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A COMPARISON OF ACTIVE LAYER THICKNESS AND SURFACE SPECTRAL
SIGNATURE AT TUKTOYAKTUK AND INUVIK,
NORTHWEST TERRITORIES, CANADA

by

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A thesis submitted to the Faculty of Graduate
Studies and Research in partial fulfilment
of the requirements for the degree of
Master of Arts
in Geography

Department of Geography
Carleton University
Ottawa, Ontario
April 29, 1983

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ABSTRACT

Active layer thickness, obtained by auger sampling, and the summer reflectance of the ground in green, red and infrared light, obtained from digitized color infrared aerial photographs, are compared for three sites at Tuktoyaktuk and two sites at Inuvik in the Northwest Territories.

At Tuktoyaktuk, the active layer was significantly thicker in gravel-mineral soils than organic soils, but spectral signature was not adequate in differentiating between ground cover types. No strong correlations were found between cover types and active layer thickness.

At Inuvik, spectral signatures could distinguish between cover types and there were significant relationships between spectral signature and active layer thickness.

Color infrared spectral signature would only appear to be useful for mapping active layer thickness in areas which possess a prodigious and continuous vegetation cover. Spectral signatures are not useful as an aid to active layer thickness mapping in sparsely vegetated areas.

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Chapter 1

INTRODUCTION

1.1 OBJECTIVES OF STUDY

The active layer is the zone of subsurface material which freezes and thaws on a seasonal basis. In regions of continuous permafrost the active layer may vary in thickness from a few centimeters to several hundred centimeters. Alteration of the ground thermal regime through climatic, pyrogenic or anthropogenic circumstances may induce severe terrain disturbances where the substrate contains unconsolidated sediments and permanent ice. A knowledge of how the substrate material responds to seasonal temperature changes may indicate how the material will respond to anthropogenically induced ground temperature alteration and aid in the design and positioning of man-made structures.

It is the objective of this study to determine if the techniques of remote sensing can be of assistance in identifying the thermal properties of the ground in representative sample areas in the continuous permafrost zone. A search will be carried out for correlation between the reflection of incident solar radiation from ground sample sites on remotely sensed imagery with the thickness of the active layer (generally at the time of its greatest vertical development) at the sites. Remotely sensed data from color infrared photographs will be compared with field samples of active layer thickness for three study sites at Tuktoyaktuk and two study sites at Inuvik in the Canadian Northwest Territories. This study will attempt to determine whether or not relationships exist between ground surface reflectance and active layer thickness and to describe the nature of any relationships.

Sections 2 and 3 of this chapter will examine the factors which govern the formation of the active layer, the relationship between active layer thickness and surface cover types and the types of remote sensing which could be used to gather information for such a study.

Chapter 2 examines collection procedures for remote sensing data and field data and how the two groups of data may be placed in comparable format for the analyses to be conducted.

Chapter 3 describes the study sites in detail and reviews the field work.

Chapter 4 discusses the relationships observed between ground reflectances and measured active layer thickness and the effects of constraints in the data. The utility of the data to provide accurate descriptions of existing relationships is also considered. Finally, Chapter 5 summarizes the findings of the study and places them in perspective with respect to both the techniques used and the current understanding of active layer mapping by indirect methods.

1.2 THE ACTIVE LAYER

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The thickness of the active layer is determined by a complex series of energy - ground interactions operating at specific locations throughout the year. In this section the active layer will be defined and discussed with respect to the many factors which influence its development.

Figure 1-1 shows an idealized plot of the annual fluctuation of ground temperatures with depth in a permafrost region. Temperatures decrease with depth until the thermal energy conducted through the substrate equals the geothermal heat flux. The envelope about the mean annual surface temperature represents the range about which the ground temperature may fluctuate during the year. This fluctuation is induced by astronomical - climatic circumstances, regulated by surficial properties and attenuated with increasing depth.

The yearly cyclic fluctuation of the ground temperature about the mean annual ground temperature, both at the surface and at depth is influenced not only by direct and diffuse incident solar radiation absorbed and conducted into the substrate vertically, but also by heat conducted laterally through the substrate. The anisotropic nature of the earth's topography, surficial deposits and moisture distribution permit some areas to absorb more incident radiation than others. Lateral heat flow results from the energy in the network of thermal highs and lows over the ground moving to equilibrium levels.

The astronomic - climatic circumstances and material properties which are widely accepted as determinants of the ground's heat budget for any terrestrial location are summarized in Table 1-1. The factors which have been found to exert a strong influence on the formation and thickness of the active layer, with specific reference to the development of the active layer in permafrost areas, will now be reviewed.

A primary requirement for the existence of an active layer is that a location be at sufficiently high latitude (or altitude) for seasonal cooling to permit freezing of the ground yet receive sufficient

FIG 1-1 SCHEMATIC REPRESENTATION OF THE ANNUAL GROUND TEMPERATURE ENVELOPE IN A PERMAFROST AREA

after Lachenbruch (1968)

TABLE 1-1

CONTROLLING FACTORS OF THE GROUND THERMAL REGIME

<u>GROSS FACTOR</u>	<u>LOCATION FACTORS</u>
Astronomical circumstances	latitude, time of day, time of year.
Atmospheric and climatic circumstances.	temperature, wind velocity, percentage of cloud cover, rainfall and snowfall.
Topography	slope, aspect, altitude.
Surficial properties.	albedo, emissivity, roughness, wetness, ground vegetation cover.
Ground material properties.	bulk density, thermal diffusivity, water content of soil.

Source: Cihlar and McQuillan (1978)

thermal radiation to thaw.

The aspect of the site is certainly important. A ground location exposed to the sun in a permafrost area is more likely to thaw to a greater depth during the summer than a location which is shaded or "sees" a low angle of incident solar radiation during the year. A site which is under cloud cover much of the year will experience an analogous situation with respect to incident solar radiation as the shaded site. Brown (1969) observed that active layers were thinner and permafrost more frequently encountered on north-facing slopes than south-facing slopes in the Yukon and northern British Columbia in Canada. The active layer was also found to be thinner on north-facing slopes than on south-facing slopes on Bank's Island in the Canadian Arctic by French (1970).

A topographically rough area will encourage greater air turbulence and experience greater convective cooling than a smooth site. A consistently windy area will undergo the same cooling as a rough site in a calmer area. Yet this cooling by convection is likely offset by the prevention of snow accumulation. Brown (1972) observed that, in the Arctic, exposed areas are frequently blown clear of snow. Nicholson and Thom (1973) have shown that at Schefferville, Quebec, windy sites developed thicker active layers than sheltered sites where most of the incident solar radiation was used in melting the accumulated snow, not warming the ground.

The presence or absence of water can have a pronounced effect on the development of an active layer. A consistently moist site will convert much of the incident solar radiation to the latent heat of

evaporation and develop a thin active layer. Active layer thickness measurements of a dry and a wet site at Eureka in the Canadian Arctic by Smith (1977) showed that by summer's end the dry site had developed an active layer of 53 cm as opposed to 36 cm at the wet site. Gold and Lachenbruch (1973) note that water bodies which do not freeze to the bottom in winter possess no frozen bottom material. The temperature in the water bottom sediments is kept above 0°C year round.

High albedo surfaces will reflect much of the incoming solar radiation and discourage the development of a thick active layer. Dark surfaces, on the other hand, will absorb much of the incident solar radiation and allow the ground to heat to a greater depth. This principle is illustrated by temperature observations made by Brown (1973) on mineral surfaces at Yellowknife, Canada, where dark mineral surfaces developed deeper active layers than high-albedo surfaces.

Vegetation has several roles in retarding the flow of heat into the substrate. It can act as a canopy to shield the ground from incident radiation. It cools the soil of the ground by transpiration, and aids cooling by capturing snow in above-ground foliage, preventing any insulation cover from reaching the ground.

Important examples of organic materials which are poor conductors and which retard heating of the ground are peat and Sphagnum. Jumikis (1966) places the conductivity of peat at $0.1080 \text{ Cal m}^{-1} \text{ hr}^{-1} ^{\circ}\text{C}^{-1}$. This is one twentieth the conductivity of gravel which is $1.74 \text{ Cal m}^{-1} \text{ hr}^{-1} ^{\circ}\text{C}^{-1}$. Brown and Williams (1972) note that the conductivity of Sphagnum is an order of magnitude less than peat. Brown and Pévé (1973) also note that

peat has a large capacity for trapping water. The poor conductivity of peat combined with the evaporative cooling of in situ moisture inhibits heat flow into the ground.

Viereck (1965) has shown that forested areas develop thinner active layers than unforested areas. This phenomenon is a result of organic detritus on the ground, beneath the trees trapping moisture (and increasing evaporative cooling), shading of the ground and capture of snowfall in the tree foliage.

Figure 1-2a shows mean annual ground temperatures measured by Brown (1973) for eight sites in close proximity at Yellowknife in the Canadian Northwest Territories. Note that cooler temperatures were measured at the spruce and sedge sites where shading of the ground, evapotranspiration and moisture abundance kept the mean annual ground temperature below 0°C . The burnt site with a low albedo but considerable trapped air in the surface material shows a ground temperature slightly above 0°C , while the till, beach and rock sites (which have a higher thermal conductivity relative to the other sites and are not shaded) show warmer ground temperatures above 0°C .

Figure 1-2b shows ground temperature envelopes for the same eight sites at the same location. Note that the envelopes display the greatest width and the active layers are thickest for the dry rock and mineral surfaces (even though these materials experience the greatest winter cooling). The burnt and vegetated sites permit little warming or cooling of the surface yet the inhibition of warming retards active layer development.

FIGURE 1-2 a

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Mean Annual Ground Temperatures, Yellowknife N.W.T.

1970 and 1971

source: Brown (1973)

FIGURE 1-2 b

Ground Temperature Envelopes, Yellowknife N.W.T.

1970

source: Brown (1973)

Figure 1-3 shows an idealized cross section through permafrost in the discontinuous zone based on observations by Brown (1967). Note that the permafrost (and therefore a thin active layer) exists in the cooler open, wet sites where incoming radiation is used in evaporating water and evapotranspiration. The higher, forested terrain experiences less direct cooling since evapotranspiration takes place on the foliage above the ground. The shelter provided by the trees inhibits convective cooling from the wind as well traps snow (an insulator).

From this discussion, an important point which emerges is the observed relationship between the thickness of the active layer and surface vegetation and surface material properties. Different vegetation assemblages and surface materials present differing tones and textures to the observer from both the ground and an aerial perspective. The techniques of remote sensing which can be used to discriminate between different surface materials, and previous studies which have used these techniques on mapping permafrost and the active layer, are examined in the following section.

1.3 REMOTE SENSING AND THE ACTIVE LAYER

In obtaining information on the thickness of the active layer with remote sensing one is generally limited to methods which measure the reflective and emissive properties of the ground and not directly, the thickness of the active layer or the depth of permafrost below the ground. What is observed in each case, whether the sensor, or the sun or

Figure 1-3 Idealized Cross Section Through Permafrost in the Discontinuous Zone

the surface itself acts as the source of energy, is the radiation flux from the ground over the range of spectral wavelengths to which the particular sensor is receptive. Generally, this range spans a sufficient portion of the electromagnetic spectrum that the reflective or emissive properties of the ground for different wavelengths can be compared. The different reflected or emitted radiation intensities for different wavelengths of the spectrum for any substance is called the spectral signature of the substance and different materials rarely display identical spectral signatures. Spectral signatures can, theoretically, serve as a good diagnostic tool for identifying different materials.

The important types of sensors which have been employed and their utility both in gathering ground spectral signature information and determining active layer thickness are summarized in Table 1-2. In using remote sensing ~~in order~~ to determine its effectiveness in mapping the thickness of the active layer, an ideal situation would be to employ various types of sensors so that the surface spectral signature can be measured over a wide range of wavelengths. Unfortunately, only color infrared photographs could be obtained for this study for the selected study areas and it was these infrared photographs which served as data sources. At this point a review of the results obtained in previous studies which used remote sensing to study permafrost and the active layer is in order.

Attempts to detect the top of the permafrost table with radar have been undertaken by Annan and Davis (1978) and Unterberger

TABLE 1-2
TYPES OF REMOTE SENSING

Sensor	Operation Wavelength	Method of Employment	Utility
Passive Microwave	1 - 25 cm	Airborne scanner records microwave emission from ground surface.	Areas of pronounced soil moisture may be detected as well as different material composition.
Active Microwave	1 - 25 cm	Microwave signal is directed towards the ground and the reflected signal recorded with an airborne sensor platform.	Surface roughness and moisture content of soil can be measured. Some subsurface penetration possible. No dependence on weather or time of day.
Thermal Infrared	3 - 5 micrometers and 8 - 14 micrometers	Airborne scanner records infrared emission from ground surface.	Thermal properties of surface properties may be determined by imaging before dawn and during the midday hours to examine how

TABLE 1-2 (Continued)

Sensor	Operation Wavelength	Method of Employment	Utility
			the ground responds to daily heating and how it radiates its stored heat at night. Imaging results are strongly affected by the presence and absence of water and of sunlight.
Color Infrared	.5 - 1.1 micrometers for infrared	Airborne multi-spectral scanners or photographic film record reflected radiation from the surface in the green, red and infrared bands.	Surface materials may be identified and classified. Image characteristics are strongly affected by sun position in the sky and atmospheric conditions.

(1978). Both studies report that subsurface ice was detected. The study by Unterberger used airborne radar in Alaska to detect subsurface ice in unconsolidated sediments. Although ice was detected, subsurface stones caused scattering problems with the radar signal. Annan and Davis were able to detect subsurface ice with radar towed overland.

Leshack et al (1973) found a comparison of day and night thermal infrared imagery useful in determining the location of ice wedges which were not visible on conventional photographs. There was, however, no verification of the thickness of the active layer or its constituent material above the ice wedges.

Tarnocai (1972), Tarnocai and Thie (1974ab), and Thie (1972) note that multi-spectral imagery was of utility in detecting the presence of palsas (ice-cored peat mounds) in northern Manitoba. The detection of the palsas was made possible by the pronounced tonal differences between the peat mounds and surrounding bogs. The thickness of the peat overlying the palsa ice cores was not compared with the observed image tones and colors.

Granberg (1973) used sequential aerial photographs to map snow cover changes during the winter and correlate the snow cover with permafrost distribution near Schefferville, Quebec, Canada in the discontinuous permafrost zone. The active layer thickness was measured with respect to the snow cover but no correlation was made between the permafrost areas and the tonal properties of the overlying surface material.

There is extensive literature concerning the use of aerial photographs to delineate the geomorphic manifestation of aggrading and degrading permafrost in unconsolidated ice-rich sediments. In such studies (e.g. Mackay on massive ice (1971) and Brown on palsas (1971)) the dimensions and morphology of the permafrost features on the imagery, and not quantitative tonal or color qualities, were considered.

Shreier and Selby (1981) used thermal infrared imagery and color infrared photographs to classify different vegetative associations on organic terrain in the Richardson Mountains of the Canadian Northwest Territories and then relate the different vegetative associations to active layer thickness using field data. The researchers found that three of their five vegetative associations showed a statistically significant relationship with active layer thickness and temperature at a depth of 20 cm. Wet lichens showed the shallowest active layer (27 - 41 cm) while wet sphagnum sites showed thicker active layers (32 - 65 cm and 40 - 100 cm). The thermal infrared imagery was not found to be useful in classifying the vegetative associations since the observed ground temperatures for different vegetative types were not statistically different from one another. The color infrared photographs were useful for classifying the vegetation but no direct correlation between spectral signature and active layer thickness was attempted.

This study investigates the relationship between active layer thickness and the reflectance of the ground in visual and infrared wavelengths by comparing the spectral signature of the ground in precise register and measured active layer thickness. Unlike the studies of Unterberger (1978) or Leschack (1973) which were tests of

techniques with minimal ground truth, this investigation will be a precise survey using the positional accuracy of ground surveys coupled with digital measurements of the ground's reflectance taken from aerial photographs.

This registration of image data and ground data will permit a classification of the different surface types and how accurately these cover types delineate areas of different active layer thickness.

Unlike the previous studies reviewed, the correlation of active layer thickness and spectral signature will be permitted through a bivariate analysis.

The study, therefore, focuses on a specific problem; how is spectral signature of the ground related to active layer thickness, undertakes the investigation in a precise quantitative manner.

In the following chapter technical considerations and logistics involved in obtaining ground data and remotely sensed data are examined with reference to respective procedures and representation of the two groups of data in compatible formats for statistical examination.

CHAPTER 2 ACQUISITION AND TREATMENT
OF DATA.

2.1 DATA COLLECTION

For each ground sample location where active layer thickness is measured, a corresponding remotely sensed ground spectral signature value is required. This chapter will describe how the study data was acquired, problems involved with data acquisition and treatment of the data in the investigation.

Active layer thickness was sampled by entering an auger into the ground and noting the depth at which the auger was no longer able to penetrate the substrate due to ice contact with the top of the permafrost table. Penetration problems were encountered where ice lenses or stones were present within the active layer. For samples of active layer thickness obtained for this study, the data values used were the average of five samples taken within three meters of one another. Since it is not possible, when drilling, to distinguish the top of the permafrost table from an ice lense, the averaging technique serves to alleviate the ambiguity. Stones produce a grinding sound on the auger and holes where stones were encountered were redrilled.

The location of each point where the active layer was to be sampled was fixed in a study area by using a compass to triangulate the point with horizon references whose coordinates were known in a fixed reference frame. The triangulation angles for each sample point had been calculated with the aid of a map prior to field work. An observer in the field locates each sample point by ensuring that the angles sighted with the compass from where he stands to the horizon references agree with those

calculated. This principle is illustrated in Figure 2-1.

Auger sampling should be undertaken when the active layer has reached its greatest vertical development. In northern Canada, this situation usually occurs in late summer as shown in Figure 2-2. Samples in this study were augered from August 19 to September 6, 1981.

Spectral signatures of the ground for this study were obtained from color infrared aerial photographs with a scanning microdensitometer. The microdensitometer shines an intense narrow beam of light through a film transparency, the transmittance of the film being measured with a photocell illuminated by the beam. The signal from the photocell is converted to a digital format and stored on magnetic tape. The transparency is scanned along a linear path at discrete, fixed intervals. When a scan line has been completed an adjacent line is scanned at the same sampling rate. When scanning has been completed the image is expressed as an array of rows and columns with each array element (called a picture element or "pixel") representing a measured film transmittance. The transmittance of the transparency may be measured for different wavelengths of light. In the case of this study the green (0.4 to 0.5 micrometers), red (0.5 to 0.6 micrometers) and infrared (0.7 to 1.1 micrometers) bands were scanned. The transmittance of the film transparency at any point on the image in the green, red and infrared bands represents the spectral signature of the ground at that point. It is this spectral signature which is compared with active layer thickness for the average of five auger measurements within the ground coverage area of each associated pixel.

FIGURE 2-1

20

Location of a Sample Point by Triangulation with Horizon
Reference Marker

A sample point may be located with respect to the three reference points by angles θ_1 , θ_2 and θ_3 , providing that the distances between the reference points d_1 , d_2 , d_3 are known.

FIGURE 2-2
Depth of 0°C and -1°C Isotherms vs Time, 1971-1972
Inuvik N.W.T.

There are some differences between collecting point samples with an auger and digital pixel values sampled from an image (corresponding to the mean reflected light intensities over a few tens of square meters of the ground) which must be considered.

An active layer thickness sample should represent the active layer thickness over the ground area corresponding to a specific image pixel. Taking the mean of several samples over a pixel's ground area fulfills this requirement. Care must be taken in order to ensure that groups of samples are not only in register with a specific pixel but that they are taken at close enough intervals so as to represent accurately the top of the permafrost table.

If the distance between pixel centers is greater or less than the auger sampling frequency (which can occur if the microdensitometer only scans at fixed sampling rates) the pixel array must be resampled so that the array elements correspond to the same ground spatial frequency as the auger sampling.

There are a variety of resampling techniques which may be employed. The modified "sinc" type resampling function (described by Shlien (1979) gives an excellent resampled image and this is the function which was used on the image data in this study.

2.2 CORRECTION OF IMAGERY

There are a number of corrections which may be applied to aerial imagery prior to analysis to account for geometric and radiometric

distortions.

Geometric corrections are required if the sensor platform's roll, pitch or yaw axes were offset from their nominal orientation at image acquisition time or if the images contain geometric distortions specific to a particular sensor. These distortions must be removed by image processing techniques prior to analysis. The bubble level recordings which accompanied the images used in this study showed no attitude offsets which were significant enough to interfere with a pixel-ground sample registration.

Sampling the active layer over ground areas which appear under shadow in the imagery should be avoided. There were no pronounced shadowed areas which required corrections on the digitized imagery in this study.

Point or global radiometric corrections may also be necessary to adjust for atmospheric transmission variation over the image or to adjust for vignetting. Sun glare occurs on oblique imagery in arctic latitudes but in any case this type of imagery is not useful for digital active layer studies because of geometric distortions. The images employed in this study display some vignetting; however, the study sites were digitized from the center of the images where vignetting was not present.

2.3 IMAGE ACQUISITION CONSIDERATIONS

The season of image acquisition for active layer thickness mapping, in studies that compare the spectral signature of the ground with active layer thickness, must necessarily be late summer. Snow cover is absent at this time and surface features, notably vegetation and surface moisture distribution, display strong tonal contrast. Imagery in the visible and reflected infrared wavelengths should be acquired during the midday hours and when the sky is clear. Color contrast will be greatest at this time for color infrared photography, while shadow effects will be minimized for vertical imaging.

Ideally imagery should be acquired at the same time as ground sampling or at least within a few weeks. Imagery which was acquired within the same seasonal time period as sampling but in years previous may prove useful provided terrain conditions have not been altered by pyrogenic or anthropogenic disturbances and provided the climatic regime of the areas has not undergone a marked departure from average conditions. Figures 2-3, 4, 5 and 6 show the deviation from normal maximum and minimum temperatures in summer and percentage of normal precipitation received at the Tuktoyaktuk and Inuvik study sites respectively from 1972 - 1981. Note that although small variations occur from year to year, they are generally equal in magnitude on either side of average.

Small temperature and precipitation variations from year to year are not likely to alter the surface vegetation within an interval such as that between imaging and field work in this study (four years). For

FIGURE 2-3

DEVIATION FROM NORMAL DAILY SUMMER MAXIMUM AND MINIMUM
TEMPERATURES AT INUVIK 1972- 1981.

Source: Environment Canada, Meteorological Observations,
Monthly Bulletin, May, June, July, August, 1972-1981.

FIGURE 2-4

DEVIATION FROM NORMAL DAILY SUMMER MAXIMUM AND MINIMUM
TEMPERATURES AT TUKTOYAKTUK. 1972-1981

SOURCE: ENVIRONMENT CANADA METEOROLOGICAL OBSERVATIONS

MONTHLY BULLETIN, MAY, JUNE, JULY, AUGUST, 1972-1981.

FIGURE 2-5

PERCENTAGE OF NORMAL SUMMER PRECIPITATION AT
TUKTOYAKTUK. 1972-1981.

SOURCE: ENVIRONMENT CANADA, METEOROLOGICAL OBSERVATIONS,
MONTHLY BULLETIN, MAY, JUNE, JULY, AUGUST. 1972-1981.

FIGURE 2-6
PERCENTAGE OF NORMAL SUMMER PRECIPITATION AT
INUVIK, 1972-1982.

SOURCE: ENVIRONMENT CANADA METEOROLOGICAL OBSERVATIONS,
MONTHLY BULLETIN, MAY, JUNE, JULY, AUGUST, 1972-1981.

example, the brightest red areas on Figure 3-2 (see Page 41) of the Tuktoyaktuk study sites correspond exactly to the observed positions of the most foliated Salix bushes in the field. The position of dark and bright red areas on Figure 3-12 (Page 54) of the Inuvik area correspond exactly with the respective position of coniferous and deciduous vegetation observed in the field.

The slight differences in temperature and precipitation from year to year did not change the distribution of surface vegetation or induce any geomorphic changes on any of the study sites between imaging and field work. This was verified by field examination of the aerial photographs.

Although small fluctuations in temperature from year to year might cause differences in active layer thickness at a specific location, spots which develop a thick active layer relative to nearby locations in one year should do the same in any year. Since no vegetation or geomorphic changes occurred in any of the study sites between imaging and field work as shown by the aerial photographs, this assumption should hold.

Once image data and field data are in identical formats with array elements in register representing equal ground areas, quantitative techniques may be employed to examine relationships between surface spectral signature and active layer thickness. These techniques are now described.

2.4 TECHNIQUES OF STATISTICAL ANALYSIS

A comparison of active layer thickness and image pixel intensity for various spectral bands was made with bivariate plots and regression analyses where the ground's spectral signature represents the

dependent variables and active layer thickness represents the independent variable. Linear or exponential relationships between surface spectral signature and active layer thickness may be described through the aid of a regression line with the Pearson product moment correlation coefficient expressing the degree of correlation between the variables and the coefficient of determination describing how much variation in active layer thickness is predicted by the ground's spectral signature.

A series of thirteen investigations employed in this study using various spectral band combinations is summarized in Appendix III

(Page 149).

The t test was used to verify that different surface cover types were significantly different from one another and that measured active layer thickness were significantly different for different surface cover types.

CHAPTER 3 STUDY SITES.

7

3.1 STUDY AREA SELECTION

The concept of relating ground spectral signature to thickness of the active layer in ice-rich sediments has been discussed in Chapter 1. The study area should possess unconsolidated ice-rich substrata and display undulating topography, with varying vegetation and moisture distributions so that ground spectral signatures may be compared with active layer thickness for a range of micro environments within sites. Study areas in the Mackenzie River Delta area of the Canadian Northwest Territories were examined with these criteria in mind. This region not only provides unconsolidated sediments with abundant ice-rich permafrost Rampton and MacKay (1971) but occupies the northern end of what may be an important future energy transport corridor.

Study sites near the towns of Tuktoyaktuk and Inuvik were chosen. Both towns provided facilities from which field work could be conducted with different terrain and vegetation types, in relatively close geographic proximity (Tuktoyaktuk is 125 km north northeast of Inuvik). Terrain characteristics near Tuktoyaktuk and Inuvik are reviewed in the next two sections. Section 3.4 describes the field work while Section 3.5 provides a detailed map and photo survey of the study sites.

3.2 TUKTOYAKTUK

The town of Tuktoyaktuk is situated on the Beaufort Sea coast at longitude $133^{\circ} 01' W$, latitude $69^{\circ} 30' N$, 100 km east of the mouth of

FIG 3-1 STUDY AREA LOCATION

INUVIK AND TUKTOYAKTUK TOWN SITES.

the Mackenzie River (see Figure 3-1).

Tuktoyaktuk lies within the zone of continuous permafrost with frozen ground extending to a depth of 300 m below the ground (Radforth 1974). The terrain surrounding exhibits an undulating topography and is inset with numerous lakes and drained lakes. Relief along the peripheries of the drained lakes is in the order of 5 m to 10 m. Pingo's with vertical relief of up to 30 m are present on many of the drained lake floors. The region was glaciated during the Wisconsin glaciation. Rampton (1974) describes the local surficial deposits as consisting of: "variable thickness of stony clay overlying a complex of marine and fluvial silts, clay and sands, fluvial glacial sands and gravels". Gravel was observed to be a common sub-strate constituent along the peripheries of the drained lakes during the field work.

Radforth (1974) describes the local vegetation as that of an upland tundra with well drained areas exhibiting hard ground upon which grow low woody shrubs, sedges, low ericaceous plants and moss while poorly drained areas display sedges and grasses.

Three study sites were chosen in the vicinity of Tuktoyaktuk and designated Tuk-1, Tuk-2 and Tuk-3.

The Tuk-1 and Tuk-2 study sites both contain drained lakes with moist *Carex* covered floors. The drained lakes are surrounded by low hills with a peat and grass vegetation cover. Gravel deposits are encountered along the lake edges. Tuk-3 spans a large drained lake edge

covering the lake floor, gravel-rich banks and a small portion of the surrounding terrain. Detailed physical characteristics of the three Tuktoyaktuk study sites are summarized in Table 3-1.

3.3 INUVIK

The townsite of Inuvik is situated on a distributary of the Mackenzie River Delta system at longitude $133^{\circ} 55'$ W, latitude $68^{\circ} 20'$ N. An aerial color infrared photograph of the townsite is shown in Figure 3-12. The terrain in the town's vicinity consists of a low-land flood plain flanked by an undulating low grade escarpment. Observations from field work showed that sediments along the flood plain consist of stoneless silts and muds while clays, stones and gravels are found on the escarpment slope. Being within the zone of continuous permafrost the ground is frozen to between one and to several hundred meters' depth in the Inuvik area (Brown 1971) but adjacent to the distributary channel permafrost was not encountered within the range of the sampling auger.

Local vegetation consists of Salix and Alnus in poorly drained areas while areas with good drainage on stone-free substrate display covers of Erica and Picea. Betula, Salix and Alnus associations are found on gravel-rich substrate.

Two study sites were chosen in the vicinity of Inuvik and designated In-1 and In-2. In-1 occupies the area around Boot Lake (see Figure 3-12, Page 54) and the ground between the lake and the East Channel of the Mackenzie River. The study site exhibits several terrain vegetation types such as Carex on wet ground, hill slopes with gravel substrate and

TABLE 3-1
DESCRIPTION OF STUDY SITES

STUDY SITE AND DATES OF FIELD WORK	PHYSICAL DESCRIPTION	VEGETATION	REMARKS
Tuk-1 Aug. 21-24, 1981	Gently undulating topography exhibiting high and low centre polygons. A drained lake which is open to the Beaufort Sea and subject to periodic inundation is found in the north west corner of the study site.	Drained lake floor exhibits pockets of standing water and possesses a peat and Carex cover. Salix and Betula shrubs cover undulating terrain marginal to a small lake in the south east portion of the study area.	Substrate ice rich and unconsolidated. Active layer deepest (95 cm.) in gravel rich substrate with Salix cover. Active layer thinnest (35 cm.) where stones are absent from the substrate and on poorly drained ground.
Tuk-2 Aug. 26-28, 1981	Undulating topography surrounds a drained lake which is open to an inlet of the Beaufort Sea. The basin floor is poorly drained and displays high and low centre polygons	Basin floor exhibits a wet peat and Carex cover. Terrain surrounding the basin has a cover of Lupin, Erica and grasses. Salix and Betula shrubs are found on gravel rich substrate.	Substrate ice rich and unconsolidated. Active layer deepest (85 cm.) on basin slopes where Salix and Betula shrubs grow on gravel rich soil. Active layer thinnest on stone free substrate an on basin floor.
Tuk-3 Aug. 25, 1981	Study site straddles the steeply sloping shore of a drained lake.	Shoulder of escarpment has a grass and Erica cover with numerous grass tussocks. Basin floor has a grass cover. Salix bushes 2 m. high are found at the slope toe.	Basin floor and slope substrate stone free with 35-45 cm thick active layer. Active layer 270 cm. thick on slope toe in gravel rich substrate.

TABLE 3-1 continued

<u>STUDY SITE AND DATES OF FIELD WORK</u>	<u>PHYSICAL DESCRIPTION</u>	<u>VEGETATION</u>	<u>REMARKS</u>
In-1 Sept. 1-4, 1981	Study site covers terrain adjacent to Boot Lake and a small water course connecting the lake to the East Channel of the MacKenzie River.	Steep slope on east side of Boot Lake possesses a mixed cover of Betula, Salix, Alnus and Picea. Flood plain by East Channel has an Alnus and grass cover. Frequently flooded areas are unvegetated	Slope substrate is gravel rich with a 50-100 cm. thick active layer. Active layer is 40-50 cm. thick on floodplain by East Channel but is 270 cm. thick by study site water bodies.
In-2 Sept. 5-6, 1981	Study site covers terrain on a slope 1/2 km. east of the Inuvik townsite. the study site is traversed by a fire break.	Open lichen woodland occupies the northern portion of the study site while Betula forest is found in the southern portion. The fire break (cut in 1969) is unvegetated.	Active layer is 35-45 cm. thick in forested areas but 150 cm. thick in the fire break. Substrate generally stoneless.

a deciduous forest cover and flood plain sediments with a cover of *Salix* and *Picea*. Site In-2 occupies an upland area with open lichen woodland and a stand of deciduous forest. Detailed physical characteristics of the study sites are summarized in Table 3-2.

3.4 DESCRIPTION OF FIELD WORK

The positions of auger samples were chosen to take into account both the diversity of the terrain and vegetation and the ordered format in which the digitized aerial photographs would be expressed. For each study site, samples were taken at approximately 30 m intervals for all observed terrain and vegetation types. At each location five holes were augered in close proximity and the measured active layer thicknesses averaged. Vegetation, soil type and moisture content were noted for each sample area.

For each hole augered, contact with permafrost was easily distinguished from contact with rocks and stones as the latter produced a grinding sound and offered resistance to the turning of the auger. Rotating the auger on top of permafrost was silent with no resistance being offered. Ice contact was verified on many occasions by using a shovel to dig away the active layer material to expose the frozen substrate. All auger samples for the study sites are listed in Appendix I (Page 121).

Transparencies of Figures 3-2, -10 and -12 (Canada Centre for Remote Sensing photographs A 374891R-43, A 22884-171, A 30855-120) were

used as data sources for digitization which was accomplished with the Canada Centre for Remote Sensing PDS color flatbed scanning microdensitometer (see: Goodenough (1979)). The study sites on the transparencies were scanned in the transmission mode using image-specific pixel intensity calibration with a 50 micrometer by 50 micrometer pixel size. Three matrices of data were obtained for each study site corresponding to the green, red and infrared spectral bands on the transparencies with the exception of Figure 3-10 where one band was scanned (the original transparency being a panchromatic photograph). The data were resampled using a sinc type interpolation function to produce a working pixel size of 32 m x 32 m on the ground for each study site. Each auger sample of active layer thickness (an average of five holes) was located with respect to its corresponding image pixel; the relationship between the thicknesses and pixel values being examined with bivariate plots and regression analysis. Results and discussions of these statistical examinations are presented in the next chapter. In the following section, a photographic survey of the study sites is presented.

3.5 SURVEY OF THE STUDY SITES

The following twenty two pages provide a cartographic overview and photographic survey of the five study sites. For each study site, an aerial photograph, terrain map showing auger sample locations and one or more ground photographs are presented.

Figure 3-2 at right shows an aerial color infrared photograph with the study sites Tuk-1 and Tuk-2 outlined in white. Note the Tuktoyaktuk townsite in the upper portion of the photograph. The large dark area in the right hand portion of the photograph is the Beaufort Sea. The brightest red areas on the ground are Salix aggregates. Peat and moss appear grey and brown.

Note: this image is inverted.

FIGURE 3-2

AERIAL COLOR INFRARED PHOTOGRAPH OF STUDY SITES TUK-1 and TUK-2

Photograph taken: Aug. 1977

Time: 13h L.S.T.

Frame Format 22.4 X 22.4 cm.

Lens: 15.2 cm.

Print No. A374891R -43

Study areas enclosed
by white border.

Figure 3-3 at right shows the study site Tuk-1 with terrain types identified and the position of auger sample holes marked. The numbers correspond to the hole numbers for Tuk-1 shown in Appendix I on page 100. The image is a 16 tone grey level Versatec print out from the C.C.R.S. digitizer. The image was scanned from Figure 3-2. Classification of the terrain was accomplished during field work.

Angle symbols on the figure represent the position and azimuthal range of ground photographs of the study site. Each symbol is labeled with the ground photograph which it represents.

FIGURE 3-3 STUDY SITE TUK-1

+ auger sample

N

0 90

SCALE
METERS

Figure 3-4

Tuk 1 PANORAMA

South eastward looking photomosaic of a small lake in t
Erica, Betula and Salix shrubs appear in the foreground
middle ground is a high centre polygon field. Active la
cm in the polygon field but 40 to 60 cm in the foregrou

Figure 3-4

Tuk 1 PANORAMA

mosaic of a small lake in the southern portion of Tuk 1.
ubs appear in the foreground. Undulating terrain in the
tre polygon field. Active layer thickness is 35 to 45
40 to 60 cm in the foreground areas.

2 OF 2

Figure 3-5

Tuk 1 PANORAMA

This eastward looking photomosaic shows an in
Sea which is subject to inundation (note por
and drift wood marking the high water line).
Erica grow in the fore ground on gravel rich
active layer thickness is 35 to 45 cm on the

Figure 3-5

Tuk 1 PANORAMA

and looking photomosaic shows an inlet to the Beaufort
subject to innundation (note ponds in inlet centre
ood marking the high water line). Salix, Betula and
in the fore ground on gravel rich substrate. The
thickness is 35 to 45 cm on the basin floor

2 OF 2

FIGURE 3-6

Tuk 1 GROUND VIEW

Ground view of a high center polygon field at Tuk 1. The height of the shovel handle above the ground near the photo centre is 1 meter. The active layer is approximately 35 cm. to 45 cm. thick for all points on the polygons as well as in the intervening trenches. The light toned material in the middle ground at right is drift wood resting on the shore of a inlet to the Beaufort Sea. The isolated conical hills on the horizon are pingoes.

FIGURE 3-7

Tuk 1 CLOSE UP OF SURFACE VEGETATION

Association of *Betula* (red leaves), *Erica* (small green circular leaves), *Lupin* (elongate leaves in stellar arrays) and Bryophytes. This ground cover is typical of well drained terrain with gravel-free substrate at Tuk 1, Tuk 2 and Tuk 3. Active layer thickness under this vegetation cover is approximately 35 cm.

Figure 3-8 at right shows the study site Tuk-2 with terrain types identified and the position of auger sample holes marked. These numbers correspond to the hole numbers shown for Tuk-2 in Appendix I. The image is a 16 tone grey level print out from the C.C.R.S. digitizer. Classification of the terrain was accomplished during field work.

The position and azimuthal range of ground photograph 3-9 is indicated by the angle symbol on this figure.

FIGURE 3-8 STUDY SITE TUK-2

+ auger sample

N

0 90

SCALE
METERS

Figure 3-9

Tuk-2 PANORAMA

This photomosaic shows the western portion of the study site Tuk-2. Active layer thickness on the basin floor is 35 to 45 cm. Standing Salix shrubs grow on gravel-rich substrate in the foreground and middle ground. The active layer thickness on the slopes is 50 to 90 cm. The mound on the left and in the background are high centre polygon fields.

Figure 3-9

Tuk-2 PANORAMA

tion of the study site Tuk-2 basin (in middle ground)
loor is 35 to 45 cm. Standing water is 12 to 15 cm deep.
strate in the foreground and on the opposite slope bank.
pes is 50 to 90 cm. The mounded terrain on the foreground *
re high centre polygon fields with 35 cm thick active layers.

2 OF 2

Figure 3-10 at right shows the study site Tuk-3 along the edge of a large drained lake. The site is situated 13 km. east of the Tuktoyaktuk townsite. The large dark areas on the photograph are lakes. This is a panchromatic photograph.

FIGURE 3-10

AERIAL PANCHROMATIC PHOTOGRAPH OF STUDY SITE TUK-3

Photograph taken: Aug. 1977
Time: 14h L.S.T.
Frame format: 22.4 X 22.4 cm.
Lens: 15.2 cm.
Print No. A22884 -171

Study area enclosed
by white border.

1 OF

2 of

Figure 3-11

Tuk-3 PANORAMA

3 of

This southward looking photomosaic shows the northern edge of a large drained
the foreground area. Note the Salix bushes which grow on gravel-rich substrat
Active layer thickness here was measured at 270 cm thinning to 40 cm on the d

Figure 3-11

Tuk-3 PANORAMA

3 of

Figure 3-11

Tuk-3 PANORAMA

4 OF 4

aic shows the northern edge of a large drained lake. Tuk -3 occupies
alix bushes which grow on gravel-rich substrate in the foreground.
measured at 270 cm thinning to 40 cm on the drained lakefloor.

Figure 3-12 at right shows the study sites In-1 and In-2 situated along the east channel of the Mackenzie river. Note the town of Inuvik at lower left. In-1, the larger study site, occupies the southern portion of Boot Lake (dark water body). In-2 occupies higher ground and is smaller than In-1 in aerial extent.

Note; this image is inverted.

FIGURE 3-12

AERIAL COLOR INFRARED PHOTOGRAPH OF STUDY SITES IN-1 AND IN-2

Photograph taken: Aug. 1977

Time: 13h L.S.T.

Frame format: 22.4 X 22.4 cm.

Lens: 15.2 cm.

Print No. A30855 -120

Study area is enclosed
by white border.

Figure 3-13 at right shows an enlarged view of In-1 presented as a 16 grey tone Versatec image. The terrain was classified according to observations made during field work. Auger samples are numbered on the image. In the discussion of the Inuvik results (see section 4.3) the study site is divided into three subsections subsections as follows:

- 1- Hillslope- auger holes 22-44.
- 2- Salix and Alnus- auger holes 1-21.
- 3- East Channel Floodplain- auger holes 45-54.

Angle symbols represent the positions and azimuthal ranges of ground photographs of the study site. Each symbol bears the number of the ground photograph it represents.

FIGURE 3-13 STUDY SITE IN-1

+ auger sample

N

0 30

SCALE
METERS

Figure 3-14

In-1 PANORAMA

This panorama mosaic was taken from the shoulder of the above the eastern edge of Boot Lake. *Alnus*, *Salix*, *Betula* be seen in the foreground and on the flood plain between the East Channel of the Mackenzie River. Note the water the East Channel to the lake.

Figure 3-14

In-1 PANORAMA

ic was taken from the shoulder of the slope which rises
edge of Boot Lake. Alnus, Salix, Betula and Picea may
eground and on the flood plain between Boot Lake and
f the Mackenzie River. Note the water course connecting
o the lake.

FIGURE 3-18

In 1 GROUND VIEW

This photograph shows a stand of Salix on wet, poorly drained terrain on the north shore of Boot Lake. The southern forested shore is visible in the background. Active layer thickness in the foreground area is approximately 45 cm.

FIGURE 3-18

In 1 GROUND VIEW

This photograph displays, in the foreground, a levee along the north shore of the water course connecting Boot Lake to the East Channel of the Mackenzie River. The active layer is approximately 45 cm. thick beneath the grasses, *Alnus* and *Salix* in the foreground but is 270 cm. thick on the levee.

Figures 3-17a and 3-17b at right are 16 tone gray level Versatec images digitized from Figure 3-12 and show study site In-2. Terrain classification in Figure 3-17a is based on field work observations.

The angle symbol denotes the position and azimuthal range of the ground photograph shown in Figure 3-18.

Figure 3-17 a Study Site In - 2

←
N

0 10
m
Scale

Figure 3-17 b Position of Auger Samples at Study Site In-2

+ auger samples

←
N

0 10
m
Scale

FIGURE 3-18

In 2 GROUND VIEW

Open lichen woodland in the northern section of study site In 2. Active layer thickness in this area is approximately 35 cm. to 45 cm. The auger used to obtain all of the active layer thickness samples is shown, fully extended to the right of centre.

Figures 3-17a and 3-17b at right are 16 tone gray level Versatec images digitized from Figure 3-12 and show study site In-2. Terrain classification in Figure 3-17a is based on field work observations.

The angle symbol denotes the position and azimuthal range of the ground photograph shown in Figure 3-18.

Figure 3-17'a Study Site In-2

←
N

0 10
m
Scale

Figure 3-17 b Position of Auger Samples at Study Site In-2

←
N

+ auger samples

0 10
m
Scale

FIGURE 3-18

In 2 GROUND VIEW

Open lichen woodland in the northern section of study site In 2. Active layer thickness in this area is approximately 35 cm. to 45 cm. The auger used to obtain all of the active layer thickness samples is shown, fully extended to the right of centre.

CHAPTER 4 DISCUSSION.

4.1 INTRODUCTION

Theoretically, spectral signatures represent the reflected light from a particular type of ground vegetation cover and surficial deposit. A typical signature for a continuous coniferous vegetation canopy is shown in Figure 4-1. This signature is typical of all healthy green plants with only the peaks at 0.550 and 0.750 through 0.900 micrometers changing in percent reflectance for individual species. In the area of this study, vegetation is sparse and intermittent. The reflected signature will include, for any image pixel, reflections from the various plant types, their stems, the direct "background soil" and the scattered soil background radiation reflected from the plant leaves and stems. This principle is illustrated in Figure 4-2.

As will be shown in the following sections, active layer thickness was found to differ for various vegetative associations. However, the distinct identity of the spectral signature for different types of vegetation and surface materials is likely to be obscured by soil background radiation. As shall be demonstrated there were, in numerous cases, no significant differences between mean spectral signatures of different cover types, especially at the Tuktoyaktuk study sites.

Spectral signatures which are indistinct may be enhanced by taking band products or band ratios, procedures which are especially appropriate where vegetation and mineral surfaces are in close proximity. Lillesand and Kiefer (1980 : 567-569) describe how band ratios can enhance imagery. The thirteen band and band combinations of the three spectral bands employed in this study are described in detail in Appendix III.

FIGURE 4-1

REFLECTANCE CURVE FOR VEGETATION

Source: Lillesand and
Kiefer (1980)

FIGURE 4-2

RADIATION SCATTER

note: a = direct radiation, b = background radiation

For clarity with relation to the discussion they will be reviewed briefly here.

Analysés one through three: Active layer thickness vs. green, red and infrared light shows how active layer thickness is related to each spectral band.

Analysés four through six: Active layer thickness vs. the product of the band pairs (eg. green multiplied with red) strengthens any relationship where the two multiplied bands are themselves related to active layer thickness.

Analyses seven through nine: Active layer thickness vs. the ratios of the band pairs(eg. green divided by red). A high correlation will result if there is a strong relationship between active layer thickness and the and the numerator in the ratio. Shadow effects are eliminated from the regression since low pixel values in both bands approach unity when the ratios are taken.

Analysis ten: Active layer thickness vs. the sums of the band pair ratios simulates a pancromatic image where shadow effects have been removed.

Analyses eleven through thirteen: Active layer thickness vs. each spectral band normalized with respect to all three bands. This provides

a standardized comparison between the bands and active layer thickness in the event that the spectral reflectances show wide ranges.

In Figure 4-1 it was shown that strong green and infrared reflectance denote the presence of a vegetation cover. It is important to note that positive relationships involving these two bands indicates that active layer thickness is affected by the presence of vegetation.

Each band and band combination was used in a bivariate analysis as an independent variable. The results of these investigations are presented in full in Appendix IV. The most significant results of bivariate analyses will be shown in tables in the next two sections and discussed. The following two sections spectral reflectances and active layer thickness will be examined for the study sites as a whole and with the site samples divided into categories based on surface cover. The categories will be compared with the t test to determine whether or not spectral reflectances and active layer thicknesses are different for the categories.

4.2 TUKTOYAKTUK RESULTS

Study sites Tuk-1 and Tuk-2 were both digitized from the color aerial infrared photograph shown in Figure 3-2. Figures 4-3 and 4-4 show histograms of active layer sample distribution over a range of thicknesses for Tuk-1 and Tuk-2. Tuk-1 shows a large number of samples with thin active layers but substantial numbers of samples with intermediate depths (60 - 70 cm) and greater depths (90 - 110 cm). The Tuk-2 sample distribution is highly skewed with many samples showing thin active layers (30 - 40 cm for 64 samples) and only a few samples with thick active layers (70 - 100 cm for 16 samples). Means and ranges of active layer thicknesses and spectral signatures obtained with the C.C.R.S. scanning microdensitometer for Tuk-1 and Tuk-2 are shown in Table 4-1. Active layer thickness and reflectances for green and red lights show means which are close to one another. In addition the range of reflectance in green and red light spans the range of the digitizer (255 units) indicating little likelihood for these bands being significantly different from one another. The narrower range for infrared light (82) makes it the most likely candidate for a relationship with active layer thickness at Tuk-1.

Data for Tuk-1 was divided into the following categories based on surface cover type: Carex, moss-peat, grass and Salix. Table 4-2 shows the means, standard deviations and ranges for active layer thickness and each spectral band for these categories. Not only do active layer thickness means for the categories occur in a narrow range (42 - 52 cm)

2

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FIGURE 4-3
HISTOGRAM OF ACTIVE LAYER THICKNESS SAMPLE
DISTRIBUTION. Tuk-1

FIGURE 4-4

HISTOGRAM OF ACTIVE LAYER THICKNESS SAMPLE DISTRIBUTION.

Tuk- 2.

TABLE 4-1

RANGES AND MEANS FOR ACTIVE LAYER THICKNESS AND REFLECTED LIGHT
FOR TUK-1, TUK-2 and TUK 3.

<u>SITE</u>	<u>ACTIVE LAYER</u> <u>THICKNESS (cm)</u>		<u>GREEN</u> <u>LIGHT</u>		<u>RED</u> <u>LIGHT</u>		<u>INFRARED</u> <u>LIGHT</u>	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
TUK-1	65	125	77	255	68	255	32	82
TUK-2	45	66	60	96	67	100	54	100
TUK-3	85	208	<u>PANCHROMATIC</u>					
			99	86				

Source : Appendix II

Note- Reflected light measurements have no units. Values presented refer to the sensitivity range of the C.C.R.S digitizer. A value of zero represents an opaque image. A value of 256 represents saturation of the instrument with light.

TABLE 4-2CENTRAL TENDENCY STATISTICS FOR TUK-1 COVERCATEGORIES.

<u>SALIX</u>	8 samples	ACTIVE LAYER	GREEN	RED	INFRARED
<u>SALIX</u>	8 samples	<u>THICKNESS (cm)</u>	<u>LIGHT</u>	<u>LIGHT</u>	<u>LIGHT</u>
range		25-93	48-128	48-110	22-82
mean		52	80	70	47
standard deviation		21	23	20	16
<u>CAREX</u>	9 samples				
range		27-93	46-127	69-110	23-63
mean		51	68	62	44
standard deviation		25	28	20	13
<u>GRASS</u>	8 samples				
range		30-122	17-143	23-105	17-82
mean		48	83	70	33
standard deviation		28	20	25	13
<u>MOSS AND</u>	17 samples				
<u>PEAT</u>					
range		30-66	33-81	41-62	17-46
mean		42	57	60	32
standard deviation		14	16	15	9

Source: Appendix V

but active layer thickness ranges overlap considerably. The same may be said of the ranges of the spectral reflectances. The t test was used to determine exactly how significantly different the categories were from one another with regard to active layer thickness and spectral reflectance.

Testing the significance of the difference in mean green, red and infrared reflectance for each group of surface cover categories showed significant differences for only three pairs of the categories. As shown in Table 4-3, the spectral signatures were significantly different from one another at the 95% confidence level in infrared light between Carex and moss-peat, Carex and Salix and in green light between Salix and moss-peat. This discrimination is not surprising since peat and moss display the darkest tones on Figure 3-2. The t test showed that the different cover types did not produce significantly different active layer thicknesses indicating that at Tuk-1, the surface cover has no significant effect on the development of the active layer. Table 4-3 shows a t value of 2.6 when the mean active layer thicknesses for organic substrate and sand gravel substrate are compared. This value is significant at the 99% confidence level showing that at Tuk-1, the properties of the substrate are the primary determinants of active layer thickness.

Means and ranges for active layer thickness and spectral reflectance for Tuk-2 are shown in Table 4-1. The mean active layer thickness and ranges at this site are smaller than at Tuk-1 (45 cm and 66 cm compared to 65 cm and 125 cm). Spectral reflectances show means between 54 and 60 and ranges which all overlap. It is difficult to determine upon inspection of this information, whether there are significant relationships

TABLE 4-3

SIGNIFICANT t TEST RESULTS FOR TUK-1

<u>CATEGORY CATEGORIES COMPARED</u>	<u>SIGNIFICANT DIFFERENCE</u>	<u>t VALUE</u>	<u>LEVEL OF SIGNIFICANCE</u>
Carex and Moss-Peat	Infrared light	2.5	95 %
Salix and Moss-Peat	Green light	3.3	95%
	Infrared light	3.3	95%
Carex and Salix	Infrared light	2.6	95%
Sand -Gravel and Organic Matter	Active layer thickness	2.6	99%

Source : Appendix VI

between surface cover types and active layer thickness.

For the t test the Tuk-2 samples were divided into three categories: moss-peat, Carex and Salix. Table 4-4 shows the reflectance means and ranges for these categories. The spectral reflectances for the categories show means which are close to one another and overlapping ranges. Note, however, the low mean and range (39 cm and 16 cm) in active layer thickness for Carex compared to the other categories showing that it seems to be different from the other two cover types.

Table 4-5 shows the significant t test results for site Tuk-2. Active layer thickness was found to be significantly different at the 95% confidence level between Salix and Carex (t value 2.4) with Salix showing the deeper active layer. This result is not surprising after having inspected the data presented in Table 4-4. Note also the discrimination between Carex and Salix in infrared light with a t value of 2.0 - significant at the 95% confidence level.

In comparing cover types, the infrared reflectance for Carex (darker on the image than moss and peat because of a high moisture content) was found to be significantly different from Salix at both Tuk-1 and Tuk-2. Yet, this limits the utility of making active layer thickness predictions with this imagery since it was the Salix and moss-peat that had significantly different active layer thicknesses and not Salix and Carex. Like Tuk-1, however, a test of the difference between the sample means divided into organic and sand-gravel categories showed a significant

TABLE 4-4

CENTRAL TENDENCY STATISTICS FOR STUDY SITE TUK-2 COVERCATEGORIES

	ACTIVE LAYER THICKNESS (CM)	GREEN LIGHT	RED LIGHT	INFRARED LIGHT
<u>MOSS AND PEAT</u> 13 samples				
range	33-84	39-83	45-93	51-95
mean	45	62	67	68
standard deviation	16	19	17	11 ₂
<u>CAREX</u> 21 samples				
range	33-49	33-105	34-120	23-105
mean	39	61	67	60
standard deviation	6	21	20	23
<u>SALIX</u> 20 samples				
range	33-89	40-103	63-101	47-99
mean	56	68	76	72
standard deviation	16	17	19	20

Source: Appendix II

TABLE 4-5SIGNIFICANT t TEST RESULTS FOR TUK-2

<u>CATEGORIES COMPARED</u>	<u>SIGNIFICANT DIFFERENCE</u>	<u>t VALUE</u>	<u>LEVEL OF SIGNIFICANCE</u>
Carex and Salix	Active layer thickness	2.4	95%
	Infrared light	2.0	95%
Sand-Gravel and Organic Matter	Active layer thickness	4.0	99%

Source : Appendix VI

TABLE 4-6

SUMMARY OF BIVARIATE ANALYSIS RESULTS WITH THE HIGHEST CORRELATION COEFFICIENTS

TUKTOYAKTUK STUDY SITES

<u>STUDY SITE</u>	<u>BAND OR BAND COMBINATION</u>	<u>CORRELATION COEFFICIENT</u>	<u>COEFFICIENT OF DETERMINATION</u>
TUK-1	green light multiplied with infrared light.	+ 0.532	0.30
	red light multiplied with infrared light.	+ 0.532	0.30
TUK-2			
(wet area removed)	red light	+ 0.405	0.16
TUK-3			
(wet area removed)	panchromatic light	+ 0.667	0.45

Source: Appendix IV

difference at the 99% confidence levels with a t value of 4.0, the sand and gravel showing the deeper active layer.

Few of the bivariate analyses for Tuk-1 and Tuk-2 showed correlation coefficients above +0.500. Among the independent variables shown in Table 4-6 for Tuk-1, the infrared spectral band and multiplicative combinations with the other spectral bands showed the highest correlation coefficients (+.532 and +.532 for the green band multiplied with the infrared band and the red band multiplied with the infrared band respectively). Figure 4-5 a bivariate plot for active layer thicknesses and the green multiplied with the red band shows the data points clustering in the lower left corner of the plot indicating that for neither dependent nor independent variable, are the samples distributed normally.

Adjusting the Tuk-1 pixel values by removing the data corresponding to the low, poorly drained areas which displayed wide tonal variations on the imagery did not raise the value of any of the correlation coefficients in the thirteen investigations above +.500. It was hoped that this procedure might unmask any relationships which might have existed between active layer thickness and surface spectral signature. Since testing, the significance of the means between the wet low ground and the higher ground showed no significant difference in active layer thickness, low correlation for the adjusted Tuk-1 samples is not surprising. When Tuk-2 was adjusted in this manner, the highest correlation coefficient observed was +0.307 for the infrared band, constituting a weak relationship.

Figure 4-6 shows a histogram of active layer thickness at sample points for Tuk-3. Note that while many samples have active layers of 50 to 150 cm (42 samples) five have active layer thicknesses between 250 - 350 cm. These values are at least 100 cm deeper than at Tuk-1 and Tuk-2.

Table 4-1 shows an active layer thickness range of 208 cm for Tuk-3. Tuk-3 was split into three categories: Salix, Erica-peat and grass. Means, standard deviations and ranges for each category are shown in Table 4-7. The mean active layer thicknesses for Erica-peat, grass and Salix are 37, 72 and 146 cm respectively.

t test results given in Table 4-8 show that the active layers were significantly different between all categories at the 99% confidence level and that the Salix and grass panchromatic reflectances were significantly different at the 95% confidence level. A comparison of active layer thickness for gravel soils and organic soils showed significant differences at the 95% confidence level.

With the bivariate analysis a correlation coefficient of +.667 shown in Table 4-5 was observed with the single panchromatic band when data for the wet grass samples were removed from the regression.

As has already been noted, the thickest active layer for all the Tuktoyaktuk study sites were encountered in gravel deposits, (often with a ground cover of Salix bushes). As the thermal conductivity of gravel is at least an order of magnitude greater than peat (see page 7), a common surface material in the area, it may be argued that a principal parameter influencing active layer thickness at the Tuktoyaktuk sites is

FIGURE 4-6
HISTOGRAM OF ACTIVE LAYER THICKNESS SAMPLE DISTRIBUTION
Tuk- 3

TABLE 4-7

CENTRAL TENDENCY STATISTICS FOR TUK-3 COVER
CATEGORIES.

	<u>ACTIVE LAYER THICKNESS</u>	<u>PANCHROMATIC LIGHT</u>
	(cm)	
<u>ERICA AND PEAT</u> 6 samples		
range	33-43	44-130
mean	37	97
standard deviation	4	36
<u>GRASS</u>		
range	60-124	63-130
mean	72	80
standard deviation	21	22
<u>SALIX</u>		
range	94-241	64-141
mean	146	117
standard deviation	67	32

Source: Appendix V

TABLE 4-8

SIGNIFICANT t TEST RESULTS FOR STUDY SITE TUK-3

<u>CATEGORIES COMPARED</u>	<u>SIGNIFICANT DIFFERENCE</u>	<u>t VALUE</u>	<u>LEVEL OF SIGNIFICANCE</u>
SALIX AND ERICA-PEAT	Active layer thick- ness	4.0	99%
SALIX AND GRASS	Active layer thickness	3.0	99%
	Panchromatic light	2.4	95%
GRASS AND ERICA- PEAT	Active layer thickness	4.3	99%
SAND-GRAVEL AND ORGANIC MATTER	Active layer thickness	2.8	95%

Source: Appendix VI

thermal properties of the surficial deposits. In the tundra environment at Tuktoyaktuk, as was noted in the field, stony deposits permit the growth of large Salix bushes. These bushes are far from lush and are often not found in dense aggregates. Their spectral signatures are also not easily distinguished from those of other cover types (as shown by the t test with only one band, infrared, showing significant differences with other cover types) rendering them difficult to classify by spectral signature. The association of Salix with thicker active layers at Tuk-2 and Tuk-3 which is quantitatively demonstrated with the t test is difficult to apply as a predictive indication of active layer thickness because of the indistinct spectral signature of Salix when compared with other cover types.

Table 4-1 shows green, red and infrared signatures means of 77, 68, 32 and 60, 67 and 54 respectively for Tuk-1 and Tuk-2. These averages indicate that when considered as a whole, both study sites display signatures which are very typical of vegetation. Recall Figure 4-1 where the order of strongest reflectance for vegetation was infrared, green and red. The Tuktoyaktuk sites are more representative of a mineral surface, indicating a soil background radiation input. In the bivariate analyses (complete results shown in Appendix IV) for all the Tuktoyaktuk study sites the coefficients of determination showed that relatively little of the variance in sampled active layer thickness was explained by the surface spectral signature. The green band multiplied with the infrared band and the red band multiplied with the infrared band at study site Tuk-1 gave coefficients of determination of 0.30 and 0.28 (see

Table 4-4) respectively, illustrating considerable inadequacy in the ability of the spectral signature to predict the thickness of the active layer in this area. The coefficient of determination of 0.45 for the adjusted Tuk-3 data of active layer thickness plotted against the panchromatic ground reflectance shows a stronger although not altogether cohesive relationship.

4.3 INUVIK RESULTS

Study sites In-1 and In-2 were digitized from Figure 3-14, In-1 was a diverse site and the data was divided into five surface cover categories: mixed conifer-deciduous forest, Picea, muck, Salix-Alnus, and Salix-grass. Means, ranges and standard deviations for each of these groups are shown in Table 4-9. Mean active layer thicknesses range from 74 cm for Salix and Alnus to 241 cm for muck indicating that surface cover is linked to different active layer thicknesses. The spectral signatures are not as easy to distinguish for the different cover types on inspection of Table 4-9 since the means are close to one another and the ranges overlap. The t test, however, permits discrimination. t test results for In-1 are shown in Table 4-10. Active layer thickness were significantly different at the 99% confidence level between muck-Salix and Alnus, muck-Salix and grass and muck-Picea. Red and infrared reflectances also showed significant differences between muck-Salix and Alnus (red, 95%) mixed forest-Picea (infrared, 5%), muck-Picea (red, 99%), Salix and grass-Picea (red, 95%), mixed forest-Salix and Alnus (infrared,

TABLE 4-9

CENTRAL TENDENCY STATISTICS FOR IN-1 COVER CATEGORIES

Active layer		GREEN LIGHT	RED LIGHT	INFRARED LIGHT
<u>ACTIVE LAYER THICKNESS</u>				
(cm)				
<u>MIXED FOREST</u> 7 samples				
range	100-132	63-85	37-50	88-139
mean	118	63	37	95
standard deviation	18	11	7	23
<u>MUCK</u> 7 samples				
range	132-227	37-153	34-208	19-139
mean	241	76	101	72
standard deviation	52	42	62	53
<u>SALIX AND ALNUS</u> 15 samples				
range	45-132	33-154	4-166	13-103
mean	74	56	37	54
standard deviation	35	57	50	39
<u>SALIX AND GRASS</u> 17 samples				
range	72-241	15-152	0-208	22-229
mean	79	67	53	77
standard deviation	61	27	57	61
<u>PICEA</u> 8 samples				
range	80-152	15-132	4-73	16-100
mean	96	55	23	61
standard deviation	30	29	23	32

Source: Appendix V.

TABLE 4-10

SIGNIFICANT t TEST RESULTS FOR STUDY SITE IN-1

<u>CATEGORIES COMPARED</u>	<u>SIGNIFICANT DIFFERENCE</u>	<u>t VALUE</u>	<u>LEVEL OF SIGNIFICANCE</u>
MUCK- SALIX AND ALNUS	Active layer thickness	8.0	99%
	Red light	2.5	95%
MIXED FOREST- PICEA	Infrared light	2.4	95%
MUCK- SALIX AND GRASS	Active layer thickness	8.0	99%
	Red light	2.5	95%
MUCK- PICEA	Active layer thickness	12.9	99%
	Red light.	3.1	99%
SALIX AND GRASS- PICEA	Red light	2.0	95%
MIXED FOREST- MUCK	Active layer thickness	5.9	99%
MIXED FOREST- SALIX AND ALNUS	Active layer thickness	4.0	99%
	Infrared light	2.4	95%
MIXED FOREST- SALIX AND GRASS	Active layer thickness	2.5	95%

Source : Appendix VI

95%), mixed forest-muck (red, 95%). Not only is active layer thickness different for specific ground cover types but spectra reflectance is able to discriminate between different cover types.

In-2 was divided into two categories: Picea and mixed forest. Means ranges and standard deviations are presented in Table 4-11. The mean active layer thickness for Picea is 38 cm while it is 70 cm for mixed forest indicating a considerable difference between the two cover types. The t test results in Table 4-12 show a t value of 11.9, significant at the 99% confidence level. In addition, red light reflectances are significantly different at the 95% confidence level. This category combination was not found to exhibit a significantly different active layer thickness in In-1 but did show a significantly different infrared reflectance from other vegetation types there.

A histogram for all In-1 active layer thickness samples is shown in Figure 4-7. The form of the distribution is similar to that of Tuk-2. The lack of a similar distribution in the spectral signature at Tuk-2 negated any clear relationships there. The signatures at In-1 on inspection of the data in Table 4-13, show that with mean values of green 62, red 46 and infrared 65, the signatures much more closely follow that expected of a vegetation cover. (In-2 shows a similar pattern with green 93, red 72 and infrared 144). Soil background radiation is less likely to be a problem at In-1 and stronger correlations should be encountered.

Active layer thickness and surface spectral signatures were compared for the entire study site and are shown in Table 4-14. Relationships

TABLE 4-11

CENTRAL TENDENCY STATISTIC FOR IN-2 COVER CATEGORIES.

	ACTIVE LAYER <u>THICKNESS</u> (cm)	GREEN <u>LIGHT</u>	RED <u>LIGHT</u>	INFRARED <u>LIGHT</u>
<u>PICEA</u>	10 samples			
range	35-40	80-127	66-106	89-127
mean	38	91	84	115
standard deviation	3	9	9	26
<u>MIXED FOREST</u>	7 samples			
range	63-96	82-103	61-76	93-148
mean	70	91	64	125
standard deviation	4	18	15	20

Source: Appendix V

TABLE 4-12SIGNIFICANT t TEST RESULTS FOR IN-2

<u>CATEGORIES COMPARED</u>	<u>SIGNIFICANT DIFFERENCE</u>	<u>t VALUE</u>	<u>LEVEL OF SIGNIFICANCE</u>
PICEA AND MIXED FOREST	Active layer thickness	11.9	99%
	Red light	2.4	95%

Source: Appendix VI

FIGURE 4-7
HISTOGRAM OF ACTIVE LAYER THICKNESS SAMPLE DISTRIBUTION.

In- 1

TABLE 4-13

RANGES AND MEANS FOR ACTIVE LAYER THICKNESS AND REFLECTED LIGHT
FOR IN-1 AND IN-2.

<u>SITE</u>	<u>ACTIVE LAYER</u> <u>THICKNESS (cm)</u>		<u>GREEN</u> <u>LIGHT</u>		<u>RED</u> <u>LIGHT</u>		<u>INFRARED</u> <u>LIGHT</u>	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
IN-1	116	233	93	140	72	204	144	145
IN-2	94	202	62	164	46	207	65	139

source : Appendix II

TABLE 4-14

BIVARIATE ANALYSIS RESULTS WITH THE HIGHEST CORRELATION COEFFICIENTS FOR THE INUVIK STUDY SITES

STUDY SITE	BAND OR BAND COMBINATION	CORRELATION COEFFICIENT	COEFFICIENT OF DETERMINATION
IN-1	Red light	+0.445	0.20
	Ratio of green to red	-0.462	0.21
	Ratio of green to infrared	+0.416	0.17
	Ratio of red to infrared	+0.530	0.28
IN-1 (hillslope)	Ratio of green to infrared	+0.738	0.55
	Ratio of red to infrared	+0.636	0.45
	Green normalized with respect to all three bands	+0.628	0.39
	Infrared normalized with respect to all three bands	-0.686	0.47
IN-1 (river bank areas and lake shore)	Green light	-0.717	0.51
	Ratio of green to infrared	-0.673	0.45
	Ratio of red to infrared	-0.577	0.31
IN-1 (floodplain)	Band ratios summed	+0.637	0.41
IN-2	Infrared light	+0.606	0.37

Source: Appendix IV

TABLE 4-14 continued

<u>STUDY SITE</u>	<u>BAND OR BAND COMBINATION</u>	<u>CORRELATION COEFFICIENT</u>	<u>COEFFICIENT OF DETERMINATION</u>
IN-2	Ratio of green divided by red	0.713	0.51
	Ratio of green to infrared	-0.618	0.38
	Ratio of red to infrared	-0.709	0.50
	Band ratios summed	-0.531	0.28
	Red standardized with respect to all three bands	-0.776	0.60
	Infrared standardized with respect to the other three bands	0.686	0.47

Source : Appendix IV

for In-1 are strongest for the red spectral band with a correlation coefficient of +.445 and a coefficient of determination of .20. The latter value shows that the variance in surface spectral signature statistically explains little of the variance in active layer thickness. This indicates that the study site as a whole, the more sparsely vegetated areas display the thickest active layer. Correlation coefficients of -.462, +.416 and +.530 were found for the ratios of green over red, green over infrared and red over infrared.

When the hill slope with a mixed conifer-deciduous cover was treated separately the green band over infrared band and red over infrared band relationships were strengthened (correlation coefficients and coefficients of determination are +.738, +.636, .55 and .45 respectively) while the green band over red band relationship became weaker. This situation indicates that the location of vegetation with a low infrared reflectance favors the development of a deeper active layer. The normalized band ratios show a positive relationship (correlation coefficient +.628, coefficient of determination .39) for the green spectral band (see the bivariate plot shown in Figure 4-8) and a negative relationship (correlation coefficient -.686 and coefficient of determination .47) for the infrared spectral band (see the bivariate plot in Figure 4-9) indicating that higher infrared reflectance is related to a thin active layer.

The second In-1 subsection (auger holes 1-21 on Figure 3-19) provides correlation coefficients for the green band, green band over the infrared band and the red band over the infrared band of -.717, -.673 and -.577 with respective coefficients of determination of .51, .45 and .31

FIGURE 4-8

ln-1 ACTIVE LAYER THICKNESS VS. $G/(R+G+IR)$ INTENSITY (HILLSLOPE)

FIGURE 4-9

In -1 ACTIVE LAYER THICKNESS VS. IR / (G+R+IR) (HILLSLOPE)

suggesting that for thin vegetation cover in this area, a thick active layer develops. This thick active layer development likely results from frequent flooding (and attendant thermal disturbance) along the channel banks and consequent deposition of thick silts. Thick silts appear dark because of their high moisture content (a result of proximity to the water) and the inability of vegetation to establish itself on the silts due to frequent flooding.

The third In-1 subsection examined on the vegetated east channel flood plain (points 45 through 54 on Figure 3-19) shows that thicker vegetation with a strong infrared reflectance were associated with a deeper active layer although none of the relationships observed are very strong. As an example, the summed band ratios show a correlation coefficient of +.637 and a coefficient of determination of 0.41.

The relationships observed in these cases appears to contradict the few consistent but tenuous results at the Tuktoyaktuk study sites where a high infrared reflectance is associated with the development of a thick active layer. In the case of the In-1 hillslope, (subsection one, auger samples 22 through 34 in Figure 3-19) the larger trees on the southern portion of the slope grow on gravel-rich substrate. The soil beneath the grasses and weeds on the northern half of the slope is gravel-free. It would seem that since the tree covered area does not possess a closed canopy the soil background radiation from unvegetated surface is added to the tree's spectral signature.

A histogram of active layer thickness for In-2 is shown in Figure 4-10 with sampled active layer thickness and spectral signatures

FIGURE 4-10

HISTOGRAM OF ACTIVE LAYER THICKNESS SAMPLE DISTRIBUTION

In- 2

FIGURE 4-11

In -2 ACTIVE LAYER THICKNESS VS. G / R INTENSITY

FIGURE 4-12

In -2 ACTIVE LAYER THICKNESS VS. G / R INTENSITY

CORRELATION COEFFICIENT 0.713

REGRESSION COEFFICIENT 0.087

given in Table 4-13.

In-2 shows a strong relationship between active layer thickness and the infrared spectral band (correlation coefficient $+0.606$ and coefficient of determination $.37$) indicating that thicker vegetation, notably are closed canopy birch forest favour the development of a thick active layer. Strong relationships were also observed for the band ratios (see the bivariate plots in Figures 4-11, 4-12) and the band normalized comparisons. Note the extreme observations in Figure 3-13 at 102 and 158 cm of active layer thickness which inflate the r values.

Results of the 13 investigations for each study site reinforce what was observed in the field and with the t test. The primary factor influencing the thickness of the active layer is the composition of the substrate with gravel and mineral soils favoring a deeper active layer over organic substrate. Gravel also permits the growth of more prodigious foliage than organic soils and accounts for the observed relationships between the infrared reflectance of the ground and active layer thickness.

Frequently flooded areas marginal to water bodies (where the water bodies may not freeze to the bottom in winter) generally display a thick active layer or possibly remain unfrozen as a result of heat flow from the water. Frequent inundation prevents the establishment of vegetation and it is this factor, coupled with the dark tone of the moist surficial deposits, which likely produced the negative relationships in all spectral bands for In-1.

Areas which are frequently inundated by water but freeze to the bottom in winter generally display strong tonal variation due to a scattered vegetation cover and a thin active layer with no strong relationship between active layer thickness and surface spectral signature in any spectral band.

4.4 DISCUSSION OF RESULTS

The quantitative results of the investigations were not consistent between study sites. Although many of the spectral bands and band combinations where "strong relationships" were observed showed similar correlation coefficients, the regression coefficients were different indicating that the rates of change between the dependent and independent variables are different for the study sites.

This situation is not unexpected as the photographs which were used were not radiometrically calibrated against a standard reference. In addition, each image possesses different radiometric properties. Also, the imagery was not acquired synchronously with the active layer thickness samples. A stronger correspondence was found at Inuvik, where the vegetation was more prodigious and coverage of greater continuity than at Tuktoyaktuk. Since there was no "pure" signature for a given vegetation type at Tuktoyaktuk, the sparseness of the vegetation allowed soil background radiation into the signature. Not having a "pure" signature for specific vegetation types prevented the soil background radiation component from being estimated and subtracted from the data. Decreasing the pixel coverage area would not have strengthened the relationships since soil background radiation is added to the spectral signature of the surface through myriads of tiny openings in the vegetation cover. Table 4-15 shows regression coefficients for the study sites which displayed high correlation coefficients for the same dependent variable. The closest regression coefficients are 0.131 and 0.369 for active layer

TABLE 4-15

REGRESSION COEFFICIENTS FOR STUDY SITES WITH HIGH SPECTRAL BAND CORRELATION COEFFICIENTS

ACTIVE LAYER VS.	STUDY SITE	REGRESSION COEFFICIENT	CORRELATION COEFFICIENT
RED	TUK-2	0.131	0.405
	IN-1	0.369	0.445
PANCHROMATIC	TUK-3	1.185	0.677
	IN-1 (floodplain)	7.859	0.637
	IN-2	-160.150	-0.531
GREEN DIVIDED BY INFRARED	IN-1	140.000	0.416
	IN-1(hillslope)	25.6	0.738
	IN-1(river bank)	-39.7	0.673
	IN-2	-114.2	-0.612
	IN-1	-0.104	-0.462
GREEN DIVIDED BY RED	IN-2	0.870	0.713
	IN-1	170.4	0.530
RED DIVIDED BY INFRARED	IN-1(hillslope)	21.3	0.636
	IN-1(river bank)	-27.7	-0.577

TABLE 4-15 continued

<u>ACTIVE LAYER VS.</u>	<u>STUDY SITE</u>	<u>REGRESSION COEFFICIENT</u>	<u>CORRELATION COEFFICIENT</u>
RED DIVIDED BY INFRARED	IN-2	-120.0	-0.709
Infrared standard INFRARED STANDARDIZED AGAINST THE OTHER BANDS	IN-1(hillslope)	-130.9	-0.686
	IN-2	332.9	0.686

Source : Appendix IV

thickness vs. red light at Tuk -2 and In-1. In some of the bivariate analyses the regression coefficients are positive while they are negative for others. This indicates that while two study sites have high correlation coefficients for the same spectral band, the nature of the relationship is quite different.

Obtaining the spectral signature of the ground in the same year as field sampling probably would not have resulted in correlation coefficients higher than those observed. Field observations showed that terrain conditions had not changed in the time between imaging and field work. Obtaining radiometrically calibrated imagery for all the study sites with the same sensor might have provided a better insight into the correspondence between the relationships between associations observed at the different study sites.

Thermal infrared imagery, had it been available, might have provided more information of the thermal properties of the substrate and yielded stronger relationships at Tuktoyaktuk as would low altitude radar, since the signal could detect the top of the permafrost table. In Inuvik, such methods could not produce interesting results since the denser vegetation would certainly alter the thermal signature of the surface materials. Likewise the scatter by vegetation of a radar signal would have prevented the detection of subsurface ice. It seems, therefore, that the utility of surface spectral signature to map the thickness of the active layer is greatest in areas of continuous vegetation distribution.

CHAPTER 5 SUMMARY.

5. SUMMARY

The spectral reflectance of the ground for green, red and infrared wavelengths in a continuous permafrost area have been compared with registered, late summer, active layer thickness samples. Higher correlation coefficients were found for the Inuvik study sites with the longer wavelengths of reflected light favouring a thin active layer. At Tuktoyaktuk, a strong infrared reflectance was associated with a thicker active layer but the relationships observed were much more tenuous than at Inuvik. Student's t test results and field observations at both study sites showed that locations where sand and gravel were found in the substrate developed a thicker active layer than other locations. Substrate composition demonstrated some control over the types of vegetation growing on the surface (and therefore the spectral signature presented to the sensor) but it was at Inuvik where the strongest relationships were found between ground spectral signature and active layer thickness.

It is evident from the results of this study that using spectral signature data to measure the thickness of the active layer is not entirely adequate especially in the tundra environment. In areas of more abundant vegetation such as Inuvik, the methodology shows encouraging promise but more refinement is needed. Some further improvements to the technique could be the use of thermal infrared imagery for tundra sites and the use of multispectral scanner imagery rather than color aerial infrared photographs and a better attempt to quantify and remove the soil background radiation.

The remote sensing techniques which have been used to study permafrost in previous investigations were reviewed in Chapter 1. Studies such as Thie and Tarnocai on Palsas (1974a), Brown on Palsas (1975), Leshack et al on thermal infrared imagery (1973) and Granberg and Nicholson (1973) on snow melt concentrated on detecting permafrost, and on mapping permafrost and massive ice. These studies were reconnaissance-oriented and not positionally exacting in their measurements. In addition, the focus was on permafrost, not active layer thickness, so comparisons of the results of these studies, which essentially try to determine whether permafrost exists or not, with this study, are not possible.

Schreier and Selby (1981) who carried out work similar to this study in the Yukon (see Page 16) found that spectral signature obtained from aerial color infrared photographs was of use in distinguishing between different ground cover types and that for three out of five plant communities there was a statistically significant difference in active layer thickness. That same study found thermal infrared imagery to be of little use for mapping active layer thickness since the plant communities all had thermal signatures within 1°C of one another. This would seem to indicate that color infrared techniques are more appropriate in well vegetated areas. On the other hand, all of the vegetation communities considered were low herbaceous plants, not trees. Mineral surfaces were also not considered. Sabins (1978) and Lillesand and Kiefer (1980) provide several examples of how thermal infrared imagery is of use in classifying mineral surfaces and surfaces which possess markedly different sizes of vegetation but more investigation is

certainly required.

Radar can only distinguish between smooth and rough surfaces where vegetation is present but could still be of use in measuring active layer thickness. Unterberger (1978) found radar signal scatter to be a substantial impediment to mapping accurately the top of the permafrost table.

In previous studies soil background radiation has been quantified and successfully removed from digital imagery but those applications focussed on agricultural areas. Mack (1977) was able to remove soil background signature from Landsat imagery of crop land. In such a study, however, the surface cover is neatly arranged in rows with all plants being of more or less the same size. In the tundra, the plant cover is irregular and soil background radiation is not received from equal-sized plant-free furrows. Measuring soil background radiation in such a situation would be much more difficult and is a study in itself. Yet resolution of the background radiation problem would be a considerable asset toward future endeavors in this field of research.

It has been demonstrated that useful results are obtainable with color aerial infrared photographs. Different surface cover types can (but do not always) indicate different active layer thicknesses and spectral signature can be used to classify different surface vegetation and materials.

Toward future work in this field, the following recommendations may serve as guidelines.

- 1) Quantify the soil background radiation contribution for different cover types. This is a formidable but

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essential operation.

- 2) Use same-day multispectral imagery and acquire the imagery synchronously with ground sampling. This would not only radiometrically standardize the imagery but conclusively remove any small variations in spectral signature and active layer thickness which may occur from year to year.
- 3) Use thermal infrared imagery in conjunction with multispectral imagery for tundra sites. This form of remote sensing requires more consideration in active layer thickness mapping.
- 4) Conduct imaging and sampling not only in late summer but in late spring and in mid-summer to observe what sort of correlations are obtained as the active layer develops.

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APPENDIX I

ACTIVE LAYER THICKNESS SAMPLES FOR THE
STUDY SITES.

APPENDIX I

SAMPLED ACTIVE LAYER THICKNESS

STUDY SITE TUK 1

HOLE	ACTIVE LAYER THICKNESS cm	SURFACE MATERIAL	MOISTURE	VEGETATION
1	43	Organic Matter, Stones and Sand	Moist	Moss and Short Grass
2	66	"	"	"
3	45	"	Dry	"
4	43	"	Moist	"
5	30	Peat	Dry	Peat
6	33	"	"	"
7	35	"	"	"
8	38	"	"	"
9	38	"	"	"
10	35	Organic Matter, and Sand	Moist	Short Grass
11	30	Peat and Silt	Moist	Wet Peat
12	33	"	"	"

TUK 1 CONTINUED

HOLE	ACTIVE LAYER THICKNESS cm	SURFACE MATERIAL	MOISTURE	VEGETATION
13	66	Organic Matter, Sand and Stones	Moist	Low Salix Bushes
14	70	Organic Matter	Saturated	Carex
15	60	Organic Muck	"	None
16	46	Silt and Sand	Dry	Salix Bushes
17	66	Silt and Organic Matter	Saturated	Carex
18	122	Gravel	Dry	Tall Grass
19	122	"	"	"
20	41	Silt and Organic Matter	Moist	Dead Drift Wood Over Unvegetated Soil
21	44	Silt and Sand	Dry	Grass
22	46	Silt and Organic Matter	Saturated	Carex
23	50	Organic Muck	"	None
24	66	Organic Matter and Silt	Moist	Moss and Erica

TUK 1 CONTINUED

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
25	63	Organic Matter and Silt	Moist	Moss and Erica
26	43	"	"	"
27	40	"	"	"
28	38	"	"	"
29	63	Silt and Sand	Dry	Grass
30	83	Silt and Stones	"	"
31	93	"	"	Grass and Salix Shrubs
32	78	"	Moist	Carex
33	66	Silt and Organic Matter	Saturated	None
34	71	"	"	Carex
35	58	Peat	Dry	Moss
36	38	"	"	"
37	31	Silt and Sand	Dry	Grass

TUK 1 CONTINUED

HOLE	ACTIVE LAYER THICKNESS cm	SURFACE MATERIAL	MOISTURE	VEGETATION
38	33	Silt and Sand	Dry	Low Salix Bushes
39	35	Peat and Silt	"	Grass Tussocks
40	38	Silt and Sand	Dry	Scattered Low Salix Bushes
41	33	"	"	"
42	38	"	"	"
43	33	"	"	"
44	35	"	"	Grass
45	27	Dry Peat	"	Moss
46	33	"	"	"
47	27	Silt and Sand	Dry	Grass Tussocks
48	38	"	"	"
49	25	"	"	"
50	36	"	"	Grass
51	38	"	"	Grass and Low Salix Shrubs

TUK 1 CONTINUED

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
52	36	Silt and Sand	Dry	Grass and Low Salix Shrubs
53	30	"	"	"
54	66	"	"	Moss
55	30	Dry Peat	"	"
56	30	Silt and Sand	"	Low Salix Shrubs
57	33	Peat and Sand	"	Moss
58	33	"	"	"
59	33	"	"	"
60	48	Silt and Organic Matter	Saturated	None (Standing Water)
61	47	"	"	Carex
62	41	"	"	"

SAMPLED ACTIVE LAYER THICKNESS
STUDY SITE TUK 2

HOLE	ACTIVE LAYER THICKNESS cm	SURFACE MATERIAL	MOISTURE	VEGETATION
1	55	Silt and Sand	Dry	Grass, Betula Shrubs and Erica
2	49	"	"	"
3	33	Peat	"	MOSS
4	35	Silt and Organic Matter	Saturated	Carex
5	35	"	"	"
6	33	"	"	"
7	55	"	"	"
8	33	Silt and Sand	Dry	Low Salix Shrubs
9	33	"	"	"
10	33	"	"	"
11	33	"	"	"
12	33	"	"	"
13	55	Organic Matter and Silt	Saturated	None

TUK 2 CONTINUED

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
14	55	Organic Matter and Silt	Saturated	None
15	48	"	"	Carex
16	71	Sand and Stones	Dry	Salix and Betula Shrubs
17	65	"	"	"
18	65	Silt and Organic	Saturated	Carex
19	76	"	"	"
20	55	"	"	"
21	38	"	Moist	Erica and Betula Shrubs
22	33	"	"	"
23	33	"	"	"
24	78	Silt and Stones with Sand	Dry	Salix Shrubs
25	96	"	"	"
26	49	"	"	"
27	49	"	"	"

TUK 2 CONTINUED

HOLE	ACTIVE LAYER THICKNESS cm	SURFACE MATERIAL	MOISTURE	VEGETATION
28	38	Silt and Stones with Sand	Dry	Salix Shrubs
29	39	Silt	"	Grass
30	38	Silt and Organic Matter	Very Moist	Carex
31	52	"	"	"
32	33	"	"	"
33	35	Silt	"	"
34	38	Silt and Organic Matter	Moist	Grass
35	38	"	Dry	Moss
36	38	"	Saturated	Carex
37	48	"	"	"
38	97	"	"	"
39	56	Organic Matter	"	Muck
40	99	Silt and Sand	Dry	Dead Salix Bushes
41	56	Silt and Organic Matter	Very Moist	Peat and Moss

TUK 2 CONTINUED

HOLE	ACTIVE LAYER THICKNESS cm	SURFACE MATERIAL	MOISTURE	VEGETATION
42	43	Dry Peat	Dry	Peat and Moss
43	50	Silt and Organic Matter	Moist	Erica
44	48	"	"	"
45	48	"	"	Salix and Betula Bushes
46	48	"	"	"
47	38	"	"	"
48	35	"	"	Carex
49	35	Silt and Peat	Dry	Moss
50	43	"	Saturated	Carex
51	35	"	"	"
52	35	"	"	"
53	35	"	"	"
54	35	"	Dry	Grass
55	43	"	Moist	Erica

TUK 2 CONTINUED

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
56	35	Silt and Organic Matter	Saturated	Carex
57	53	"	Moist	Tall Carex
58	43	Sand and Stones	Dry	Salix and Betula Shrubs
59	44	"	"	"
60	33	"	"	"
61	33	Silt and Organic Matter	Saturated	Carex
62	43	"	"	"
63	33	"	Dry	Grass
64	33	"	"	"
65	35	"	Moist	Grass and Carex
66	35	"	"	"
67	41	"	"	"
68	33	"	"	Erica and Betula Shrubs
69	33	"	"	"
70	33	"	"	"

TUK 2 CONTINUED

HOLE	ACTIVE LAYER THICKNESS cm	SURFACE MATERIAL	MOISTURE	VEGETATION
71	35	Silt, and Organic Matter	Moist	Thick Betula Shrubs
72	35	"	Saturated	Carex
73	56	"	"	"
74	68	"	Moist	Erica
75	33	"	Saturated	Carex
76	43	"	"	"
77	56	"	Dry	Dead Betula Shrubs
78	43	"	Saturated	Carex
79	43	"	Dry	Salix and Betula Shrubs
80	35	"	"	"
81	43	"	"	Grass and Carex
82	43	"	Moist	Carex
83	61	"	"	"
84	61	"	"	Erica
85	61	"	Saturated	Carex

TUK 2 CONTINUED

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
86	84	Silt and Stones	"	"
87	86	"	Dry	Erica
88	85	"	"	Salix Shrubs and Erica
89	76	"	"	"
90	84	"	"	"
91	71	"	"	"
92	71	"	"	"
93	33	"	"	"
94	71	"	"	"
95	71	"	"	"
96	71	"	"	"
97	84	"	"	"
98	33	Silt and Organic Matter	"	Grass

SAMPLED ACTIVE LAYER THICKNESS
STUDY SITE TUK 3

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
1	33	Silt and Organic Matter	Dry	Betula Shrubs and Erica
2	33	"	"	"
3	43	"	"	"
4	241	Silt and Gravel	Very Moist	Salix Bushes
5	83	"	"	"
6	83	Silt and Organic Matter	Moist	Grass and Carex
7	60	"	"	"
8	124	Gravel	Very Moist	Salix Bushes
9	240	"	"	"
10	99	"	"	"
11	94	"	"	"
12	94	Silt and Stones	Moist	Moss and Grass
13	78	"	"	"

TUK 3 CONTINUED

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
14	75	Silt and Stones	Moist	Moss and Grass
15	68	"	"	"
16	43	"	"	Betula Shrubs and Erica
17	38	Silt	"	"
18	35	"	"	"
19	60	"	"	Moss and Carex

SAMPLED ACTIVE LAYER THICKNESS

STUDY SITE IN 1

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
1	170	Silty Clay	Moist	None
2	277	Silt, Sandy Clay	"	"
3	152	"	"	"
4	241	"	"	"
5	125	"	Dry	"
6	167	Silt and Organic Matter	Saturated	Grass
7	277	"	Moist	Salix and Alnus Bushes
8	277	Silt	"	None
9	277	"	"	"
10	122	"	"	Carex
11	79	"	"	Alnus and Salix Bushes
12	86	"	"	"
13	73	"	"	"

IN 1 CONTINUED

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
14	77	Silt	Moist	Alnus and Salix Bushes
15	77	Peat	"	Alnus and Picea
16	77	"	"	"
17	77	"	"	"
18	77	"	"	"
19	96	Organic Matter	Saturated	Salix Shrubs
20	96	"	"	"
21	80	Silt	Moist	Alnus
22	60	Silt and Stones	Dry	"
23	51	"	"	Salix, Lupin, Erica
24	53	"	"	Salix Shrubs
25	55	Silt	"	Lupin, Erica
26	53	"	"	"
27	91	Gravel	Moist	"

IN 1 CONTINUED

HOLE	ACTIVE LAYER THICKNESS cm	SURFACE MATERIAL	MOISTURE	VEGETATION
28	35	Silt and Organic Matter	Moist	Salix, Alnus and Picea
29	38	"	"	"
30	50	"	"	"
31	104	"	"	Carex, Salix
32	122	Organic Matter	"	Carex
33	122	"	Saturated	"
34	277	Silt and Stones	Moist	Weeds, Grass
35	35	"	"	"
36	35	"	"	"
37	100	Silt and Stones	"	Salix and Betula
38	100	"	"	"
39	100	"	"	"
40	122	Silt	"	Salix, Carex
41	100	Silt and Stones	"	Pic, Acer, Betula, Salix

IN 1 CONTINUED

HOLE	ACTIVE LAYER THICKNESS cm	SURFACE MATERIAL	MOISTURE	VEGETATION
42	100	Silt and Stones	Moist	Picea, Acer, Betula, Salix
43	100	"	"	"
44	132	Silt	"	Salix and Carex
45	106	"	"	"
46	129	"	"	"
47	127	"	"	Thick Grass
48	127	"	"	Salix Shrubs
49	152	"	"	"
50	132	"	Saturated	None
51	106	"	Moist	Salix, Grass
52	91	"	"	Salix and Alnus
53	76	"	"	"
54	91	Silt and Clay	Dry	None
55	45	"	Moist	Alnus and Picea
56	45	"	"	"

SAMPLED ACTIVE LAYER THICKNESS

STUDY SITE IN 2

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
1	33	Peat	Dry	Erica, Populus, Picea, Betula, Salix, Alnus
2	37	"	"	"
3	36	"	"	"
4	40	"	"	"
5	38	"	"	"
6	45	"	"	"
7	152	"	"	"
8	152	"	"	"
9	96	"	Moist	Betula
10	75	"	"	"
11	75	"	"	"
12	66	"	"	Picea, Populus, Alnus, Salix
13	67	"	"	"
14	70	"	"	Betula

IN 2 CONTINUED

HOLE	ACTIVE LAYER THICKNESS CM	SURFACE MATERIAL	MOISTURE	VEGETATION
15	65	Peat	Moist	Betula
16	64	"	"	"
17	68	"	"	"
18	63	"	"	"
19	60	"	"	"
20	60	"	"	"

APPENDIX II

SPECTRAL SIGNATURES FOR THE STUDY SITES.

APPENDIX

II

ACTIVE LAYER THICKNESS AND SURFACE SPECTRAL
SIGNATURE AT TUK-1

A.L.T.	G	R	IR
48.000	80.000	76.000	38.000
66.000	60.000	60.000	34.000
45.000	78.000	73.000	30.000
43.000	36.000	41.000	21.000
30.000	44.000	48.000	26.000
33.000	54.000	57.000	28.000
35.000	72.000	73.000	34.000
38.000	63.000	66.000	38.000
38.000	40.000	40.000	31.000
35.000	50.000	55.000	45.000
30.000	74.000	75.000	48.000
33.000	74.000	75.000	48.000
66.000	128.000	105.000	82.000
70.000	85.000	63.000	63.000
60.000	95.000	84.000	34.000
46.000	17.000	23.000	18.000
66.000	66.000	61.000	43.000
122.000	143.000	123.000	54.000
122.000	126.000	83.000	48.000
41.000	193.000	164.000	39.000
44.000	58.000	62.000	46.000
46.000	124.000	108.000	48.000
50.000	0.0	0.0	0.0
66.000	61.000	54.000	45.000
63.000	48.000	51.000	32.000
43.000	33.000	38.000	20.000
40.000	39.000	43.000	22.000
38.000	52.000	55.000	39.000
63.000	67.000	70.000	38.000
83.000	47.000	48.000	55.000
93.000	76.000	72.000	59.000
78.000	127.000	110.000	60.000
66.000	96.000	81.000	23.000
71.000	70.000	63.000	59.000
58.000	61.000	59.000	40.000
38.000	78.000	64.000	36.000

ACTIVE LAYER THICKNESS AND SURFACE SPECTRAL
SIGNATURE AT Tuk-1 (continued)

33.000	64.000	61.000	53.000
31.000	64.000	61.000	53.000
25.000	53.000	46.000	38.000
38.000	77.000	70.000	34.000
33.000	75.000	67.000	33.000
38.000	52.000	53.000	22.000
33.000	39.000	50.000	15.000
35.000	76.000	74.000	29.000
27.000	41.000	45.000	22.000
33.000	57.000	59.000	27.000
27.000	46.000	46.000	38.000
38.000	56.000	54.000	57.000
27.000	63.000	58.000	48.000
31.000	108.000	95.000	43.000
31.000	58.000	55.000	55.000
36.000	103.000	87.000	27.000
30.000	73.000	65.000	17.000
66.000	72.000	74.000	29.000
30.000	72.000	74.000	29.000
30.000	67.000	70.000	28.000
33.000	72.000	75.000	33.000
33.000	81.000	92.000	33.000
33.000	80.000	83.000	17.000
48.000	72.000	77.000	33.000
41.000	52.000	53.000	33.000
41.000	76.000	74.000	29.000
35.000	208.000	176.000	37.000
43.000	255.000	255.000	39.000
41.000	255.000	239.000	33.000
150.000	255.000	255.000	55.000
96.000	255.000	255.000	33.000
38.000	238.000	201.000	33.000
35.000	217.000	172.000	27.000

means

77

68

32

ACTIVE LAYER THICKNESS AND SURFACE SPECTRAL
SPECTRAL SIGNATURE AT TUK-2.

A.L.T.	C	R	IR
55.000	62.000	64.000	61.000
49.000	65.000	67.000	81.000
33.000	88.000	92.000	71.000
35.000	92.000	93.000	68.000
35.000	76.000	74.000	61.000
33.000	90.000	95.000	60.000
55.000	82.000	80.000	56.000
33.000	101.000	101.000	83.000
33.000	91.000	85.000	60.000
33.000	36.000	41.000	62.000
33.000	34.000	68.000	67.000
33.000	57.000	57.000	59.000
55.000	105.000	101.000	92.000
55.000	98.000	111.000	55.000
48.000	70.000	79.000	47.000
71.000	44.000	49.000	40.000
65.000	77.000	79.000	46.000
65.000	82.000	84.000	56.000
76.000	77.000	81.000	44.000
55.000	72.000	74.000	63.000
38.000	69.000	70.000	63.000
33.000	47.000	51.000	68.000
33.000	39.000	45.000	47.000
78.000	56.000	52.000	105.000
96.000	56.000	52.000	105.000
40.000	45.000	59.000	32.000
49.000	45.000	48.000	20.000
38.000	36.000	71.000	78.000
52.000	44.000	53.000	36.000
35.000	44.000	53.000	36.000
52.000	71.000	81.000	42.000
33.000	39.000	45.000	80.000
38.000	39.000	45.000	80.000
38.000	85.000	89.000	54.000
48.000	85.000	89.000	54.000
99.000	42.000	44.000	42.000
56.000	105.000	120.000	62.000
43.000	96.000	110.000	57.000
56.000	72.000	77.000	49.000
48.000	63.000	65.000	82.000
48.000	41.000	43.000	78.000
48.000	81.000	82.000	70.000
38.000	59.000	71.000	47.000
35.000	84.000	95.000	60.000
35.000	52.000	61.000	61.000
43.000	82.000	82.000	33.000
35.000	44.000	41.000	25.000
35.000	31.000	37.000	25.000

ACTIVE LAYER THICKNESS AND SURFACE SPECTRAL
SIGNATURE AT Tuk-2

35.000	45.000	50.000	36.000
35.000	56.000	58.000	59.000
43.000	67.000	63.000	49.000
35.000	109.000	107.000	54.000
53.000	74.000	77.000	70.000
43.000	45.000	48.000	78.000
33.000	73.000	82.000	89.000
33.000	58.000	63.000	74.000
33.000	41.000	54.000	35.000
43.000	41.000	54.000	35.000
33.000	38.000	45.000	58.000
33.000	32.000	40.000	43.000
35.000	71.000	71.000	33.000
35.000	66.000	64.000	34.000
41.000	66.000	78.000	68.000
33.000	45.000	56.000	48.000
33.000	25.000	31.000	42.000
33.000	83.000	83.000	37.000
35.000	15.000	20.000	5.000
35.000	38.000	46.000	50.000
56.000	59.000	66.000	51.000
68.000	47.000	50.000	82.000
33.000	33.000	42.000	21.000
43.000	43.000	54.000	18.000
56.000	62.000	71.000	19.000
43.000	57.000	68.000	46.000
43.000	37.000	49.000	55.000
35.000	30.000	34.000	41.000
43.000	33.000	44.000	23.000
43.000	41.000	53.000	20.000
61.000	81.000	82.000	75.000
61.000	99.000	96.000	79.000
84.000	78.000	75.000	68.000
86.000	40.000	89.000	70.000
84.000	49.000	62.000	51.000
71.000	72.000	74.000	94.000
71.000	66.000	78.000	68.000
33.000	83.000	86.000	95.000
71.000	70.000	78.000	65.000
71.000	76.000	77.000	99.000
71.000	76.000	77.000	99.000
71.000	76.000	77.000	99.000
71.000	76.000	77.000	99.000
71.000	76.000	77.000	99.000
71.000	76.000	77.000	99.000

means

60

67

54

ACTIVE LAYER THICKNESS AND SURFACE
SPECTRAL SIGNATURE AT Tuk-3.

A.L.T.	panchromatic
33.000	128.000
33.000	116.000
43.000	44.000
241.000	141.000
83.000	132.000
83.000	86.000
60.000	95.000
124.000	63.000
240.000	160.000
99.000	119.000
94.000	89.000
95.000	68.000
78.000	88.000
75.000	61.000
68.000	66.000
43.000	48.000
38.000	117.000
35.000	130.000
60.000	130.000

ACTIVE LAYER THICKNESS AND SURFACE SPECTRAL
SIGNATURE AT In-1.

A.L.T.	G	R	IR
170.000	51.000	97.000	22.000
227.000	73.000	208.000	110.000
152.000	40.000	69.000	44.000
241.000	153.000	162.000	149.000
241.000	140.000	130.000	139.000
125.000	152.000	176.000	47.000
167.000	107.000	94.000	49.000
277.000	74.000	76.000	29.000
277.000	37.000	34.000	19.000
277.000	50.000	34.000	19.000
122.000	41.000	15.000	48.000
79.000	34.000	13.000	34.000
86.000	36.000	11.000	68.000
74.000	33.000	11.000	68.000
77.000	25.000	6.000	19.000
77.000	13.000	4.000	29.000
77.000	18.000	4.000	46.000
77.000	20.000	6.000	38.000
96.000	42.000	5.000	18.000
96.000	52.000	20.000	35.000
80.000	32.000	8.000	80.000
60.000	53.000	19.000	14.000
51.000	59.000	27.000	83.000
43.000	91.000	53.000	66.000
55.000	61.000	28.000	83.000
53.000	42.000	20.000	41.000

ACTIVE LAYER THICKNESS AND SURFACE

SPECTRAL SIGNATURE AT In-2

A.L.T.	G	R	IR
35.0	94.000	73.000	89.000
37.0	93.000	69.000	62.000
36.000	80.000	64.000	72.000
40.000	127.000	106.000	127.000
38.000	117.000	96.000	122.000
45.000	80.000	75.000	96.000
152.000	87.000	58.000	166.000
152.000	87.000	58.000	166.000
96.000	98.000	74.000	98.000
75.000	99.000	69.000	146.000
66.000	82.000	59.000	81.000
66.000	103.000	82.000	85.000
67.000	92.000	74.000	130.000
70.000	79.000	62.000	93.000
65.000	90.000	67.000	117.000
64.000	94.000	71.000	148.000
63.000	74.000	61.000	122.000
66.000	95.000	76.000	159.000
75.000	103.000	83.000	96.000
means	93	72	144

ACTIVE LAYER THICKNESS AND SURFACE SPECTRAL
SIGNATURE AT In-1. (continued)

91.000	45.000	20.000	41.000
35.000	41.000	20.000	42.000
38.000	56.000	29.000	110.000
50.000	54.000	18.000	103.000
104.000	33.000	12.000	31.000
122.000	15.000	0.0	33.000
227.000	4.000	0.0	0.0
35.000	101.000	63.000	166.000
35.000	91.000	48.000	229.000
25.000	45.000	33.000	68.000
100.000	63.000	33.000	94.000
100.000	69.000	38.000	97.000
100.000	77.000	43.000	88.000
122.000	18.000	11.000	10.000
100.000	77.000	45.000	132.000
100.000	84.000	50.000	139.000
100.000	81.000	50.000	121.000
132.000	67.000	37.000	115.000
106.000	140.000	155.000	92.000
129.000	136.000	73.000	58.000
152.000	168.000	207.000	51.000
127.000	76.000	44.000	42.000
152.000	56.000	48.000	42.000
132.000	158.000	166.000	103.000
106.000	27.000	7.000	13.000
91.000	19.000	2.000	58.000
76.000	22.000	6.000	30.000
91.000	53.000	18.000	100.000
45.000	58.000	24.000	115.000
45.000	30.000	8.000	28.000

means

62

46

65

APPENDIX III

INVESTIGATIONS EMPLOYED IN STUDY

APPENDIX III

INVESTIGATIONS EMPLOYED IN STUDY

Investigation	Band or Band Combination Compared With Active Layer Thickness	Significance of Band or Band Combination Used	Investigation Utility
1	Green	Surface vegetation reflects strongly in green light wavelengths. Mineral soils have a lower green reflectance than vegetation.	A positive relationship indicates that dense vegetation is correlated with a thick active layer. A negative relationship indicates the opposite.
2	Red	Vegetation reflects little red light. Mineral soils reflect red light in similar intensity to green light.	A positive relationship indicates that sparse vegetation favors a thick active layer.
3	Infrared	Vegetation reflects very strongly in the infrared. Mineral soils reflect	A positive relationship indicates that dense vegetation favors a thick active layer.

Investigation	Band or Band Combination Compared With Active Layer Thickness	Significance of Band or Band Combination Used	Investigation Utility
		weakly in the infrared.	
4	Green and red multiplied together	Minerals soils reflect almost equally in the green and red bands. If vegetation distribution is inversely related to active layer thickness, multiplication of the green and red bands will accentuate the relationship. This facility will be negated if shadow effects are present on the imagery.	A positive relationship indicates that vegetation favors a thick active layer. A negative or weak relationship indicates that vegetation is not related to active layer thickness or that there was significant shadow effects or noise on the imagery used. Image noise effects are accentuated for this investigation.
5	Green multiplied with infrared	Vegetation has a strong reflectance in green and	As above.

Investigation	Band or Band Combination Compared With Active Layer Thickness	Significance of Band or Band Combination Used	Investigation Utility
		infrared light. Topographic shadows may cause problems.	
6	Red multiplied with infrared	As in "4".	As above.
7	Ratio of green to red	Green reflectance of vegetation is much greater than the red reflectance.	Useful combination for observing how vegetation is related to active layer thicknesses. A positive relationship indicates that dense vegetation favors a thick active layer. Shadow effects are eliminated.
8	Ratio of green to infrared	Mineral soils reflect weakly in the infrared vegetation	A positive relationship indicates that dense vegetation

Investigation	Band or Band Combination Compared With Active Layer Thickness	Significance of Band or Band Combination Used	Investigation Utility
		reflects strongly in the infrared.	favors a thick active layer.
9	Ratio red to infrared	Vegetation reflects weakly in red but strongly in infrared.	A negative relationship indicates that dense vegetation favors a thick active layer.
10	Ratios of green to red, green to infrared and red to infrared summed	Simulates a panchromatic image where shadow effects are removed.	A strong positive relationship indicates that thin or sparse vegetation favors a thick active layer.
11	Ratio of green to green, red and infrared summed.	The green band is standardized with respect to the other bands. Shadow effects are removed.	As above.

Investigation	Band or Band Combination Compared With Active Layer Thickness	Significance of Band or Band Combination Used	Investigation Utility
12	As above but with the red band as the numerator.	As above with the red band.	As above.
13	As above with the infrared band as the numerator.	As above with the infrared band.	As above.

APPENDIX IV

INVESTIGATION RESULTS

APPENDIX IV

INVESTIGATION RESULTS

<u>STUDY SITE</u>	<u>SPECTRAL BAND *</u>	<u>REGRESSION COEFFICIENT</u>	<u>INTERCEPT</u>	<u>CORRELATION COEFFICIENT</u>	<u>COEFFICIENT OF DETERMINATION</u>
Tuk-1	1	1.616		0.346	.12
	2	1.508		0.332	.11
	3	0.657		0.405	.16
	1x2	0.015		0.331	.11
	1x3	0.014		0.532	.30
	2x3	0.015		0.532	.28
	1/2	500.0	0.956	0.315	.10
	1/3	148.8	2.242	0.097	.01
	2/3	200.0	2.333	0.074	.01
	1/2 + 1/3 + 2/3	0.013	5.431	0.098	.01
	1	0.080	37.908	0.140	.02
	2	0.091	37.356	0.127	.02
	3	0.498	27.735	0.393	.15
	1/2	20.472	22.537	0.116	.01
Tuk-1 (ad justed) -wet areas-removed	1/3	-2.328	48.832	0.097	.04
	2/3	-3.332	50.698	-0.189	.04
	1/2 + 1/3 + 2/3	-1.357	50.862	-0.162	.03
	1/(1 + 2 + 3)	-50.912	63.849	-0.127	.02
	2/(1 + 2 + 3)	-109.113	86.126	-0.251	.06
	3/(1 + 2 + 3)	49.821	33.059	0.211	.05
	1	0.017	52.997	0.140	.02
	2	0.175	58.978	0.269	.07
	3	0.351	39.778	0.093	.01
	1x2	15.994	3775.404	0.225	.05
	1x3	28.208	2290.133	0.229	.05
	2x3	28.510	2593.474	0.229	.05
	1/2	0.001	0.867	0.128	.02
	1/3	-0.003	1.375	-0.088	.01
Tuk-2	2/3	-0.004	1.554	-0.010	.01
	1/2 + 1/3 + 2/3	-0.006	3.796	-0.083	.01

<u>STUDY SITE</u>	<u>SPECTRAL BAND</u>	<u>REGRESSION COEFFICIENT</u>	<u>INTERCEPT</u>	<u>CORRELATION COEFFICIENT</u>	<u>COEFFICIENT OF DETERMINATION</u>
Tuk-2 (ad justed) -wet areas removed	1	0.089	44.528	0.109	.01
	2	0.131	41.341	0.154	.02
	3	0.269	32.907	0.307	.09
	1/2	9.632	41.372	0.063	.01
	1/3	-4.486	54.592	-0.119	.01
	2/3	-3.601	54.142	-0.114	.01
	1/2 + 2/3 + 1/3	-1.884	55.872	-0.110	.01
	1/(1 + 2 + 3)	-35.889	61.337	-0.093	.01
	2/(1 + 2 + 3)	-36.688	62.714	-0.097	.01
	3/(1 + 2 + 3)	0.000	49.980	-	-
	panchromatic	0.220	80.159	0.388	.16
	panchromatic	1.185	-11.254	0.667	.45
		0.147	45.811	0.237	.06
		0.369	6.036	0.445	.20
In-1 (1st ad justment on hillslope)	2	-0.104	79.992	-0.152	.02
	3	43.991	-154.937	0.358	.13
	1x2	7.998	4203.211	0.093	.01
	1x3	7548.504	-223422.437	0.334	.11
	2x3	140.0	3.472	-0.462	.21
	1/2	190.0	0.575	0.416	.17
	1/3	125.0	-0.090	0.530	.28
	2/3	500.0	3.918	0.084	.01
	1/2 + 1/3 + 2/3				
	1	0.308	22.723	0.248	.06
	2	0.615	-28.464	0.417	.17
	3	-0.180	121.595	-0.212	.04
	1/2	-2.525	118.541	-0.210	.04
	1/3	28.659	75.964	0.738	.55
	2/3	21.394	94.203	0.636	.40
	1/2 + 1/3 + 2/3	3.180	94.718	0.255	.07

<u>STUDY SITE</u>	<u>SPECTRAL BAND</u>	<u>REGRESSION COEFFICIENT</u>	<u>INTERCEPT</u>	<u>CORRELATION COEFFICIENT</u>	<u>COEFFICIENT OF DETERMINATION</u>
In-1					
(1st adjustment continued)	$1/(1 + 2 + 3)$	108.860	94.718	0.255	.07
	$2/(1 + 2 + 3)$	156.400	79.562	0.628	.39
	$3/(1 + 2 + 3)$	-130.984	165.641	-0.686	.47
In-1	1	-0.798	322.501	-0.717	.51
(2nd adjustment on bank areas)	2	-0.392	292.941	-0.458	.21
	3	-0.009	245.745	-0.009	.00
	$1/2$	3.906	241.346	0.034	.01
	$1/3$	-39.700	307.659	-0.673	.45
	$2/3$	-27.735	298.881	-0.557	.31
	$1/2 + 1/3 + 2/3$	-19.571	332.201	-0.661	.44
	$1/(1 + 2 + 3)$	-208.986	315.744	-0.336	.11
	$2/(1 + 2 + 3)$	-48.926	265.001	-0.100	.01
	$3/(1 + 2 + 3)$	295.762	170.273	0.469	.22
In-1	1	-0.122	51.882	-0.307	.09
(3rd adjustment on East Channel floodplain)	2	-0.171	50.701	-0.393	.15
	3	-0.070	50.986	-0.455	.21
	$1/2$	6.669	31.517	0.504	.25
	$1/3$	9.753	36.973	0.361	.33
	$2/3$	0.025	44.601	0.002	.00
	$1/2 + 1/3 + 2/3$	7.897	18.489	0.637	.41
	$1/(1 + 2 + 3)$	51.899	27.341	0.453	.20
	$2/(1 + 2 + 3)$	-5.527	45.727	-0.078	.01
	$3/(1 + 2 + 3)$	-14.133	51.200	-0.201	.04
In-2	1	1.091		-0.212	.04
	2	-0.826		-0.474	.22
	3	1.463		0.606	.37
	1×2	77.338		0.363	.13
	1×3	134.589		0.383	.15
	2×3	100.628		0.176	.03

<u>STUDY SITE</u>	<u>SPECTRAL BAND</u>	<u>REGRESSION COEFFICIENT</u>	<u>INTERCEPT</u>	<u>CORRELATION COEFFICIENT</u>	<u>COEFFICIENT OF DETERMINATION</u>
In-2	1/2	0.087	1.143	0.713	.51
(continued)	1/3	-114.2	1.188	-0.618	.38
	2/3	-120.0	0.978	-0.709	.50
	1/2 + 1/3 + 2/3	-160.0	3.310	-0.531	.28
	1/(1 + 2 + 3)	-244.447	149.304	-0.328	.11
	2/(1 + 2 + 3)	-617.558	234.666	-0.776	.60
	3/(1 + 2 + 3)	332.930	-65.193	0.686	.47

* 1= green, 2= red, 3= infrared

APPENDIX V

CENTRAL TENDENCY STATISTICS FOR ACTIVE LAYER THICKNESS
AND SPECTRAL SIGNATURE DATA.

APPENDIX V

CENTRAL TENDENCY STATISTICS FOR ACTIVE LAYER THICKNESS AND SPECTRALSIGNATURE.

Tuk-1

Salix 17 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	25-93	47-128	48-110	22-82
Mean	52	80	70	47
Standard Deviation	21	23	20	16

Tuk-1

Carex 9 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	27-93	46-127	69-110	23-63
Mean	51	68	62	44
Standard Deviation	25	28	20	13

3 3

OF / DE

Tuk-1

Grass

8 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	30-122	17-143	23-105	17-82
Mean	48	83	70	33
Standard Deviation	28	20	25	13

Tuk-1

Moss and Peat

17 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	30-66	33-81	41-92	17-46
Mean	42	57	60	32
Standard Deviation	11	16	15	9

Tuk-2

Moss and Peat

13 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	33-84	39-83	45-93	51-95
Mean	45	62	67	68
Standard Deviation	16	19	17	11

Tuk-2

Carex

27 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	33-49	33-105	34-120	23-105
Mean	49	61	67	60
Standard Deviation	16	21	20	23

Tuk-2

Salix

20 samples

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	33-89	40-103	63-101 ¹⁵	47-99
Mean	56	68	76	72
Standard Deviation	16	17	19	20

Tuk-3

Salix

6 samples.

<u>Active Layer Thickness</u>		<u>Panchromatic</u>
Range	94-241	63-141
Mean	146	117
Standard Deviation	67	32

Tuk-3

Erica and Betula

6 samples.

Active Layer ThicknessPanchromatic

Range 33-43

44-130

Mean 37

97

Standard
Deviation 4

36

Tuk-3

Moss and Grass

7 samples.

Active Layer ThicknessPanchromatic.

Range 60-124

63-130

Mean 72

80

Standard
Deviation 21

22

In-1

Mixed Forest

7 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	100-132	63-85	37-50	88-139
Mean	118	63	37	95
Standard Deviation	18	11	7	23

In-1

Muck

7 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	132-227	37-153	34-208	19-139
Mean	241	76	101	72
Standard Deviation	52	42	62	53

In-1

Salix and Alnus

15 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	45-132	37-153	4-166	13-103
Mean	74	56	37	54
Standard Deviation	35	57	50	39

In-1

Salix and Grass

17 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	75-241	15-152	0-208	22-229
Mean	79	67	53	77
Standard Deviation	61	27	57	61

In-1

Picae		8 samples.		
<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	80-152	15-132	4-73	16-100
Mean	96	55	23	61
Standard Deviation	30	29	23	32

In-2

Picae		10 samples.		
<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	35-40	80-127	64-106	89-127
Mean	70	91	64	115
Standard Deviation	6	9	9	26

In-2

Mixed Forest

7 samples.

<u>Active Layer Thickness</u>		<u>Green</u>	<u>Red</u>	<u>Infrared</u>
Range	63-96	82-103	61-76	93-148
Mean	70	91	64	115
Standard Deviation	4	18	15	20

Tuk-1

Gravel and Mineral Soil

23 samples

Active Layer Thickness.

Range 33-122

Mean 57

Standard Deviation 27

Tuk-1

Organic Soil

22 samples

Active Layer Thickness

Range 30-66

Mean 40

Standard
Deviation 11

Tuk-2

Gravel and Mineral Soil

35 samples

Active Layer Thickness

Range 33-99

Mean 57

Standard
Deviation 23

Tuk-2

Organic Soil

54 samples

Active Layer Thickness

Range 33-97

Mean 40

Standard
Deviation 11

Tuk-3

Gravel and Mineral Soil

Active Layer Thickness

Range 68-241

Mean 116

Standard
Deviation 85

Tuk-3

Organic Soil
Active Layer Thickness

9 samples

Range 33-60

Mean 42

Standard 15
Deviation

note: Active layer thickness is in centimetres.

Pixel values range from 0 to 256.

APPENDIX VIT TEST RESULTS FOR THE STUDY SITES.

APPENDIX VI

t Test RESULTS FOR THE STUDY SITES

Tuk-1

Cover Types Compared	Variable	T	Significant at the 95% Confidence Level.
Carex-Moss and Peat	A.L.T.	1.2	no
	green	1.1	no
	red	0.2	no
	infrared	2.5	yes
Grass-Moss and Peat	A.L.T.	0.5	no
	green	2.0	no
	red	1.2	no
	infrared	0.8	no
Salix-Carex	A.L.T.	0.01	no
	green	1.1	no
	red	1.8	no
	infrared	0.5	no
Salix-Grass	A.L.T.	0.3	no
	green	0.02	no
	red	0.0	no
	infrared	1.7	no
Salix-Moss and Peat	A.L.T.	1.7	no
	green	3.3	yes
	red	1.6	no
	infrared	3.3	yes

t Test RESULTS FOR THE STUDY SITES

TUK-1

Cover Types Compared	Variable	T	SIGNIFICANT AT THE 95% Confidence Level.
Carex and Grass			
Carex and Grass	A.L.T.	0.2	no
	green	1.0	no
	red	0.3	no
	infrared	1.3	no
Carex and Salix	A.L.T.	1.4	no
	green	1.2	no
	red	1.7	no
	infrared	2.0	yes

TUK-2

Moss-Peat and Carex	A.L.T.	0.7	no
	green	0.2	no
	red	0.0	no
	infrared	1.5	no
Moss-Peat and Salix	A.L.T.	2.4	yes
	green	1.3	no
	red	1.0	no
	infrared	0.8	no

t Test RESULTS FOR THE STUDY SITES

TUK-2

Cover Types Compared	Variable	T	Significant at the 95% Confidence Level.
Carex and Salix	A.L.T.	1.4	no
	green	1.2	no
	red	1.7	no
	infrared	2.0	yes

TUK-3

Salix and Erica-Peat	A.L.T.	4.0	yes
	panchromatic	1.1	no
Salix and Grass	A.L.T.	3.0	yes
	panchromatic	2.4	yes
Erica-Peat and Grass	A.L.T.	4.3	yes
	panchromatic	0.4	no

t Test RESULTS FOR THE STUDY SITES

IN-1

Cover Types Compared	Variable	T	SIGNIFICANT AT THE 95% Confidence Level.
Mixed Forest and Muck	A.L.T.	5.9	yes
	green	1.0	no
	red	3.0	yes
	infrared	1.0	no
Mixed Forest and Salix-Alnus	A.L.T.	4.0	yes
	green	0.4	no
	red	0.0	no
	infrared	2.4	yes
Muck and Salix -Grass	A.L.T.	8.0	yes
	green	1.0	no
	red	2.5	yes
	infrared	0.9	no
Mixed Forest and Salix-Grass	A.L.T.	2.5	yes
	green	0.7	no
	red	1.2	no
	infrared	0.9	no

t Test RESULTS FOR THE STUDY SITES

IN-1

Cover Types Compared	Variable	T	SIGNIFICANT AT THE 95% Confidence Level.
Muck and Salix-Alnus	A.L.T.	8.0	yes
	green	1.0	no
	red	2.5	yes
	infrared	0.9	no
Mixed Forest-Picea	A.L.T.	1.1	no
	green	0.8	no
	red	1.7	no
	infrared	2.4	yes
Muck and Salix-Grass	A.L.T.	10.1	yes
	green	0.5	no
	red	1.8	no
	infrared	0.2	no
Muck-Picea	A.L.T.	12.9	yes
	green	1.3	no
	red	3.1	yes
	infrared	0.5	no

t Test RESULTS FOR THE STUDY SITES

IN-1

Cover Types Compared	Variable	T	SIGNIFICANT AT THE 95% Confidence Level.
Salix-Alnus and Salix-Grass	A.L.T.	0.3	no
	green	0.7	no
	red	0.8	no
	infrared	1.4	no
Salix-Alnus and Picae	A.L.T.	1.5	no
	green	0.1	no
	red	1.0	no
	infrared	0.5	no
Salix-Grass and Picae	A.L.T.	0.9	no
	green	1.0	no
	red	2.0	yes
	infrared	0.9	no

IN-2

Picae-and Mixed Forest	A.L.T.	11.9	yes
	green	1.0	no
	red	2.4	yes
	infrared	1.8	no

t Test RESULTS FOR THE STUDY SITES

Tuk-1

Cover Types Compared	Variable	T	SIGNIFICANT AT THE 95% Confidence Level.
Gravel-Mineral Soil and Organic Soil	A.L.T.	2.6	yes

Tuk -2

Gravel-Mineral Soil and Organic Soil	A.L.T.	4.0	yes
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Tuk-3

Gravel-Mineral Soil and Organic Soil	A.L.T.	2.8	yes
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