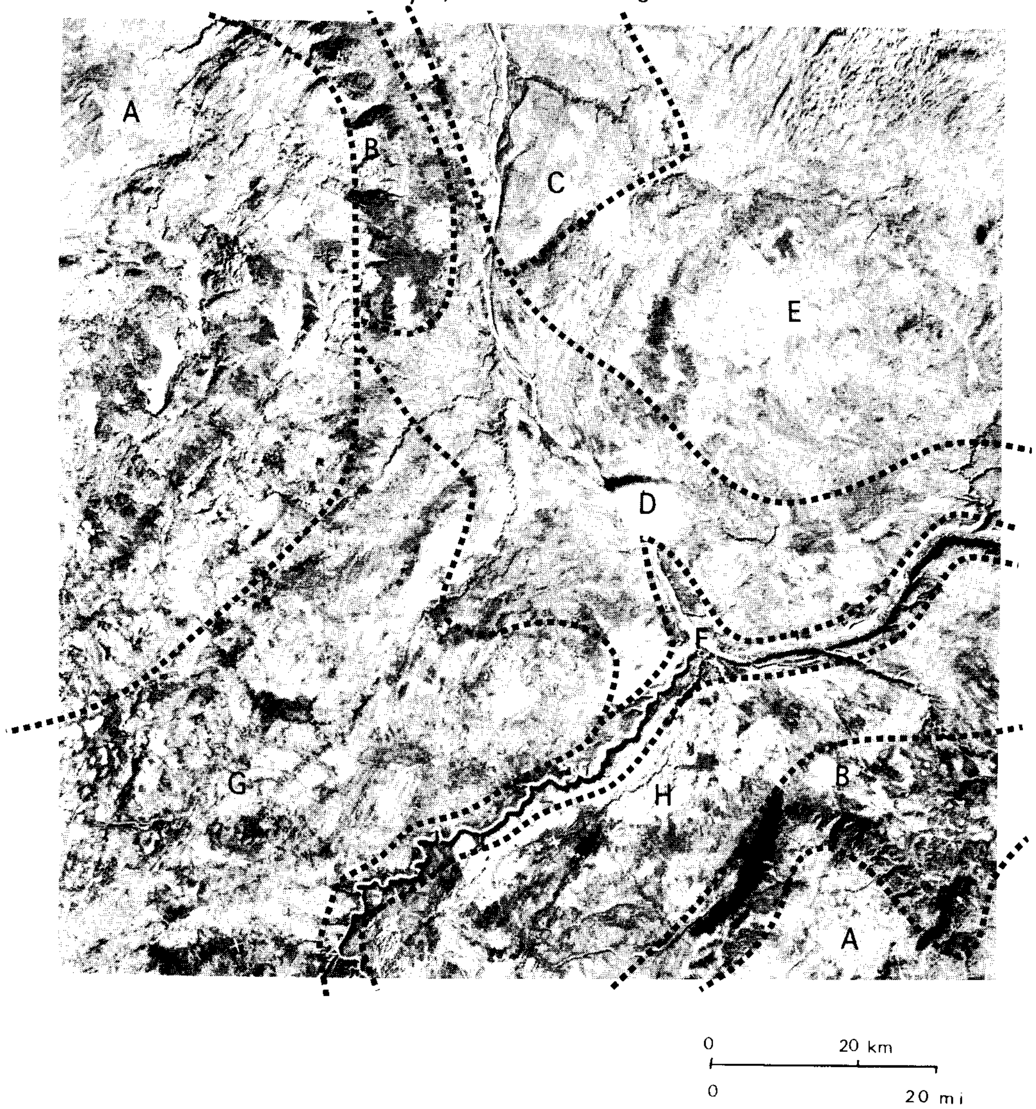
D Gentle slopes with coniferous forest.

E Low relief outwash with complex of lakes, muskeg and mixed forest.

F Deep river valley with poorly drained floor.

G Flat area, largely with muskeg, some lakes.

H Gently sloping area with mixed forest; muskeg and coniferous forest on flatter parts to the west.



THE EARTH RESOURCE TECHNOLOGY SATELLITE, (ERTS-1), launched by NASA in 1972, orbits the earth on a north- south path which progresses westward so that each location is passed at least once every 18 days.

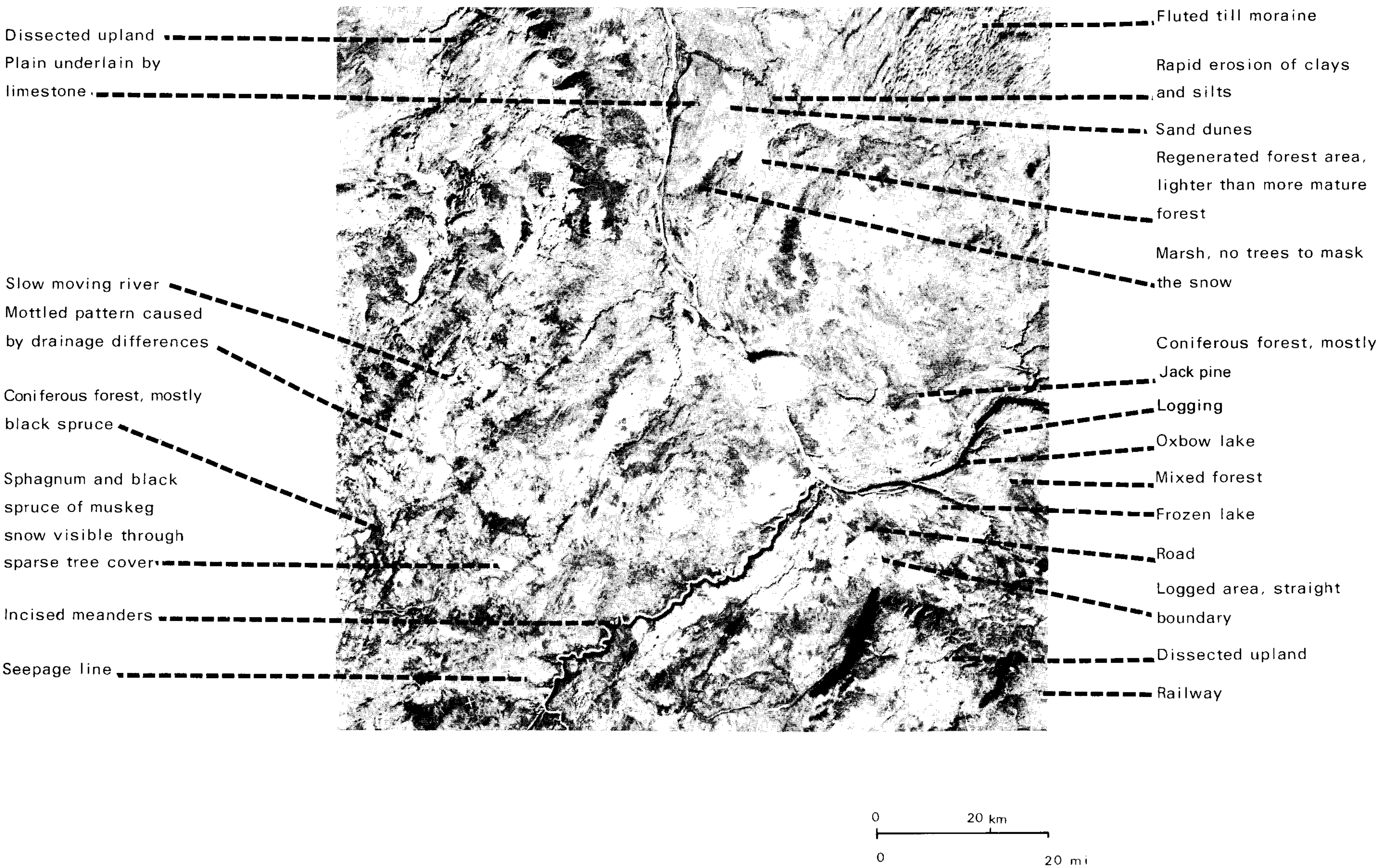
The satellite's electro-magnetic sensors monitor the earth in four spectral bands, observation and data transmission are continuous.

Signals received at stations such as the Prince Albert Satellite Station are transformed into images such as this example, four images for each location and time of observation.

Each feature of the earth earth's surface tends to have distinctive spectral properties, so that it may appear dark on one image and light on another, so aiding interpretation of the imagery.

Figure 9

ERTS NEAR INFRARED IMAGERY OF THE ATHABASCA TAR SANDS January 3, 1973



of development. ERTS data can be used to locate adversely affected areas and to estimate and monitor the areas.

In the context of the general observations of the environmental studies of the Athabasca tar sands, it would seem, then, that ERTS data offer a valuable resource for regional planning, analysis, and monitoring of the environment.

V. REMOTE SENSING FOR LEASE AREAS

A. Colour Infrared Photography for Lease Areas

An example of the type of monitoring and survey described above is provided by the 1972 and 1973 Sibbald Group report entitled "Soils and Vegetation in the Syncrude and Great Canadian Oil Sands Lease". This report, which was commissioned by Syncrude Canada Ltd., includes examples of stressed vegetation and of disruption of drainage. Such disruption has resulted from the damming activities of beaver, which have caused some trees to be drowned. The trails, seismic lines, drainage, and clearing around the Syncrude development are also clearly shown on the photographs (Section III above and Figure 7).

Some areas of stress are created by removal of vegetation, which causes subsequent change in the soil surface. The report provides much useful comment. Moreover, recording of the results on soils and vegetation maps on a standard scale, when done as part of an integrated study of the tar sands, would greatly increase the value of such a complete work.

The selection of the colour infrared images contained above in Section III serves to illustrate the level of detail and the overview of the environmental conditions that colour infrared photography provides. The scale of this imagery (1:10,000 and 1:31,680) also illustrates the limitation of air photographs because each 1:10,000 scale view is about 1½ miles square. It is, therefore, difficult to relate the individual features to their regional context. The examples of 1:31,680 (2" - 1 mile) black and white photography, which are also included, show more regional information, but the loss of detail by both the change in scale and the change from colour-infrared to black and white film can readily be appreciated.

B. Scanner Data for Lease Areas

The problems associated with the discharge of tailings and other effluent might be readily reduced when detailed knowledge of the extent of their influence is easily available. Multi-spectral scanners in aircraft can map thermal changes that result from the discharge of heated water into rivers. Moreover, scanners are possibly the most efficient systems of monitoring growth of aquatic vegetation, which growth is often associated with thermal effects of effluent. Detailed classification of habitat can also be effectively achieved in this way.

The scanner system is a tool for recording data concerning the environment. Use of this data requires a detailed statement of the aims and needs of the environmental scientist. However, consideration should be given to the flexibility of scanner data that may be kept as a permanent computer file. This file could be searched to provide maps of chosen items (identified by specific signature) at any time. Scanners have been successfully used to monitor open-pit mining areas in Ohio and have proved effective in monitoring effluent in the Great Lakes (University of Michigan studies 1965-74, pers. comm.). Scanner data have also been used to produce land use maps and terrain maps in automated computer mapping systems. Given the 11,000 square miles of tar sands that must be monitored, an appropriate consideration would be the establishment of an environmental data bank that could be used to create such maps as they are required.

C. Remote Sensing and the Priorities for Research Data, Aquisition and Planning

There are several categories of information supplied by remote sensing data that can be of aid to studies of the tar sands. The list of these categories is as follows:

1. regional data to assist in the construction of a master plan for industrial and regional development;
2. scanner data to assist in continuation of work on the modified Canada Land Inventory for applications in the mapping of the area;
3. time sequence data to be used for preparation of implementation and monitoring of a long-range land-use plan;
4. integrated data to serve as a basis for uniform reporting of environmental studies;
5. and regional scale environmental data to assist in the definition of zones to be reserved for human habitat, urban development and recreation.

The first three recommendations have as a common ingredient the mapping of present conditions. Without such mapping the planning of the industrial and regional development that is most appropriate for the area would be difficult. In the compilation of such maps some form of environmental classification system is required. The Canada Land Inventory systems of classification are not necessarily the most appropriate systems; and modification and application of the environmental classification system to the oil sands would be useful. These two recommendations come together to create the need for the third recommendation: the long-range land use plan. Detailed remote sensing data would provide the regional and local data, and annual (or more frequent) updating of this data would monitor changes which should, when proceeding correctly, be comparible with the long-range land use plan.

Information needed for environmental planning is too often distributed across many different maps; and each of these maps is often on a different scale and prepared by an expert in one disciplinary area. Remote sensing data are fully integrated data that show environmental conditions over an area at a single point in time. Through integration of the input from many different disciplines with the remote sensing data, a more complete synthesis of the environmental factors can be achieved. A colour infrared photograph will, for example, clearly show the edge of a forested area. If this boundary is abrupt (along a steep river bank or adjacent to a large area of muskeg) it is probable that the animal activity associated with the woodland will have an equally firm boundary. Soil type, vegetation cover, habitat for animals, forest areas, well drained areas with sufficient top soil for growth, and many other types of classification will, then, coincide with either a steep river bank or, perhaps, the edge of the muskeg. In an area of rolling country where forest cover possibly thins out, soil types change slowly and animals range widely; and the maps produced by a specialist in each discipline would probably each show a different boundary. Both situations involve assessments of similar sets of environmental associations. The explanation for any agreement over a specific boundary in the first case and the apparent lack of agreement and various boundaries in the second becomes apparent when remote sensing data are used as the base. In the first case, a clear linear boundary exists in reality; in the second, conditions change slowly, and the "boundary" exists in a more theoretical sense.

Availability of uniform base data can be effectively achieved through integration of data into new types of maps. These maps, based on remote sensing data, are a new form of photomap. Experimental use of this type of system for the tar sands lends support to the integrating function of remote sensing data and renders the same information more available for multi-disciplinary interpretation. This integration of remote sensing data in environmental data management would be a pertinent task that could be coordinated through the Research Secretariat, Alberta Department of the Environment, which is presently coordinating environmental studies in the tar sands.

The definition of zones for human settlement and recreation can best be accomplished through use of detailed data of the type illustrated above by the colour infrared imagery. The use of remote sensing data in the planning of special management zones that would protect certain natural features can be illustrated by Figures 10 and 11, which show the leases in relation to the whole tar sands region and the relationship of the leases to drainage basins and to the major environmental regions revealed by ERTS data. The definition of zones in both these cases must, of course, proceed within the context of the long-range land-use plan. The development both of the zone definitions and of the long-range land use plan requires the use of regional data of the type generated by ERTS.

D. Seasonal Change Revealed by Remote Sensing Data

One of the greatest criticisms of environmental studies is that they are frequently a product of fair-weather investigation. Data on the thaw of muskeg is sporadic; and the more difficult the conditions are, the more sporadic the data are; the more remote the area is, moreover, the fewer the

Figure 10

THE ATHABASCA TAR SANDS, LEASES, PROJECTED ONTO AN ERTS IMAGE

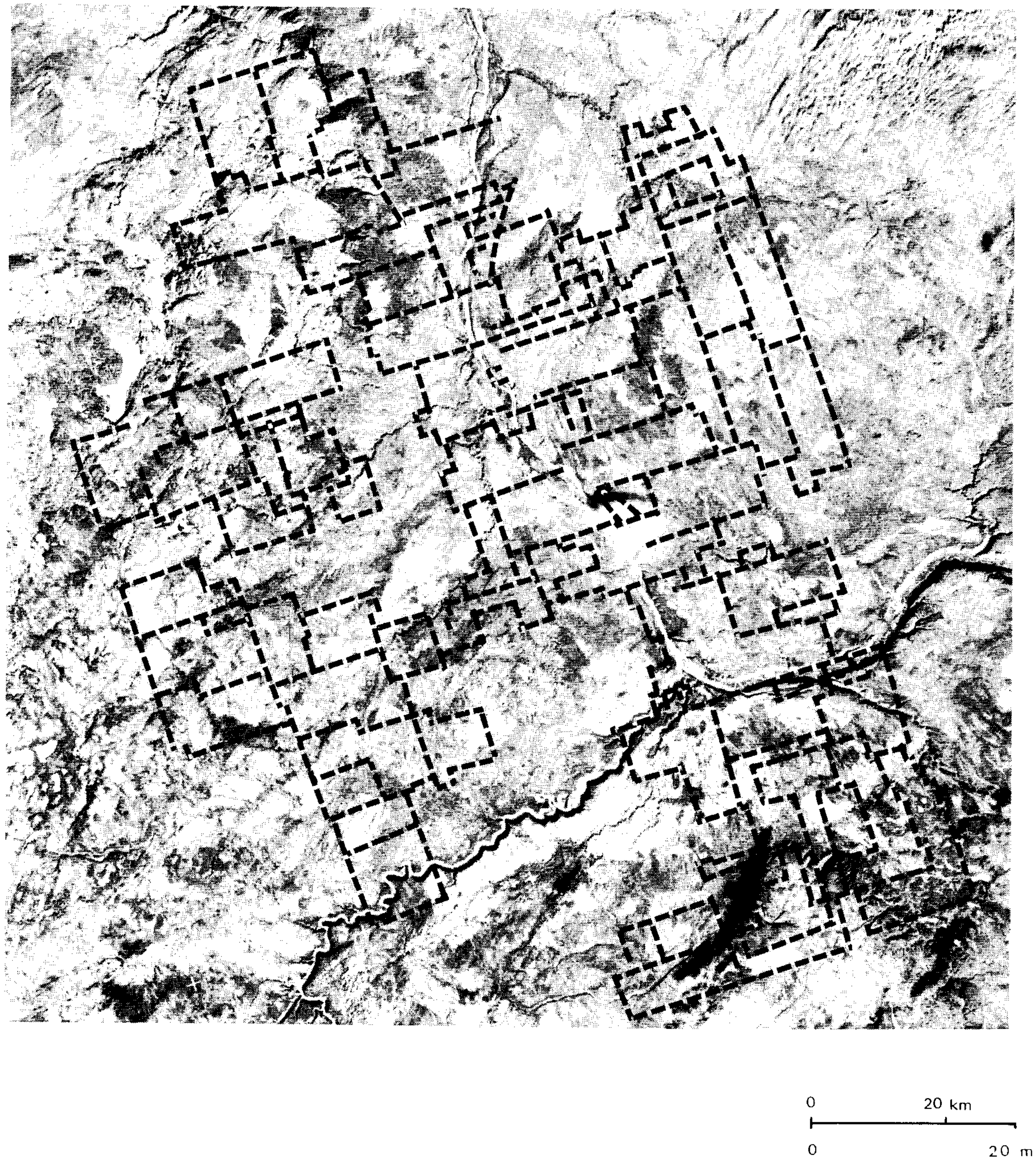


Figure 11

THE ATHABASCA TAR SANDS, DRAINAGE BASINS AND LEASES PROJECTED ONTO AN ERTS IMAGE.

active researchers are. Remote sensing provides a means of collecting data on a regional basis in order to reveal the changes that take place from season to season. Figures 12, 13, and 14 show samples of the changes observed. When the January 3, 1973, image used in Figure 9 is also considered as part of the sequence, a seven-month-long monitoring of the tar sands can be seen in this report. This report considerably advances our present level of knowledge, and the appropriate seasonal image can be used as the base for the display of environmental data described above in Section V. From the ERTS data, appropriate sample areas can be chosen for each season; and more detailed imagery can, if necessary, be gathered by aircraft (Thie,1974, in press).

Often environmental planning requires this dynamic component in order that changes in environmental conditions can be assessed on a year-round basis. There is a strong possibility that ecologically sensitive areas differ in definition and location from season to season. Remote sensing data can greatly improve our understanding of this variation in definition and location.

E. Future Applications of Remote Sensing by Syncrude Canada Ltd.

Syncrude plans to continue and expand remote sensing on Lease 17 and to begin work on other leases in order to obtain baseline information. Syncrude feels that environmental studies of the tar sands should be undertaken within the context of a full regional study of the environment. The regional study should make maximum use of the available ERTS data.

Regional studies of the tar sands can use standard ERTS imagery on a scale of 1:250,000 and/or 1:1,000,000. Local studies will be keyed to the regional studies and should

Figure 12

THE ATHABASCA TAR SANDS, SEASONAL CHANGES AS SHOWN BY ERTS IMAGERY

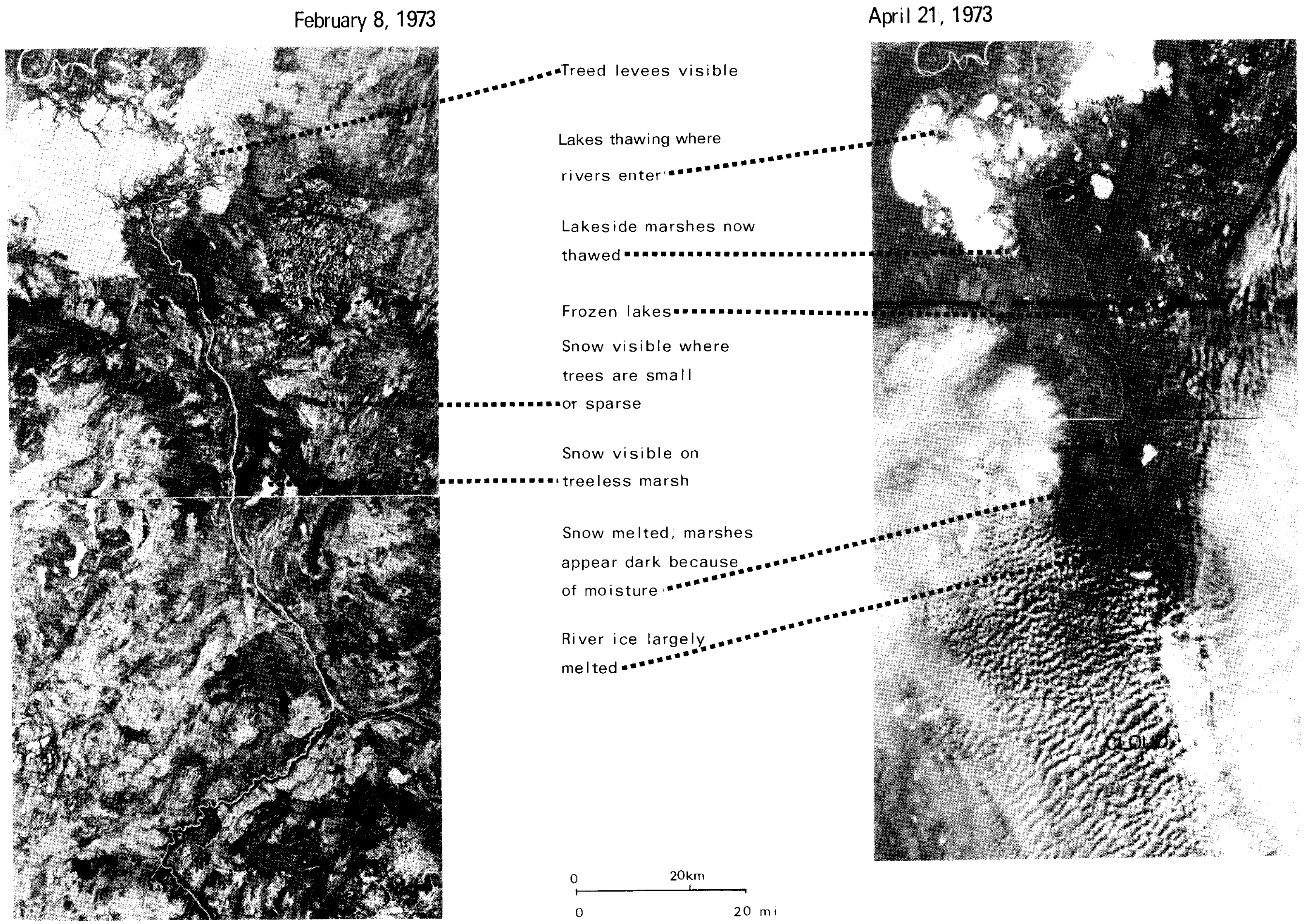


Figure 13

THE ATHABASCA TAR SANDS, SEASONAL CHANGES AS SHOWN BY ERTS IMAGERY

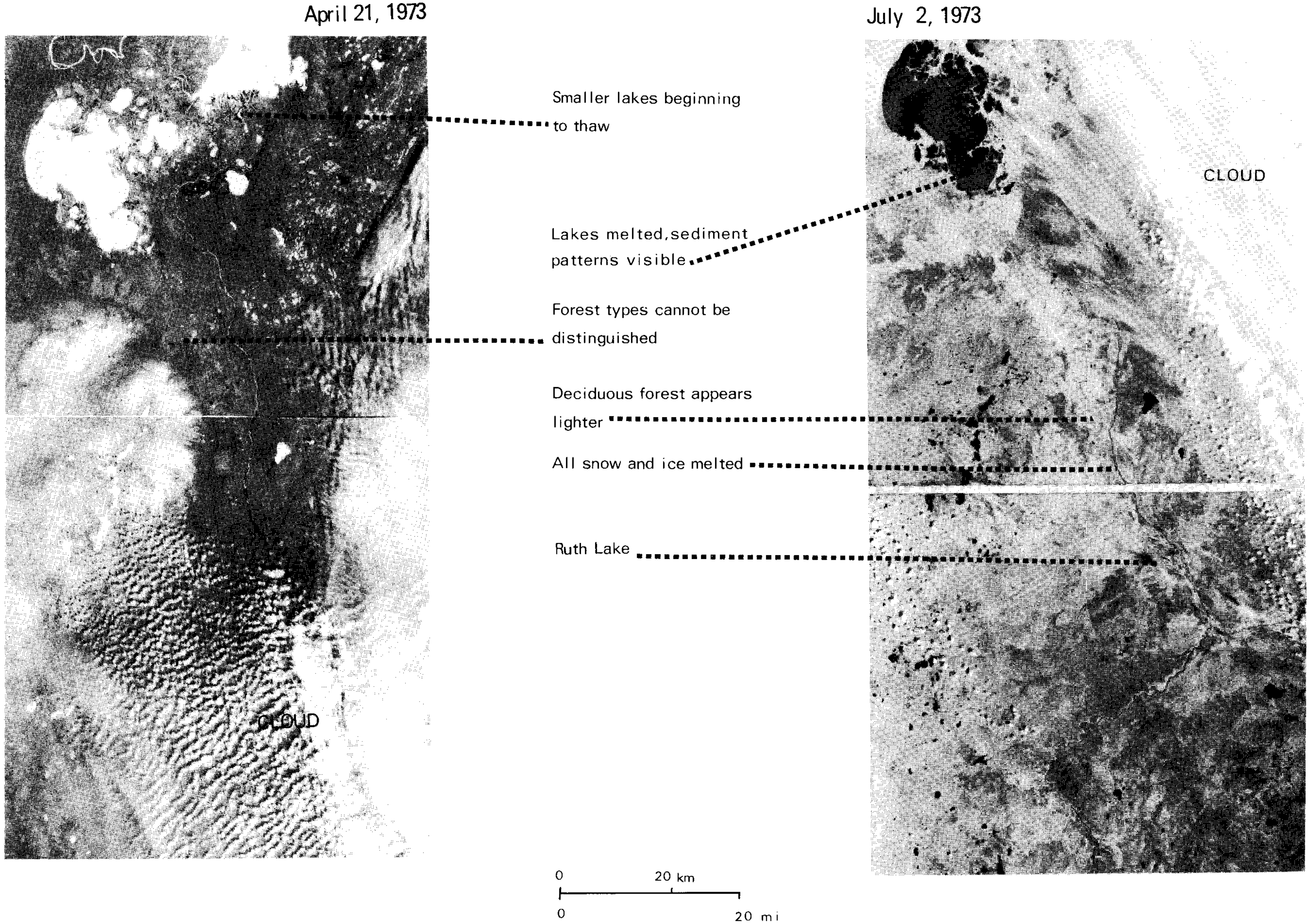
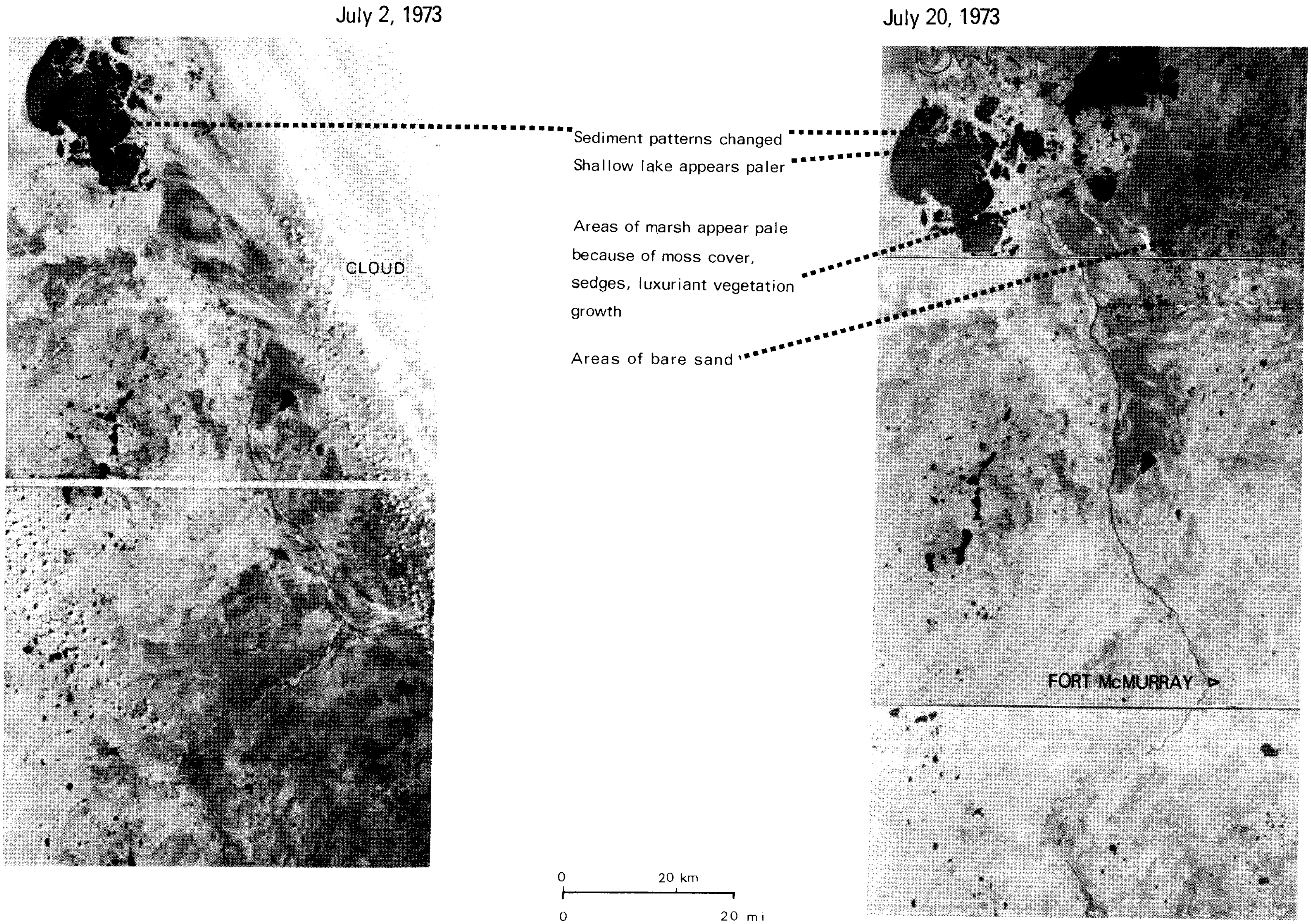


Figure 14

THE ATHABASCA TAR SANDS, SEASONAL CHANGES AS SHOWN BY ERTS IMAGERY



use scales of about 1:50,000 and 1:25,000 according to the suitability of these scales.

Each operating area will be surveyed initially through use of black and white and infrared imagery on a scale of 1:10,000, and the areas of active development will be surveyed annually in order to determine the extent of the changes taking place. Where warranted, surveys may be undertaken on a more frequent basis.

Syncrude Canada Ltd. will attempt to carry out further environmental studies that will use remote sensing in the tar sands area and will use satellite and aircraft data obtained from multi-spectral scanner systems to explore the monitoring of the environment. These systems may become major tools for environmental management. The possibilities of using automated analysis and mapping systems based on computer processing of the scanner data will be fully evaluated.

The use of mapping systems based on remote sensing data may become a matter of priority. These maps provide a means of integrating regional information for management purposes, and, when effectively presented, also represent a significant contribution from the agency producing them.

Remote sensing data can be used to monitor change in the environment and to guide legislative actions concerning land clearing, overburden stripping, drainage diversion, tailings ponds, and other types of environmental activity.

VI. CONCLUSIONS

The several forms of remote sensing provide a fully integrated view of the conditions at the surface of the earth. The detail required by the investigator defines the scale at which the data should be recorded and produced. Hence, a study of timber stands can be done on a scale of 1:5,000 or larger in a way that simplifies definition of detail and that permits individual trees to be viewed with comparative ease. Studies of environmental conditions are more usefully conducted on a scale of 1:10,000 or on a smaller scale that allows the extent of habitat types to be more easily viewed.

In the tar sands region there is clearly a need for fully integrated regional planning. Such planning requires a fully integrated data base that provides a single view of 10,000 square miles. The data produced from ERTS-1 are the most suitable for this purpose. Regionalisation can proceed from this data base, and detailed study of the individual regions can be completed through use of scanners or camera systems. ERTS contributes a dynamic component to the study by gathering data every eighteenth day, which permits the environmental condition of the whole region to be reviewed under the changing seasonal conditions. We can, then, regionalise the area on the basis of various seasonal conditions. The changing seasonal conditions are of significance in ecological studies, and a record such as that produced by ERTS greatly improves our ability to record and evaluate the seasonal changes in our environment.

Remote sensing technology has now advanced to the stage where the data collection systems are operational methods of recording environmental conditions. The planners, environmental managers, ecological study groups, regulatory agencies, and policy makers have only to utilise this data source to their advantage in the various levels of planning required.

Of Primary importance is the need for a regional plan for the tar sands. The appropriate scale of data is available from ERTS, and it is evident that such a plan must be created by a government agency acting in cooperation with the concerned parties in industry and with national and local planning agencies. Advice to be related directly to the reality of the environment as recorded by ERTS at each season is greatly needed from these sources. Seasonal maps and the full interpretation of the ERTS record will provide data more advanced than any used to date in such a regional planning context; and for a major development such as that envisioned for the tar sands area this data system is particularly suitable.

Future developments in the use of ERTS data will include the production of a monitoring system that will enable an interested party to view the most recent scene gathered by ERTS and to compare this scene with previous scenes. This will enable the investigator to establish the location of changes that have occurred. It is entirely possible that such change detection can be realized through use of a computerized system (with a cathode ray tube display) and in a way that will enable ERTS data to be displayed in a colour map form in response to a request from a computer data bank. If this system is developed with a user interaction capability, the investigator should be able to manipulate data and to create colour maps of change for given time periods, or colour maps of environmental conditions at a given point in time merely by submitting his requests to a computer terminal. Such a facility would be a considerable asset to any group charged with the management and monitoring of change in the tar sands regions.

Remote sensing data on scales larger than the regional scale of ERTS data are presently in use by Syncrude Canada Ltd. The establishment of a regional plan would permit this larger scale applied to lease areas and development sites to be keyed into the regional planning base. An establishment of standard specifications for data products would mutually benefit all involved parties. As environmental studies continue, such establishment of specifications will permit rapid integration of compatible products into a full, detailed understanding of the tar sands environment. Only when such a record is compiled can the effect of development be adequately assessed. The reclamation of land following development can equally be monitored, and a full evaluation of the entire process will require an accurate, compact record of environmental conditions at appropriate points in time. There can be no doubt that such a record would be efficiently obtained through the judicious use of remote sensing techniques.

LITERATURE CITED

American Society of Photogrammetry, 1968. *Manual of color aerial photography.* George Banta Co., Menasha, Wisconsin.

Anonymous, 1973. *An Environmental Study of the Athabasca Tar Sands.* By Intercontinental Engineering of Alberta Ltd. for the Alberta Department of the Environment. Published by Alberta Environment, Queen's Printer. 112 pp.

Colvocorresses, A.P., 1973. *The ERTS image format as a basis for a map series. In: Symposium Proceedings: Management and Utilization of Remote Sensing Data.* America Society of Photogrammetry, Falls Church, Virginia.

ERIM, 1973 (Environmental Research Institute of Michigan; formerly Willow Run Laboratories, University of Michigan). This institute is a leading research agency that evaluates the applications of remote sensing data to a variety of problems. Reports published by ERIM over the last 2 decades are the basis of many comments made above.

Fritz, N.L., 1965. *Film sees a New World of Color.* Citrus World 2 (2).

Heller, R.C., 1970. *Imaging with Photographic Sensors.* Chapter in Remote Sensing with special reference to Agriculture and Forestry. National Academy of Sciences, Washington, D.C.

Holter, M.R. et al, 1970. *Imaging with Nonphotographic Sensors.* Chapter in Remote Sensing with special reference to Agriculture and Forestry. National Academy of Sciences, Washington, D.C.

Krumpe, P.F. et al., 1973. *ERTS-1 Analysis of Wildland Resources using Manual and Automatic Techniques. In: Symposium Proceedings: Management and Utilization of Remote Sensing Data.* American Society of Photogrammetry, Falls Church, Virginia.

Myers, V.T. et al., 1970. *Soil Water and Plant Relations.* Chapter in Remote Sensing with special reference to Agriculture and Forestry, National Academy of Sciences, Washington, D.C. 426 pp.

Rhodes, J.B., 1973. *Application of ERTS-1 Data to Landscape Change in Eastern Tennessee. In: Symposium Proceedings: Management and Utilization of Remote Sensing Data.* American Society of Photogrammetry, Falls Church, Virginia.

Sibbald Group, 1973. *Soils and Vegetation in the Syncrude and Great Canadian Oil Sands Leases.* Report prepared for Syncrude Canada Limited by the Sibbald Group, Edmonton, Alberta, August, 1973.

Thie, J., et al., 1974. *A Quick Northern Resource Inventory by means of Satellite and Airborne Remote Sensing.* Paper presented to the Second Canadian Symposium on Remote Sensing, Guelph. 1974. Forthcoming in the symposium Proceedings (in press).

Organization for a National Program on Remote Sensing of the Surface Environment - A working paper, Ottawa, 1970.

For detail of the ERTS system and application of ERTS data, reference should be made to the following:

ERTS Data Users Handbook, NASA, Goddard Space Flight Centre, 1972.

The Earth Resources Technology Satellite - 1 Symposium Proceedings, September 29, 1972.

The Proceedings of the Symposium on Significant Results obtained for ERTS-1, March, 1973, NASA.

Goddard, S.F.C. *The Proceedings of the Symposium on Management and Utilization of Remote Sensing Data*, October, 1973, published by the American Society of Photogrammetry, Falls Church, Virginia, 1973.

The Proceedings of the Second Canadian Symposium on Remote Sensing (in press).

OTHER REFERENCES

Adams, J.A.S., Clark, H.C., et al, *Development of Remote Methods for Obtaining Soil Information and Location of Construction Materials Using Gamma Ray Signatures,* Rice University Houston,Texas Department of Geology, December, 1971, 182 pp.

Barnes, James C., *Evaluate the Application of ERTS-A Data for Detecting and Mapping Snow Cover,* Environmental Research and Technology Inc., Lexington, Mass., November, 1972, 8 p.

Canadian Aeronautics and Space Institute, *Canada's Role in Remote Sensing,* Toronto, Ontario, March, 1971, 18 pp.

Colwell, R. N., *Monitoring Earth Resources from Aircraft and Spacecraft,* California University, Berkeley, Forestry Remote Sensing Lab., 1971, 203 p.

Euckmeier, F. J., Pressman, A.E., et al., Technical report, *Airborne Remote-Sensing Techniques for Site Selection,* Texas Instruments, Inc., Dallas, December 1968, 95 p.

Foster, K., Garcia, A., *The Use of High Altitude Remote Sensing in Determining Existing Vegetation and Monitoring Ecological Stress,* Office of Arid Lands Studies, Arizona University, Tucson, August, 1972, 33 pp.

Gumerman, George J., Final report, *The Identification of Archaeological Sites by False Color Infrared Aerial Photography,* Geographic Applications Program, Geological Survey, Washington, D.C., May, 1971, 16 pp.

Johnson, Philip L., Refer to article on Remote Sensing as an Ecological Tool, *Ecology of Subarctic Regions,* United Nations Educational, Scientific and Cultural Organization, Paris, France, 1970, 169-187 pp.

Larsen, James A., *Vegetation and Terrain (Environment): Canadian Boreal Forest and Tundra,* Wisconsin University Madison Center for Climatic Research, Final Report, 1970-72, 248 pp.

Schertler, R. J., *Remote Sensing: The Application of Space Technology to the Survey of the Earth and Its Environment,* National Aeronautics and Space Administration, Conference-Presented at National Conference of the National Science Teachers' Association, Cleveland, Ohio, 1973, 13 pp.

Conditions of Use

Syncrude Canada Ltd., 1974. Remote sensing and the Athabasca tar sands: An overview. Syncrude Canada Ltd., Edmonton, Alberta. Environmental Research Monograph 1974-1. 47 pp. plus references.