
EFFECTS OF SUMMER TRAFFIC ON TUNDRA

Long Term Effects of Summer Traffic By Tracked Vehicles on Tundra

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While the studies and investigations were initiated to provide information necessary for the assessment of pipeline proposals, the knowledge gained is equally useful in planning and assessing highways and other development projects.
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1. SUMMARY

In 1970 tests were carried out with tracked vehicles on test sites at Tuktoyaktuk and Tununuk, N.W.T., and at Shingle Point, Y.T. This was the beginning of a program to determine the immediate and long-term effects of operating tracked vehicles on tundra during the summer.

During the summer of 1972, the test sites were visited to observe the development of new vegetation on the disturbed ground, and measure changes in rut depth and frost depth in the tracks left by the vehicles.

The sites were also photographed from various altitudes in order to assess the possibility of using aerial photography to evaluate disturbance levels and terrain sensitivity to disturbance by vehicle traffic. The results have been related to a vegetation and structure disturbance classification system previously developed by the Muskeg Research Institute.

Also, a measurement program conducted by the Division of Hydrology, University of Saskatchewan was carried out at Tununuk to determine quantities corresponding to components in the energy budget at ground level. Some of these measurements have been related to terrain disturbance levels measurements.

The major conclusions of the study are as follows:

1. The amount of vegetative regrowth on a disturbed site is dependent on the level of disturbance initially inflicted upon the site. Lower levels of disturbance result from low numbers of passes and from use of light weight vehicles.

2. Thermokarst is related to disturbance level but, for all terrain types tested, stabilizes within two years following disturbance so that the new permafrost table beneath the vehicle rut is roughly equal to its original depth below the undisturbed ground surface.

3. Any vehicle traffic in excess of 40 passes should be avoided if ground surface disturbance is to be minimized. In any case, it is recommended that vehicle traffic not be allowed to proceed to the point where ground surface disturbance exceeds level 4 on the vegetation and structure disturbance classification system referred to above.

4. Multi-band aerial photography from altitudes below 1,000 feet enables detection of terrain surface disturbance over large areas, but requires the availability of complex equipment and a trained photo interpreter. Multi-band photography at altitudes of 5,000 to 10,000 feet offers considerable promise in delineating areas of varying disturbance sensitivity.

5. The tundra vegetation and structure disturbance classification system proposed by the Muskeg Research Institute shows promise of being acceptable as a quasi-quantitative measure of tundra disturbance. This has been confirmed by the relationship found between tundra disturbance levels and albedo measurements.

2. INTRODUCTION

2.1 Background

In 1970, the Arctic Land Use Research Program of the Department of Indian Affairs and Northern Development initiated a research program by the Muskeg Research Institute to determine the immediate and long-term effects of tracked vehicle traffic on tundra. The information provided by this study is intended to assist in the development and administration of Land Use Regulation in tundra areas of the Canadian Arctic. Test sites were established at Tuktoyaktuk and Tununuk, N.W.T. and Shingle Point, Y.T. in 1970, using several tracked vehicles in order to determine the effect of vehicle weight and the number of passes. Observations were made on the depth of rut formed and of the extent of destruction of vegetation; the observations were repeated in 1971. In 1972, further observations were carried out in the field to provide more information in order to evaluate the long-term effects of vehicle traffic.

Throughout the program, field logistic support for the work has been provided by members of the Arctic Petroleum Operators Association, notably Imperial Oil Limited, Gulf Oil Canada Limited, and Shell Canada Limited. Their contribution is gratefully acknowledged.

2.2 Objectives

Based on the results of the previous two years' work, objectives of the 1972 program were defined as follows:

1. To assess changes in vegetation, ground surface structure, and ground thermal relationships in relation to the traffic carried out previously, in order to evaluate the long-term effects of tracked vehicle traffic.

2. To define terrain surface disturbance levels on some quantitative basis.

3. To evaluate multi-band aerial photography as a tool for monitoring large tundra areas for disturbance.

3. CURRENT STATE OF KNOWLEDGE

The reports listed in the bibliography section describe work which has already been carried out to determine the immediate impact of tracked vehicle traffic on tundra. Assessment of long-term effects of known amounts of traffic is still lacking, however, and the work described in this report attempts to fill that gap.

4. STUDY AREAS

The test sites have been described in earlier reports in this series (Muskeg Research Institute, 1970, Muskeg Research Institute, 1971). They were selected as representative examples of tundra conditions in the Mackenzie Delta area, and were located near Tununuk on Richards Island, N.W.T., Tuktoyaktuk, N.W.T., and Shingle Point, Y.T. A description of the sites is included in Table 1.

The terrain types represented by the test sites are typical of terrain throughout the Richards Island - Tuktoyaktuk peninsula region north of the treeline.

Test Site	Characteristic Features
Shingle Point 1	Very wet, predominant sedge cover, adjacent to small lake.
Shingle Point 2	An area of depressed centre polygons in a large shallow depression.
Shingle Point 3	A south-facing well-drained hillside with a stream crossing at its base; possibility of erosion after traffic.
Shingle Point 4	An upland, almost level area, moist, with mixed sedge, shrub and moss cover.
Tununuk 1	High, dry, level plateau with moderately abundant woody shrubs.
Tununuk 2	Moist, sedge, and shrub covered depressed centre polygons adjacent to a small lake, merging into a south-facing hillside at one end of the test lanes.
Tununuk 3	Wet to very wet (June), becoming much drier by August, depressed centre polygons, sedge covered adjacent to a thaw lake.
Tununuk 4	Southwest facing shrub covered slope, possible thermokarst by high exposure to sunlight, slope encourages runoff erosion.
Tuktoyaktuk 1	Low-lying, moist depressed centre polygons covered by a mixture of sedges and shrubs.
Tuktoyaktuk 2	South-facing dry, rough slope covered with heavy shrub growth.
Tuktoyaktuk 3	Sedge and shrub covered plateau with good drainage only at edges; otherwise drainage poor and conditions moist to wet.

Table 1 Description of Characteristic Features of Tundra Disturbance Test Sites

5. METHODS AND SOURCES OF DATA

5.1 Field Techniques and Data Analysis

The tests, carried out in the summer of 1970, had consisted of operating a number of vehicles of different weights at the three locations on terrain types typical of those found on the tundra in the Mackenzie Delta area. Up to 100 passes over the same ground were made by each vehicle at each test site and the progress of the reaction of the ground surface to the traffic was observed as traffic proceeded. Since that time there have been certain developments in the vegetation in the tracks and, to a lesser degree, changes in the ground surface structure and permafrost table.

During the visits made to the test sites in the summer of 1972, the sites were photographed, estimates of vegetation disturbance level were made and measurements were taken of rut depths and frost depths. These data were compared with measurements and photographs obtained in 1970 and 1971 and the comparisons were analyzed to determine trends of change in vegetation cover and ground surface structure.

Aerial photographs of the test sites were taken from altitudes of 500 feet, 1,000 feet, 5,000 feet and 10,000 feet using Kodacolour-X, High Speed Ektachrome, and Infrared Ektachrome films. The photographs were examined to determine if known disturbance features of the ground were visible and also to determine whether tundra areas having different disturbance sensitivities could be identified for mapping purposes.

Finally, the Muskeg Research Institute collaborated with the Division of Hydrology, University of Saskatchewan to investigate the quantification of disturbance levels. The University of Saskatchewan group collected data corresponding to terms in the energy budget equation which describes the relationship between incident, reflected, and re-radiated components of energy at the ground surface level. Some of these data were then compared with terrain disturbance level measurements carried out earlier by the Muskeg Research Institute and the relationships between the two sets of measurements were examined. This work is the subject of a separate section of the report prepared by Division of Hydrology, University of Saskatchewan.

The Muskeg Research Institute proposed terrain disturbance classification system is described in Table II.

In using the system, a disturbed site is inspected and two digits are used to classify the disturbance observed. The first digit represents structure disturbance level and the second, separated from the first by a period, represents vegetation disturbance level.

For example, a site classified as 5.4 is one where ruts have started to form, less than 50 per cent of the surface structure has been destroyed (5) and there has been tearing and scattering of vegetation which is less than 10 per cent destroyed (4).

Disturbance Level	Structure	Vegetation
1	Undamaged	Undamaged
2	Slight damage	Shrubs broken, leaves knocked off
3	Mound top scuffing/ flattening	Cutting and/or flattening of all vegetation
4	Mound top destruction	Tearing and scattering of vegetation - 10% destroyed
5	Ruts start to form, less than 50% structure destroyed	25% destroyed
6	Ruts slightly deeper, more than 50% structure destroyed	50% destroyed
7	Ruts half bare	90% destroyed
8	Ruts entirely bare	100% destroyed
9	Ruts to permafrost	

Table II Vegetation and structure disturbance classification system

6. RESULTS

6.1 Observations of Vegetation Development

In order to assess the progress of vegetation regrowth during the two years following the traffic tests, vegetation disturbance level estimates were made in 1972 and compared with those made in 1970 and 1971, for each test lane at each test site. The data are presented in Appendix I.

In using the terrain disturbance classification system to evaluate vegetation regrowth, the digit corresponding to surface structure disturbance level has been omitted. This was done because new or recovered vegetation tends to obscure the terrain surface contours from visual inspection and also careful inspection in the field has revealed little or no apparent change in the ground surface structure, even where thermokarst has evidently taken place. That is to say, if the terrain surface structure was originally disturbed to Level 5 after a two-year period it still appears to be at Level 5.

While the terrain disturbance levels used to determine relative amounts of vegetative recovery are satisfactory for that purpose, they still do not convey a clear picture with respect to the change in appearance of the terrain with time following vehicle traffic. To overcome this, several photographs of changes in vegetation with time are presented in figures 1-11.

It is apparent from the data that most of the vegetation recovery occurred between the summer of 1970 and the summer of 1971 and appeared to proceed at a slower rate between the summer of 1971 and the summer of 1972. Furthermore, vegetation in tracks made by light vehicles has recovered more successfully than in tracks made by heavy vehicles for the same number of passes. This indicates that the rate of vegetative recovery decreases as the initial level of disturbance increases.

It should be noted that following the tests in 1970, disturbance level 4 for vegetation was recommended as the maximum acceptable. Following the two year period which has elapsed, it appears that there has been vegetative recovery amounting to one or two levels in areas disturbed up to level 4. For areas disturbed to a level greater than 4 there appears to be no significant vegetative recovery, thus confirming the validity of the original recommendation.

It may also be concluded from the results that, once more than 40 passes have been run, the extent of disturbance to the terrain is more dependent on vehicle weight than for traffic amounting to less than 40 passes. That is, for more than 40 passes terrain is more sensitive to traffic by heavy vehicles than by light vehicles.

The site of the stream crossing test at Shingle Point has apparently experienced little or no vegetative recovery and there is a slight amount of run-off erosion which occurred mainly between 1971 and 1972.

6.2 Albedo Variations Resulting from Vehicular* Traffic on Tundra

6.2.1 Introduction:

With increasing oil and gas exploration and subsequent interest generated by this activity in Canada's Arctic, the movement of machines and goods and the damage which they may cause becomes increasingly important. Of particular interest is the disturbance to the thermal regime caused by traffic during the summer months. In general, travel with any type of vehicle on the undisturbed tundra will result in some level of disturbance of the surface vegetal regime and possibly affect the thermal behaviour of the active layer because the insulating properties are disturbed, thereby increasing the melt rate of the permafrost.

This section of the report examines the effects of vehicle disturbance on the albedo term of the natural radiation balance equation of the tundra regime, and on disturbance levels as defined in the vegetation and structure disturbance classification system proposed by the Muskeg Research Institute.

Albedo is defined as the ratio of the amount of solar radiation (short wave) reflected by a surface to the amount of incident radiation (usually expressed as a per cent). That is:-

$$R = \frac{R_R}{R_{SI}} \times 100$$

A = Albedo (%)

R_R = Reflected radiation x (ly/min)

R_{SI} = Incoming radiation x (ly/min)

ly = langleys = calories per square centimetre,

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Albedo may therefore be expected to change according to different levels of disturbance to the ground surface with different vehicles. The change in albedo between undisturbed and disturbed tundra, will depend upon the type of vehicle used and the number of passes it makes over a given terrain type.

Measurements of the albedos were taken at the vehicle test sites described in section 4.

6.2.2. Method

Measurements of surface albedo were made by means of inverted and upward facing Kipp pyranometers mounted on a portable stand over the vehicle tracks. Also, for the measurement of albedo on narrow tracks, the inverted Kipp pyranometer was replaced by a beam system, developed by the Division of Hydrology. In each case, the data were recorded on a two-channel 7100 B strip chart recorder.

The relationship between readings obtained with the inverted Kipp pyranometer and the beam system was determined by comparing measurements obtained from the downward-facing pyranometer with the beam value when both were inverted simultaneously over undisturbed tundra.

The measurements were taken with the inverted Kipp pyranometer mounted three feet above the ground surface and scanning a full 2π field of view. The beam system was also located approximately three feet above the ground, scanning an area of approximately three square feet; in order to increase the field of view of the system, the beam was moved along the tracks. Readings were taken at each successive location along the tracks and an average value was calculated.

Date	Location	Disturbance Classification	Mean	Standard Deviation	Range	McFadden & Ragotzi 1967, Albedo Finding
July 30/72	Site #1	1 - 1	19.6			18.5 - 19.9
	Tununuk, N.W.T.	5.4-6.5	17.9	0.36	17.6-18.1	
Aug.13-19/72	Site #2	1 - 1	18.9	0.15	18.8-19.0	
	Tununuk, N.W.T.	5.4-6.5	22.3	0.02	22.3-22.4	
		6.6	16.4	1.18	15.2-18.2	
		6.6	14.0	0.96	12.6-14.8	
		6.6-8.8	10.7	0.75	9.6-11.6	
		8.8-9.8	1.6	-	-	
Aug 25-31/72	Site #1	1 - 1	15.8	0.79	15.2-16.4	
	Tununuk, N.W.T.	5.4-6.5	-	-	-	
		6.6	16.4	-	-	
		6.6	14.1	0.34	13.8-14.5	
		6.6-8.8	10.0	2.20	6.7-11.8	
		8.8-9.8	1.1	-	-	

Table III. Albedo Means, Standard Deviations & Ranges in Per Cent for Various Vehicle Trials Plus Ranges for Tundra Disturbance Classification System

Disturbance Classification Ranges	Description
1 - 1	Undisturbed tundra (natural state)
5.4 - 6.5	Light brown, crushed, dead vegetation with complete cover (vegetation dry)
6.6	Dark brown, crushed, dead vegetation with complete cover (vegetation wet)
6.6 - 8.8	Dark brown, wet, exposed earth with incomplete vegetation cover
8.8 - 9.8	Water lying in bare exposed tracks

Table IV. Tundra Disturbance Classification System Ranges and Description for each Range of Albedo

6.2.3 Results and Observations

The results of the albedo disturbance level studies are presented in Figs. 12 - 20 and in Table III. The average values are plotted in Figure 21.

Preliminary examination of the data indicates that when vehicles are operated on the tundra to the extent that they do not tear up the ground surface but rather result in crushing of the surface vegetation, the albedo of the disturbed surfaces initially may increase by as much as 3.4% over that of a natural undisturbed tundra surface. This effect is attributed to the change in surface colour of the disturbed regime - from brownish to yellow - as a consequence of the destruction of the cover. The figure is based on observations over surfaces which were initially dry.

On the other hand, if sufficient passes are made by similar vehicles - even under "dry ground" conditions - to the extent that the surface degenerates to dark brown in colour, the albedo may decrease by up to 2.5%.

As the initial moisture content of the surface increases there is a corresponding decrease in albedo. For example, under "wet" conditions and an initial dark-brown vegetal surface, decreases in albedo of up to 4.9% were observed. The results suggest that changes in surface albedo may not be solely a function of the degree of disturbance to the vegetative cover but also depends to a large extent on the initial soil moisture content. This result is not entirely unpredictable as the albedos of dead vegetal matter are greater than that of a water-soil interface.

Similarly, the data provide rather conclusive evidence that for higher levels of disturbance, there is a corresponding decrease in albedo. For example, using the figures obtained on August 13, 1972, the albedo for a relatively undisturbed surface (Muskeg Research Institute disturbance level 1.1) was 19% compared to that for a very disturbed surface containing a large amount of water (Muskeg Research Institute disturbance level 9.8) for which the albedo was only 1.6%

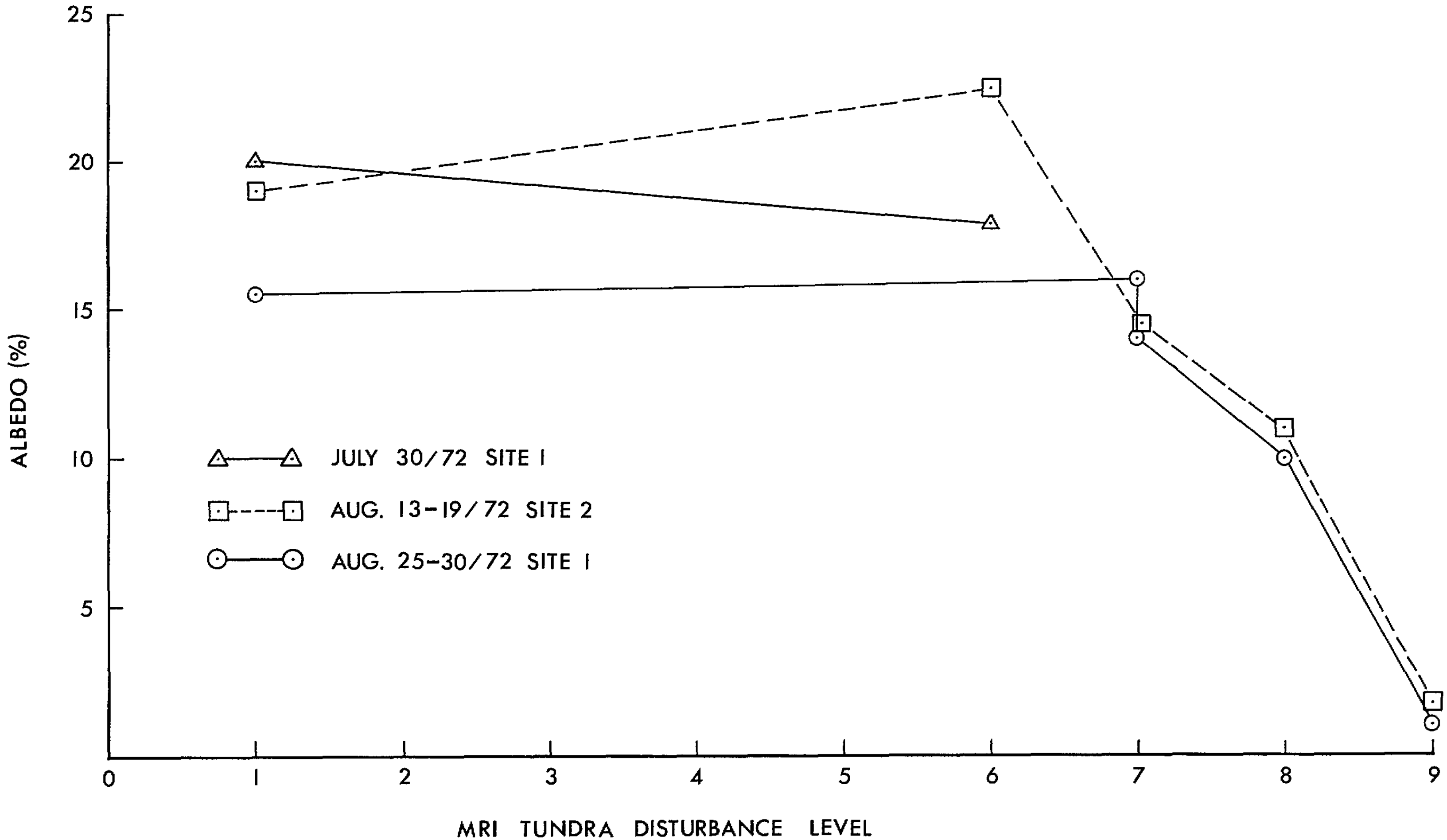

Fig. 21. Relationship Between Albedo and MRI Disturbance Classes

6.3 Use of Aerial Photography for Terrain Studies

6.3.1 Detection of Terrain Disturbance from Aerial Photographs

The use of low altitude (500 feet and 1,000 feet) aerial photography for ground disturbance investigation was discussed in an earlier report (Muskeg Research Institute, 1971). The results from that work showed that low altitude photography could be used to define quite accurately the levels of disturbance along a vehicle track and also for assessing recovery of vegetation. Ektachrome colour infrared film proved to be especially suitable for these purposes and slightly superior to other film types utilized. The best results were obtained by utilizing colour infrared film together with Ektachrome colour film.

During the summer of 1972, aerial photographs were taken from altitudes of 5,000 feet and 10,000 feet with 35 mm hand-held cameras through a hatch in the bottom of a light aircraft. The purpose of this exercise was to try to assess the scale factor in disturbance studies. For this purpose Kodacolour and Ektachrome colour infrared film were used.

Figures 22 and 23 are stereo pairs of Site 2 and Sites 3 and 4, respectively, at Tununuk taken from an altitude of 5,000 feet with a camera with a two inch lens. The scale of the print shown is 1:8,500 (approximately) and corresponds to the scale obtainable by conventional 6 inch lenses and 9 inch picture size from an altitude of 4,250 feet.

This scale appears to be suitable for rough estimates of disturbance level along the track. For instance, in Figure 22 at a, the ground disturbance is of level 4, while in area b it is higher than 4. Regrowth of vegetation is visible in area c of Figure 22. In Figure 23, area a represents a site where the original disturbance was of level 4 or less, and at b, even small areas about two or three feet in diameter with slight (level 2 to 3) disturbance are visible. Also the regrowth of vegetation in low disturbance areas is visible in some parts of the photographs at this scale (eg. at c in Figure 23).

These pictures also show clearly how the degree of disturbance is related to the original water regime of the test site. Thus in Figure 22, the vegetation disturbance did not exceed level 7 after 100 passes due to relatively low water regime. In Figure 23, however, in wet areas, total destruction of terrain structure and vegetation resulted from less than 10 passes. Also, it is evident that the totally disrupted areas even after three growing seasons have not shown any recovery. (e.g. at d in Figure 23)

In some cases, slight disturbance (level 2) of vegetation by one vehicle pass may be almost totally invisible to an observer on the ground but is clearly observable from the air (e.g. at e in Figure 23). Actually, the vehicle pass was made two years before the photograph was taken and there was no resultant disturbance to the soil. Thus, it appears that aerial photography is a very sensitive tool for detecting terrain disturbance. In these cases the photo scale is 1:8,000 to 1:10,000 which therefore appears to be useful for observing vegetational disturbance. The areas concerned in this case are mostly relatively well drained and dry and the vegetation is composed predominantly of shrubs. The damage to the shrubs consists of breaking of branches and scuffing of stems.

6.3.2 Assessment of Terrain Disturbance and Terrain Sensitivity from Aerial Photographs

As indicated earlier in the report, low altitude (500 feet to 1,000 feet) photography is suitable for investigating localized terrain disturbance. However, in order to investigate larger areas, photography at a smaller scale is desirable. Furthermore, for assessment of an area and for mapping purposes, keeping in mind activities such as pipeline construction or off-road traffic on tundra, the scale range of 1:8,500 to 1:20,000 appears to be most suitable.

Figures 24 and 25 are examples of tundra near Tuktoyaktuk on colour infrared and ordinary colour films. The approximate scale of these pictures is 1:8,500. The areas with high water regime and either depressed centre polygons (a) or channel type polygons (b) show the greatest disturbance to vegetation and terrain structure. Areas with lower water regime characterized by channel-type ice wedge polygons (c) are less disturbed. The least disturbed areas are composed of well-drained slopes and sometimes also of fairly flat areas with relatively good drainage. These areas generally have strong shrubby vegetation (d).

Consequently, the sensitivity of terrain to disturbance by vehicular traffic can be identified from aerial photographs. Ordinary coloured film is quite suitable for this purpose, but in most cases colour infrared imagery is superior to other types utilized due to its special characteristics. Wet areas have high absorption of energy at the infrared end of the spectrum and appear in dark tones on the photographs. Thus areas with high water regimes (Figure 25 a) and consequently high sensitivity to disturbance are relatively easily definable on infrared images. With decreasing moisture content and consequently lower sensitivity to disturbance the dark colour turns to blue and finally to yellowish orange depending on vegetation (areas e and f in Figure 25).

Areas of least sensitivity appear red due to low moisture regime; they appear both as large areas (d) and small localized spots (g) within the generally high sensitivity surroundings. Certain of these features are also visible on regular colour photographs but distinctions between them are ambiguous and interpretation is difficult.

6.4 Effects of Vehicle Traffic on the Active Layer

Since the tracked vehicle tests were conducted in 1970, measurements of rut depth and vertical distance to permafrost in and away from the tracks have been made. This has provided data for analysis of the rut history to determine:

(a) whether the ruts have become deeper during the two year observation period;

(b) whether any significant changes in the permafrost level have occurred in the immediate vicinity of the tracks relative to the rest of the test site.

In addition to these measurements, general observations of the occurrence of thermokarst conditions were made. A summary of the results is given in Appendix II. In order to assess rut history with reference to site conditions as well as to vehicle weight, sites with similar characteristic features have been grouped in this summary. Data from 100 pass sections of test lanes were used. These data are felt to be indicative of the effects of a maximum amount of disturbance.

Several general observations can be made concerning the rut history data. Although an increase in vehicle weight produced deeper ruts on a given site, there appeared to be no consistent pattern of change in rut depth over the period of measurement which could be related either to the initial rut depth or to the weight of the vehicle which formed the ruts. Measured changes in rut depth varied from -5 inches to +5 inches and it should be noted that measurements of surface elevation varied to at least this extent and therefore tended to obscure any evidence of measurable rut subsidence occuring with the passage of time.

Similarly, measurement of frost depth under the ruts showed variations which were comparable to those measured in adjacent undisturbed locations and it therefore appears that there is little evidence for recession of the permafrost table on the disturbed sites.

7. DISCUSSION

7.1 Vegetation Recovery

The changes in vegetation and appearance of the ground surface in the vehicle tracks at the test sites have been described on a quasi-quantitative basis. However, the objective was to assess the immediate and long-term effects of tracked vehicle traffic, implying that some judgement should be made concerning how much terrain surface and vegetation disturbance constitutes damage. But it is difficult to suggest criteria for damage which are not subjective or arbitrary. It can be said that so far there is no evidence to suggest that any amount of traffic along a single path results in instability of an ecosystem over a wide area. That is, it appears that damage or disturbance is confined within the tracks and does not result in erosion or thermokarst of a magnitude comparable to some natural instances of these phenomena.

It is evident that lighter vehicles cause less damage than heavy vehicles and that a low number of passes results in less disturbance than a high number of passes for any given vehicle. A single pass with a vehicle can in some cases leave a track on the ground surface which will endure at least for several years. This is not to say, however, that vegetation has been damaged, because healthy vegetation covers the entire track surface. Also, while thermokarst can occur beneath the track where only a single pass has been run, it usually amounts to only one or two inches of subsidence of the permafrost table.

At the other end of the disturbance scale, deep and prominent ruts are formed in the ground surface and all vegetation is removed at the time of traffic and the ground surface remains unvegetated thereafter, at least for several years. Thermokarst amounting to several inches ensues if the original ground surface level is used as a reference. However, it is apparent that a stable active layer develops beneath the ruts such that its depth is comparable to the depth of the original active layer.

On the basis of our general observations in the Mackenzie Delta region only in a few isolated instances has this level of disturbance resulted in an unstable thermokarst condition in which subsidence and melt continues over a number of years. This has led to slumping of hillsides, exposure of ice lenses, and heavy localized runoff erosion. It must be emphasized that this type of occurrence is very rare and is likely to be non-existent in the presence of land-use regulations which control summer traffic so as to minimize ground surface disturbance. It should also be noted that this type of instability has not occurred in any of the test sites.

As a result of this and other research programs, as well as general observation in tundra areas, there is no evidence to support the hypothesis that terrain surface disturbance by tracked vehicles operated in accordance with present common practice has resulted in damage to ecosystems on a broad scale. It is still possible, however, that ecosystem collapse could result from a much higher level of vehicle activity than is presently occurring. It is clear that a range of disturbances can disfigure the landscape to varying degrees and understandable that this can be offensive from an aesthetic point of view to many people. For these reasons unnecessary ground surface disturbance by tracked vehicles in tundra areas or indeed any form of disturbance of the landscape should be avoided.

7.2 Relation of Albedo Measurements to Terrain Disturbance Level*

The results presented in section 6.2.3 must be considered as preliminary and incomplete although they do suggest some important suppositions:

1. For low levels of disturbance, i.e., less than level 6 on the Muskeg Research Institute proposed classification system, albedo measurements may not be useful in quantifying the absolute level of disturbance. This is probably due in part to seasonal differences in vegetation and consequent effects of vegetative cover and to specular problems associated with the measurement sensors.

2. For levels of disturbance greater than 6 on the Muskeg Research Institute proposed classification system, there is a direct (nearly linear) decrease in albedo with increasing disturbance level. Consistent with this result is the fact that at these high levels of disturbance activity, traffic destroyed from 50 per cent to 100 per cent of the vegetation exposing bare ruts and water. The albedo of these disturbed sites did not improve significantly during the year and hence there was much less variation in the measured values of albedo.

Although there is apparently a close relationship between albedo and the land disturbance classification system it must be recognized that this tentative conclusion is based on a preliminary treatment of the overall energy budget. Also, albedo is strongly influenced by many factors and the variations in albedo cannot at this time be interpreted directly in terms of the net transfer flux to the soil. Therefore, the use of ground flux values in development of a quantitative classification system to assess the level of damage will not be possible until the other components of the energy budget equation can be determined. Recognizing that albedo may or may not be the most important term to consider in quantifying a classification system, it will be necessary to evaluate its contribution to the radiation exchange by means of a complete energy budget approach. In other words, the predominant component related to disturbance cannot be properly identified and evaluated, without solution of the partitioning of the energy budget equation into its different components.

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7.3 Use of Aerial Photographs in Assessment of Terrain Disturbance and Terrain Sensitivity

As indicated earlier, aerial photography at altitudes of 500 feet to 1,000 feet is a viable method of assessing terrain and vegetation disturbance by off-road vehicles, and also of assessing vegetation recovery in disturbed sites. However, for any large operation, aerial photography from this low altitude would not be attractive for economic reasons.

The results obtained in this study have shown that photography at altitudes of 4,000 feet to 5,000 feet provides information accurate enough for assessing disturbance levels along tracks with sufficient resolution to determine whether the disturbance is slight (1 - 3), at the suggested line between acceptable and unacceptable level (4) or high (5 - 9). The scale of the photographs for this purpose should not be smaller than 1:8,000 to 1:10,000. Photographs of smaller scale (approximately 1:20,000) and taken from an altitude of about 10,000 feet have proven to be suitable for terrain sensitivity assessment. However, their scale is too small to allow for assessment of disturbance levels along the tracks in detail, at least by visual observation.

Additional work will be necessary to fully evaluate aerial photography as a means of assessing terrain disturbance and terrain sensitivity, including:

1. Procurement of aerial photography at various altitudes by conventional refined aerial survey on 9 inch film format and using controlled processing of both colour and colour infrared films, in order to eliminate variations in processing quality;

2. Microdensitometer studies along the tracks to determine quantitative correlations between density readings and disturbance levels and between density readings and disturbance sensitivty characteristics of the terrain;

3. Determination of correlation between density values of airphoto images and energy budget measurements taken at ground level;

These steps should provide the information necessary to develop a comprehensive disturbance analysis system based on data from aerial and ground level measurement programs.

7.4. Relation of Rut Depth and Depth to Permafrost to Terrain Disturbance

The results indicate that changes in rut depth and frost depth values have been influenced more by variations due to local differences in ground elevation than by any other variable.

In the case of both rut depth and frost depth measurements, negative numbers appear in some instances. For rut depth, this would correspond to a decrease in the depth of the rut. No visible evidence existed to show that material had filled up any of the ruts or that the ground surface adjacent to the ruts had sagged and the negative numbers are attributed to the effect on the measurements of ground surface irregularities. (It was not possible to mark permanently the exact measurement locations in each section of each test lane for future reference. It should be noted that the values quoted in this report are the average of six field measurements.)

In evaluating these results it must be remembered that the active layer freezes completely every winter. Therefore, unless local thermokarst results in runoff erosion during a single summer, the same set of ground conditions is exposed to heating each year. This would seem to be a stable situation so that even heavy traffic along a single path causing removal of soil to permafrost is not likely to result in instability of the ground surface over a long period of time.

This might not be the case however for ground suffering from heavy disturbance over a large area, or on terrain further south where more heat energy is available and rainfall is higher during the summer.

Over an area larger than a single pair of vehicle tracks, surface disturbance could conceivably overcome the stabilizing effect of undisturbed ground adjacent to the disturbance and the heat sink formed by massive permafrost beneath the tracks. The results of this program however are not suitable for evaluating this possibility.

The main conclusion which can be drawn from our results is that subsidence of the frost table beneath a rut does not exceed the original depth beneath the undisturbed surface within the limits of accuracy possible in the measurements taken.

8. CONCLUSIONS

1. There is a relationship between tracked vehicle traffic and vegetation recovery such that initial disturbance exceeding level 4 (on the Muskeg Research Institute proposed classification system) severely inhibits vegetative recovery. Initial disturbance less than level 4 allows for almost complete vegetation recovery within two years following traffic.

2. Any vehicle traffic in excess of 40 passes should be avoided if ground surface disturbance is to be minimized. In any case, it is recommended that vehicle traffic not be allowed to proceed to the point where ground surface disturbance exceeds level 4.

3. The tundra disturbance classification system suggested by the Muskeg Research Institute shows promise of being useful as a quasi-quantitative measure of tundra disturbance. This view is reinforced by the relationship found between tundra disturbance levels and albedo measurements.

4. Multi-band aerial photography from altitudes below 1,000 feet enables detection of terrain surface disturbance over a wide area, but requires the availability of complex equipment and a trained photo interpreter. Multi-band photography from altitudes of 5,000 feet to 10,000 feet offers considerable promise in delineating areas of varying disturbance sensitivity.

5. Thermokarst is also related to disturbance level, but, for all terrain types tested, stabilizes within two years following disturbance so that the new permafrost table beneath the vehicle rut is roughly equal to its original depth below the undisturbed ground surface.

9. RECOMMENDATIONS

1. The test sites at Tununuk, Tuktoyaktuk and Shingle Point should continue to be monitored at two-year intervals to confirm long-term trends in vegetation development and thermokarst.

2. The development of high altitude multi-band photography as an aid to terrain sensitivity mapping should be investigated.

3. Attempts to determine quantities corresponding to components in the energy budget equation over disturbed and undisturbed ground areas should be continued.

4. Attempts to correlate the information obtained as a result of recommendation number 3., with other expressions of terrain surface disturbance level should be continued.

5. In order to extend application of results of the type presented here over a wider geographic area similar research projects should be established in other locations. The results obtained should be related to presently available mapped terrain sensitivity in order to improve the effectiveness of analysis of the probable impact on landscape of vehicle activities related to exploration and development projects.

6. In carrying out land use activities, operators should have the freedom to select from the spectrum of common practice those procedures and techniques which result in a minimum of environmental disturbance. Once the procedures and equipment used in a vehicle operation are specified, present knowledge of terrain conditions and seasonal effects makes it possible to predict the impact of the operation on the ground surface.

7. Operators should also be encouraged to develop new techniques to further reduce environmental disturbance levels. They should not be restricted to an inflexible set of operating specifications but allowed to design their operations to conform to minimum disturbance levels which are known to be within reach.

8. In order to achieve effective utilization of the results of this and other related research programs, all parties having an interest in the controversy over terrain disturbance should be encouraged to propose criteria of permissible levels of terrain disturbance.

9. The results expressed in this report would be rendered more relevant if some analysis were made of the types of summer operations desired by petroleum operators and if all interested parties were encouraged to agree upon a maximum acceptable level of terrain disturbance.

10. NEEDS FOR FURTHER STUDY

10.1 Knowledge Deficiencies

Although quantitative information about impact of tracked vehicle traffic on tundra is now available, its application to actual operations needs to be established and documented. The results produced here and in similar work will be of limited value until they are applied.

There is also no proven way as yet to extend prediction of terrain impact over large areas by means of mapping procedures.

10.2 Programs to alleviate the deficiencies described in 10.1 need to be designed and applied.

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APPENDIX I

Vegetation Regrowth as Represented by Vegetation Disturbance Level Changes from 1970 to 1972

TEST SITE: Shingle Pt. 1 LANE NO. 1 VEHICLE: Bombardier

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	7.6	6	6	Ruts underwater in 1971 and 1972
5	7.7		6	
10	8.7		7	
20	8.8		8	
40	8.8		8	
60	8.8		8	
80	8.8		8	
100	8.8	8	8	

TEST SITE: Shingle Pt. 2 LANE NO. 1 VEHICLE: Bombardier

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	2.1		1	
5	2.2		1	
10	2.3		1	
20	6.5		4	
40	7.7		5	
60	8.7		6	
80	8.7			Open water in tracks
100	8.8			

TEST SITE: Shingle Pt. 3 LANE NO. 1 VEHICLE: Bombardier

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	2.5	3.4	5	Site of stream crossing test, low traffic end at top of hill, vegetation sparse, apparently suffered from slight amount of traffic
5	2.5		6	
10	3.6		6	
20	4.7		6	
40	7.7		7	
60	8.7		8	
80	8.8		8	
100	8.8	8.8	8	

TEST SITE: Shingle Pt. 4 LANE NO. 1 VEHICLE: Bombardier

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	2.3	1	1	High traffic end of tracks submerged in 1972
5	3.3	4	5	
10	4.3		6	
20	5.4			
40	6.5			
60	7.7			
80	8.7			
100	8.8	8		

TEST SITE: Shingle Pt. 4 LANE NO. 2 VEHICLE: CAT D7

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1		8		In 1972, tracks under water
5				
10				
20				
40				
60				
80				
100		8		

TEST SITE: Tuk 1 LANE NO. 1 VEHICLE: RN 110

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	4.2		1	
5	5.3		1	
10	5.3		2	
20	6.5		6	
40	7.6		6	
60	8.7		7	
80	8.8		7	
100	8.8	8.8	8	

TEST SITE: Tuk 1 LANE NO. 3 VEHICLE: Bombardier

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	1.1		2	
5	4.2		2	
10	5.3		2	
20	6.4		2	
40	6.5		6	
60	7.7		6	
80	7.7		6	
100	8.7		6	

TEST SITE: Tuk 1 LANE NO. 4 VEHICLE: Foremost 30T

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	5.3		2	
5	6.6		6	
10	7.7		7	
20	8.8		8	
40	9.8	8	8	
60				
80				
100				

TEST SITE: Tuk 1 LANE NO. 4 VEHICLE: RN 110 (Sept.)

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	1.1		2	
5	2.2		2	
10	3.3		2	
20	5.5		4	
40	6.6		5	
60	6.6		6	
80	7.7		7	
100	8.8	8	8	

TEST SITE: Tuk 2 LANE NO. 2 VEHICLE: RN 110

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	1.1		2	
5	2.2		4	
10	3.3		4	
20	4.5		5	
40	4.6		6	
60	6.6		6	
80	7.7		6	
100	7.7	6	7	

TEST SITE: Tuk 2 LANE NO. 3 VEHICLE: Bombardier

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	1.1		1	
5	2.2		1	
10	3.3		2	
20	4.3		3	
40	5.4		4	
60	5.5		6	
80	6.7		6	
100	6.7		6	

TEST SITE: Tuk 2 LANE NO. 5 VEHICLE: Foremost 30T

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	2.2		2	
5	4.4		2	
10	6.6		5	
20	7.7		8	
40	9.8		8	
60	9.8		8	
80				
100				

TEST SITE: Tuk 2 LANE NO. 6 VEHICLE: RN 110 (Sept.)

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	1.1		1	
5	2.2		3	
10	3.3		5	
20	5.4		6	
40	5.5		6	
60	6.6		7	
80	7.7		7	
100	8.8		8	

TEST SITE: Tuk 3 LANE NO. 1 VEHICLE: RN 110

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	1.1		1	
5	3.2		1	
10	4.2		2	
20	5.3		2	
40	6.4		5	
60	7.5		7	
80	8.6		8	
100	8.7	7	8	

TEST SITE: Tuk 3 LANE NO. 4 VEHICLE: Foremost 30T

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1			2	
5			4	
10			5	
20	9.8		7	
40	9.8		8	
60				
80				
100				

TEST SITE: Tun 2

VEHICLE	Disturbance Level			Remarks
	1970	1971	1972	
Foremost	9.8	7	7	Both lanes have 100 passes
Bombardier	8.7	6	6	

TEST SITE: Tun 3

VEHICLE	Disturbance Level			Remarks
	1970	1971	1972	
Bombardier	8.6		6	Both lanes have 100 passes
Foremost	9.8		8	

TEST SITE: Tun 4

VEHICLE	Disturbance Level			Remarks
	1970	1971	1972	
Foremost	8.8	8	7	Both lanes have 100 passes
Bombardier	8.8	8	6	

TEST SITE: Tuk 3 LANE NO. 6 VEHICLE: Bombardier

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	1.1		2	
5	2.2		2	
10	2.3		2	
20	4.3		4	
40	5.4		5	
60	6.5		5	
80	6.6		5	
100	7.7	6	6	

TEST SITE: Tuk 3 LANE NO. 7 VEHICLE: RN 110 (Sept)

No. of Passes	Disturbance Level			Remarks
	1970	1971	1972	
1	1.1		1	
5	2.2		2	
10	3.3		4	
20	5.5		6	
40	6.6		7	
60	8.8	7	7	
80				
100				

TEST SITE: Tun 1 LANE NO. VEHICLE:

Lane	Disturbance Level			Remarks
	1970	1971	1972	
1	8.8	7	6	100 passes were completed in all lanes
2	8.8	6	6	
3	8.8	6	6	
4	8.7	6	6	
5	8.8	7	7	
6	8.8	6	6	

APPENDIX II

Permafrost and Rut Depth

Measurements

1970 to 1972

TEST SITE GROUP NO. 1

INCLUDES SITES: Shingle Point 1 (SP1), Tununuk 3 (TUN3)

COMMON SITE CHARACTERISTICS: Predominantly sedge and moss cover, wet to very wet conditions

TEST SITE VEHICLE	RUT DEPTH			DEPTH TO PERMAFROST					
	R 71	R 72	ΔR	Du 71	Du 72	ΔDu	S 71	S 72	ΔS
SP1, L	2	0	-2	18	19	1	0	1	1
TUN3, L	5	5	0	13	15	2	8	7	-1
TUN3, M	4	6	2	13	15	2	9	8	-1

ALL DATA FOR 100 PASSES OF TEST VEHICLE

SYMBOL CODE:

L = Light tracked vehicle

M = Medium tracked vehicle

H = Heavy tracked vehicle

71 = 1971 (August)

72 = 1972 (August)

R = Rut depth in inches

ΔR = Change in R from 1971 to 1972 in inches

Du = Depth to permafrost in undisturbed ground in inches

ΔDu = Change in Du from 1971 to 1972 in inches

S = Difference in depth to permafrost between track and undisturbed ground in inches

ΔS = Change in S from 1971 to 1972 in inches

TEST SITE GROUP NO. 2

INCLUDES SITES: Shingle Point 2 (SP2), Tununuk 2 (TUN2), Tuktoyaktuk 1 (TUK1)

COMMON SITE CHARACTERISTICS: Moderately wet polygon areas mostly sedge covered with some mosses and ericaceous plants

TEST SITE VEHICLE	RUT DEPTH			DEPTH TO PERMAFROST					
	R 71	R 72	ΔR	Du 71	Du 72	ΔDu	S 71	S 72	ΔS
SP2, L	6	6	0	14	14	0	6	7	1
TUN2, L	4	4	0	14	14	0	5	7	2
TUN2, M	5	6	1	14	14	0	8	11	3
TUK1, L	4	8	4	13	11	-2	4	10	6
TUK1, M	8	13	5	15	12	-3	8	15	7
TUK1, H (20 Pass)	22	24	2	17	18	1	20	25	5

ALL DATA FOR 100 PASSES OF TEST VEHICLE

SYMBOL CODE:

L = Light tracked vehicle

M = Medium tracked vehicle

H = Heavy tracked vehicle

71 = 1971 (August)

72 = 1972 (August)

R = Rut depth in inches

ΔR = Change in R from 1971 to 1972 in inches

Du = Depth to permafrost in undisturbed ground in inches

ΔDu = Change in Du from 1971 to 1972 in inches

S = Difference in depth to permafrost between track and undisturbed ground in inches

ΔS = Change in S from 1971 to 1972 in inches

TEST SITE GROUP NO. 3

INCLUDES SITES: Shingle Point 4 (SP4)
Tuktoyaktuk 3 (TUK3)

COMMON SITE CHARACTERISTICS: Moist upland tundra, nearly level, incipient polygons, predominant cover sedges, low ericaceous plants

TEST SITE VEHICLE	RUT DEPTH			DEPTH TO PERMAFROST					
	R 71	R 72	ΔR	Du 71	Du 72	ΔDu	S 71	S 72	ΔS
SP4, L	10	8	-2	19	28	9	11	-1	-12
TUK3, L	10	10	0	12	14	2	12	12	0
TUK3, M	17	12	-5	14	11	-3	19	19	0
TUK3, H	16	20	4	18	14	-4	16	27	9

ALL DATA FOR 100 PASSES OF TEST VEHICLE

SYMBOL CODE:

L = Light tracked vehicle

M = Medium tracked vehicle

H = Heavy tracked vehicle

71 = 1971 (August)

72 = 1972 (August)

R = Rut depth in inches

ΔR = Change in R from 1971 to 1972 in inches

Du = Depth to permafrost in undisturbed ground in inches

ΔDu = Change in Du from 1971 to 1972 in inches

S = Difference in depth to permafrost between track and undisturbed ground in inches

ΔS = Change in S from 1971 to 1972 in inches

TEST SITE GROUP NO. 4

INCLUDES SITES: Shingle Point 3 (SP3) Tununuk 1 (TUN1) Tununuk 4 (TUN4) Tuktoyaktuk 2 (TUK2)

COMMON SITE CHARACTERISTICS: Up to 15% slope, well drained, upland tundra rough, hard ground surface woody shrubs, sedges, some moss

TEST SITE VEHICLE	RUT DEPTH			DEPTH TO PERMAFROST					
	R 71	R 72	ΔR	Du 71	Du 72	ΔDu	S 71	S 72	ΔS
SP3, L	6	10	4	9	14	5	4	10	6
TUN1, L	5	5	0	13	8	-5	5	19	14
TUN1, M	5	5	0	13	8	-5	7	11	4
TUN4, L	2	6	4	15	15	0	3	9	6
TUN4, M	9	10	1	15	15	0	10	11	1
TUK2, L	8	8	0	16	18	2	8	7	-1
TUK2, M	15	15	0	18	24	6	14	14	0
TUK2, H (60 Pass)	25	24	-1	20	25	5	23	21	-2

ALL DATA FOR 100 PASSES OF TEST VEHICLE

SYMBOL CODE:

L = Light tracked vehicle

M = Medium tracked vehicle

H = Heavy tracked vehicle

71 = 1971 (August)

72 = 1972 (August)

R = Rut depth in inches

ΔR = Change in R from 1971 to 1972 in inches

Du = Depth to permafrost in undisturbed ground in inches

ΔDu = Change in Du from 1971 to 1972 in inches

S = Difference in depth to permafrost between track and undisturbed ground in inches

ΔS = Change in S from 1971 to 1972 in inches

Fig. 1 Light tracked carrier tracks at Tuktoyaktuk Site 3 immediately after 100 passes

Fig. 2 Same tracks as in Fig. 1 as they appeared one year later

Fig. 3 The same tracks again two years after traffic was run

Fig. 4 Tracks from medium tracked carrier after 100 passes. Tuktoyaktuk Test Site 3, July, 1970

Fig. 5 The same tracks as in Fig. 4 one year later. High water level was partly due to recent heavy rainfall

Fig. 6 The same set of tracks as they appeared two years after traffic. There is substantial regrowth on the central ridge, almost none in the ruts

Fig. 7 Operating a similar medium tracked vehicle on upland tundra in June results in less initial disturbance than traffic in July (cf. Fig. 4)

Fig. 8 The tracks in Fig. 7 after one year's recovery

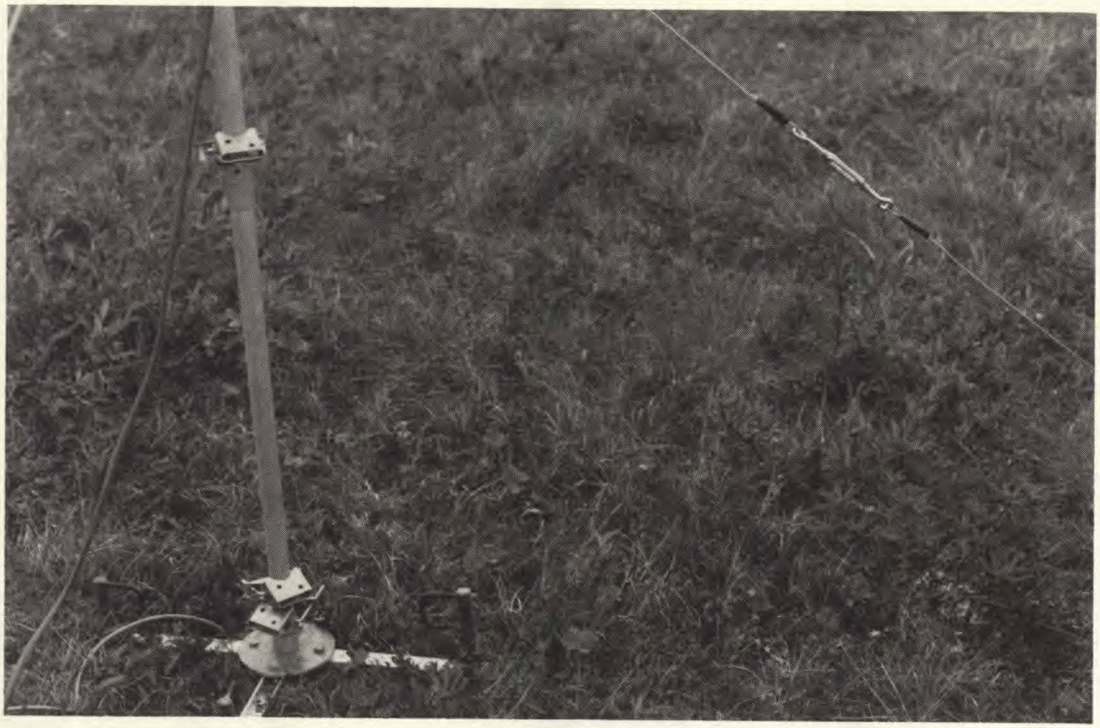
Fig. 9 Two years after traffic, there is little vegetation recovery beyond the one year point

Fig. 10 Sixty passes of a Heavy (GVW-60 Ton) tracked vehicle develop ruts to permafrost on a tundra hillside

Fig. 11 After two years, the site in Fig. 10 has dried near the surface, collected runoff at the base of the slope, and exhibits almost no vegetative regrowth

Fig. 12 General view of Site No. 2 Tununuk (Bar C) to the South West

Fig. 13 General view of Site No. 2 Tununuk (Bar C) to the North East



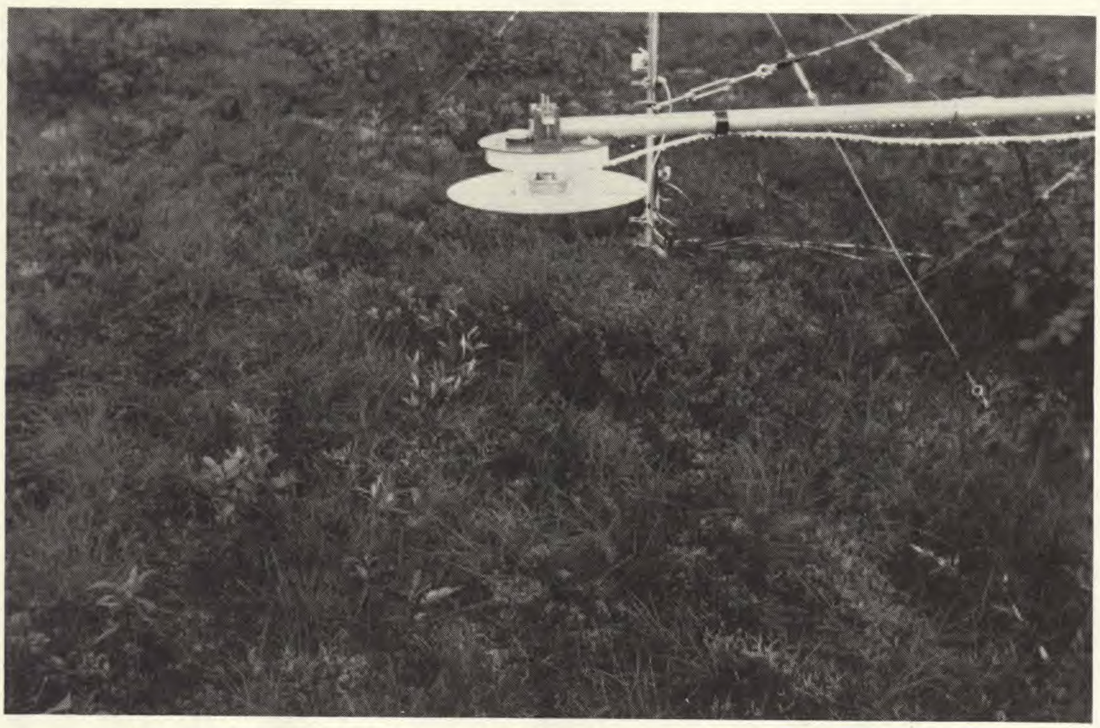
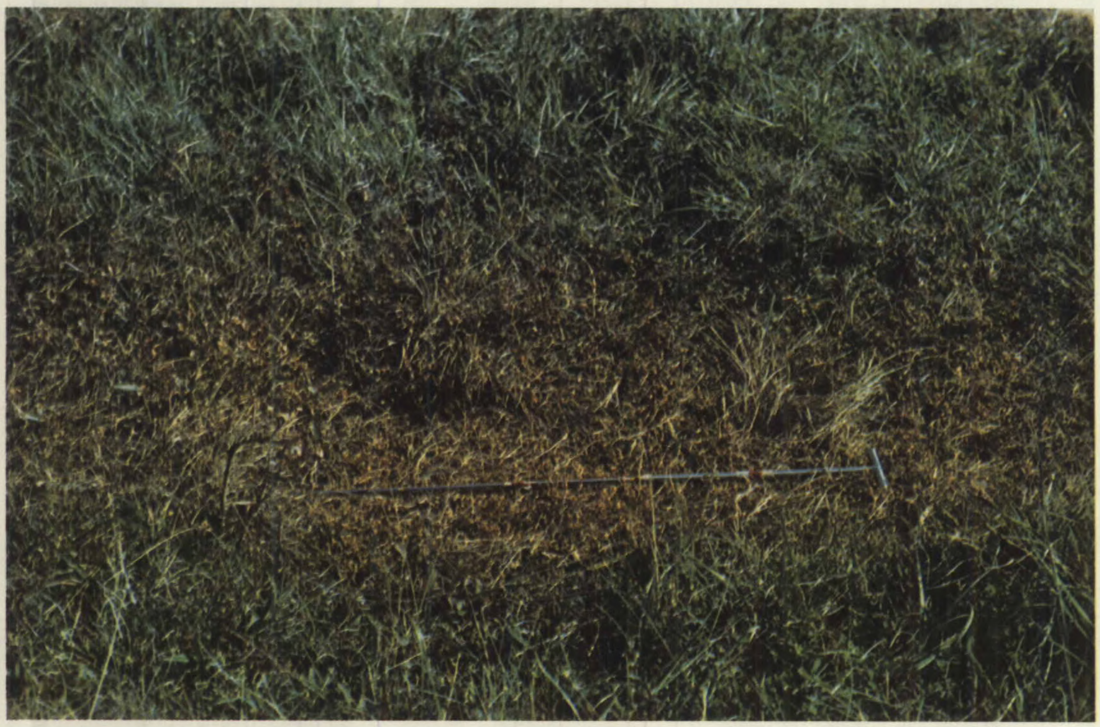
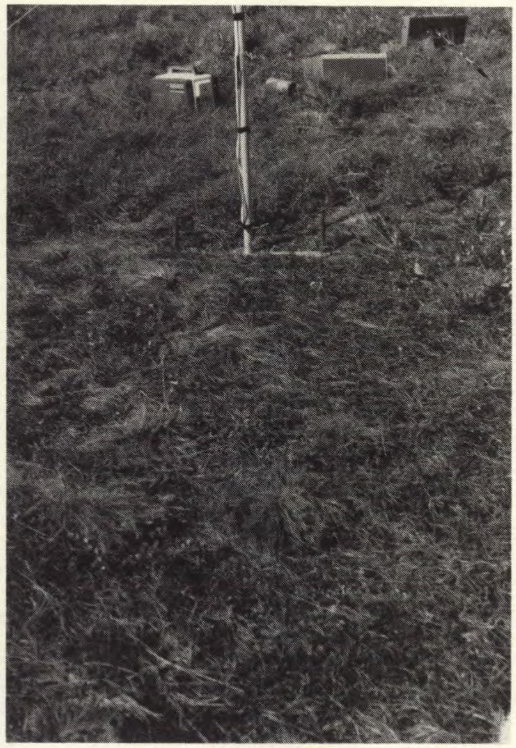


Fig. 14a and 14b Undisturbed tundra (natural state); Site No. 1
Albedo - 19.6% July 30/72
Albedo - 18.9% Aug. 13-19/72
Albedo - 15.8% Aug. 13-19/72
Aug. 25-31/72
Disturbance level - 1.1



Figs. 15a and 15b Light brown colored, crushed, dead vegetation with complete cover. Site No. 2
Albedo - 22.3% Aug. 13-19/72
Disturbance level - 5.6



Figs. 16a and 16b Dark brown colored, crushed dead vegetation with complete cover; Site No. 3

Albedo - 16.4% Aug. 13-19/72
Albedo - 16.35% Aug. 25-31/72

Disturbance level - 6.3

Figs. 17a and 17b Dark brown, wet, crushed, dead vegetation with complete cover; Site No. 4

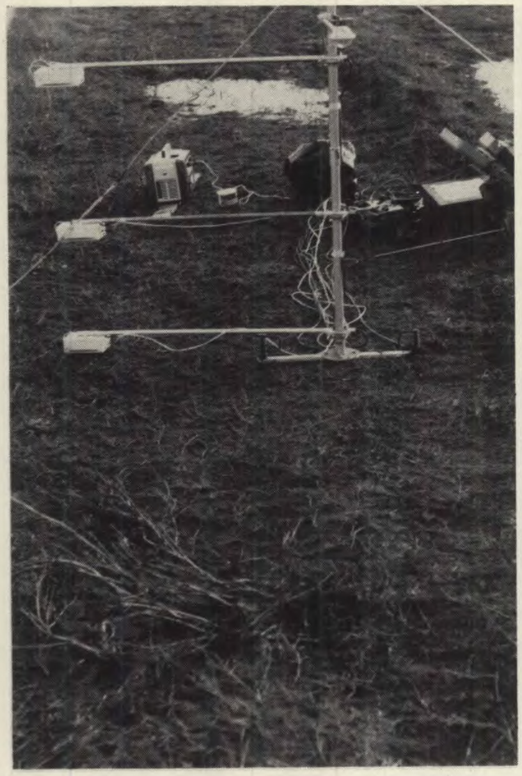
Albedo - 14.0% Aug. 13-19/72
Albedo - 14.1% Aug. 25-31/72

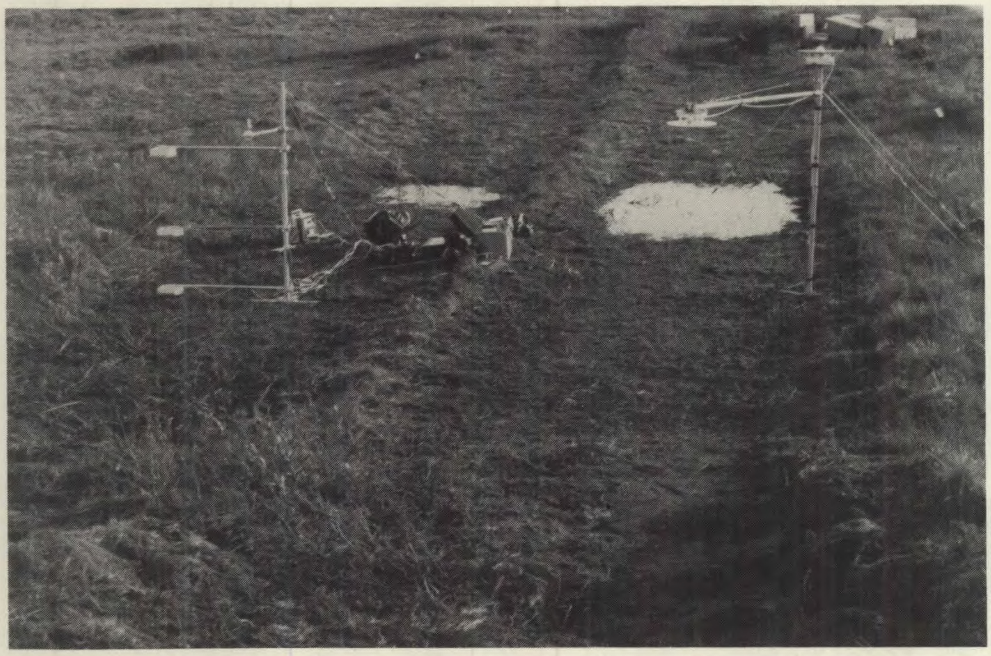
Disturbance level - 6.6

Figs. 18a and 18b Dark exposed mud with little or no regrowth in tracks; Site No. 5

Albedo - 10.7% Aug. 13-19/72
Albedo - 10.0% Aug. 25-31/72

Disturbance level - 7.7





Figs. 19a and 19b Dark brown (black), wet, exposed mud, curshed dead vegetation with incomplete vegetation cover; Site No. 5

Albedo - 10.7% Aug. 13-19/72
Albedo - 10.0% Aug. 25-31/72

Disturbance level - 7.7

Figs. 20a and 20b Water lying in tracks; Site No. 6

Albedo - 1.6% Aug. 13-19/72
Albedo - 1.1% Aug. 25-31/72

Disturbance level - 8.8

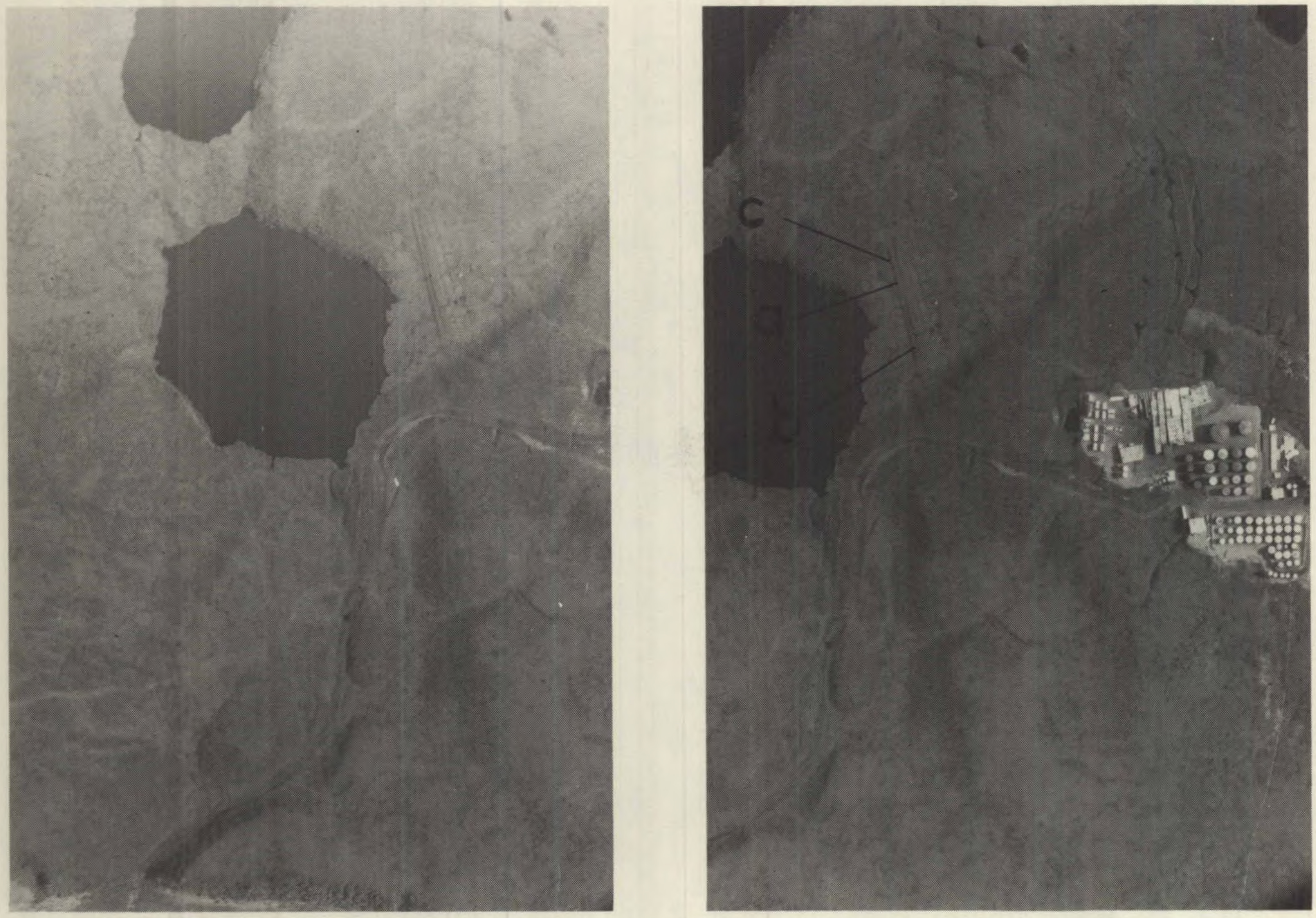


Fig. 22 Aerial view of Site II in Tununuk
App. scale 1:8,500 (stereopairs).

A= ground disturbance equal to or less than level 4

B= ground disturbance equal to or higher than level 4

C= regrowth of vegetation visible

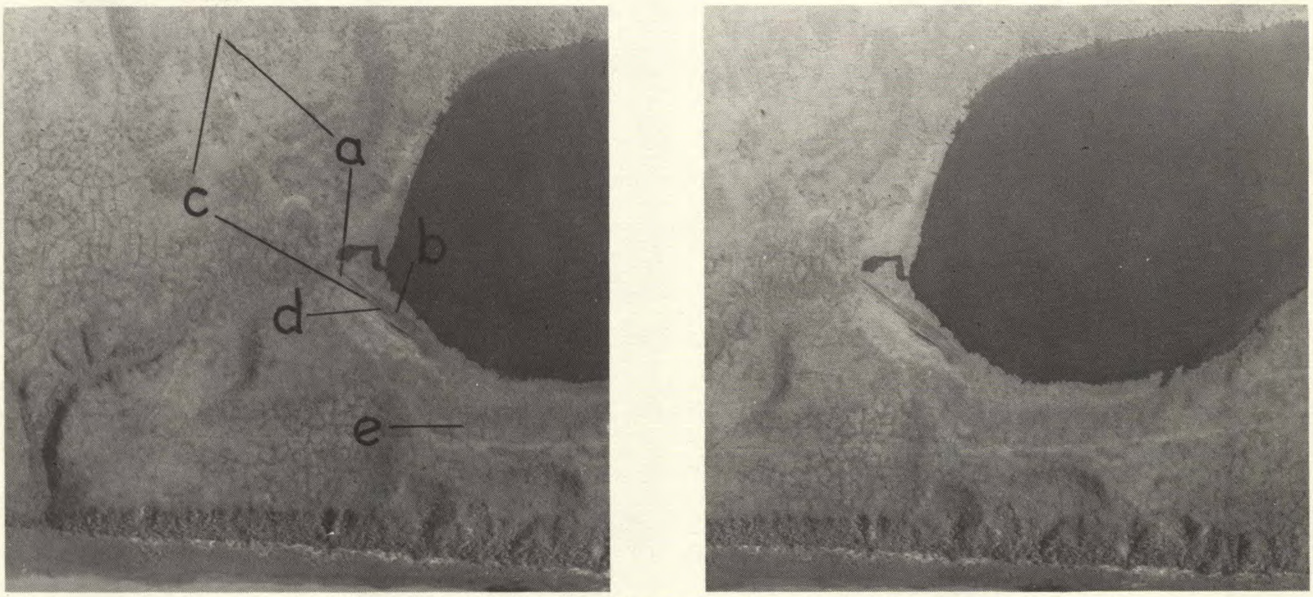


Fig. 23 Aerial view of Sites III (at the lake) and IV (towards the top of figure) in Tununuk. App. scale 1:8,500 (stereopair).

a - ground disturbance equal to or less than level 4

b - small localized areas with ground disturbance equal to or less than level 4

c - visible regrowth of vegetation

d - totally destroyed area after only a few passes by a vehicle, high water regime

e - very slight disturbance by one pass, hardly visible to a ground observer- clearly seen from the air

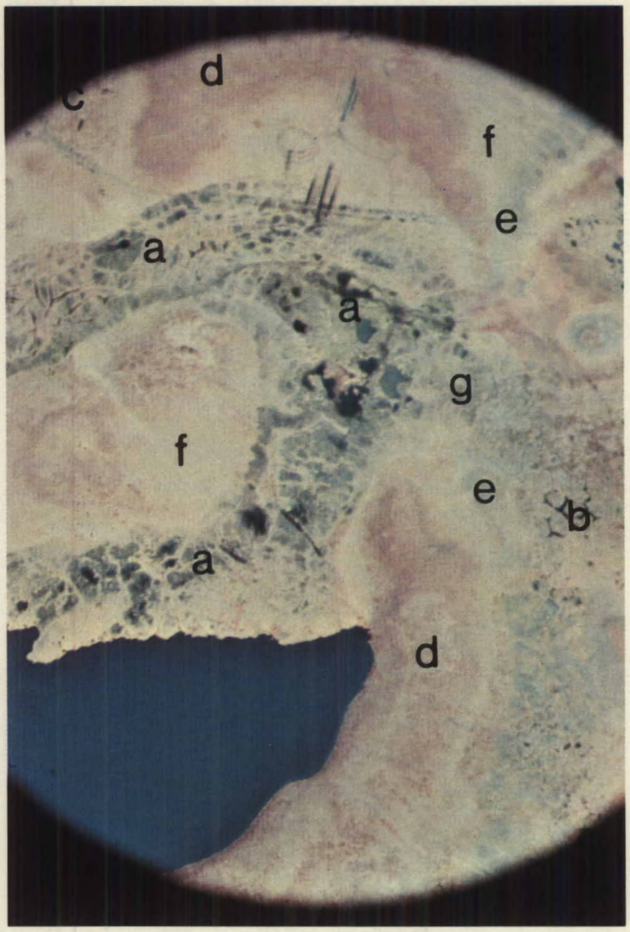


Fig. 24 (on the left) and 25 (on the right)
Aerial views on Kodak Colour (left) and Ektachrome Infrared (right) of Tuktoyaktuk test sites.
App. scale 1:8,500

a - high water regime area with depressed centre ice wedge polygons

b - high water regime area with channel type ice wedge polygons

c - lower water regime area with channel type ice wedge polygons

d - fairly well drained slopes and flats

e - area of moderately high sensitivity to disturbance but lower than a - c

f - areas with moderate sensitivity to disturbance less than a - c and e

g - a localized area with low sensitivity to disturbance

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