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Tundra Disturbance Studies in the Western Canadian Arctic

D. E. Kerfoot

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D. E. Kerfoot
Department of Geography
Brock University

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Denis E. Kerfoot.

INTRODUCTION

This report covers the results of research undertaken on a contract basis as part of the Arctic Land Use Research (ALUR) Programme of the Department of Indian Affairs and Northern Development during the summer of 1971. The broad terms of reference for this contract were to investigate and assess the immediate and long-term effects on the surface vegetation and terrain of various types, designs and operating procedures of vehicles employed by the resource exploration industry in both the forested and tundra regions of far northern Canada. The specific studies to be investigated as part of this contract included:

(a) the 1970 vehicle test sites at Tuktoyaktuk, Tununuk and Shingle Point.

(b) representative sites of winter road operations near the Blow River, Y.T., on the Tuktoyaktuk Peninsula, and on the Gulf Oil ice road from Inuvik to the site of rig C-38.

(c) two sites, to be selected by the Director, where seismic operations were carried out during the winter of 1970-71 in forested areas of discontinuous permafrost, the one subjected to wheeled vehicular traffic, and the other to flexible tracked vehicles only

(d) the site of winter seismic operations carried out in 1970-71 by Elf Oil Exploration and Production Canada, Limited, and Deminex (Canada) Limited, on

Banks Island, N.W.T.

This research programme was to be undertaken in collaboration with Dr. J.D. H. Lambert, Department of Biology, Carleton University, and Mr. John D. Radforth of the Muskeg Research Institute of the University of New Brunswick.

Problems relating to the inadequate arrangements for logistical support and the absence of any necessary background information on the terrain disturbance features to be investigated, resulted in an exclusion of the studies of seismic lines in the forested areas and winter roads on the Tuktoyaktuk Peninsula from the summer field programme. Similar difficulties, together with problems in scheduling a field programme that coincided with that of Mr. Radforth, led to a further exclusion of investigations of the 1970 vehicle test sites. However, since Mr. Radforth was the only research worker to have done the preliminary studies on these sites during the previous summer, it was considered to be appropriate that he should continue these investigations. In contrast to these omissions, investigations of a winter road site near Sitidgi Creek, the 1970 and 1971 summer seismic operations of Gulf Oil Canada Limited, and a drill-rig site near Storkerson Bay on Banks Island were added to the programme of field studies. The general locations of the various field areas are shown in Figure 1.

The field work for this programme was carried out, in collaboration with Dr. Lambert, between June 4 and September 4, 1971. Both quantitative and qualitative procedures were utilized to assess the degree of tundra terrain disturbance. Quantitative data was collected to evaluate relative changes in surface microrelief features and the thickness and thermal regime of the active layer in disturbed as compared to adjacent

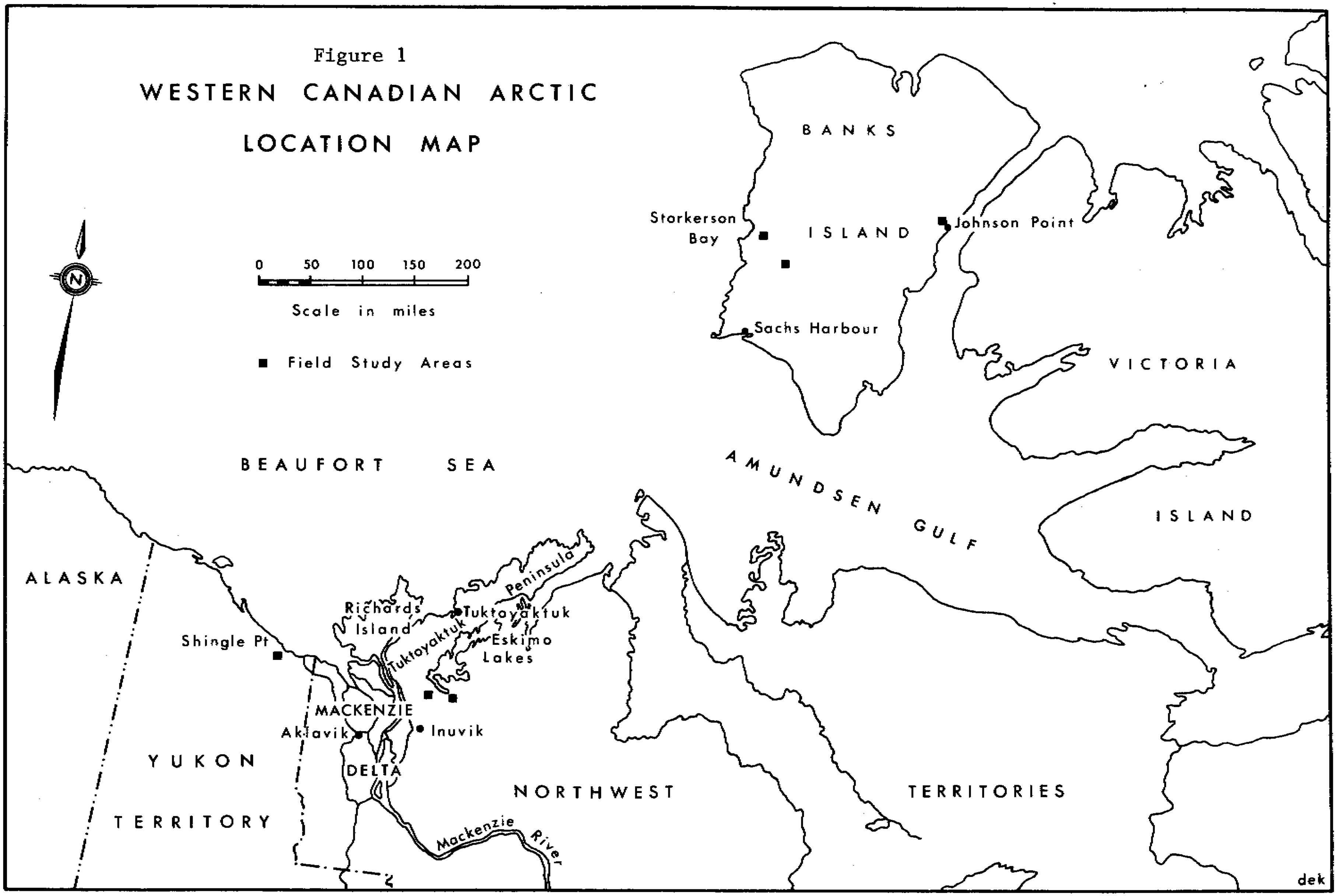


Figure 1

WESTERN CANADIAN ARCTIC LOCATION MAP

undisturbed sites. Wherever possible, soil samples were collected for determinations of the granulometric composition and potential for thermokarst development of the frozen substrate. In addition to these quantitative measurements, qualitative assessments were also made of the degree of disturbance of the tundra vegetation cover. Although some of the latter material has been incorporated into this report, to provide a more comprehensive description of the research programme, more specific and detailed analyses of this particular aspect of the tundra disturbances can be obtained from Dr. Lambert's report.

For clarity and convenience, the various studies of the tundra disturbances investigated under the contract are grouped according to specific types of activity associated with the resource exploration industry operating in the north. The first section of the report incorporates the results of studies of winter road sites which were selected to provide relative data on the optimum type of construction and period of usage of these access routes. These sites included examples of winter roads which were constructed using conventional snow packing techniques, blading of the organic layer or the ice road method, and which were used for one or two consecutive years. The second section presents the results of investigations designed to assess the feasibility of summer seismic operations in certain parts of the Mackenzie Delta area, and includes descriptions of summer seismic lines from one to nine years old, as well as a detailed series of observations made during the course of an actual seismic programme in the summer of 1971. The third section of the report covers a largely qualitative assessment of winter seismic operations and includes some observations of a programme in the Caribou Hills area in February, 1971, and the terrain disturbances associated with the first winter seismic operations on Banks Island together with some preliminary surveys of the site of the first well to be drilled on the island. The concluding pages of the report contain a summary of the findings and some recommendations for consideration or possible incorporation in the application or enforcement of the Land Use Regulations in far northern Canada.

WINTER ROADS

The cross-tundra movement of heavy, especially wheeled, vehicles or loads is restricted to those months of the year when the active layer is frozen. Even at these times, however, the establishment of access routes for the movement of drilling rigs, camps, equipment and supplies necessitates the use of certain construction techniques in order to minimize the disruptive effects of such localized, intense traffic on the terrain. The most common method of building these winter roads in the Mackenzie Delta area involves the packing or consolidation of a layer of wet snow in an attempt to provide a smooth, compact surface capable of supporting the heavier wheeled or tracked vehicles. The scant nature of the snow cover, particularly in exposed, wind-swept areas, or the dry, powdery consistency of the snow, frequently combine to limit the protective effectiveness of this method of construction and, consequently, many of the winter roads are almost completely denuded of their surface vegetation cover.

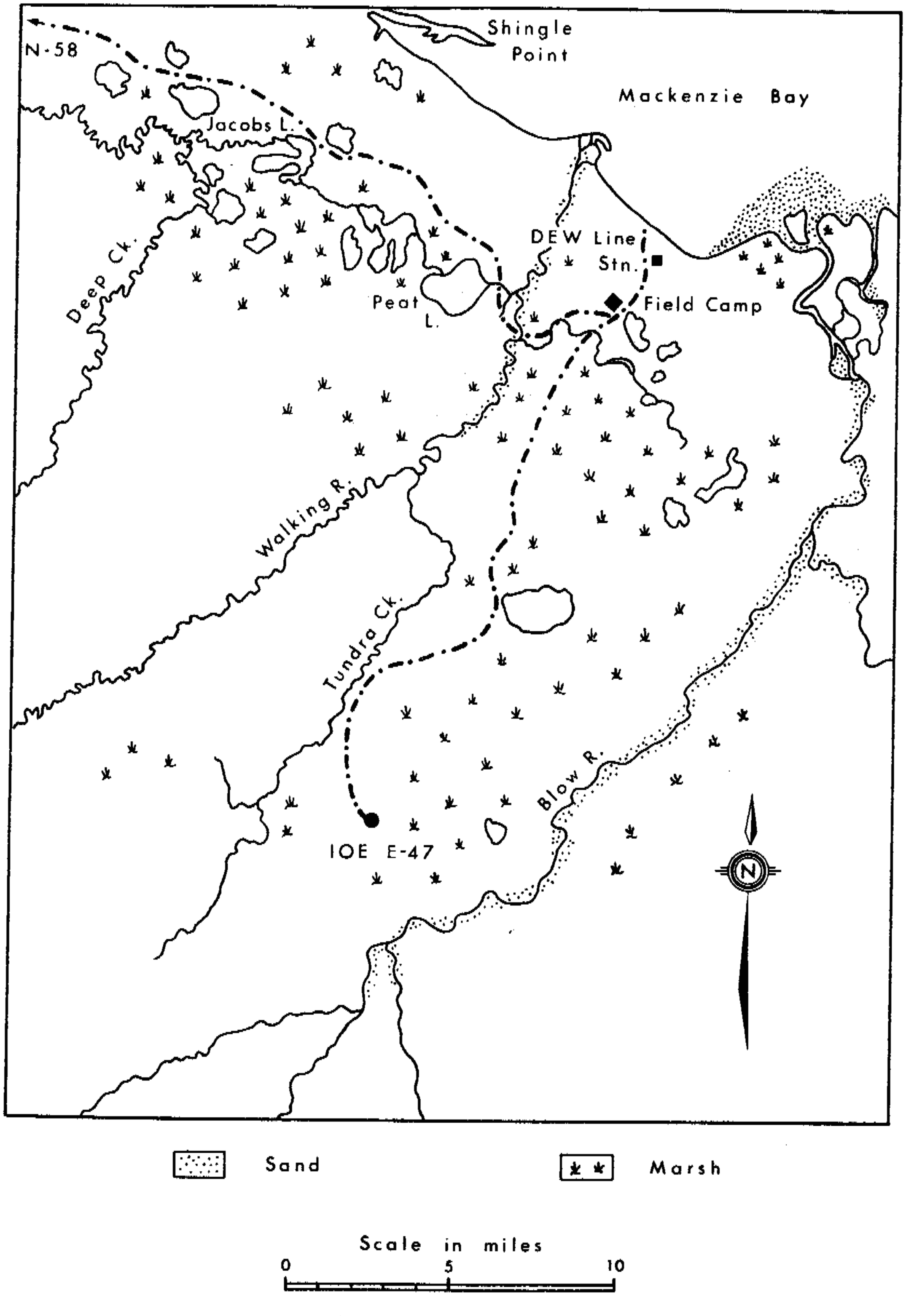
The intensity of the terrain disturbance associated with such a localized concentration of cross-tundra traffic presents two primary problems with respect to winter road operations. The first centres around the adequacy of the conventional snow packing technique, and the relative merits of alternative methods of construction. eg. ice roads. The second problem relates to the optimum length of time for which individual access routes should be used. Since the use of a road often results in a severe disruption of the surface vegetation cover after only one winter's operations, it is debatable as to whether or not the same access route should be utilized in following years. Certainly, any re-use of a winter road can only result in an intensification or compounding of the degree of disturbance, thereby prolonging the time period required for a re-establishment of the vegetation layer and increasing the risk that thermokarst development will take place. On the other hand, if an access route is not to be used again, this may require the construction of a second winter road in the same area, and this results in a corresponding increase in the areal extent of the terrain disturbance.

These apparently conflicting aspects of either restricting the intensity of terrain damage to acceptable levels, or minimizing its areal extent, have yet to be resolved, and a considerable part of the 1971 field programme centred around the collection of quantitative data pertaining to the optimum method of construction and period of usage of these winter roads.

Shingle Point Site.

In the winter of 1969-70, Imperial Oil Limited built a winter road, approximately fourteen miles in length, from their staging point on the coast, near the DEW Line Station at Shingle Point, to their IOE Blow River (E-47) rig site located at about longitude 137° 27' W and latitude 68° 47' N (see Figure 2). Sections of this road were investigated under the ALUR programme during the summer of 1970, when it was found that, despite an extreme pulverization of the organic layer, some plant species,

Figure 2
WINTER ROADS NEAR SHINGLE POINT



especially the Cloudberry (Rubus chamaemorus), appeared to have survived through the disturbance and some regeneration was in progress. Furthermore, it was felt that the existence of some shredded organic material would assist in the re-growth of these species as well as contributing to the retardation of surface runoff and providing some form of insulation for the underlying frozen ground. Rather than promote an intensification of the existing level of disturbance, through a further reduction in the thickness of the organic layer, it was suggested that the access route should not be used again during the winter of 1970-71, and it was recommended that a new winter road be constructed to haul the drilling rig and camp to the N-58 site located a few miles to the west of the Spring River at longitude 138° 58' W and latitude 69° 15' N.

In direct contrast to this recommendation made for the Shingle Point area, Dr. L.C. Bliss, of the University of Alberta, was of the view that Imperial Oil's winter roads on the Tuktoyaktuk Peninsula could be utilized for a second year without involving an excessive intensification of the terrain disturbance. In light of these contrasting opinions, Imperial Oil elected to move their drilling rig northward, along the 1969-70 winter road, to a point approximately three miles south of the staging area at Shingle Point, before turning westward and constructing a new winter road to the N-58 site (see Figure 2). The section of the road between the coast and the turn-off, three miles to the south, was also used again to transport supplies for the camp at the N-58 site.

This sequence of events provided an opportunity to compare the terrain disturbances associated with winter roads that had been used for either one or two years and were constructed using the snow packing method. A field camp was established just to the north of the turn-off

(Figure 2) in early June and observations of the sites continued through to late August. Three permanent profile transects were established across the roads near the camp to provide long-term data on changes in the thickness of the active layer and the incidence of any subsequent thermokarst development. Nine quadrat plots, each one metre square in size, were set up to obtain comparative data on the rate and total depth of thaw, the configuration of the frost table and the rate of vegetation recovery. In addition, two temperature cables were installed to monitor changes in the thermal regime of the near-surface soil layers.

Depth of Thaw Profiles. Three profile transects were established to provide data on the relationships between surface microrelief, vegetation, thickness of organic material and the rate and depth of thaw. Two of these transects were located across the winter road that had been used for two consecutive seasons, and the other profile was located across the winter road that was used for the first time in 1970-71. Detailed topographic profiles were surveyed across each transect, and bench-marks were placed at the end points of the profiles to establish reference markers for the detection of any long-term changes in the position of the permafrost table. The bench-marks consisted of two-metre lengths of aluminum tubing, which were installed so that the lower two-thirds penetrated into the perennially frozen ground. In an attempt to ensure that the markers would be firmly anchored in the permafrost, and not influenced by frost-heaving forces developing each winter in the active layer, metal collars were attached to the outside of the tubing which was also perforated so that water, poured down the centre of the tube, would spread into the remainder of the drill hole before freezing. The depth of thaw was measured periodically throughout the summer by probing, at one-metre intervals, across the disturbed area and at representative points in adjacent undisturbed sites. The details of the surface topography, and the position of the frost table at the beginning and end of the observation period, are shown in Figure 3, and additional data on the depth of thaw measurements are presented in Table I.

The first transect was located just to the north of the turn-off, where the winter road, which had been used for two years, traversed an area dominated by the tussock-like forms of the Sheathed Cotton-grass (Eriophorum vaginatum). The other major component of the plant cover consisted of mosses (chiefly Sphagnum species), and other minor species present included the Mountain Cranberry (Vaccinium vitis-idaea), Cloudberry (Rubus chamaemorus), Narrow-leafed Labrador-tea (Ledum palustre ssp. decumbens), Alpine Bearberry (Arctostaphylos rubra), Glandular Birch (Betula glandulosa), Mournful Sedge (Carex lugens) and the Veiny-leafed Willow (Salix phlebophylla). The principal diversity to this pattern consisted of occasional earth hummocks which supported greater quantities of the ericaceous species together with small mats of crustose lichens.

The tussocks, averaging 15-20 cms in height and 10-15 cms across at the crown, and the earth hummocks, averaging 20-30 cms in height and one metre in diameter, impart a distinctive irregularity to the surface micro-relief of the undisturbed terrain which contrasts with the smooth, relatively even surface of the winter road (Figure 3, Profile I). Virtually all the tussocks, together with most of the other vegetation, had been destroyed along the line of the road. Approximately 60 per cent of the road surface was mantled by a veneer of friable, shredded organic material which attained maximum thicknesses of 10-15 cms. Over approximately 40 per cent of the length of the transect, the entire organic layer had been removed and bare mineral soil was exposed at the ground surface. In certain areas, adjacent

Figure 3
WINTER ROAD NEAR SHINGLE POINT

DEPTH OF THAW TRANSECTS

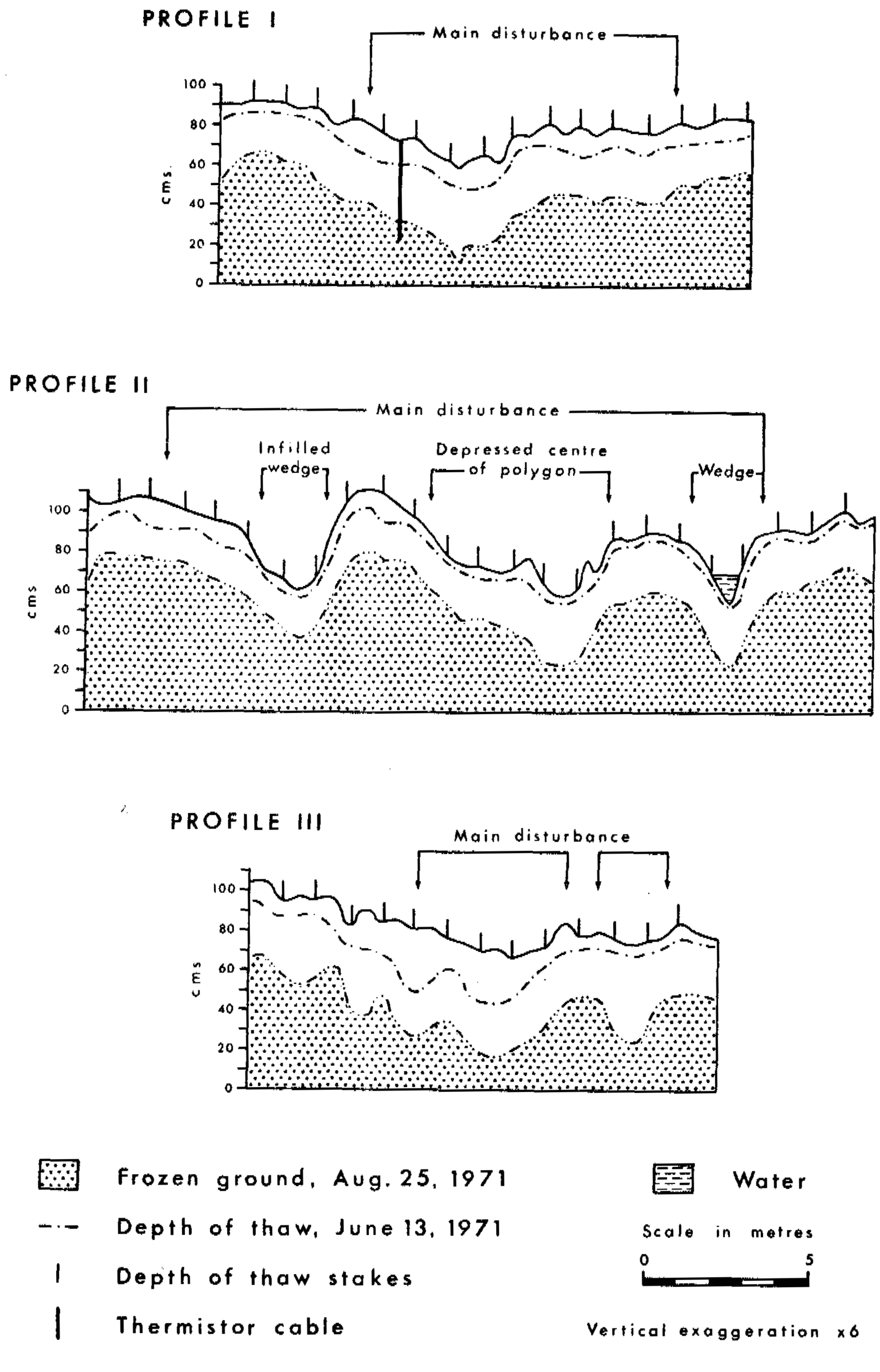


TABLE I

WINTER ROAD PROFILE TRANSECTS, SHINGLE POINT.

DEPTHS OF THAW (Cms)

Date	Site I (2-Year Use)		Site II (2-Year Use)		Site III (1-Year Use)	
	Disturbed	Undisturbed	Disturbed	Undisturbed	Disturbed	Undisturbed
June 14	11.0	11.2	9.6	9.4	15.4	12.4
June 21	16.5	16.5	14.1	16.0	24.5	22.7
June 28	20.3	17.5	17.0	20.5	31.4	24.0
July 5	22.3	18.8	19.9	22.8	33.6	24.7
July 12	25.8	20.3	21.7	23.1	35.6	26.3
July 19	28.0	23.3	22.4	24.5	37.3	27.8
July 26	31.6	28.3	25.1	27.0	40.2	29.5
Aug. 2	34.4	30.3	26.7	28.5	42.3	31.2
Aug. 9	35.4	30.8	28.2	29.8	43.0	31.8
Aug. 16	36.2	31.3	29.6	30.2	43.3	32.5
Aug. 25	36.4	31.3	30.8	31.1	44.2	34.9

to the transect line, the exposure of the mineral soil had initiated some thermokarst development and the formation of shallow depressions, several metres in length and up to 50 cms deep, which contained pools of standing water.

As Table I shows, when the profile was first investigated in early June, there was no appreciable difference in the depth of thaw beneath the winter road as compared to the adjacent undisturbed sites. As the summer progressed, however, the thaw penetration beneath the disturbed area increased slightly more rapidly, until by August 25, the average thickness of the active layer on the winter road amounted to 36.4 cms. This value represents an average increase of 5.1 cms, or 16.3 per cent, over the depths recorded beneath the undisturbed sites. The maximum thaw penetration occurred in the areas of exposed mineral soil, where the frost table was encountered at depths of 45-50 cms below the ground surface, and this value represents slightly more than a 30 per cent increase over the maximum thaw depths recorded in the undisturbed tussock community.

The second transect (Figure 3, Profile II), was located just to the south of the turn-off at a point where the winter road, assumed to have been used for two years, traversed an area of high-centred polygons. In actual fact there were two roads crossing this area of polygonal ground, and it is not known if either route was used for two years or if each route corresponds to a single year's usage. The polygonal forms averaged 12-15 metres across, and the majority were either flat-topped or contained shallow, saucer-shaped depressions in their centres. At their highest points, usually around the margins, the polygon surfaces were about 50-60 cms above the level of the surrounding troughs. The latter, marking the positions of the ice-wedges, contained pools of water 15-60 cms deep.

The dominant vascular species growing on the raised centres of the tundra polygons included the Glandular Birch (Betula glandulosa), Narrow-leafed Labrador-tea (Ledum palustre ssp. decumbens), Cloudberry (Rubus chamaemorus), Mountain Cranberry (Vaccinium vitis-idaea) and Common Crowberry (Empetrum nigrum). Various lichen and moss species also formed an almost continuous ground cover. Some of the more moist areas in the central parts of the polygons supported small tussocks of the Sheathed Cotton-grass (Eriophorum vaginatum). Sedge species, particularly the Aquatic Sedge (Carex aquatilis), Common Cotton-grass (Eriophorum angustifolium) and the Arctic Cotton-grass (E. scheuchzeri), and mosses were the principal components of the vegetation growing along the lines of the ice-wedges.

The most obvious effects of the terrain disturbance consisted of an almost complete destruction of the surface vegetation cover, over a width of approximately 20 metres, and an exposure of the underlying organic material. Some organic matter was also scraped from the tops of the polygons since many of the wedge lines were filled with up to 20-30 cms of shredded peat. In places, the edges of the polygons had been more heavily damaged, and larger blocks of peat had been dislodged from the sides into the adjacent troughs.

The depth of thaw measurements shown in Figure 3 (Profile II) and Table I indicate that the removal of the vegetation layer had little or no effect on the thickness of the active layer. Throughout most of the summer, the average thaw depth in the undisturbed sites was 2-3 cms greater than that in the disturbed areas, but by late August the differential amounted to less than 0.5 cms. Since the typical substrate in these polygonal areas consists of thick accumulations of peat material, the absence of any marked differential in the depth of thaw is perhaps to be expected, particularly as the frozen peat often contains substantial quantities of ice. The high heat capacity of this material, together with the insulating properties of the organic active layer, would mitigate against any rapid changes in the thickness of the thawed zone. The slow response to any augmented heat influx into the ground may account for the slightly lower depth of thaw in the disturbed areas at the end of the observation period.

The third transect (Figure 3, Profile III), was situated just to the west of the turn-off on the new winter road, built in 1970-71, to move the rig and camp to the N-58 site. The transect was located on the floor of a flat terrace surrounded by low bluffs, and the vegetation cover was similar to that described for the first profile study. The dominance of the Eriophorum tussocks was less pronounced however, and there was an increase in the area of earth hummock forms.

The main disturbed area was approximately 5 metres in width, and the impressions of the tracks were 5-10 cms below the level of the surrounding terrain. Bare mineral soil was exposed over about 45 per cent of the width of these tracks, and the remaining areas were mantled with a layer of shredded organic material with little or no living plant cover. The less disturbed areas on either side of the main tracks contained isolated patches of exposed organic material and mineral soil, but most of the surface was littered with broken tussocks and other fragmented plant debris.

The depth of thaw measurements in Figure 3 (Profile III) and Table I reflect the effects of the destruction of the vegetation layer. Although there was no appreciable difference in the thickness of the active layer in the disturbed and undisturbed sites in the middle of June, the average depth of thaw beneath the surface of the winter road was in excess of 44 cms by the end of the summer: a value which corresponds to a 9.3 cms or 27 per cent increase over the average thaw depths in the vegetated areas. The maximum thaw penetration in the disturbed area, amounting to 52 cms in the bare mineral soil patches, however, represents an approximate increase of only slightly more than 15 per cent over the maximum depths of thaw recorded in the earth hummock areas in the undisturbed sites.

The greater average increase in the thickness of the active layer in the winter road which was used for only one year, as compared to the road followed for two years, suggests that the re-use of these access routes has not resulted in any real intensification of the topographic aspects of the terrain disturbance. On the other hand, it should be noted that the extent of the more severely disrupted areas in the winter road used for only one year averaged less than one-third of the width of similar areas on the roads which were re-used. Moreover, the combination of the narrower width involved, the slightly higher proportion of exposed mineral soil, and the possibility that a larger percentage of the road surface may have traversed earth-hummock structures could limit the statistical validity of the data obtained. To some extent, this problem could have been alleviated by more extensive sampling and the establishment of additional transects, but the scope of the field programme posed restrictions on this possibility. Moreover, as in all post-mortem studies, the difficulty of determining the precise pre-disturbance conditions still presents the greatest obstacle to any rigourous evaluation of the extent of the damage to the terrain.

Quadrat Studies. In addition to the observations of the three depth of thaw transects, a number of quadrats, each measuring one metre square, was established by Dr. Lambert to investigate the impact of the winter road operations on the vegetation communities. Nine of these quadrats were selected for further comparative studies of changes in the configurations of the surface microrelief and the frost table. For each quadrat, the surface contours were measured by erecting a horizontal frame, graduated in decimetres, over the plot and taking plumb readings to the ground surface on a 10 cms grid pattern. This same network of points was used to obtain data on the thickness of the active layer which was probed on a two-weekly basis over the period June 18 to August 13, and again on August 25.

At the end of the field season, a standard total of 700 data values, 100 for the surface microrelief and 600 for the position of the frost table, had been collected for each metre quadrat. These values were processed using the SYMAP computer mapping programme, developed by the Laboratory for Computer Graphics at Harvard University, to produce the series of contour maps shown in Figures 4-12. As far as possible, each of these maps was drawn using a 2.5 cms contour interval, although in two cases, Quadrats 'D' and 'G', the extreme range of values obtained necessitated a departure from this standard procedure and the use of a 5.0 cms contour interval to illustrate the position and configuration of the frost table. In interpreting these maps, it is important to note that since the isolines represent the depth of the frozen ground beneath the ground surface, the higher values thus correspond to depressions in the frost table. Statistical data, including the mean, maximum, minimum, standard deviation and coefficient of variation of the depths of thaw at selected times throughout the summer, are summarized for each quadrat in Table II.

Four of the quadrats were located to the north of the turn-off, in and adjacent to the winter road that had been used in 1969-70 and again

TABLE II

METRE QUADRAT STUDIES, SHINGLE POINT

DEPTH OF THAW (Cms)

	Date	Mean	Maximum	Minimum	Standard Deviation	Coeff. of Variation
Quadrat 'A'						
	June 18	16.0	19.0	11.5	1.65	0.10
	July 2	22.0	30.0	15.5	3.46	0.16
	July 16	30.2	33.5	27.5	1.59	0.05
	July 30	31.3	36.5	27.0	1.47	0.05
	Aug. 13	32.9	40.0	27.5	1.97	0.06
	Aug. 25	31.7	38.5	27.5	1.57	0.05
Quadrat 'B'						
	June 18	13.4	18.5	10.5	1.22	0.09
	July 2	19.5	25.5	15.0	1.76	0.09
	July 16	30.2	33.0	27.0	1.19	0.04
	July 30	34.3	37.5	31.0	1.31	0.04
	Aug. 13	35.7	38.5	32.5	1.36	0.04
	Aug. 25	35.5	38.5	31.5	1.31	0.04
Quadrat 'C'						
	June 18	10.8	13.5	6.5	1.31	0.12
	July 2	13.1	16.5	9.5	1.55	0.12
	July 16	19.8	24.5	15.0	1.93	0.10
	July 30	24.7	28.0	20.5	1.73	0.07
	Aug. 13	26.8	31.0	22.0	1.67	0.06
	Aug. 25	26.5	31.0	23.0	1.61	0.06
Quadrat 'D'						
	June 18	13.4	25.5	8.0	3.76	0.28
	July 2	26.1	51.0	11.5	10.50	0.40
	July 16	46.3	66.0	29.5	8.69	0.19
	July 30	56.3	72.5	39.0	8.00	0.14
	Aug. 13	57.5	74.0	42.5	7.49	0.13
	Aug. 25	57.1	72.0	42.5	7.21	0.13
Quadrat 'E'						
	June 18	10.0	13.0	6.5	1.07	0.11
	July 2	16.5	20.5	13.0	1.56	0.09
	July 16	23.2	26.0	21.0	1.12	0.05
	July 30	27.1	31.0	24.0	1.25	0.05
	Aug. 13	28.1	31.0	24.5	1.26	0.05
	Aug. 25	28.5	34.5	25.5	1.20	0.04

TABLE II (Cont'd)

	Date	Mean	Maximum	Minimum	Standard Deviation	Coeff. of Variation
Quadrat 'F'						
	June 18	14.5	20.0	10.5	2.00	0.14
	July 2	19.1	24.5	9.5	2.02	0.16
	July 16	24.4	31.0	20.0	2.48	0.10
	July 30	29.8	36.5	25.5	2.42	0.08
	Aug. 13	32.1	38.0	27.0	2.88	0.09
	Aug. 25	33.2	39.5	29.0	2.81	0.08
Quadrat 'G'						
	June 18	24.6	41.0	11.5	8.28	0.34
	July 2	32.3	45.5	17.0	7.10	0.22
	July 16	38.5	48.5	21.0	6.39	0.17
	July 30	45.6	54.5	34.5	4.79	0.11
	Aug. 13	48.7	56.0	40.5	3.33	0.07
	Aug. 25	48.8	55.5	41.5	2.64	0.05
Quadrat 'H'						
	June 18	21.1	24.0	16.5	1.30	0.06
	July 2	30.4	34.0	27.0	1.18	0.04
	July 16	37.0	41.0	32.0	1.96	0.05
	July 30	43.6	48.0	39.5	1.78	0.04
	Aug. 13	46.3	50.0	41.0	1.73	0.04
	Aug. 25	46.7	50.5	43.0	1.52	0.03
Quadrat 'J'						
	June 18	17.0	24.5	8.0	3.03	0.18
	July 2	22.4	30.0	14.5	2.69	0.12
	July 16	29.5	34.5	21.5	2.58	0.09
	July 30	36.0	42.0	26.0	3.08	0.09
	Aug. 13	39.0	44.0	30.0	2.63	0.07
	Aug. 25	39.5	45.0	31.0	2.78	0.07

in 1970-71. Two of the plots, Quadrat 'A' (Figure 4) and Quadrat 'B' (Figure 5) were situated in the disturbed area where the vegetation cover had been completely removed and the ground surface was blanketed with a layer of fragmented peat material. The other two plots were established in the adjacent undisturbed terrain, with Quadrat 'C' (Figure 6) being representative of the dominant Eriophorum tussock community, and Quadrat 'D' (Figure 7) the less-common earth hummock structures.

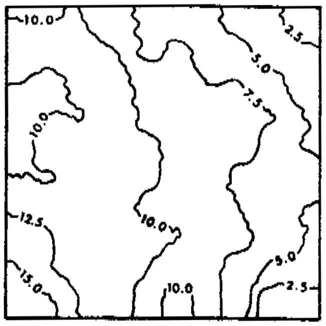
Comparisons of the contour maps in Figures 4-7, and the data in Table II, confirm the results of the measurements in the first depth of thaw transect (Figure 3, Profile I). By late August, the average thaw depth in Quadrat 'A' was 31.7 cms and in Quadrat 'B' was 35.5 cms, and these values correspond to increases of 5.2 and 9.0 cms, or 19.6 and 34.0 per cent, respectively over the average obtained from the undisturbed tussock community (Quadrat 'C'). Comparisons with the second undisturbed site (Quadrat 'D'), however, indicate that the average thaw penetration in the winter road quadrats was 20-25 cms less than that recorded in the earth hummock area, and the maximum depth of thaw in the latter site was almost twice as great as that observed in either of the disturbed plots. The contrasting nature of the differential thaw depths in the winter road sites and each of the quadrats in the undisturbed area further emphasizes the inadequacies of this type of post-mortem investigation, since the degree of disruption of the terrain is such that it is almost impossible to determine what the original, pre-disturbance conditions were like along the route of the winter road.

Comparisons of the contour maps, and the data in Table II, also demonstrate the effects of a disruption of the surface microrelief forms, and associated plant covers, on the areal configuration of the frost table.

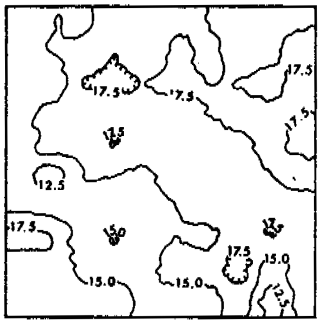
Figure 4

METRE QUADRAT 'A'

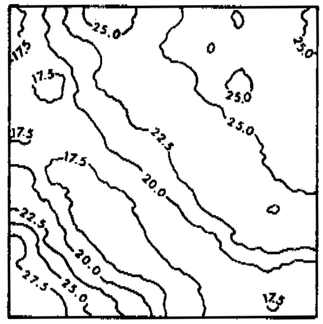
SURFACE CONTOURS ABOVE DATUM



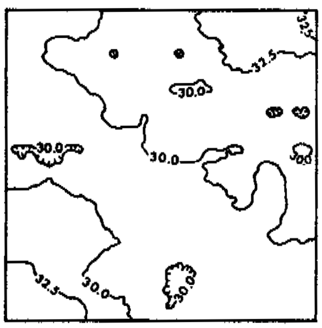
POSITION OF FROST TABLE (DEPTH BELOW GROUND SURFACE IN CMS.)



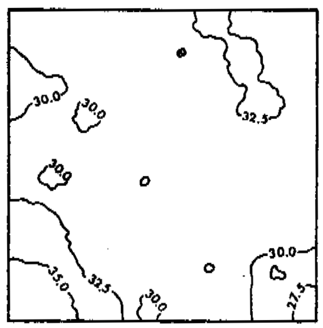
June 18, 1971



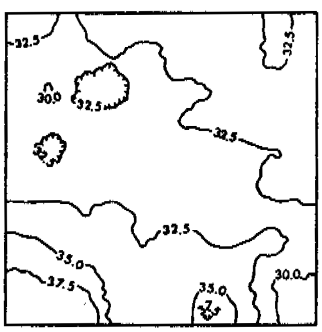
July 2, 1971



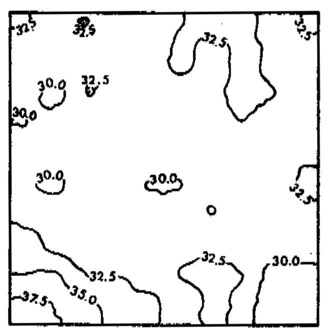
July 16, 1971



July 30, 1971



August 13, 1971

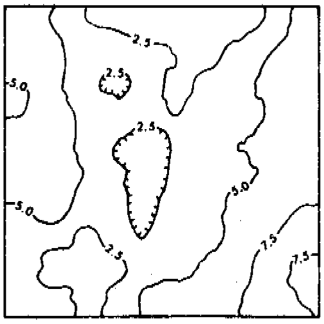


August 25, 1971

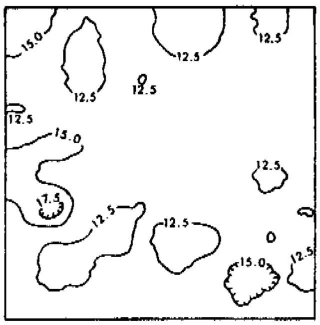
Contour interval 2.5 cms.

Figure 5
METRE QUADRAT 'B'

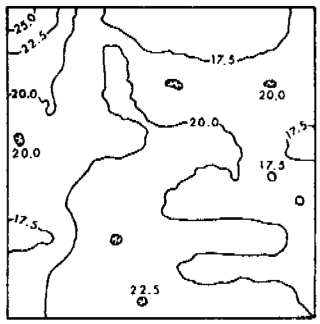
SURFACE CONTOURS ABOVE DATUM



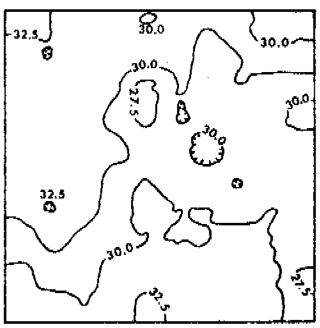
POSITION OF FROST TABLE (DEPTH BELOW GROUND SURFACE IN CMS.)



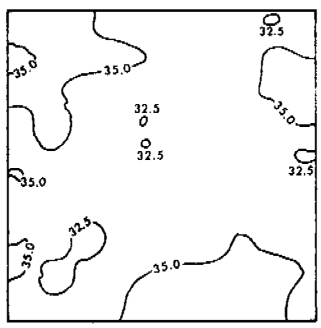
June 18, 1971



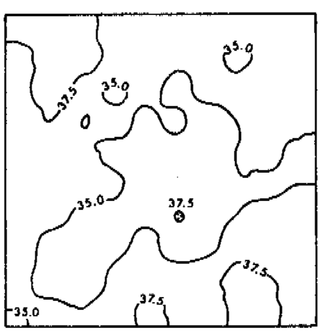
July 2, 1971



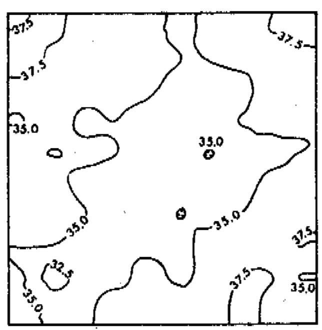
July 16, 1971



July 30, 1971



August 13, 1971



August 25, 1971

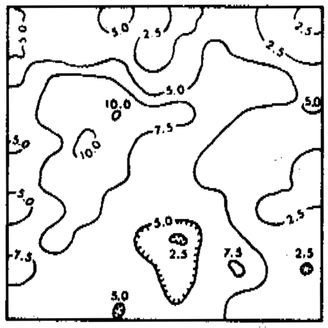
Contour interval 2.5 cms.

dek

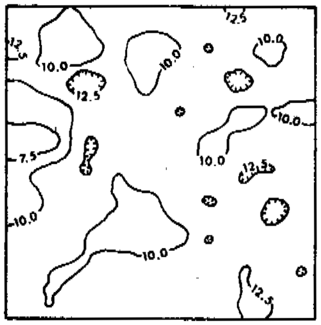
Figure 6

METRE QUADRAT 'C'

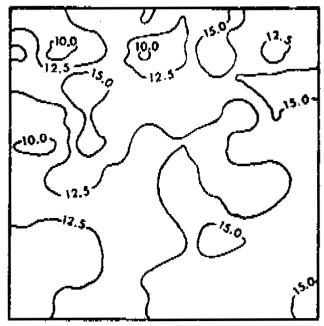
SURFACE CONTOURS ABOVE DATUM



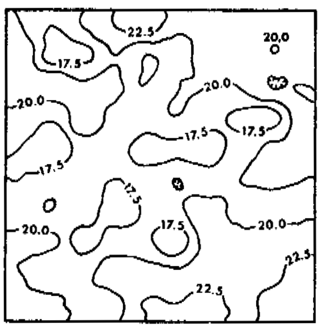
POSITION OF FROST TABLE (DEPTH BELOW GROUND SURFACE IN CMS.)



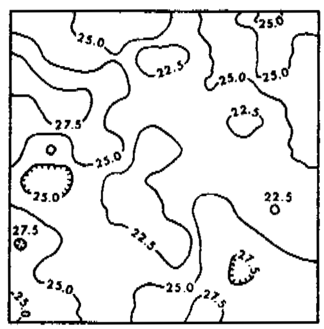
June 18, 1971



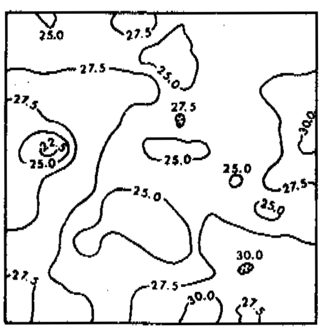
July 2, 1971



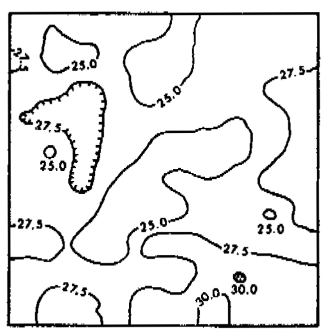
July 16, 1971



July 30, 1971



August 13, 1971



August 25, 1971

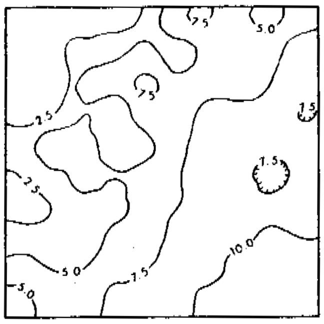
Contour interval 2.5 cms

dek

Figure 7

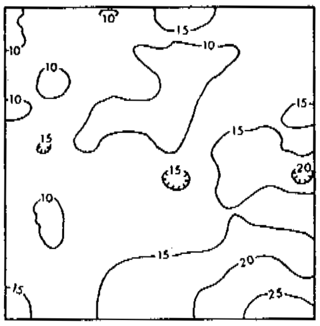
METRE QUADRAT 'D'

SURFACE CONTOURS ABOVE DATUM

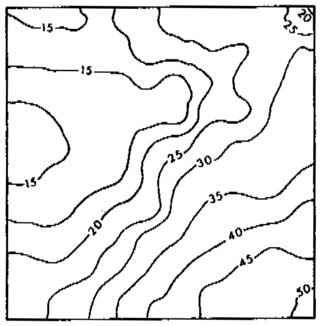


Contour interval ... 2.5 cms.

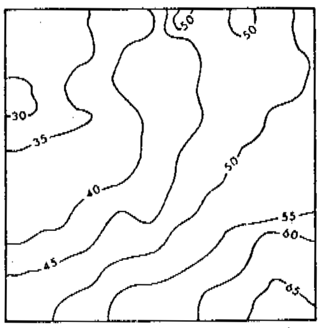
POSITION OF FROST TABLE (DEPTH BELOW GROUND SURFACE IN CMS.)



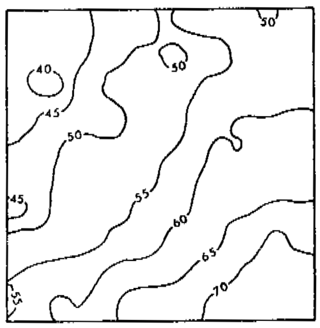
June 18, 1971



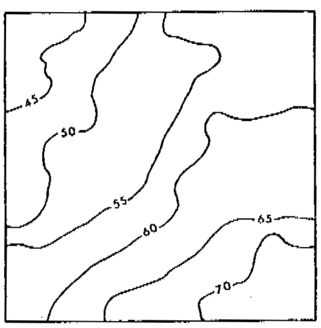
July 2, 1971



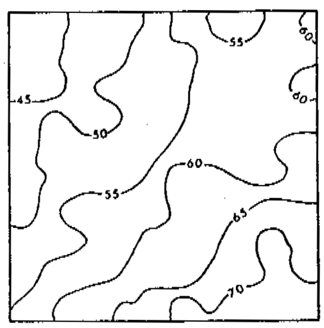
July 16, 1971



July 30, 1971



August 13, 1971



August 25, 1971

Contour interval ... 5 cms.

dek

In the undisturbed sites, variations in the microrelief factor, type of vegetation cover, and amount of organic material in the substrate, combine to impart an irregular topography to the top of the frozen ground. In general, the upper surface of the frozen ground occurs at greater depths under elevated portions of the ground surface, as in the tussock and earth hummock forms, and where the substrate is composed primarily of mineral soil. Conversely, the lowest depths of thaw occur beneath the depressions in the ground surface which also usually correspond to the sites of greater accumulations of organic material. The influence of these factors is reflected in the irregular nature, and number of closed depressions, of the contour patterns for the upper surface of the frozen ground, and the higher coefficient of variation in the depths of thaw (Table II), in the undisturbed sites of Quadrats 'C' and 'D' (Figures 6 and 7). The relative complexities of these contour patterns contrast with the simpler nature of the isolines, indicating a more uniform depth of thaw, exhibited by the quadrats located in the disturbed area (Figures 4 and 5).

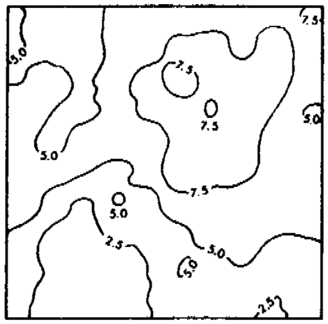
Two of the quadrats were located in and adjacent to the section of the winter road traversing the area of high-centred polygons described in the second depth of thaw transect (Figure 3, Profile II). One of the plots, Quadrat 'E' (Figure 8) was established on the disturbed area, where the ground surface consisted of bare organic material from which the plant cover had been completely removed. The other site, Quadrat 'F' (Figure 9), was established on an undisturbed surface of a polygon where the principal components of the vegetation consisted of lichens and mosses together with a few ericaceous species.

The results obtained from comparative studies of these two quadrats agree closely with the observations in the depth of thaw transect

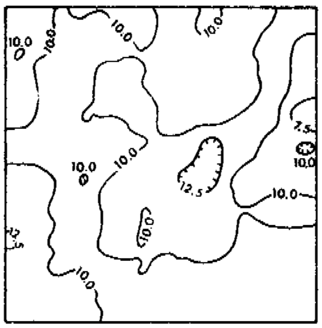
Figure 8

METRE QUADRAT 'E'

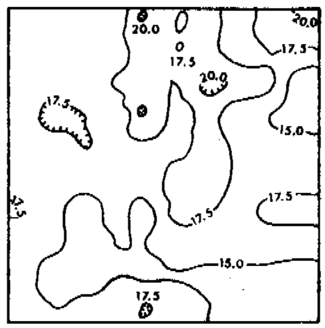
SURFACE CONTOURS ABOVE DATUM



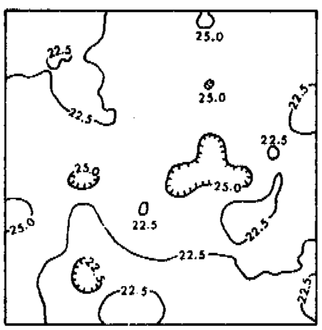
POSITION OF FROST TABLE (DEPTH BELOW GROUND SURFACE IN CMS.)



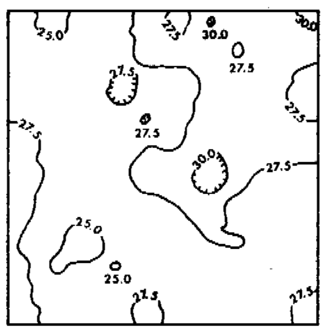
June 18, 1971



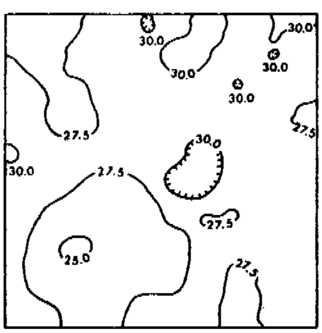
July 2, 1971



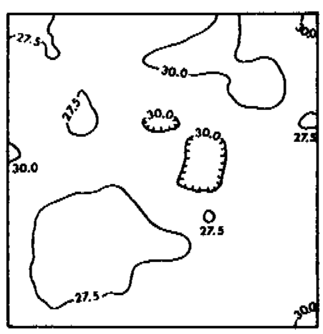
July 16, 1971



July 30, 1971



August 13, 1971



August 25, 1971

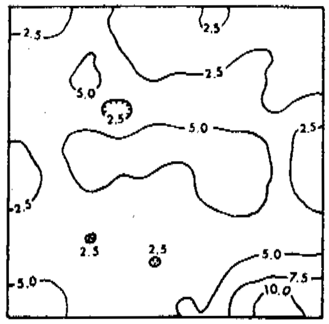
Contour interval ... 2.5 cms.

dek

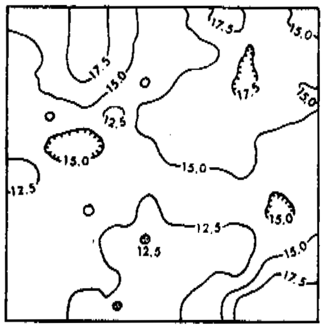
Figure 9

METRE QUADRAT 'F'

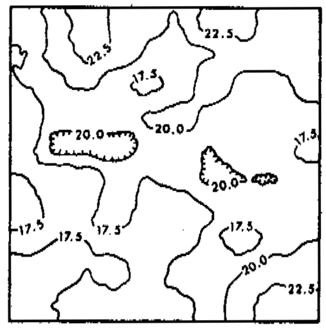
SURFACE CONTOURS ABOVE DATUM



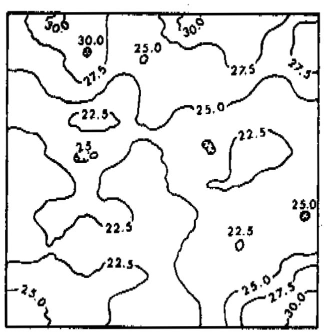
POSITION OF FROST TABLE (DEPTH BELOW GROUND SURFACE IN CMS.)



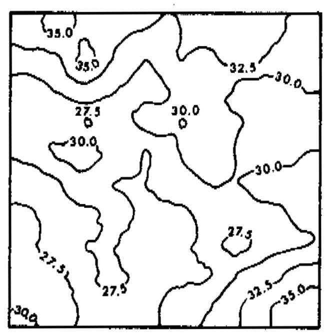
June 18, 1971



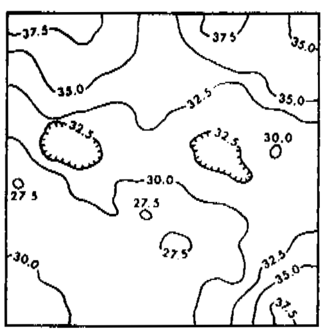
July 2, 1971



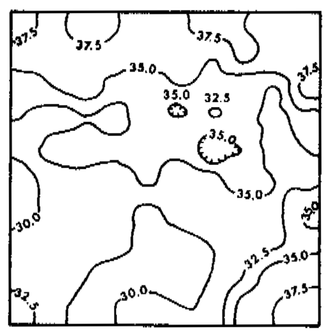
July 16, 1971



July 30, 1971



August 13, 1971



August 25, 1971

Contour interval 2.5 cms.

dek

which was located in the same general area. Throughout the summer, the average thaw penetration in the undisturbed site (Quadrat 'F') was several centimetres greater than that recorded in the undisturbed area. Whereas the transect study indicated that this differential was virtually eliminated by late August, however, the quadrat measurements showed that, at the end of the summer, the average thickness of the active layer in the vegetated site was 4.7 cms, or 16.0 per cent, greater than that beneath the surface of the winter road. As Figures 8 and 9 also show, the greater diversity of the ground surface conditions in the undisturbed site (Quadrat 'F') contributed to a more complex pattern of thaw depths as is indicated by the irregular contour patterns of the frost table illustrated in Figure 9. These patterns again contrast with the much simpler configuration of the upper surface of the frozen ground under the more uniform terrain characteristics of Quadrat 'E' in the winter road site (Figure 8). Further indication of the contrasting nature of the thaw penetrations is contained in Table II, where the coefficient of variation statistics show that, even at the end of the summer, the relative *dispersion* in the depths of thaw in the undisturbed site was exactly twice as much as that in the disturbed area.

The final three quadrats were located in and adjacent to a section of the winter road used for the first time in the winter of 1970-71. Two of the quadrats, Quadrat 'G' (Figure 10) and Quadrat 'H' (Figure 11) were established on the disturbed area. Quadrat 'G' was situated on one of the most severely disrupted sections of the access route, where approximately one-third of the surface area of the plot consisted of exposed mineral soil and the remainder was covered with a layer of loose, shredded organic material. The entire surface of Quadrat 'H' was mantled by a layer of similar organic material which, by late August, supported a sparse

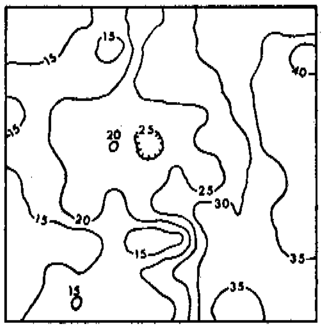
Figure 10

METRE QUADRAT 'G'

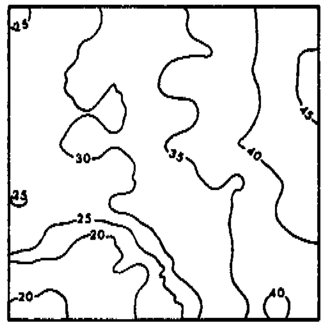
SURFACE CONTOURS ABOVE DATUM

Contour interval ... 2.5 cms.

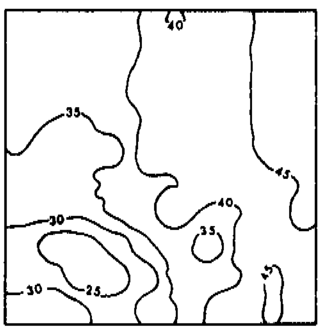
POSITION OF FROST TABLE (DEPTH BELOW GROUND SURFACE IN CMS.)



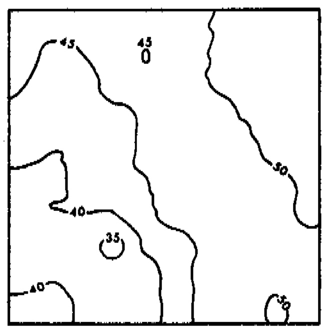
June 18, 1971



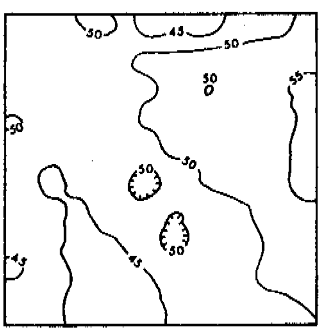
July 2, 1971



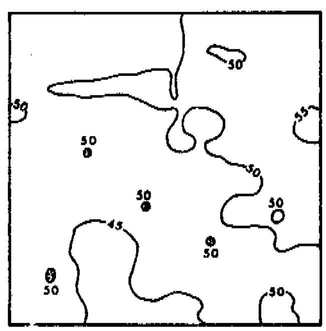
July 16, 1971



July 30, 1971



August 13, 1971



August 25, 1971

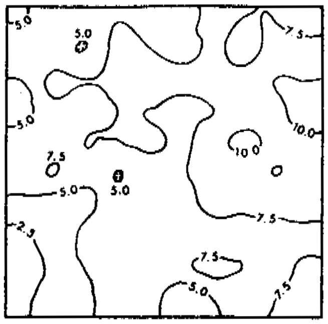
Contour interval ... 5 cms.

dek

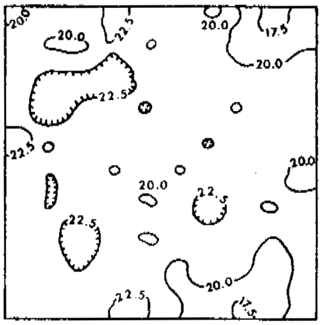
Figure 11

METRE QUADRAT 'H'

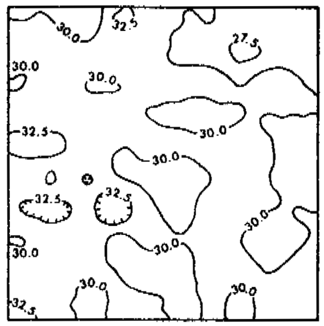
SURFACE CONTOURS ABOVE DATUM



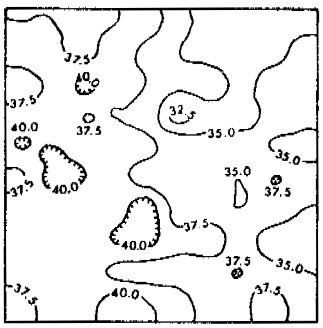
POSITION OF FROST TABLE (DEPTH BELOW GROUND SURFACE IN CMS.)



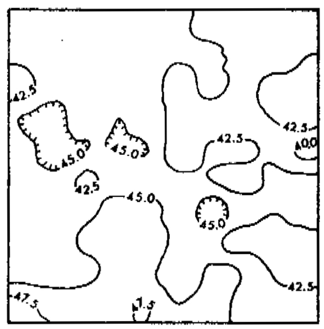
June 18, 1971



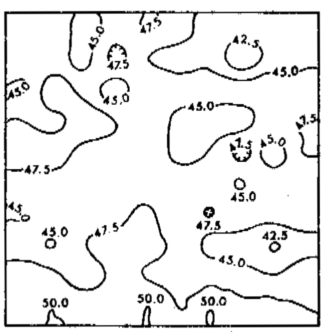
July 2, 1971



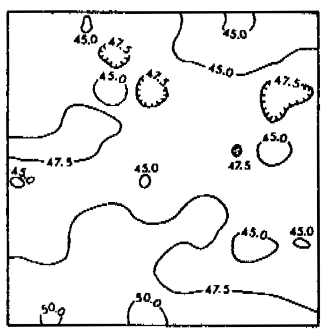
July 16, 1971



July 30, 1971



August 13, 1971



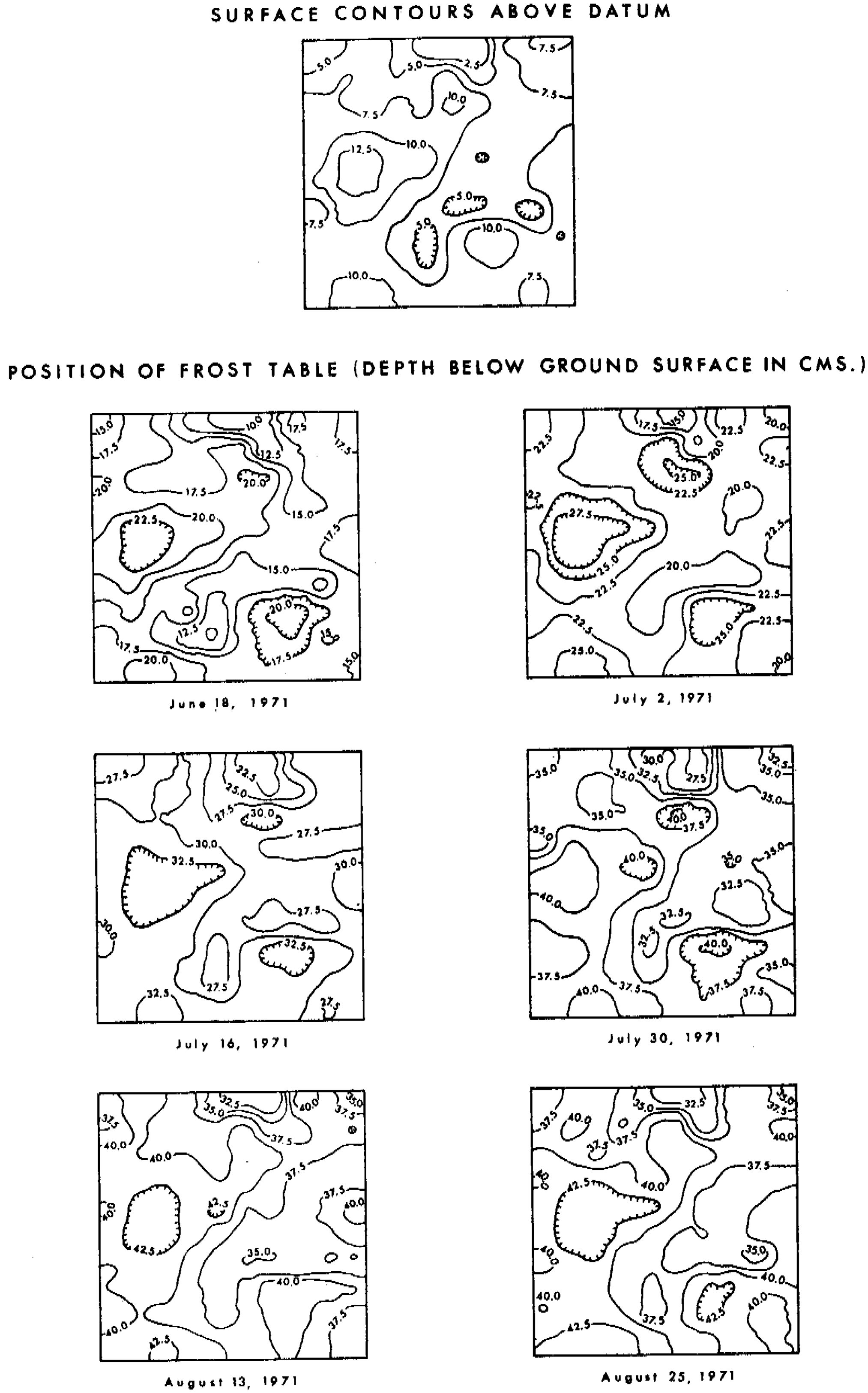
August 25, 1971

Contour interval 2.5 cms

dek

Figure 12

METRE QUADRAT 'J'



Contour interval 2.5 cms.

dek

vegetation cover that included the Sheathed Cotton-grass (*Eriophorum vaginatum*), Cloudberry (*Rubus chamaemorus*), Aquatic Sedge (*Carex aquatilis*), Narrow-leafed Labrador-tea (*Ledum palustre ssp. decumbens*) and *Sphagnum*. The third plot, Quadrat 'J' (Figure 12), was established in the adjacent undisturbed area characterized by Eriophorum tussocks, which accounted for 35-40 per cent of the vascular species present, and subdued earth hummocks which supported such species as the Cloudberry, Glandular Birch (*Betula glandulosa*), Mountain Cranberry (*Vaccinium vitis-idaea*), Common Crowberry (*Empetrum nigrum*) and the Narrow-leafed Labrador-tea. The depressions, between the tussocks and earth hummocks, also contained significant quantities of moss (chiefly *Sphagnum* species) in their vegetation cover.

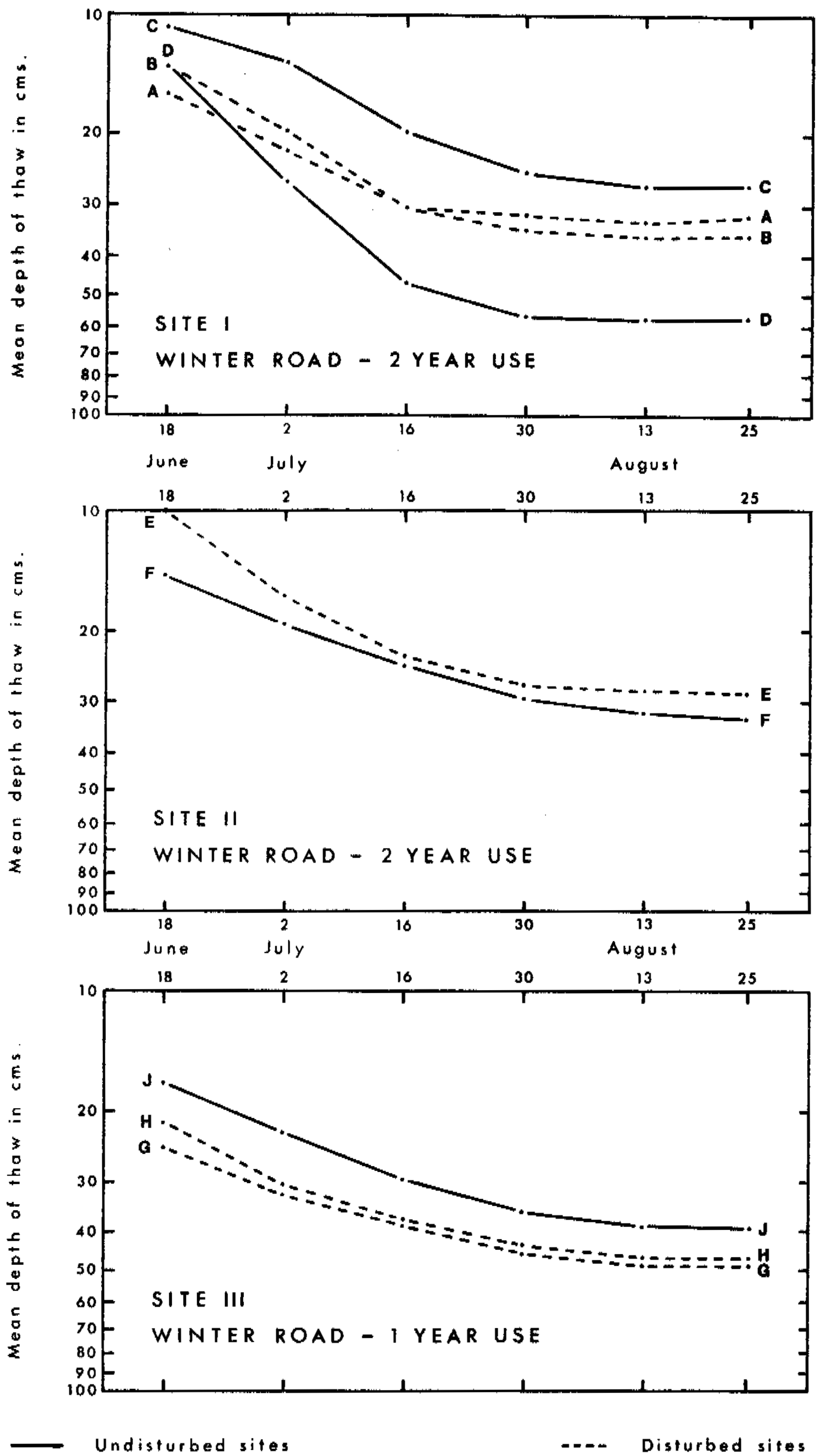
Comparative studies of these three quadrats also agree closely with the results of observations in the depth of thaw transect (Figure 3, Profile III). The thaw penetration proceeded more rapidly, and to greater depths, beneath the darker, unvegetated surfaces of the plots on the winter road, so that by the end of the summer, the mean thickness of the active layer in Quadrats 'G' and 'H' was respectively 9.3 and 7.2 cms, or 23.5 and 18.2 per cent, greater than the average thaw depth in the undisturbed site (Quadrat 'J'). The slightly higher increase in the thickness of the active layer, and the larger relative dispersion of the thaw values (see Table II), in Quadrat 'G', as compared to the other plot (Quadrat 'H') in the disturbed area, can be accounted for by the occurrence of bare mineral soil at the ground surface in this site. As Figures 10-12 show, the influence of changes in the diversity of the surface characteristics is again reflected in the configuration of the upper surface of the frozen ground, with the more complex, irregular contour patterns of the frost table beneath the undisturbed surface forming a marked contrast with the simpler, more uniform thaw depths in the quadrats located on the winter road.

The depth of thaw measurements in the quadrat studies are summarized in Figure 13 which shows the changes in the mean thaw depths for each quadrat over the entire observation period. With the exception of Site II, located on the area of high-centred polygons, and the earth hummock quadrat in Site I, it can readily be observed that the destruction of the vegetation cover and surface microrelief forms, resulting from the construction of the winter roads, has produced a predictable increase in the thaw depths beneath the disturbed areas. However, whereas the observations of the transects indicated that a re-use of the access routes did not contribute to any real intensification of the topographic effects of the terrain disturbance, the data from the quadrat studies would appear to suggest that this is not the case. As Figure 13 illustrates, comparisons with the quadrats located in the undisturbed areas in Sites I and III, indicate that there was a greater increase in the relative thickness of the active layer, amounting to an average of almost 27 per cent, beneath the surface of the winter road that was used for two consecutive years, which compares to an average increase of slightly less than 21 per cent in the thaw depths under the winter road which was used for only one year's operations. Once again, however, in interpreting these measurements it is imperative to note that the limited sample size, the inability to establish the pre-disturbance terrain conditions with any real degree of accuracy, and the absence of information pertaining to the operating conditions, especially such factors as the depth of snow, amounts and types of vehicular activity, place severe limitations on the statistical validity of the data obtained.

Ground Temperature Measurements. To complement the observations on the comparative rate and total depth of thaw in the disturbed and

Figure 13

MEAN DEPTH AND RATE OF THAW IN METRE QUADRATS



adjacent undisturbed sites, two temperature cables, each of which consisted of five thermistors, were installed to monitor variations in the thermal regime of the near-surface soil layers. The cables were encased in lengths of plastic tubing which were sealed to prevent the entry of soil moisture. One of these cables was installed in the central part of a section of a winter road that had been used for two years (see Figure 3, Profile I), where the vegetation cover had been completely destroyed and the mineral soil was overlain by 10-15 cms of pulverized organic material. The other cable was located in an undisturbed site nearby, where the vegetation cover consisted primarily of the tussock forms of the Sheathed Cotton-grass (Eriophorum vaginatum) and mosses (chiefly Sphagnum species).

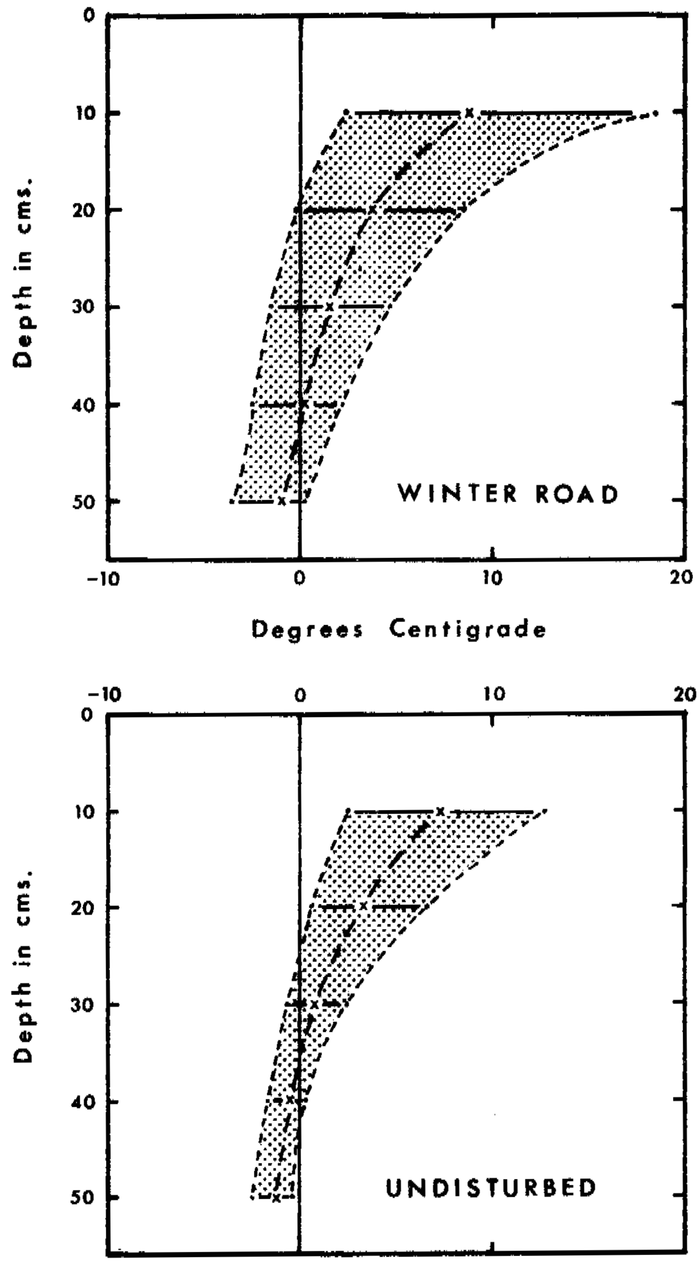
On each of the cables, the uppermost thermistor was placed at a depth of 10 cms beneath the ground surface, and the remaining four thermistors were spaced at intervals of 10 cms to a total depth of 50 cms. With the exception of the thermistor located at a depth of 10 cms below the ground surface in the undisturbed site, which did not function over the period June 29 to July 12 inclusive, the ground temperatures were recorded on a daily basis from June 14 to August 25, 1971. On the latter date, each thermistor was attached to an Arctic Thermograph to provide comparable data over the winter months.

The mean ground temperature profile, and the amplitude of the ground temperature fluctuations, for each site are illustrated in Figure 14. Table III also shows the mean, maximum and minimum ground temperatures, together with the date of occurrence of the maximum and minimum temperatures, recorded by each of the thermistors.

Each site exhibits the typical pattern in which the highest mean and maximum ground temperatures, and the greatest amplitude of ground

Figure 14

MEAN GROUND TEMPERATURES AND GROUND TEMPERATURE FLUCTUATIONS



Levels of Thermistors

Mean Ground Temperature Profile

Amplitude of Ground Temperature Fluctuations

DEK

TABLE III

GROUND TEMPERATURES RECORDED AT DIFFERENT DEPTHS

UNDER A WINTER ROAD AND ADJACENT UNDISTURBED SITE NEAR SHINGLE POINT

(in Degrees Centigrade)

Depth below Surface (Cms.)	Mean	Max.	Date of Max.	Min.	Date of Min.	Amplitude
WINTER ROAD:						
10	8.9	18.5	Aug. 18	2.3	June 14	16.2
	(9.0)	(18.5)	(Aug. 18)	(2.3)	(June 14)	(16.2)
20	3.7	8.6	July 27	-0.1	June 14	8.7
30	1.5	4.7	July 27	-1.5	June 14	6.2
40	0.1	2.2	Aug. 20	-2.4	June 14	4.6
50	-1.0	0.1	Aug. 20*	-3.3	June 14	3.4
UNDISTURBED SITE:						
10**	7.3	12.7	July 27	2.5	Aug. 13	10.2
20	3.1	6.7	July 27	0.7	June 14	6.0
30	0.8	2.5	July 27	-0.7	June 14	3.2
40	-0.4	0.3	Aug. 24	-1.7	June 14	2.0
50	-1.1	-0.4	Aug. 19*	-2.4	June 14	2.0

* Earliest date at which temperature was attained.

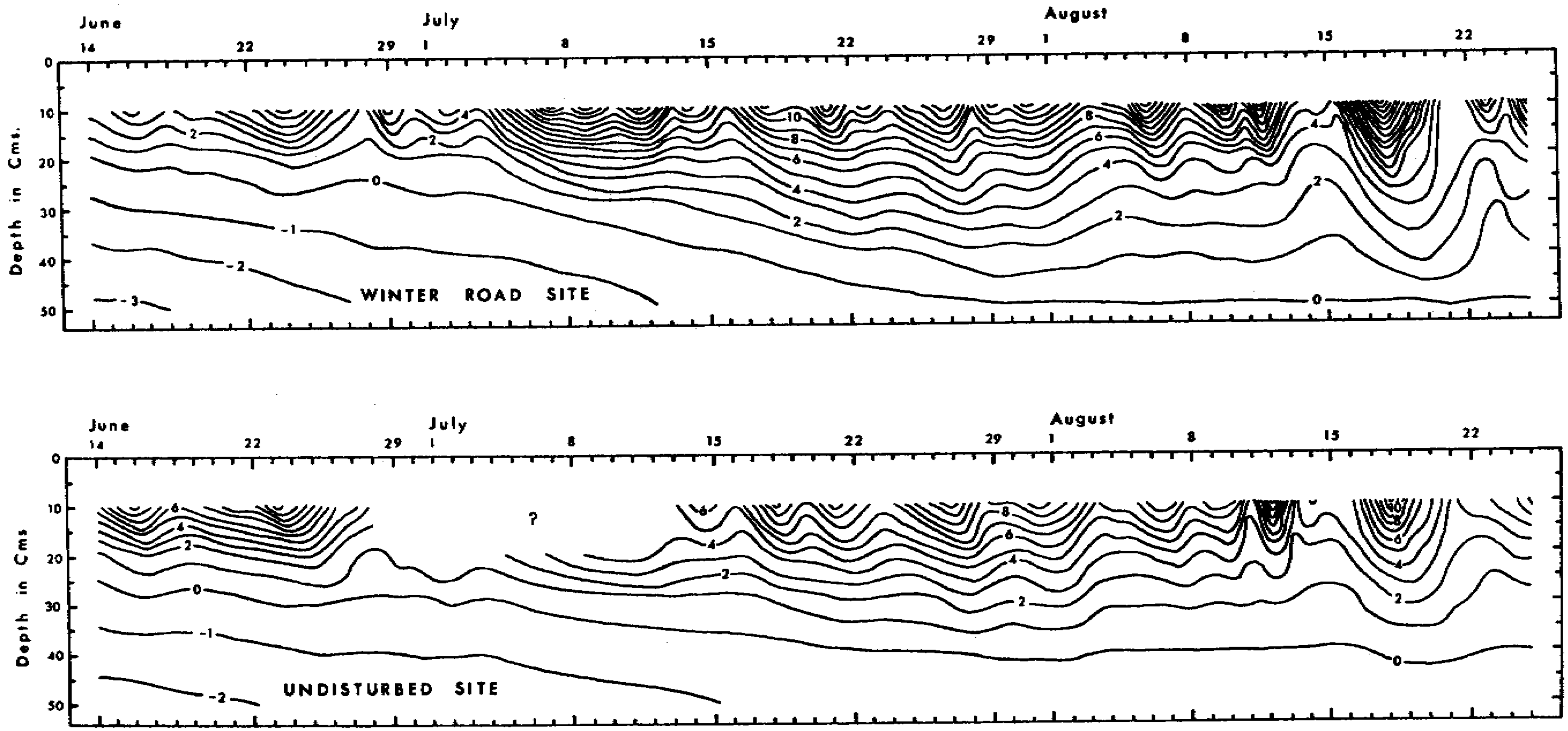
** The ground temperature values for the thermistor located at a depth of 10 cms beneath the undisturbed surface are for the period June 14 - June 28 and July 13 - August 25. Comparable values, for the same time period, for the thermistor located at a similar depth beneath the surface of the winter road are shown in brackets.

temperature fluctuations, were recorded by the thermistors located at the shallowest depths beneath the ground surface. As Table III shows, the mean summer ground temperature at a depth of 10 cms below the disturbed surface of the winter road was approximately 1.7°C higher than that recorded at a comparable depth in the undisturbed site. The near-surface soil layers in the disturbed area also experienced a much greater range of temperature fluctuations, and the maximum recorded temperature of 18.5°C and the range of 16.2°C both represent increases of about 6.0°C over corresponding values measured beneath the vegetation cover. Each site also exhibits the characteristic pattern in which the mean ground temperature, and the amplitude of the temperature fluctuations decrease with increasing depth beneath the ground surface but, as Figure 14 shows, the rate of decrease differed appreciably between the two sites. The most gradual decrease occurred below the surface of the winter road, where the mean ground temperature for the summer months did not fall below 0°C until a depth of 44 cms beneath the surface, and the amplitude of the temperature fluctuations was still in excess of 3°C at a depth of 50 cms. These figures contrast with the much more abrupt rate of decrease in the undisturbed area, where the mean ground temperature reached 0°C at a depth of approximately 35 cms, and amplitudes in excess of 3°C were not experienced below a depth of about 31 cms.

The graphs in Figure 14 and the data in Table III summarize the absolute magnitude of the ground temperature changes at each site over the entire observation period. This general account conceals the number, and depth of penetration, of short-term temperature fluctuations which bear a distinct temporal relationship to changes in the mean daily air temperature. Figure 15 presents a more detailed illustration of these smaller temperature fluctuations by showing the pattern of isotherms in the near-surface soil

Figure 15

GROUND TEMPERATURE PATTERNS IN A WINTER ROAD SITE AND ADJACENT UNDISTURBED SITE (°C)



layers over the same time period.

The near-surface soil layers at each site underwent a number of definite cycles of warming and cooling over time periods ranging from two to seven days. Maximum temperatures achieved during these cycles reflected an almost immediate response to a warming of the ambient air temperatures, with the lag factor involved being generally less than one day in the disturbed area and only slightly longer in the vegetated site. Although the number of cycles was similar at each site, the response was most rapid and the fluctuations were largest beneath the surface of the winter road, where temperature changes of as much as 7-8^{o}C over a 24-hour period were observed at a depth of 10 cms. As in the case of the overall seasonal amplitudes, these short-term cycles generally penetrated to lower depths, and more slowly in the undisturbed as compared to the disturbed site. In both sites, however, most of the fluctuations were damped out completely below depths of 30 cms beneath the ground surface where the thermal regime exhibits a fairly consistent, progressive warming trend, with the extremes of the temperature record occurring at the beginning (coldest) and end (warmest) of the observation period.

The data obtained in the ground temperature studies support the results of the depth of thaw measurements. Just as the destruction of the surface vegetation layer results in a total increase in the depth of thaw to the frost table, so it also influences the ground temperature patterns in the active layer and uppermost parts of the underlying permafrost. The partial or complete removal of the organic material with its important insulating properties, the possible reduction of heat losses from reduced evapotranspiration activity, and the decreased albedo of the exposed peat material, combine to augment the heat input into the ground in the disturbed sites with a concommitant increase in the ground temperatures in the near-surface soil layers.

The small magnitude of the relative increases in the total depth of thaw, averaging only 5.1 cms or less than 20 per cent, and mean summer ground temperatures, less than 2°C, under a winter road that has been used for two consecutive years is rather surprising. In part this may reflect limitations of the sampling procedure with respect to the number of sites investigated, or it may be that the section of the access road to the north of the turn-off was not used very intensively during the winter of 1970-71. Yet another alternative explanation may be contained in the initial part of the temperature record shown in Figure 15, where it can be seen that, throughout the latter half of the month of June and possibly into early July, the ground temperatures recorded at a depth of 10 cms below the undisturbed surface were several degrees warmer than those at a similar depth beneath the surface of the winter road. Although most of the snow had disappeared from the open tundra when the field observations commenced in early June, accumulations in the valleys of the small creeks were still several metres thick. It is possible therefore that there may have been sufficient snowfall during the winter of 1970-71 to render the snow-pack method of winter road construction effective. The development of a substantial thickness of compacted snow on the road could account for the general absence of any pronounced intensification of the topographic effects of the terrain disturbance during the second year of use, and the persistence of this layer of snow could delay the penetration of the summer thaw which could, in turn, account for the lower depths of thaw and ground temperatures observed in the disturbed area during the early part of the summer.

Sitidgi Creek Site.

The second site selected for investigations of winter road operations was located at about longitude 132° 49' W and latitude 68° 40' N, near the outflow of Sitidgi Lake into Sitidgi Creek. In the absence of any official record of the history of the resource exploration activities at this site, an attempt was made to establish the sequence of events through discussions with local residents in Inuvik. Since this area is important in the recreational patterns for many of these residents, and there is a fishing lodge on the lake at the site, the following account is probably quite accurate although the specific years mentioned may be questionable.

The terrain disturbances at Sitidgi Creek appear to represent the cumulative effects of at least three separate periods of activity. Although some residents thought that the area may have been used as an access route at an earlier date, the first of these periods of activity appears to have been in the winter of 1964-65, or 1965-66, when the French company, Petropar, constructed an access route to move equipment and supplies for their winter seismic operations in the vicinity of the Anderson River. Whether or not the crews simply attempted to scrape up additional supplies of snow from the adjacent tundra, or deliberately bladed away the organic layer, to build up the surface of the winter road is not known, but there is no doubt that the method of construction employed resulted in a complete removal of the surficial organic layer. The exposure of the mineral soil led to pronounced thermokarst development during the following summer thaw. There is also no doubt that this thermokarst development, which is responsible for the most severe aspects of the terrain damage, had already taken place before the second identifiable period of activity which occurred in 1966. In this year, Imperial Oil Limited located a winter seismic line along exactly the same route, and the existence of shot-holes, which are still open at the ground surface, on the floor of the settled areas testifies to the fact that the subsidence had already taken place prior to this date. The third, and most recent, activity contributing to the terrain disturbance at this point occurred in 1968-69, or 1969-70, when Gulf Oil Canada Limited also used this same route as an access road for their winter seismic operations.

It is impossible to ascertain as to whether or not these second and third uses of the same winter road resulted in any further intensification of the topographic effects of the terrain disturbance, but they did, in all probability, retard the rate of re-establishment of the plant cover. In any case, this re-use of the same access route for a second and third occasion, thereby compounding the degree of disturbance or prolonging the time period required for recovery of the vegetation, raises an important question with respect to the Land Use Regulations which require that any company make use of existing 'lines' or 'rights of way' wherever possible. In view of the severity of the damage to the tundra which resulted from the construction of the first winter road in the Sitidgi Creek area, it may be argued that this question is of minor relevance, but additional examples, to be referred to later in the report, from this and other areas will also serve to illustrate some of the ambiguities in this regulation.

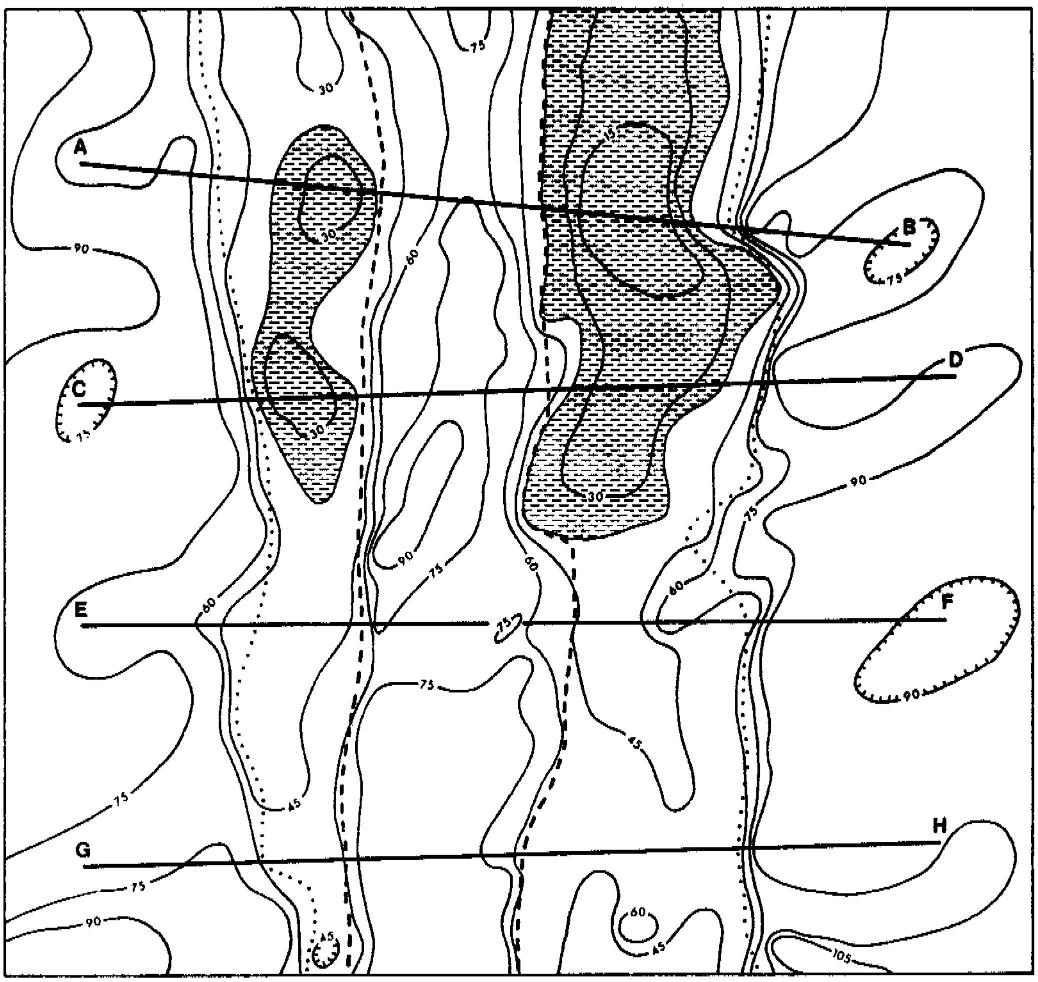
The field investigations at the Sitidgi Creek site included the surveying of a section, 30 metres in length, of the winter road to prepare a contour map illustrating the topographic aspects of the terrain disturbance. Eight transects, or profiles, were also established across various parts of the access route to illustrate comparative changes in the thickness of the active layer in the disturbed and undisturbed areas. As at the Shingle Point site, described earlier (p. 9), bench marks were installed on these transects to assist in the detection of any subsequent, long-term changes in the position of the upper surface of the frozen ground, and, in particular, to see whether any future establishment of a continuous vegetation cover is reflected in a corresponding aggradation of the permafrost table. Six of the transects were also selected to examine the precise role of thermokarst action in the development of the topography of the disturbed area, and drill core samples were collected for analyses of their ice content.

The topographic features of a section of the winter road are illustrated in the contour map of Figure 16. The main disturbed area, ranging from 15-20 metres in width, can be subdivided into three distinct units. The first of these, the winter road itself, consists of a narrow ridge-like feature, averaging 5-7 metres across, and accounts for approximately one-third of the total width of the damaged area. The road is bounded on either side by the other two units, varying from 5-8 metres and 3-4 metres across on the eastern and western sides of the road respectively, which delimit the areas from which the organic layer was either inadvertently or deliberately removed. The exposure of the mineral soil in these sections has been followed by a subsidence of the ground surface, so that the floors of the settled areas are now as much as 90-100 cms below the level of the surfaces of the winter road and adjacent undisturbed terrain. As Figure 16 also indicates, many of the depressions in the floors of these subsided areas are occupied by pools of standing water which are several metres in length and as much as 30 cms deep. On either side of the main disturbed area, and particularly to the east, and extending for distances of up to 1-2 metres, the ground surface has been buried beneath a

Figure 16

WINTER ROAD

NEAR SITIDGI CREEK



...... Edge of bulldozed area

--- Edge of winter road

Water

A—B Profile lines

Scale in metres

0 5 10

Contour interval 15 cms.

dek

litter of bulldozed organic material.

The undisturbed terrain was characterized by the development of small earth hummock structures, up to 50-60 cms across and in the order of 15-20 cms high. The most important vascular species represented in the vegetation cover of these areas included the Glandular Birch (Betula glandulosa), Mountain Cranberry (Vaccinium vitis-idaea), Narrow-leafed Labrador-tea (Ledum palustre ssp. decumbens), Cloudberry (Rubus chamaemorus), Common Crowberry (Empetrum nigrum) and Lapland Butterbur (Petasites frigidus), together with occasional tussocks of the Sheathed Cotton-grass (Eriophorum vaginatum). In many parts, however, extensive mats of lichen (especially Cetraria and Cladonia species) and moss provided the dominant form of ground cover.

In contrast to these areas, the surface of the winter road was largely devoid of any living plant cover, and most of the road surface consisted of loose accumulations, as much as 20-25 cms thick in places, of dead organic litter. The floors of the trenches, on either side of the winter road, contained large expanses of bare, compacted mineral soil, whilst the moister areas often supported a flourishing growth of grasses and sedges (principally Arctagrostis, Calamagrostis and Eriophorum species) which, in places, were as much as 50-70 cms tall. These disturbed sites were also characterized by increased percentages of Cloudberry and the Lapland Butterbur in the plant species composition.

Further examples of the magnitude of the topographic effects associated with the terrain disturbance at Sitidgi Creek are illustrated in the profiles contained in Figures 17 and 18, which also show the position of the upper surface of the frozen ground when the site was visited in the middle of July. The locations of the four profiles in Figure 17 are

Figure 17

WINTER ROAD NEAR SITIDGI CREEK

PROFILES I – IV

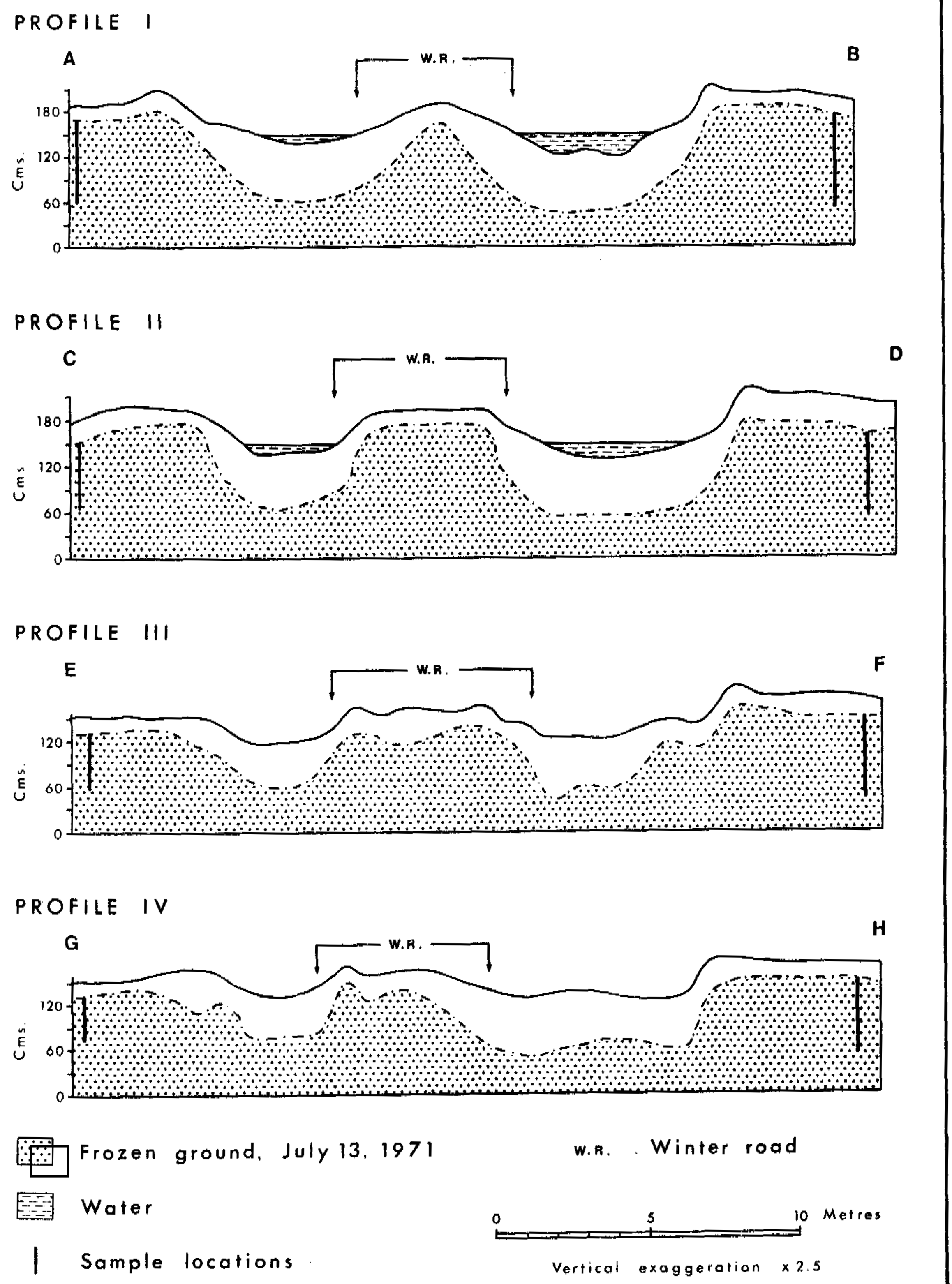
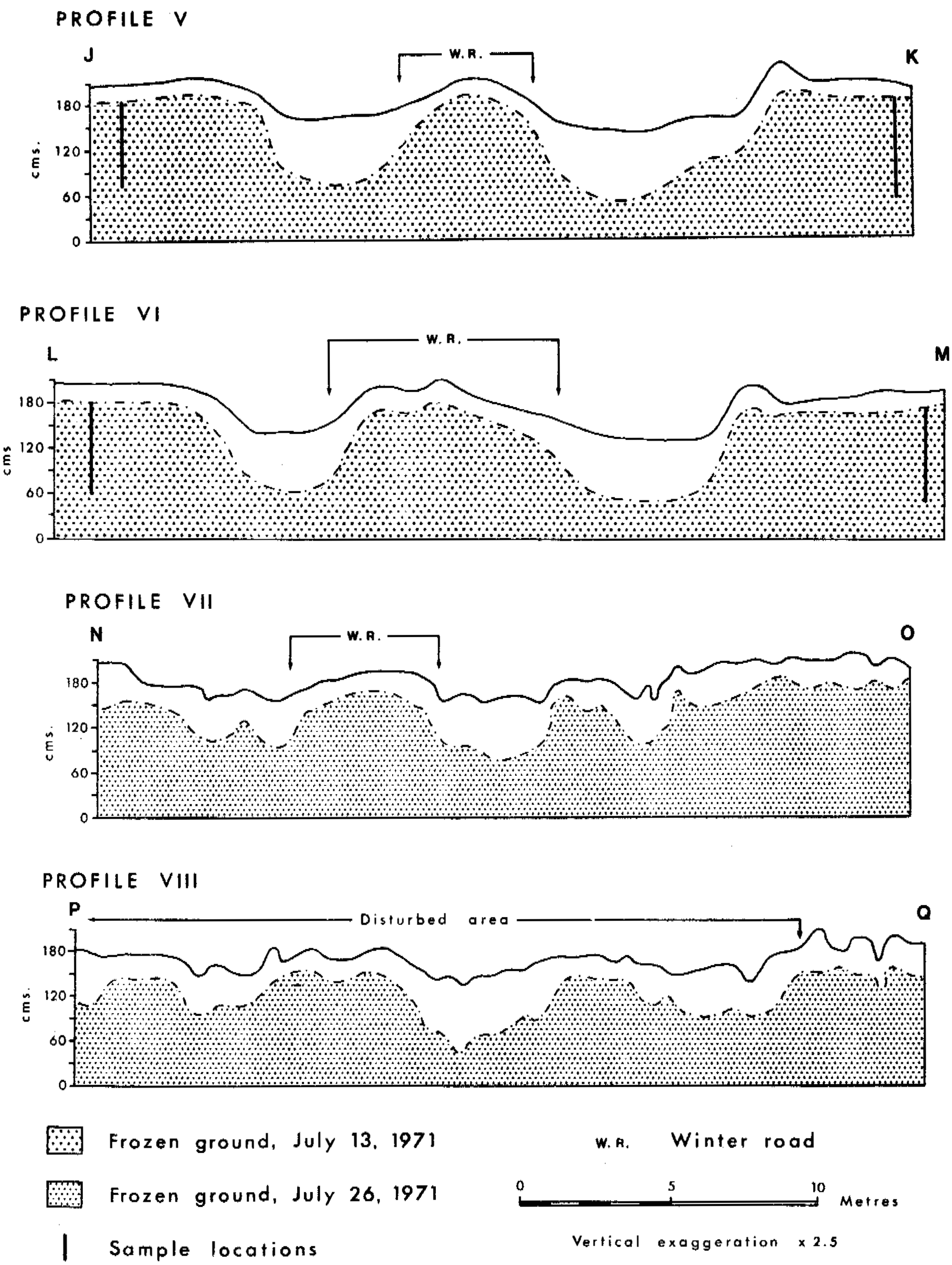


Figure 18

WINTER ROAD NEAR SITIDGI CREEK

PROFILES V–VIII



indicated on the contour map of Figure 16. Profiles V and VI (Figure 18) represent two additional transects across the winter road immediately to the south of the area shown in Figure 16. Profiles VII and VIII (Figure 18) characterize a rather different type of disturbance found nearer to the actual creek crossing located just to the north of the same area.

The effects of the removal of the surface organic layer on the position of the frost table is evident in each of these transects, where it can be seen that the average thickness of the thawed layer in the undisturbed areas was 20-30 cms. The mean thaw depths under the surface of the winter road showed no appreciable difference as compared to the undisturbed sites, and this can possibly be attributed to the insulating properties of the additional organic material which was placed along the line of the road. Indeed, the lower thaw values associated with certain sections of the access route may indicate that there has been a slight rise in the permafrost table in these areas. In contrast to this, the depth of thaw measurements across the floors of the settled areas indicate a substantial degradation or lowering of the upper surface of the frozen ground. The thickness of the thawed layer in these areas typically ranged from 50-70 cms in the bare mineral soil sections, to more than one metre in and adjacent to the pools of water. In the extreme cases, these values represent increases in excess of 300 per cent over the maximum thaw depths recorded in the undisturbed areas.

The general appearance of the terrain disturbance exhibited by this section of winter road near Sitidgi Creek is similar to the many miles of 1965 bulldozed summer seismic lines on the Tuktoyaktuk Peninsula. (The principal difference is the absence of any prominent ridge of bulldozed material along the outer edges of the disturbed area associated with the winter road). The transformation of these seismic lines into shallow trenches or canals over much of their length has been cited as proof of the dangers of chronic erosion by surface water moving along the lines, and there appears to be a general reluctance, by some writers, to accept the fact that thermokarst development is frequently the primary explanation for the transformations.

Data obtained from the measurement of individual blocks of material lying loose along the margins of the disturbed area and the edges of the winter road, suggest that a layer of organic material, averaging less than 10-13 cms in thickness, was removed from the bladed area during the initial construction of the winter road. In places, the floors of the depressed areas are now almost one metre below the level of the adjacent undisturbed terrain. The absence of any signs of surface erosion by running water, leads to the conclusion that any accentuation of the topographic effects of the disturbance must have been the result of thermokarst subsidence. In order to verify this conclusion, the comparative measurements of the depth of thaw in the disturbed and immediately adjacent undisturbed sites were used to provide an approximation of the amount of relative displacement of the frost table created by the damage to the terrain. Drill core samples, the lengths of which corresponded to the displacement values obtained, were then collected from the frozen substrate in the undisturbed areas as shown in Profiles I - VI (Figures 17 and 18). Analyses of the ice content of these samples provided a measure of the potential amount of thermokarst subsidence that could be expected as a result of a thawing of these columns of material, and these values were compared to the estimated amount of settlement of the ground surface as recorded in the topographic profiles.

Data pertaining to the drill core samples, together with calculations of the thermokarst potential, are presented in Table IV, together with the estimates of the settling of the ground surface obtained from the profile studies. The average volume of each of the twelve samples collected was almost 500 ccs, of which an average of 83.5 per cent consisted of ice. A combination of this value with a calculated mean lowering of the frost table of about 101 cms, is enough to provide for an average settling of the ground surface of 84 cms if complete thermokarst subsidence were to occur. Estimates of the amount of settling of the ground surface that has occurred range from 35-90 cms, and yield an average of slightly more than 64 cms. As Table IV shows, the potential for thermokarst subsidence indicated by individual samples, in each case, exceeds the estimated amount of lowering of the ground surface that has taken place by values ranging from 5.0 to 38.0 cms. Although the waterlogged nature of the disturbed sites suggests that the thermokarst subsidence did not achieve its maximum potential in many areas (i.e. much of the water remained in the pore spaces of the soil), and despite the inherent inaccuracies of the method employed (principally in the form of inaccurate estimates of the height of the original ground surface), the results obtained would appear to justify the conclusion that the lowering of the ground surface in the disturbed areas can be attributed solely to thermokarst subsidence.

Each phase of the resource exploration activity in the Sitidgi Creek area was faced with the problem of constructing an access route across the creek. The strength of the outflow from Sitidgi Lake is such that the channel does not freeze over during the winter months, and the absence of an ice cover necessitated the dumping of large quantities of snow into the creek to form a bridge. The rapid removal of much of this material by the

TABLE IV

ICE CONTENTS OF SAMPLES TAKEN FROM UNDISTURBED SITES ADJACENT TO A WINTER ROAD NEAR SITIDGI CREEK

	Sample	Sample Volume (ccs)	Volume of Ice (ccs)	Ice Content (%)	Drill Core Length (Cms)	Thermokarst Potential (Cms)	Ground Subsidence (Cms)
Profile I	A	515.6	436.6	84.7	105	88.9	65
	B	584.3	513.0	87.7	119	104.4	90
Profile II	C	417.6	319.6	76.5	85	65.0	60
	D	505.7	409.4	80.9	103	83.3	80
Profile III	E	353.5	324.8	91.9	72	66.2	45
	F	510.6	417.2	81.7	104	85.0	55
Profile IV	G	270.1	239.4	88.6	55	48.7	35
	H	486.1	395.3	81.3	99	80.5	65
Profile V	J	554.8	436.0	78.6	113	88.8	55
	K	618.7	581.8	94.0	126	118.4	80
Profile VI	L	613.8	474.9	77.4	125	96.8	75
	M	525.4	412.3	78.5	107	84.0	65
	Average	496.4	413.4	83.5	101	84.2	64

flow of the river contributed to a further increase in the amount of snow that had to be scraped from the adjacent tundra on either side of the stream. Although each of these efforts was temporarily frustrated by the velocity of the flowing water, Imperial Oil built such a strong bridge in 1966 that it required the use of dynamite for its eventual removal, and the explosion produced a local widening of the creek of almost 50 per cent.

The repeated attempts to obtain adequate supplies of snow fill for the bridge crossing have increased the areal extent of the terrain disturbance immediately adjacent to the creek. Whereas the width of the damaged area associated with the actual winter road averages approximately 20 metres, the disturbed area closer to the creek banks is anywhere from 60 to 100 metres across. Profiles VII and VIII (Figure 18), illustrate some aspects of the terrain disturbance in these areas. In Profile VII, it is still possible to detect the line of the winter road, but in Profile VIII, the route of the access road is virtually indistinguishable from the disturbed areas on either side. The scraping of snow from the tundra was inevitably accompanied by a removal of some of the organic material. As Profiles VII and VIII show, however, the destruction of the organic layer was not as severe as in the winter road location, and the effects of thermokarst subsidence are not as pronounced. Qualitative assessments would suggest that the ground surface in these areas has been lowered by an average of 25-35 cms relative to the level of the undisturbed terrain. In the most extreme cases, where the organic cover was removed completely, there has been a total collapse of the hummock structures and settling has resulted in the formation of small pits or depressions in the ground surface. The thaw penetration in the bare mineral soil of these areas reached depths of 86 cms, which was almost twice as great as the maximum value recorded in the undisturbed hummocks. Elsewhere, much of the vegetation appeared to have been killed, rather than removed, and the average thaw depths in these disturbed areas were approximately 30-35 per cent in excess of those in the adjacent undisturbed sites.

The terrain disturbances associated with the winter road operations in the vicinity of Sitidgi Creek demonstrate the extreme form of damage that can result when the surface organic layer is destroyed to a point where pronounced thermokarst subsidence will take place. Although the major aspects of the damage to the tundra appear to have resulted from extreme carelessness during the construction of the first winter road at this site, it is quite conceivable that a similar level of disturbance could have developed over a longer period of time, by a repeated usage of the same route,which is encouraged in the present Land Use Regulations.

The sequence of events at Sitidgi Creek also raised questions pertaining to the adequacy of the planning procedures used by the resource exploration industry in the selection of routes for the winter roads. The problems of having to cross the open water of Sitidgi Creek could have been anticipated, either as a result of discussions with local residents in Inuvik or on the basis of difficulties encountered by the previous attempts to bridge the stream, and modifications of the programmes, or at least their timing, might have been introduced. For example, scheduling the movements for later in the winter when the ice thickness on Sitidgi Lake is capable of supporting vehicles, might have been possible. Furthermore, the high ice content of the frozen ground in this area is apparent in the slumping along the shore of Sitidgi Lake, and this should have indicated the need for extreme caution if thermokarst subsidence were to be avoided.

Jimmy Lake Site.

The third site selected for investigations of winter road operations was located at about longitude 133° 47' W and latitude 68° 40' N, a few miles to the west of Jimmy Lake. The section of winter road studied was used in the winter of 1969-70 to move a drilling rig, camp and supplies from the Gulf P-60 rig site to the location of their C-38 well. The same access route was used to move the rig southward, in the winter of 1970-71, to the A-01 well site in the Caribou Hills area just south of Reindeer Station. This re-use of the winter road for two consecutive years is thus comparable to the situation at Shingle Point, described earlier in this report. Whereas the winter road at Shingle Point was constructed using the conventional snow packing technique, the access route in the Jimmy Lake area was an ice road, and it was hoped that these observations would permit comparative evaluations of the two methods of construction employed in terms of their impact on the tundra landscape.

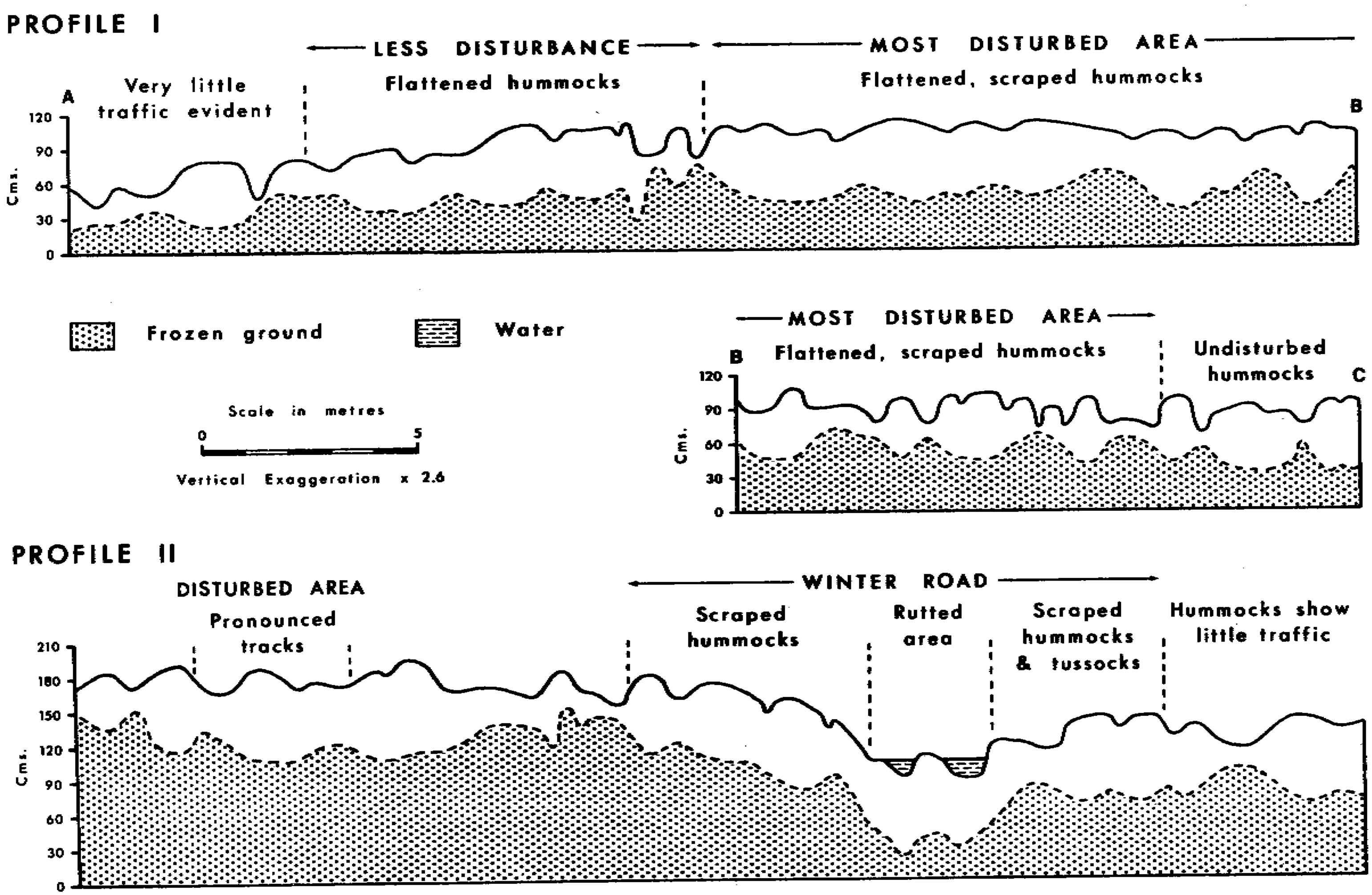
The first stage in the construction of the Gulf winter road involved using a tracked vehicle to drag a beam along the proposed route to fill in most of the depressions in the ground surface with snow, and create a relatively smooth surface. Flat-tracked vehicles, with water tanks mounted on the back, were then used to spray water on the surface of the road, and this procedure was repeated several times until a layer of ice was developed which was capable of supporting a similar water truck mounted on wheels. This vehicle was then used to spray additional quantities of water on the road surface until the layer of ice was strong enough to support the heavier wheeled vehicles used to transport the drilling rig. Throughout the earlier part of the winter, a route was selected which followed the areas of higher ground and detours were made around the major water bodies. Later in the winter, as the thickness of ice on the lakes increased, many of these detours were abandoned in favour of more direct routes across the lakes.

A helicopter surveillance was made along the entire length of the ice road, and Profile I (Figure 19) represents a transect across a typical section of the road immediately north of the P-60 well site. The undisturbed terrain in the vicinity of the profile was characterized by the development of prominent earth hummocks, one to two metres across, with the hummock centres rising 25-35 cms above the levels of the intervening depressions. The principal vascular species growing in these sites included the Glandular Birch (Betula glandulosa), Arctic Blueberry (Vaccinium uliginosum), Mountain Cranberry (Vaccinium vitis-idaea), Common Crowberry (Empetrum nigrum), Narrow-leafed Labrador-tea (Ledum palustre ssp. decumbens), Arctic Lupin (Lupinus arcticus) and Alpine Bearberry (Arctostaphylos rubra), together with Salix species and a ground cover of mosses and lichens. When the site was visited in early August, the maximum depths of thaw in the hummock centres ranged from 50-65 cms, and in the inter-hummock depressions the frost table was encountered at depths varying from 12-25 cms below the ground surface.

As Profile I (Figure 19) shows, the total width of the disturbed area was approximately 34 metres, but the degree of damage to the tundra varied considerably across the road. The main disturbance, covering a width of almost 16 metres, consisted of scraped and flattened hummocks from which some of the organic material had been removed. The majority of the hummock structures were still intact, however, and a major factor contributing to the subdued microrelief in this section of the transect was the infilling of the inter-hummock depressions with loose organic debris. Many of the hummock surfaces consisted of bare organic material, but there was a noticeable lack of any extensive areas of exposed mineral soil. Although

Figure 19

WINTER ROAD NEAR JIMMY LAKE



dek

there were few plants growing on the scraped hummocks, the intervening depressions supported pockets of vegetation which, compared to the undisturbed sites, contained greater percentages of grasses in their plant species composition. Profile I (Figure 19) also shows that the terrain disturbance had had relatively little effect on the thickness of the active layer. The maximum thaw penetration in the scraped hummocks was only 68 cms, which was less than 5 per cent greater than the value recorded in the undisturbed site.

The lesser used areas adjacent to the main section of the road exhibited correspondingly fewer signs of disturbance. Some of the more prominent hummocks showed obvious signs of flattening and there were occasional patches of bare organic material. Some of the depressions also appeared to have been widened as a result of a compression of material on the sides of the hummocks. Apart from a slight reduction in the amount and height of the shrub layer, the vegetation cover of these areas appeared to have suffered minimal disruption. The depths of thaw in these parts of the winter road also showed no appreciable differences from those in the adjacent undisturbed sites.

The type of terrain disturbance exemplified by the transect in Profile I is characteristic of most of the length of the access route, and the low degree of damage involved indicates the value of this method of winter road construction. It would seem appropriate, therefore, to encourage a more frequent adoption of this method, particularly if any inadequacy in the thickness of the snow cover threatens to limit the effectiveness of the snow packing technique, or if it is proposed to use the same access route for more than one winter's operations.

Attempts to locate the route of the Gulf ice road were complicated by the absence of any maps, showing the position of the road, and the maze of lines traversing the tundra landscape in this area. The reconnaissance surveys revealed the existence of one set of lines which indicated an excessive degree of damage to the terrain. Over much of its length, this route consisted of two prominent ruts of black organic material which, in wetter areas, contained substantial quantities of standing water. In some areas, however, the number of ruts increased to as many as twelve and, even worse, in a few places extensive slumping had occurred and widespread thermokarst subsidence had been initiated.

The route of these trails intersected the line of the Gulf ice road a few miles to the south of the P-60 well site, and Profile II (Figure 19) represents a transect across the combined routes just south of the intersection. This particular location was selected because it illustrated the differences in the type of terrain disturbance resulting from the use of the ice road and the newer route. The area traversed by the winter road in this second transect was similar in its microrelief features and vegetation cover to that described for the profile study above, with the exception that the greater availability of water at this second site was reflected in the presence of such species as the Sheathed Cotton-grass (Eriophorum vaginatum) and the Lapland Butterbur (Petasites frigidus). Apart from the existence of a number of broken tussocks, the terrain disturbances associated with the winter road were also similar to those described for the first transect, consisting primarily of flattened and scraped hummocks and exposures of bare organic material.

As Profile II (Figure 19) shows, the level of damage incurred along the route of the ice road was relatively insignificant compared to the disturbances associated with the two parallel tracks of the additional trail. In the most heavily damaged area, where the new trail traversed the route of the older ice road, the disturbance was characterized by two prominent ruts, covering a total width of about 3 metres and ranging from 30-50 cms in depth, which were filled with 15-20 cms of standing water. All of the vegetation had been completely destroyed in this section, and bare mineral soil was exposed along the ridge formed between the lines of the main tracks. The thickness of the thawed layer beneath the rutted area averaged 65-70 cms, which represents an increase of 10-15 cms over the mean values recorded in other parts of the winter road and the adjacent undisturbed sites. The greater thaw depths, combined with the lower level of the ground surface in the ruts, indicate that there has been a marked degradation of the upper surface of the frozen ground following the disturbance.

A second trail, traversing undisturbed terrain adjacent to the line of the winter road (Figure 19, Profile II), exhibited less severe forms of damage to the tundra, but the lines of the tracks were also evident in the shape of prominent ruts. The entire organic layer had also been removed from the tops of the larger hummocks, and parts of the route, immediately adjacent to the transect, revealed that large blocks of organic material and mineral soil, as much as one metre across and 30-35 cms thick, had been dislodged during the passage of the vehicles.

Even though sections of the newer route exhibited more severe levels of terrain disturbance than those shown in Figure 19, Profile II, this field evidence does indicate that more physical damage to the tundra was incurred during a single passage of these vehicles than in two years' use of the winter road. As far as we can ascertain, this damage was the result of two crews moving southward, from the Tuktoyaktuk Peninsula to Inuvik, after the spring thaw had commenced. Such movements, involving heavy vehicles (bulldozers), constitute a blatant violation of the stipulations of the Land Use Regulations. It is also understood that these crews requested permission to travel along the route of the Gulf winter road and that, although this request was denied, at least one crew did follow the line of the road in places.

The above sequence of events, if correct, is further evidence for the need to clear up some of the inadequacies or ambiguities of the Land Use Regulation which encourages a company to make use of an existing line or right of way wherever possible. If the regulations are to have any real meaning, and are to be enforced properly, any individual company must be held responsible for any damage to the terrain incurred as a result of its operations on the tundra. This should also include the requirement that these companies be made to take any appropriate restorative measures if the level of disturbance is deemed to be excessive by the land use inspectors. In theory, therefore, the terrain disturbances associated with the use of the winter road should be the responsibility of Gulf Oil Canada Limited, but it is known that this company was not responsible for the severe damage which has occurred along certain sections of the route. Clearly, such matters as the extent of this responsibility, the period over which it applies, and the right to control movements of other companies along the lines, require further consideration if the type of damage that has occurred in the Jimmy Lake area is to be prevented in the future.

SUMMER SEISMIC OPERATIONS

In a recent article describing the effects of oil exploration activity on the tundra landscape in the vicinity of the Mackenzie Delta, Kevan concludes that all cross-tundra traffic should be prohibited on the unfrozen tundra and when air temperatures at the ground exceed freezing.[1] There is little doubt that the primary basis for this argument consists of the miles of 1965 summer seismic lines bulldozed across the tundra landscape of the Tuktoyaktuk Peninsula. In this area, the complete removal of the active layer, and the insulating vegetation cover in particular, by the bulldozers exposed high ice-content sediments in the upper part of the permafrost, and subsequent thermokarst development has transformed the original seismic lines into shallow trenches or canals over much of their length. This unquestionable evidence of unnecessary, excessive damage to the tundra, combined with prevailing, though often unsubstantiated, concepts of the fragility or vulnerability of the arctic environment, appears to explain why seismic operations in the Mackenzie Delta area are primarily restricted to the winter months.

Although a subjective basis for the restricted exploration activity in the summer months is quite easily derived, the quest for a more objective rationale for the decision constitutes a much more difficult task. As with most aspects of oil and gas exploration in arctic Canada, many of the reports published to date have tended to give undue emphasis to the more severe examples of tundra damage. Dr. Kevan's reference to the 1965 bulldozed summer seismic lines on the Tuktoyaktuk Peninsula illustrates this situation admirably. No reference is made to other summer seismic operations, utilizing different methods and carried out prior to 1965, which took place a few miles to the west. On Richards Island, for example, in many places it is almost impossible to find traces of seismic lines completed

[1]Kevan, P.G. (1971) "Oil under the Tundra in the Mackenzie Delta Region", The Canadian Field-Naturalist, Vol. 85, No. 2, p. 99.

during the summer of 1962. In the Caribou Hills area to the south, seismic lines completed during the summers of 1962 and 1963, although still visible, support an almost continuous vegetation cover. Dr. Kevan also expresses the fear that thermokarst development may lead to chronic erosion as water flows along the subsided tracks.[1] Although this possibility does exist, careful studies of most of the seismic lines in the Mackenzie Delta area reveal that any subsequent erosion by running water is very seldom of more than minor significance.

This apparently conflicting nature of the field evidence poses the real question as to just how sensitive is the tundra to the artificial stresses of human activity and, in particular, whether the present tendency to place an embargo on summer seismic operations on the tundra is really warranted. In an attempt to obtain additional information on this problem, a series of investigations was made of 1970 and other past summer seismic lines, and during an actual seismic programme undertaken in the summer of 1971.

1970 Summer Seismic Lines.

All of the seismic lines investigated in this project were run for Gulf Oil Canada Limited on their holdings in the Parsons Lake area to the east of the Caribou Hills. This Parsons Lake area includes examples of seismic lines which were completed during the summers of 1962, 1963 and 1970, (see Figure 20). With very few exceptions, the 1962 and 1963 seismic lines exhibit extremely fine rates of recovery. Although the lines are often quite readily descernible from the air, it is sometimes, as in the case of line BA 10-26, very difficult to locate the track impressions on the ground.

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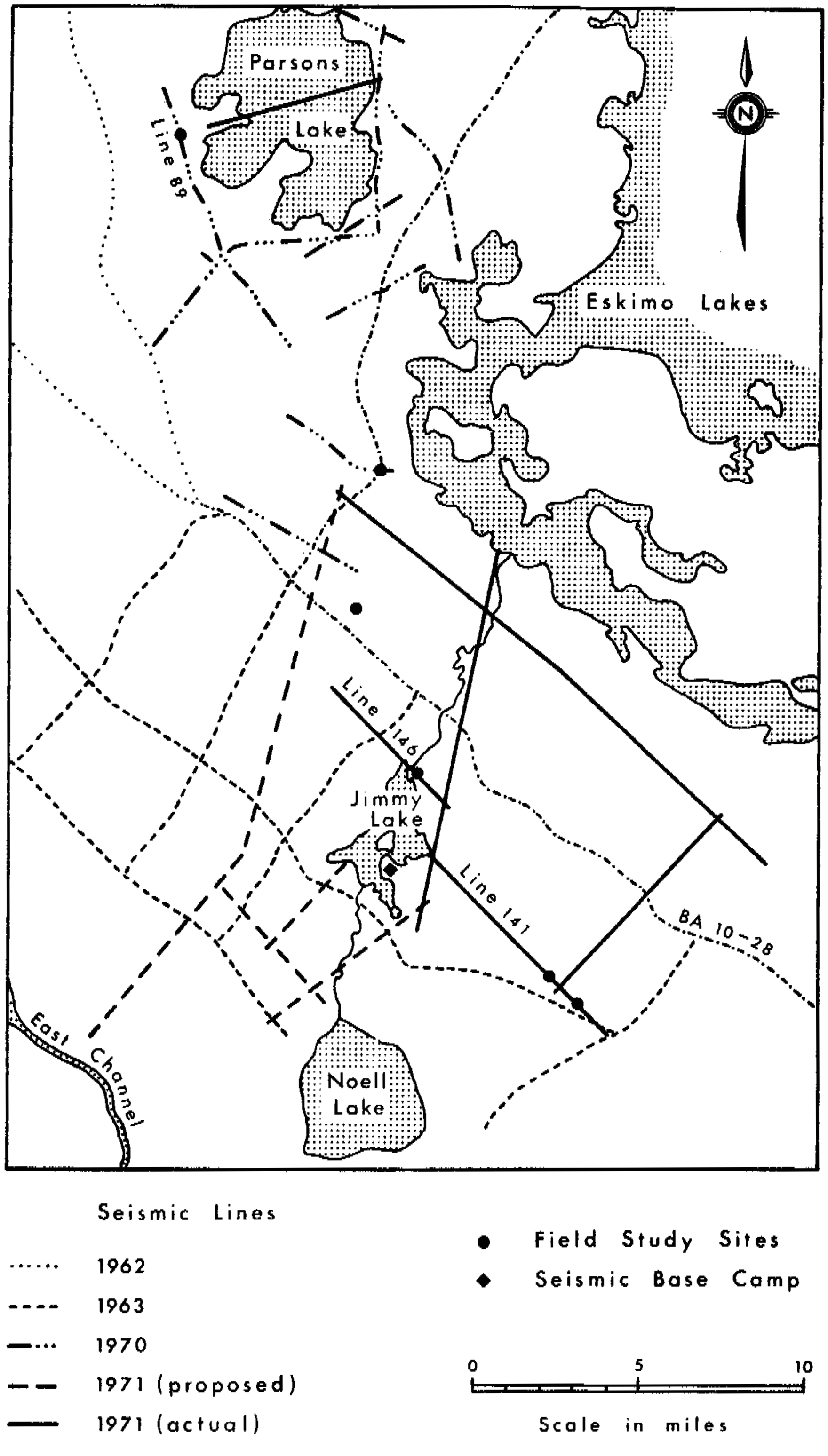
[1] *Ibid*.

Figure 20

SUMMER SEISMIC LINES PARSONS LAKE AREA



This is particularly the case in many of the drier upland areas where the initial degree of disturbance to the vegetation cover may have been less pronounced. In other areas, with more abundant moisture supplies, the imprint of the vehicle tracks remains in the form of shallow ruts reaching maxima of 25-30 cms in depth. Comparative measurements of the thickness of the active layer, made in mid-July, revealed that the depth of thaw in the disturbed areas was only slightly greater than in adjacent undisturbed areas. Almost all sections of the lines now possess a continuous vegetation cover. In terms of species composition, however, the disturbed sites usually contain much higher percentages of grass and sedge, and it is this attribute which is primarily responsible for the persistence of the lines as identifiable features in the tundra landscape.

Studies of the 1970 summer seismic lines were of particular interest because the disturbances associated with these operations are of such recent origin. Furthermore, the seismic survey method employed involved the establishment of a permanent, as opposed to mobile, base camp with the vehicles remaining in the field, rather than returning to the camp each day, and the movement of personnel by helicopter. The adoption of such a survey method has the obvious benefits in that it reduces the amount of cross-tundra traffic to a minimum.

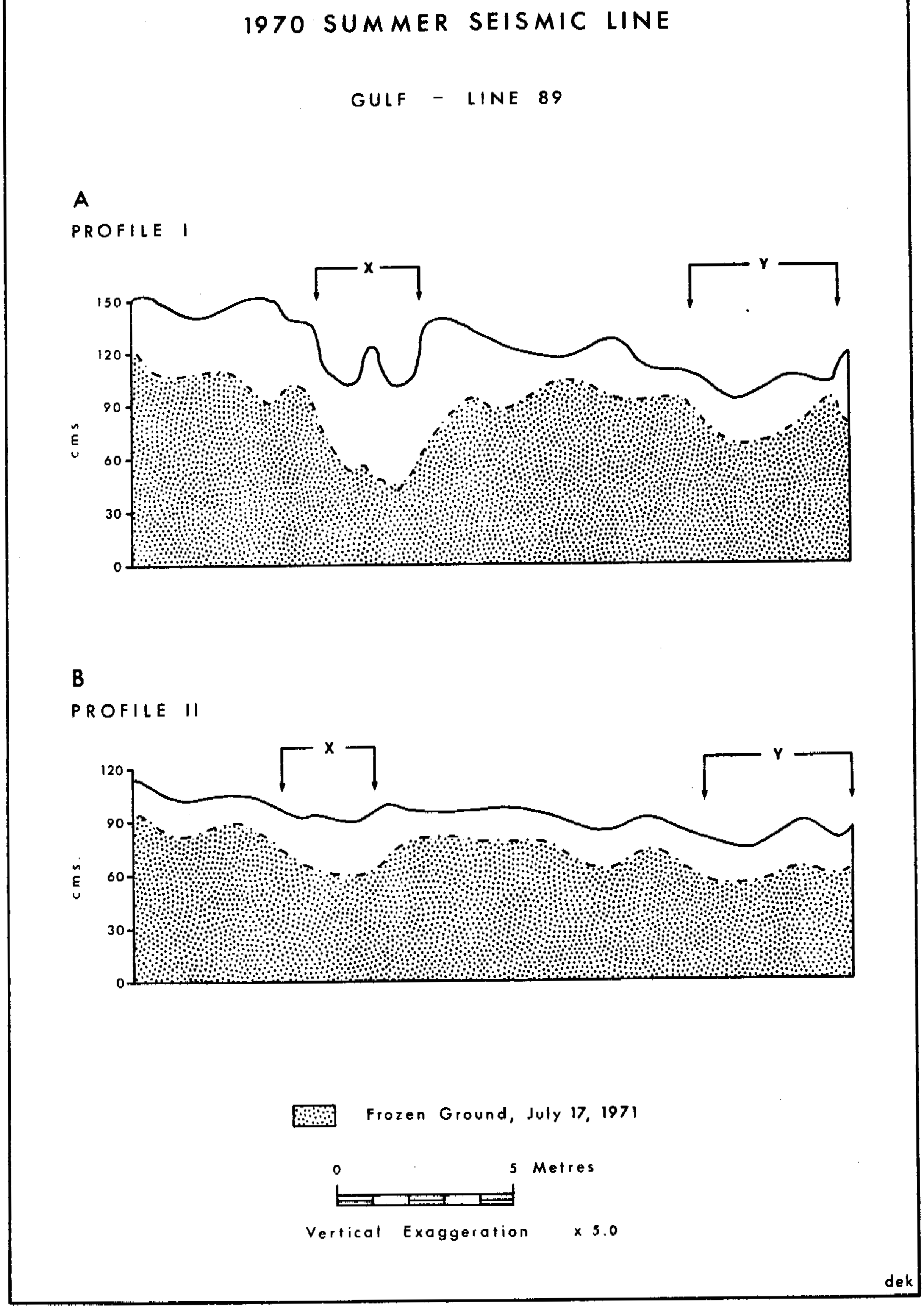
A helicopter surveillance was made along almost the entire length of the 1970 summer seismic lines, and detailed field observations and measurements were taken at two locations. These particular locations were selected on the basis of being representative of examples of the maximum and minimum amounts of disturbance observed along the lines.

An example of the maximum type of disturbance associated with the 1970 summer seismic operations occurred on Line 89 at approximately 68° 57'N and longitude 133° 47' W. Figure 21-A represents a detailed topographic profile and the thickness of the active layer across a section of the line where it traversed the lower part of a gradual slope of 1 in 16. As Figure 21-A shows, the severest form of disturbance, corresponding to section 'X', consists of two prominent ruts, each approximately 1.0 - 1.5 metres across and 30-60 cms deep, coinciding with the major track routes. In places, the thickness of the active layer along the ruts was almost one metre: a value which represents more than a 100 per cent increase over those obtained from adjacent undisturbed sites. Large expanses of bare mineral soil were exposed along the sides and floors of the troughs and, locally, this had contributed to minor slumping along the edge of the track. Minor quantities of water were also observed flowing along the line.

Within the track areas, the only vegetation species present was the Mournful Sedge (Carex lugens), and within this sparse vegetation cover there was an absence of flowering plants which suggests that any preformed buds may have been destroyed by vehicles moving over the site in late summer. The occurrence of vegetative shoots, however, suggests that next summer's flowering shoots were presently being formed and the process of re-establishment of a vegetation cover is already under way. Additional evidence of the intensity of the terrain disturbance at this point is clearly indicated by the highly disrupted nature of the vegetation along the central ridge between the ruts, where the undersides of the vehicles had worn off the shrubs and ericaceous species and, to a lesser extent, the moss cover.

The severity of the terrain disturbance at this site is obviously related to an excessive number of vehicle passes over the same route. In this respect, it is important to note that the type of disturbance shown in section 'X' of Figure 21-A is representative of but a small part of the

Figure 21


1970 SUMMER SEISMIC LINE
GULF - LINE 89
A
PROFILE I
X
Y
150
120
90
60
30
0
cms
B
PROFILE II
X
Y
120
90
60
30
0
cms.
Frozen Ground, July 17, 1971
0
5 Metres
Vertical Exaggeration x 5.0
dek

seismic lines. Line 89 is an example of a seismic line which did not 'link up' with many other lines in the exploration programme. Consequently, the vehicles moved northward along the line and then returned southward along the same route rather than elsewhere along another seismic route. This double passage of the vehicles is undoubtedly responsible for the degree of disturbance involved, and additional evidence suggests that the severity of the damage could have been reduced considerably if the vehicles had followed a separate route on the return journey. Section 'Y' of Figure 21-A illustrates the terrain disturbance in the vicinity of a shot hole. The topographic effect of this type of disturbance is considerably less than that associated with section 'X', and the vegetation cover was also less adversely affected. The significance of these observations is related to the fact that, although fewer vehicles moved over the tundra at this point, the damage is associated with the movement of the drill rig unit which is the heaviest vehicle used in the seismic operation.

Figure 21-B represents a second profile across Line 89 at a point where it traverses a low-lying, relatively wet area immediately at the base of the slope referred to in the first profile (Figure 21-A). In terms of vehicular activity, section 'X', showing the effects of the double passage of most of the traffic, and section 'Y', the passage of the drill rig unit, correspond to the similarly labelled sections of Figure 21-A. It is readily apparent that the degree of terrain disturbance was much less pronounced at this second site in terms of its topographic effect, and contrasts in amount of damage to the vegetation cover were equally pronounced. The dominant species growing in the disturbed areas was again Carex lugens and this was estimated to account for almost 50 per cent of the plant cover. Approximately 40 per cent of the line area consisted of black organic material exposed at

the surface, but viable root and rhizome systems were present in the substrate. Shrub species along the line exhibited the scarred effects of contact with the vehicle tracks, but, in many instances, new leaves were developed on several of the branches and the growth of sucker shoots was also evident.

In other similar environments, the type of terrain disturbance more closely resembled the form shown in Figure 21-A (section 'X'), with the existence of prominent ruts and large exposures of black organic material. In a number of areas these ruts were filled with pools of standing water. Even at these locations, however, despite their unaesthetic appearance, the level of disturbance did not seem to be unduly severe. The existence of viable root systems in the organic substrate, and the abundance of hydrophilic species in the vegetation of adjacent undisturbed areas, seem to assure a reasonably rapid recolonization of the disturbed areas.

The second area investigated in detail was located at the intersection of a 1963 and 1970 line at approximately latitude 68° 47'N and longitude 133° 32'W. Although the existence of several parallel trails was evident from the air, the majority of these had little or no topographic expression at the ground surface. Despite the fact that the lines traversed a number of hummocky mud-boils, up to two metres across and 30 cms high, there was virtually no disturbance of the irregular terrain save for the occasional presence of cleat impressions on parts of the 1970 line. Comparative measurements of the thickness of the active layer revealed that there were no appreciable differences between disturbed and undisturbed sites. The minimal impact upon the hummock tundra vegetation was equally striking. Small mats of lichens showed some signs of disturbance, but the moss cover, especially _Sphagnum_ species, appeared to be virtually undisturbed.

Occasionally, where vehicles had traversed the sides of the hummocks, there was some minor tearing of the vegetation cover.

The information collected during this study would suggest that, in certain areas at least, and with the adoption of suitable operational techniques, terrain disturbances associated with summer seismic operations in a tundra environment need not be of a serious nature. Indeed, the evidence that a drilling unit, the heaviest vehicle used in a summer seismic operation, can traverse the unfrozen tundra surface with minimal disruption of the terrain, suggests that the real question with respect to cross-tundra traffic in the summer thaw period is the maximum number of vehicle passes that the ground surface can tolerate before the degree of disturbance begins to exceed acceptable levels. This critical number of passes is quite obviously related to such factors as the terrain conditions and the types of vehicles involved, and will vary accordingly; and a unique opportunity to investigate this problem occurred last summer in the form of observations of an actual summer seismic programme in the Jimmy Lake area (see Figure 20).

1971 Summer Seismic Lines.

In July 1971, Gulf Oil Canada Limited obtained permission to perform summer seismic work in the Jimmy Lake area, as part of an experiment designed to assess the feasibility of summer seismic operations on the tundra. This seismic programme involved the establishment of a base camp on the shore of Jimmy Lake (Figure 20), and the daily transportation of crews by helicopter, to and from the operations. As part of the terms of the experiment, Gulf also agreed to underwrite the costs of the logistics involved in our on-site research and during follow-up investigations of any long-term effects of the disturbances for a period of up to five years, as well as taking the risk of being shut down if the terrain disturbance exceeded acceptable levels as determined by a land use inspector. The acceptance of these terms, and the unsparing efforts of Gulf Oil and Globe Universal Sciences Canada Limited, who carried out the seismic work, in assisting us to meet our research objectives, is a tribute to the genuine willingness of these companies to cooperate on research into the activities of the resource exploration industry in northern Canada.

As far as possible, we hoped that the results of our research would reflect the operations of a typical summer seismic programme. In this respect, in addition to studies of the terrain disturbance, we were also interested in the selection criteria used by the field parties in establishing the precise route of the seismic lines. Once these routes had been marked by pin flags, a number of field sites (see Figure 20), representative of various terrain units, was selected for investigations of the terrain disturbances. Only at this stage did we request movements of vehicles over particular routes. For example, it was soon observed that many vehicle operators showed a tendency to avoid the wetter areas of the tundra; and in order to obtain data on levels of disturbance in these areas we suggested local modifications of the routes by directing them across these sites. Furthermore, in order to establish any tolerance levels for the various terrain units, in terms of the number of passes of vehicles, it was also necessary to ask the field crews to follow specific tracks in places.

Eight transects were selected to examine the effects of the seismic operations on various terrain units found in the Jimmy Lake area. A series of sequential profiles was surveyed at each of the sites and these are shown in Figures 22-29. On each of these diagrams, the first profile (A), shows the surface configuration of the terrain prior to the passage of any vehicles across the line of the transect. In some cases, as in Figures 26-29, difficulties in scheduling other parts of our summer programme with those of the seismic party, resulted in these initial surveys being made after the passage of the bombardier used to survey the lines. Since in many places it was almost impossible to find the tracks of the vehicle, it was felt that these initial surveys were still representative of the undisturbed terrain conditions. The second and third profiles (B and C) represent the surface configurations immediately following the passages of the drilling units and line crew/recording units respectively, and the dotted lines on each of these profiles illustrate the changes at the ground surface which were associated with each of these phases of the seismic operation. The final profile (D) on each of these diagrams, shows the net changes in the surface topography produced by the entire seismic operation, and the dotted line in this case represents the original, undisturbed terrain.

The sequential profile studies of Figures 22-29 record the magnitude of the immediate or short-term disturbances associated with the vehicle passes. After the passage of the last vehicle in the seismic programme across each transect, a probe was used to establish the thickness of the thawed layer as shown in the profile (D) on each of the diagrams. Bench marks were also installed on each transect to facilitate observations of any further long-term changes in the relative positions of the ground surface and the upper surface of the frozen ground. In order to correlate any changes in the topographic profile with the development of thermokarst subsidence, core samples for analysis of their ice content were collected in 10 cms increments over a total depth of 30 cms, from the upper part of the frozen substrate in the most disturbed areas. In some of the transects, however, the waterlogged nature of the thawed layer made the collection of such samples impossible.

The first four transects were located towards the south eastern end of the main section of Line 141 (see Figure 20). One of the transects, Profile I (Figure 22), was established where a section of the line between shot points 42 and 43 traversed a series of very prominent earth hummocks. These hummock structures averaged one to two metres across and the raised centres were as much as 50-60 cms above the levels of the intervening depressions (Figure 22-A). The vegetation cover included a shrub layer of Mountain Alder (*Alnus crispa*) and the more prominent vascular species growing on the hummocks consisted of the Narrow-leafed Labrador-tea (*Ledum palustre ssp. decumbens*), Mountain Cranberry (*Vaccinium vitis-idaea*) and tussocks of Sheathed Cotton-grass (*Eriophorum vaginatum*). The drier surfaces of some of the larger hummocks also supported thin mats of lichens.

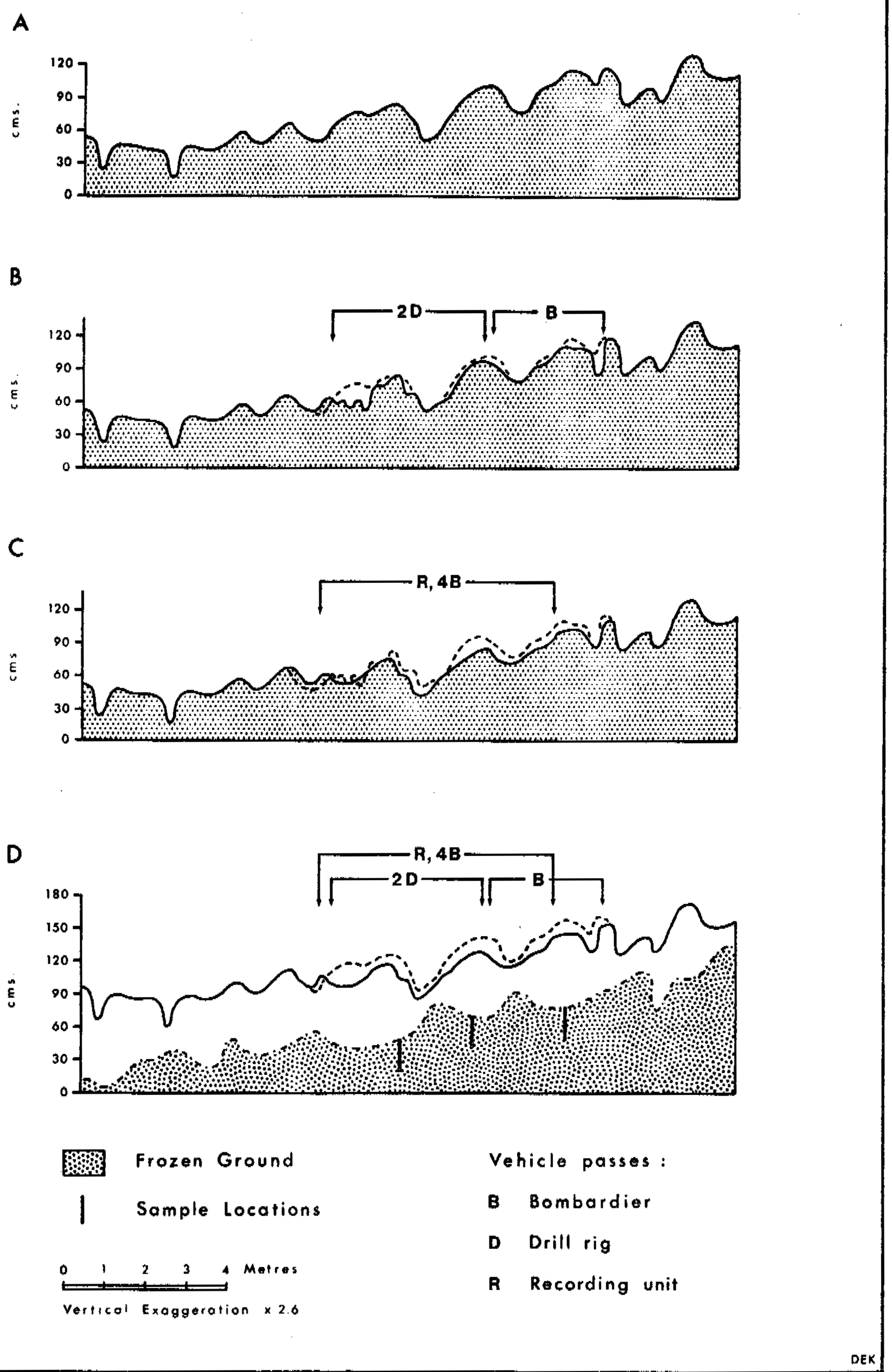
As Figure 22-B shows, the maximum change at the ground surface following the passage of two drill rig units, each weighing about 11 tons, was in the order of 15-18 cms where the two vehicles moved along identical tracks. Most of this value represents a compression of the loose vegetation cover growing on the side of an earth hummock. Elsewhere, the changes in the surface profile were less than 5 cms, and for the most part these also represented a compression of the organic layer, although there was some local removal of the lichen mat and some exposure of bare mineral soil in the deeper cleat marks of the tracks.

Other sections of the line, traversing similar irregular terrain, were characterized by a more severe form of damage in which large blocks of vegetation and mineral soil, one to two metres across and up to 20 cms thick, were peeled from the surfaces of the hummocks. It was observed that this damage was being created by the rear end of the underside of the vehicle,

Figure 22

1971 SUMMER SEISMIC LINE

GULF - LINE 141 - PROFILE I



which did not provide adequate clearance for moving over the irregular terrain. Other examples of more localized, though less severe, damage occurred where the edges of the vehicle tracks cut obliquely across the sides of the hummocks.

Figure 22-C shows that the passage of the recording unit, weighing about 6-7 tons, and four bombardiers, each weighing about 3 tons, produced a maximum lowering of the ground surface of approximately 10-12 cms, but the average amount was less than 5 cms. Once again most of these changes represent a compression of the organic layer rather than the physical removal of material.

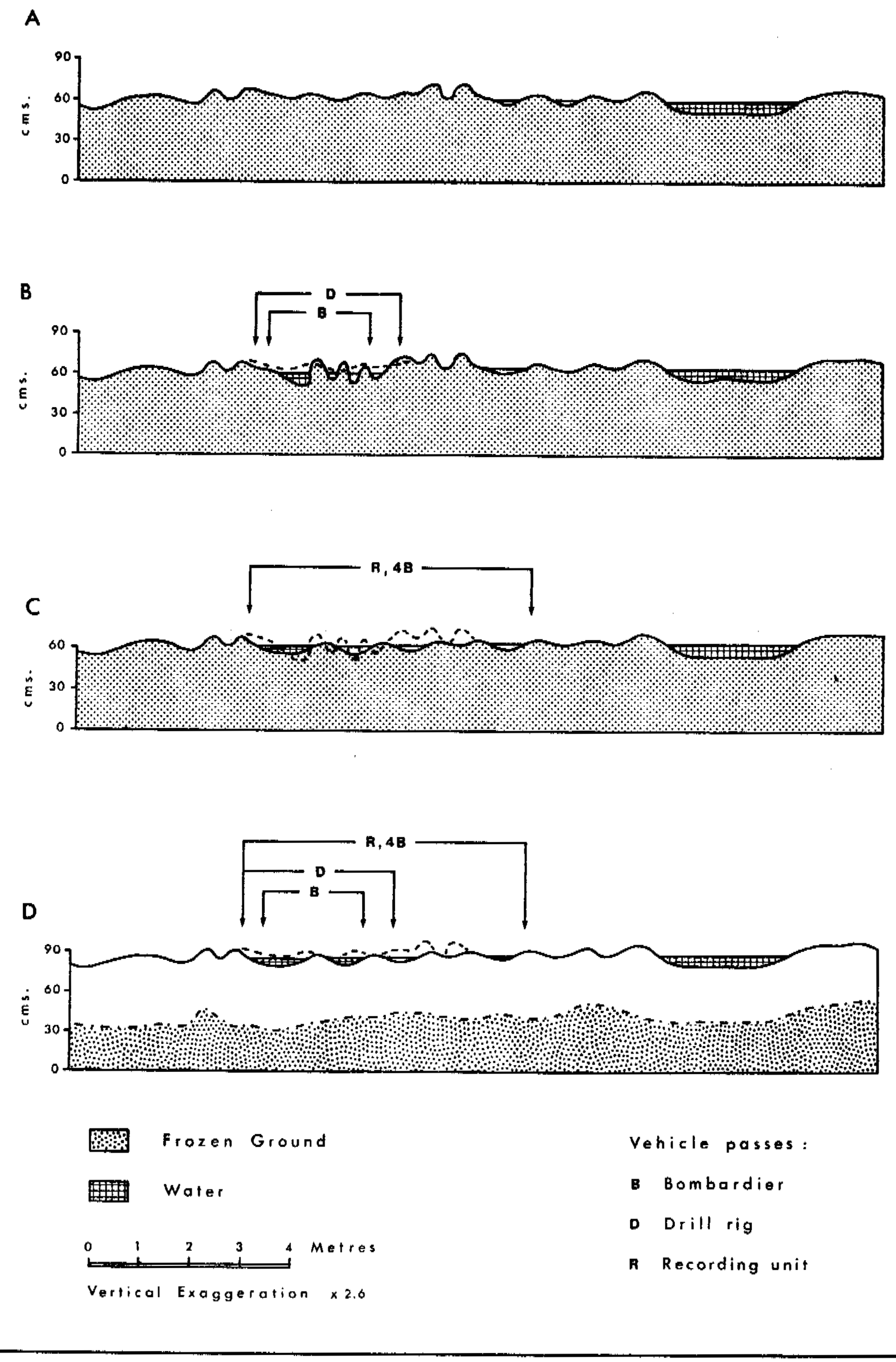
The net changes in the surface profile resulting from the passage of a total of eight vehicles, with a combined weight of approximately 40 tons, are shown in Figure 22-D, where it can be seen that the total width of the disturbed area was in the order of seven metres. The average lowering of the ground surface across the disturbed section was about 10 cms, and the maximum change indicated was in the order of 18-20 cms. Most of this latter value was associated with the passage of the two drill units and, as Figure 22-D shows, the movement of additional vehicles over the same route had a negligible impact on the terrain. In view of the highly irregular nature of the ground surface in this transect, the fact that most of the changes in the topographic profile represent a compression of the organic layer rather than the physical removal of material, and the implied minimal disruption of the vegetation cover, the overall level of disturbance can reasonably be classified as negligible.

The second transect, Profile II (Figure 23), was established between shot points 41 and 42 on Line 141, at a point where the proposed route of the line crossed the floor of a small valley. This site was selected

Figure 23

1971 SUMMER SEISMIC LINE

GULF – LINE 141 – PROFILE II



since it represented one of the wetter areas, referred to earlier, which many vehicle operators tend to avoid. In fact, both of the drill rig units avoided the line of our transect and, although one of the vehicles did cross the floor of the depression via another route, the other vehicle followed a much more circuitous route along the edge of the firmer ground. It is interesting to note that in addition to increasing the length of the 'damaged' area, this alternate route along the higher ground, which incidentally was favoured by the land use inspector, also resulted locally in greater levels of terrain disturbance than those developed along the more direct route across the floor of the depression. This higher level of damage to the tundra reflected the greater irregularity of the hummocky terrain along this path and the need for the vehicle to make fairly tight turns to change direction. It was also learned that the primary reason for avoiding the wetter areas was a fear that the vehicle would get stuck in the 'muskeg' and it was difficult, at first, to convince the operator that the upper surface of the frozen ground was only about 20 cms beneath the ground surface. Further evidence of the willingness of the geophysical company to cooperate in the research was provided when the party manager requested one of the drill units to return to the area and to move across the line of our transect.

Figure 23-A shows that the ground surface in this second transect was relatively featureless with an average microrelief of only 10-15 cms. Although no permanent stream occupied the floor of the valley at this point, the thawed layer consisting entirely of organic material, was waterlogged and the larger depressions in the ground surface were filled with shallow pools of standing water. Sedges (chiefly _Carex_ species) and mosses were the principal components of the vegetation community which also included such species as the Narrow-leafed Labrador-tea (_Ledum palustre ssp. decumbens_),

Cloudberry (Rubus chamaemorus), Common Crowberry (Empetrum nigrum), and Arctic Blueberry (Vaccinium uliginosum), together with occasional tussocks of the Sheathed Cotton-grass (Eriophorum vaginatum) and isolated patches of the Mountain Alder (Alnus crispa).

The passages of the survey bombardier and the drill rig unit (Figure 23-B) produced some accentuation of the microrelief by the compression of organic material along the main lines of the tracks. In some parts, this compression produced a lowering of the ground surface in the order of 10-15 cms and the impressions of the tracks were filled with shallow pools of water 5-10 cms deep. The other most noticeable aspect of the disturbance was a flattening of many of the sedges. The traffic associated with the line crew and recording unit produced a further compression of the organic material, primarily in the areas between the tracks of the drill rig unit, and an increase in the extent of the area occupied by pools of standing water.

The disturbed area associated with the passage of a total of seven vehicles, with a combined weight of approximately 30 tons, covered a width of 6-7 metres. Within this area the net changes in the level of the ground surface consisted of a lowering of 10-12 cms and, as Figure 23-D shows, a large proportion of the depressed area contained pools of standing water. As indicated above, however, the depression of the ground surface was entirely the result of a compression of the organic layer and not the physical removal of material.

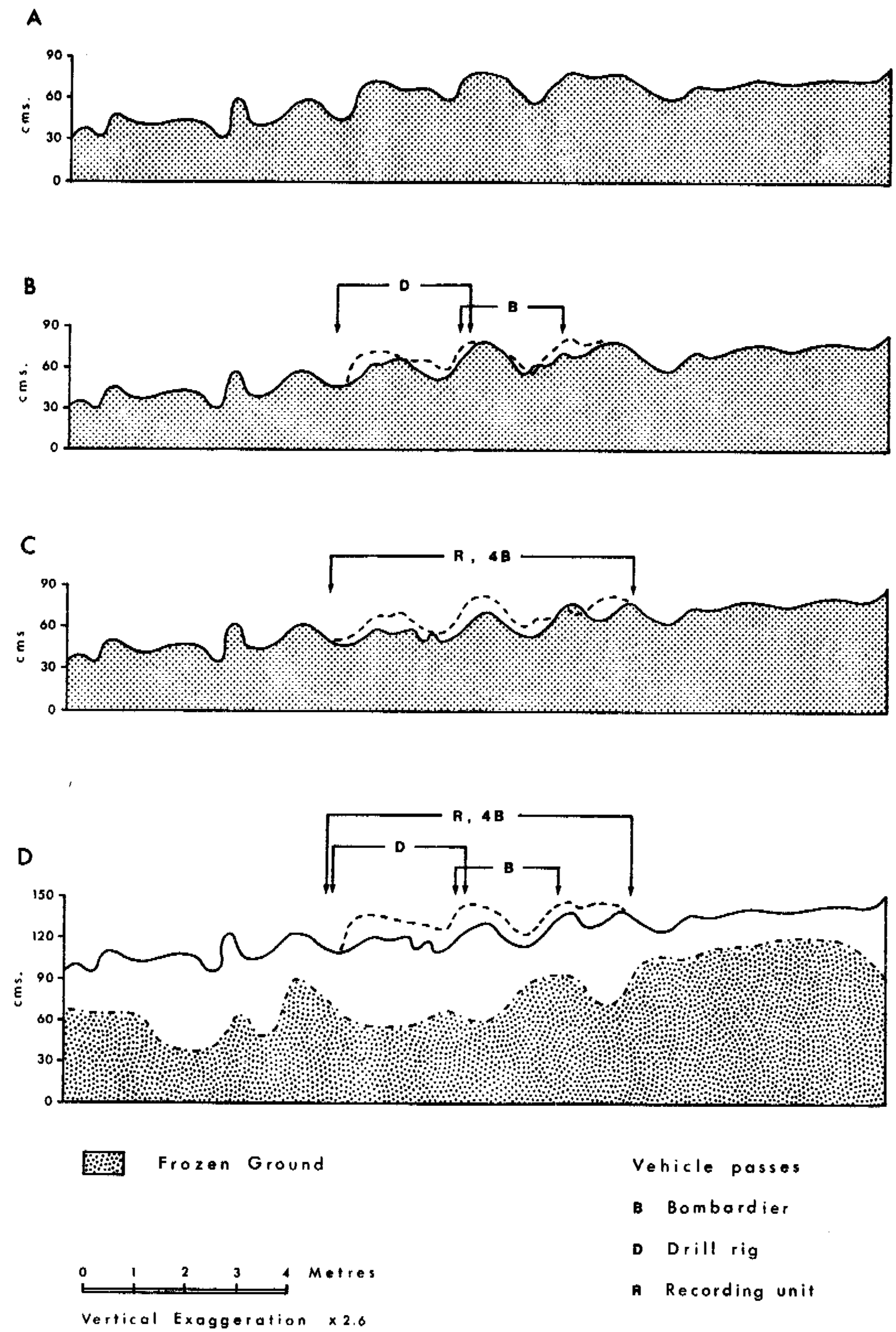
There is no doubt that the type of disturbance incurred in this second transect shows up very prominently from the air, to a point where the appearance of the route often results in the level of terrain damage being described as excessive. The darker colouration of the lines, resulting from a flattening of the vegetation, and the emphasis of the main tracks due to the pools of standing water, are the most prominent factors influencing the appearance of the lines. The existence of water in the main tracks often leads to fears that water is moving along the lines and may eventually lead to chronic erosion. Despite the appearance of the lines in this transect from the air, the data obtained from the sequential profiles would suggest that the actual level of terrain disturbance is negligible. Since the most prominent ruts were the result of a compression of the organic layer it may be assumed that the ground surface in the depressed areas will rise as the organic material expands. Furthermore, there was no observed flow of water in the track areas, and the fact that these are aligned almost at right angles to the drainage route precludes any major accentuation of the ruts as a result of water flowing along the lines. Finally, apart from a flattening of the taller species, there appeared to be little or no obvious signs of any permanent damage to the vegetation cover, and most of the species can be expected to show rapid rates of recovery from any minor disruption. Since much of this recovery may not take place until the summer of 1972, there may be some merit in scheduling any future summer seismic programmes for the month of July, rather than August, to enable more recovery to take place in the same growing season rather than in that of the following year. Only time will tell whether the long-term effects of the terrain disturbance are different from those postulated above, or whether the rate of recovery differs appreciably from that in the higher and drier terrain units.

The third transect, Profile III (Figure 24) was established on the slightly higher ground adjacent to the depression referred to in the previous transect. As Figure 24-A shows, the surface microrelief averaged 20-30 cms

Figure 24

1971 SUMMER SEISMIC LINE

GULF - LINE 141 - PROFILE III



and this consisted of subdued earth hummocks interspersed with the tussock forms of the Sheathed Cotton-grass (Eriophorum vaginatum). The thawed layer in this site also contained substantial quantities of water.

Figures 24-B and 24-C show that the maximum depression of the ground surface associated with the passages of the drilling crews and line crews amounted to about 15 cms and averaged 5-10 cms. In each case, most of the change was attributed to a flattening of the tussocks and a compression of other components of the organic layer, although there was a local scraping of the surfaces of some of the larger hummocks and minor exposures of mineral soil in some of the deeper cleat marks.

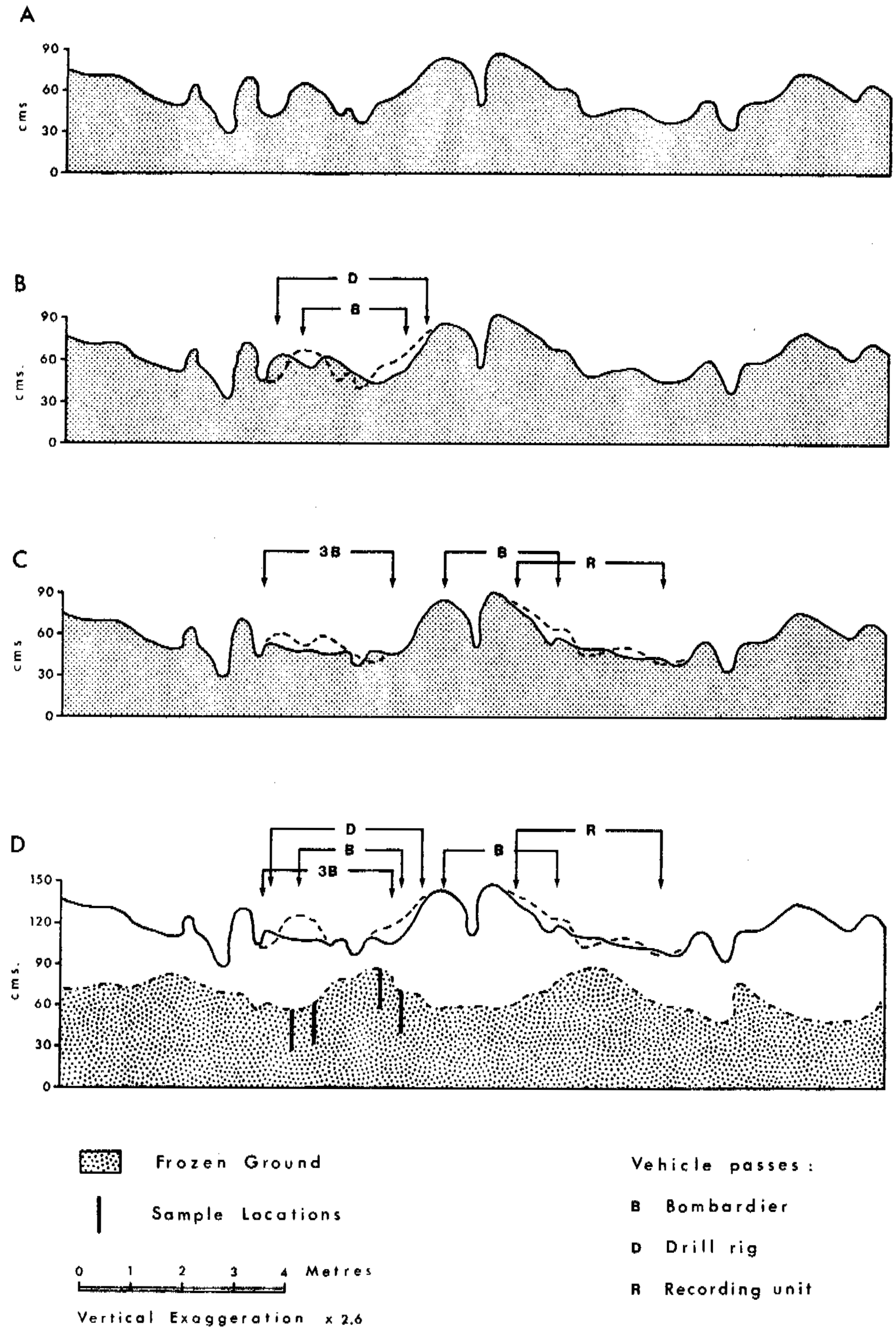
The overall width of the damaged area amounted to 6-7 metres (Figure 24-D) over which there was an average depression of the ground surface of 10-15 cms. Apart from a few broken limbs of the Mountain Alder (Alnus crispa) and the Glandular Birch (Betula glandulosa), and despite a flattening of many of the tussocks, there seemed to be no marked or permanent damage to the vegetation cover. The level of terrain disturbance in this transect, therefore, also could be classed as negligible and there is little reason to expect that this level will be accentuated in the future.

The final transect in this first study area was established on terrain similar to that described for Profile I (Figure 22). This site was selected, however, to reveal any differences in damage that might occur where the vehicles ascend, rather than descend (as in the case of the first transect location) a slope. As Figure 25-A illustrates, the terrain conditions in this fourth profile study were even more irregular than those in any of the previous sites, and the most prominent earth hummocks were as much as 3-4 metres across and up to 60-70 cms high. Bare mineral soil was exposed on the tops of some of the hummocks, whilst others supported a thin

Figure 25

1971 SUMMER SEISMIC LINE

GULF - LINE 141 - PROFILE IV



dek

layer, 1-2 cms thick, of organic material.

Most of the changes in the surface topography shown in Figures 25-B, 25-C, and 25-D again represent the compression of the looser accumulations of organic material found on the sides of the hummock structures. The maximum depression of the surface (Figure 25-D), amounted to approximately 20 cms, but even in these areas there was no marked break in the continuity of the vegetation cover. The movement of five of the seven vehicles along virtually the same route, resulted in a cumulative flattening of the microrelief in the inter-hummock areas, and the more even surfaces of these depressions, combined with the steepening of the sides of the hummocks has tended to exaggerate the prominence of the main tracks relative to the actual level of disturbance which was involved.

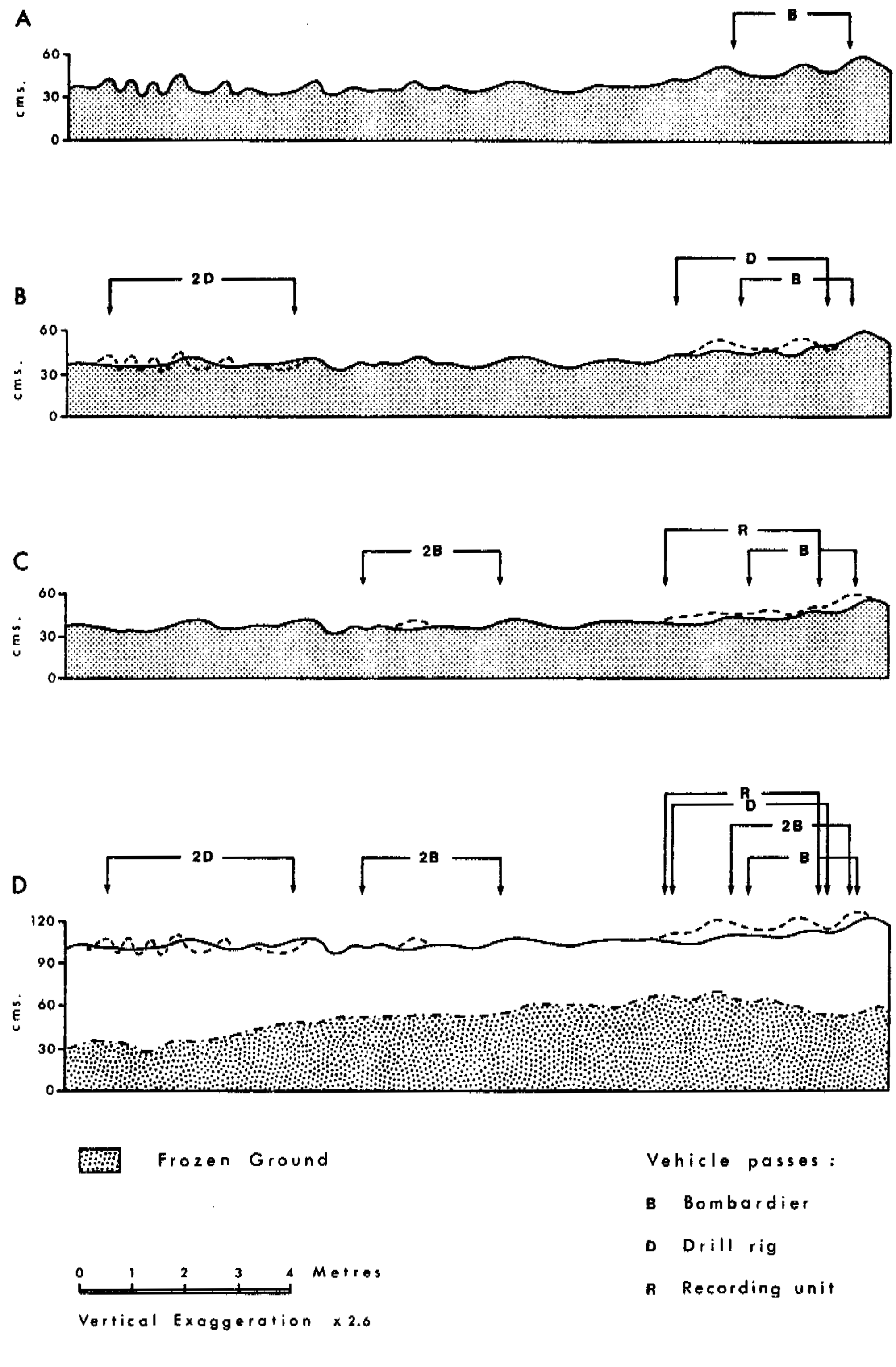
The second study area, also containing four transects, was located on Line 146 just to the east of the creek draining from Jimmy Lake towards the Eskimo Lakes (see Figure 20). As noted previously, due to scheduling difficulties the initial surveys of each of these transects were made after the survey bombardier had already moved along the line. Another contrast with the first study area was the use of an additional rig unit in the drilling of the shot holes along Line 146.

Profile V (Figure 26) was established on the floor of an infilled lake immediately adjacent to the creek crossing, and this particular site was selected to provide additional data on the types of terrain disturbance associated with the passage of vehicles across the wetter areas of the tundra. The substrate in this old lake basin was composed of saturated organic material and small pools of water occupied the depressions in the ground surface. The smooth nature of the topographic profile in this transect is illustrated in Figure 26-A, and the principal diversity in the

Figure 26

1971 SUMMER SEISMIC LINE

GULF - LINE 146 - PROFILE V



surface conditions consisted of small mounds of peaty material averaging 20-40 cms across and 15-20 cms in height. A lack of diversity also characterized the vegetation community in this site which was dominated by almost pure stands, 20-60 cms tall, of two species: the Aquatic Sedge (*Carex aquatilis*) and the Marsh or Purple Cinquefoil (*Potentilla palustris*), together with a ground cover of mosses.

In an attempt to evaluate the effects of varying amounts of traffic on the terrain, two of the drilling rigs were requested to move along exactly the same route across the line of the transect and the other rig was asked to follow the earlier tracks of the survey bombardier. As Figure 26-B shows, there was no appreciable difference in the level of disturbance along each of these routes. In both areas, the ground surface was depressed by amounts ranging from 5-10 cms as a result of a compression of the organic layer under the main lines of the tracks. The ground surface in the inter-track areas of the route followed by the two drill rigs was actually raised in places, as some of the mounds were flattened across the intervening depressions and some organic material was squeezed up from beneath the track areas. Small pools of water, 1-2 cms deep, collected temporarily in the more heavily compressed areas, but these did not persist for any length of time. Most of the vegetation was flattened along each route, but very few plants were either broken or uprooted.

The passage of the line crew and recording unit (Figure 26-C) produced an additional lowering of the ground surface, also as a result of compression of the organic substrate, and a further flattening of the vegetation. Most of these vehicles followed the same route as the single drill rig and survey bombardier, yet despite the movement of five vehicles over the same part of the transect the maximum net change in the position of the ground surface was only 10-15 cms. The observations from this transect thus support those obtained from the other wet habitat (Figure 23, Profile II), in that despite the appearance of the lines from the air, in these areas the level of terrain disturbance, as shown in Figure 26-D, is actually quite low, and this site should also exhibit a reasonably rapid rate of recovery from the effects of the cross-tundra traffic.

The lake basin, referred to in the previous transect, was surrounded by a small ridge supporting small stands of White Spruce (*Picea glauca*) and a fairly dense underbrush cover, one to two metres tall, of the Diamond-leaf Willow (*Salix pulchra*) and the Glandular Birch (*Betula glandulosa*). Observations of the effects of winter seismic operations have revealed that these shrub layers often suffer extensive damage, and a transect was established across this site to measure the comparable effects of a summer seismic operation.

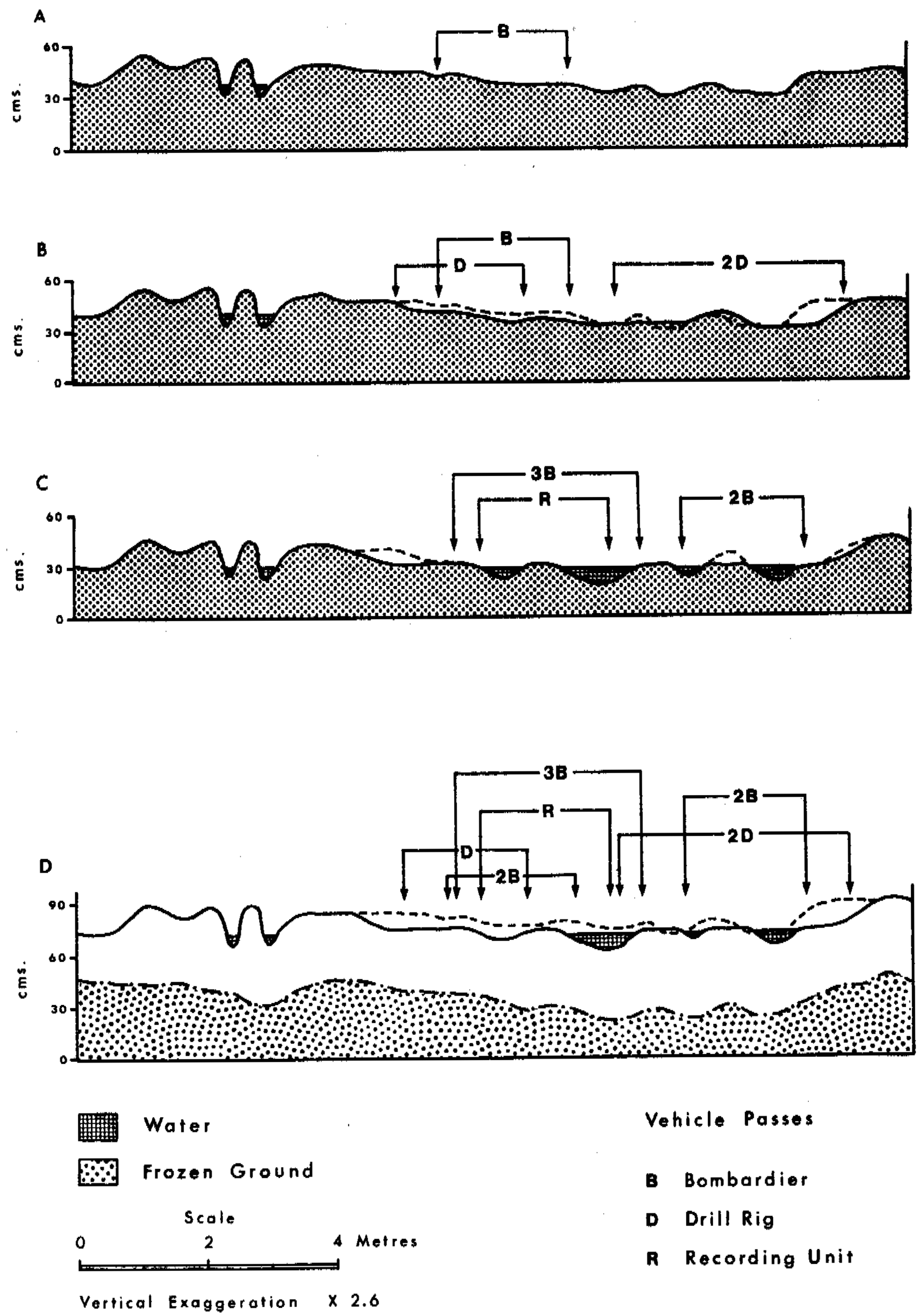
The even nature of the ground surface at this site is illustrated in Profile VI (Figure 27-A) and most of the microrelief shown represents the tussock forms of the Sheathed Cotton-grass (*Eriophorum vaginatum*). The thawed layer was waterlogged and much of the ground surface was covered with *Sphagnum* together with the Arctic Blueberry (*Vaccinium uliginosum*) and the Common Horsetail (*Equisetum arvense*).

The principal changes in the surface topography associated with the passage of the drill rigs are shown in Figure 27-B, where it can be seen that the ground surface was depressed by an average of less than 5 cms, except in the tracks made by the movement of two of the rigs along the same route, where locally the surface was lowered by as much as 15 cms. Due to the spongier nature of the organic material, compared to the lake basin site, the general imprint of the tracks was more pronounced than in the other

Figure 27

1971 SUMMER SEISMIC LINE

GULF - LINE 146 - PROFILE VI



areas, and there was more evidence of this material being squeezed up along the inner and outer margins of the tracks. Although a few willows were uprooted by the vehicles, much of the shrub layer appeared to have suffered only moderate abrasion, and despite being flattened under the weight of the vehicles, most of the willows sprang up again as soon as the weight was removed.

Figure 27-C indicates that there was a further compression of the organic layer as a result of the passage of the line crew and recording unit. Although relatively minor in amount, in absolute terms, this additional lowering of the ground surface gave added prominence to the main lines of the tracks, transforming them into more distinct rut-like features which were filled with pools of standing water 8-10 cms deep (see also Figure 27-D). Many of the species in the ground cover were crushed and submerged in these pools of water, and there was also evidence of more extensive damage to the shrub layer in that more of the willows and ground birch showed the effects of scraping, more twigs were stripped of their leaves, and there was an increase in the number of crushed or broken branches. Even so, the extent of the damage to the shrubs appears to be less than that incurred as a result of winter operations, when the brittle nature of the stems and branches often contributes to a greater proportion of the plants being broken off at ground level.

Profiles VII and VIII (Figures 28 and 29) were located between shot points 458 and 459 on Line 146, and were established to provide additional data on terrain units similar to those represented in the other transect sites. Profile VII was selected as being representative of the conditions in an area of very subdued earth-hummocks, i.e. lacking the pronounced microrelief exhibited by Profiles I and IV (Figures 22 and 25

Figure 28

1971 SUMMER SEISMIC LINE

GULF - LINE 146 - PROFILE VII

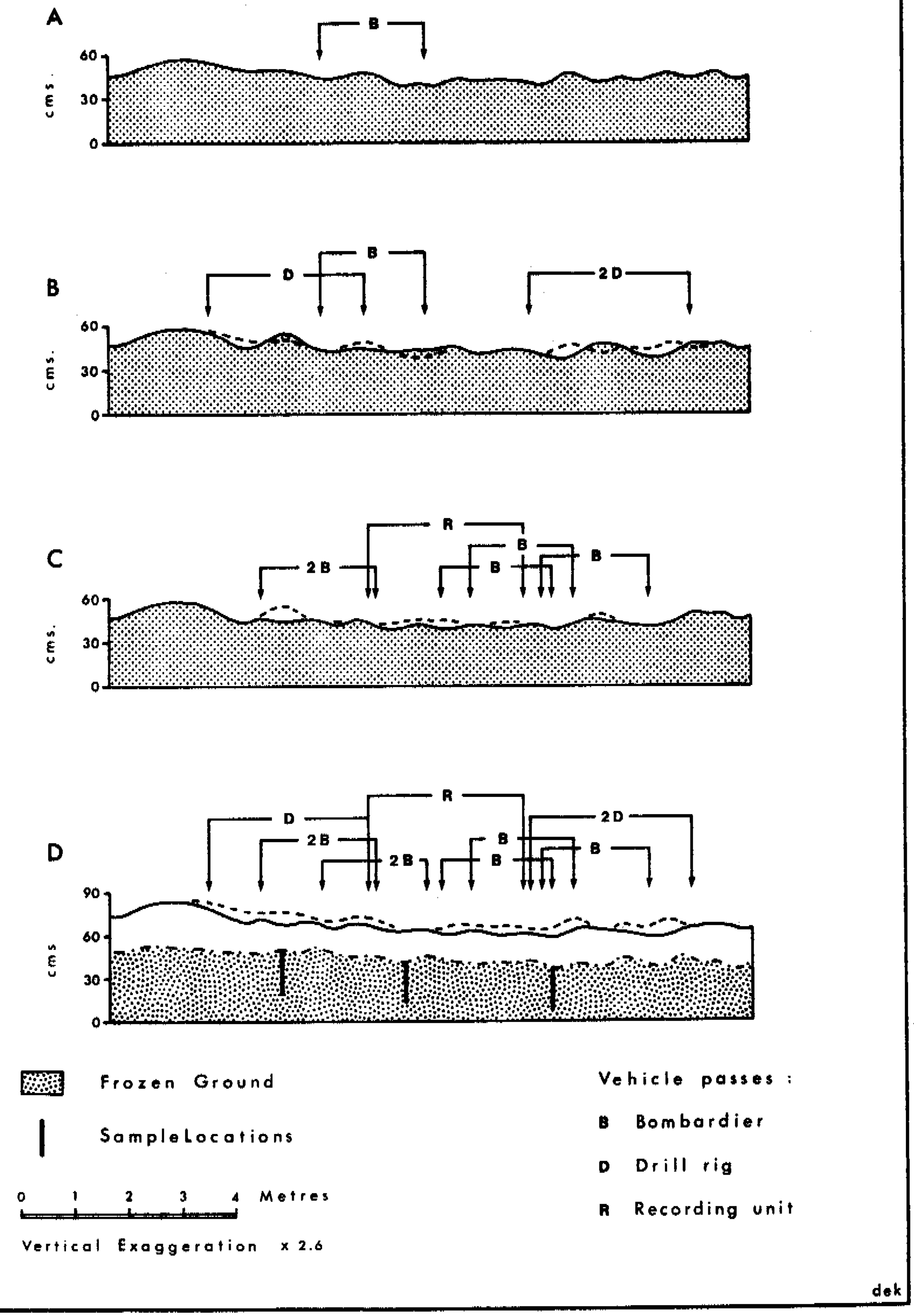
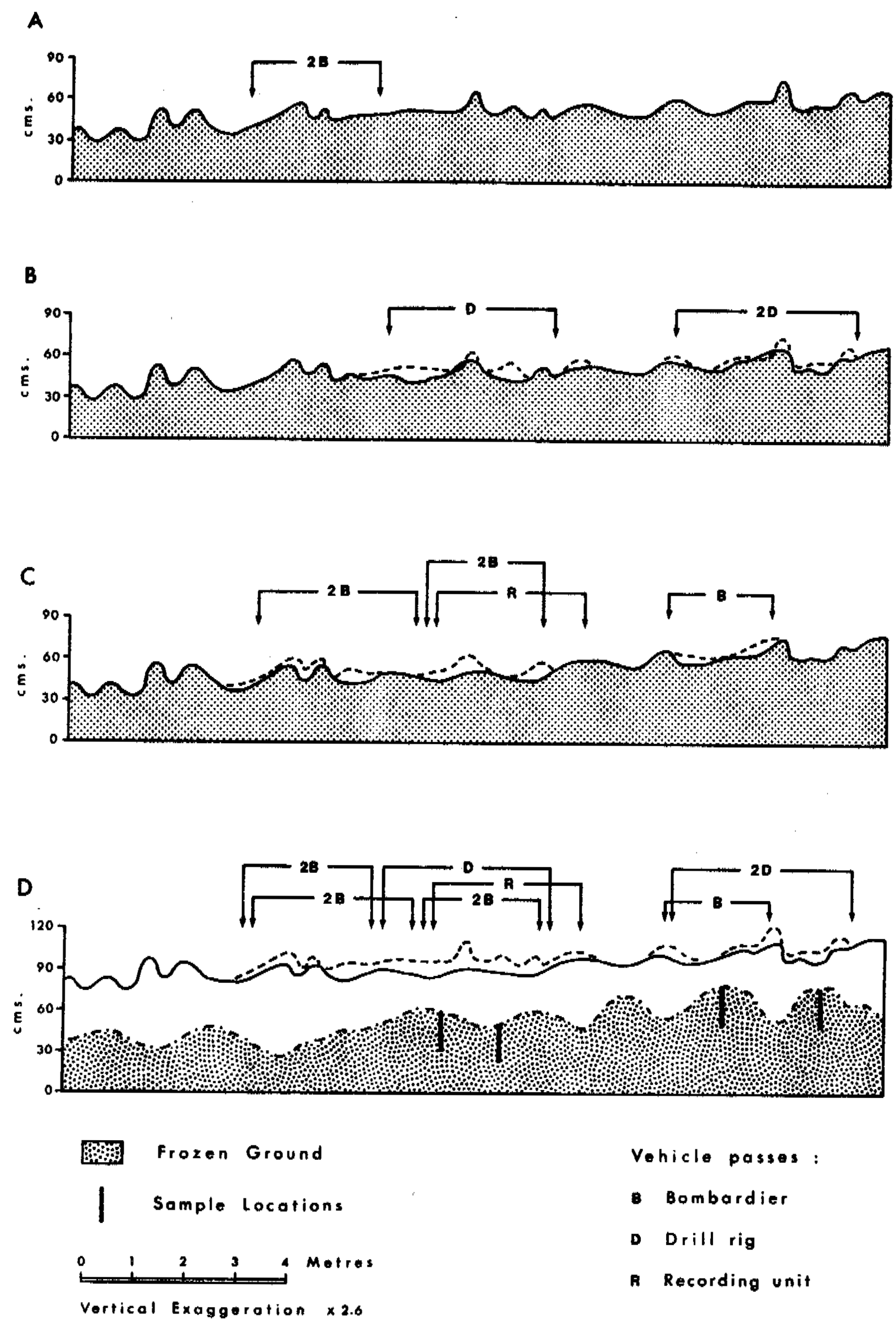


Figure 29

1971 SUMMER SEISMIC LINE

GULF - LINE 146 - PROFILE VIII



respectively). Profile VIII was selected to yield further examples of the type of terrain disturbance associated with areas dominated by the tussock forms of the Sheathed Cotton-grass (Eriophorum vaginatum).

The short-term effects of the disturbance in both of these transects were similar to those recorded in the other sites. Comparisons of the sequential profiles in Figures 28 and 29, show that the concentration of eleven vehicle passes, with a combined weight in the order of 60 tons, over approximately a 9-10 metre width of the tundra, produced an average depression of the ground surface of no more than 5-10 cms. As in the other transect studies, most of this change can be attributed to a compression of the surface organic layer, including a flattening of the tussock forms, and there was a minimal physical removal of material from the ground surface.

The cumulative evidence from each of the eight transects indicates that, on a short-term basis at least, the minimal amount of terrain disturbance involved establishes the feasibility of this method of summer seismic operation in the type of terrain found in the Jimmy Lake area. Indeed, because of the low level of terrain damage incurred along the 1971 summer seismic lines, there would appear to be every indication that similar operations, perhaps also incorporating an experimental approach, could be permitted in other, adjacent areas, without involving any greater risks of severe damage to the tundra. One important exception to this general statement consists of the newly burnt-over areas of the tundra, where it is recommended that at no time should summer seismic work be permitted. Figure 20 shows that a part of the proposed 1971 summer seismic programme included a line running in a northeast-southwest direction to the East Channel of the Mackenzie River. A considerable part of this line crossed one of these burnt-over areas, and preliminary field inspections indicated that the terrain was extremely soft and almost akin to a floating bog. Apart from our view that much of this terrain was generally incapable of supporting any form of tracked vehicle, we felt that the cross-tundra traffic would also destroy the vegetation which was beginning to establish itself again after the fire. Furthermore, the proposed route of the line also crossed a number of entrenched streams, and the widespread occurrence of slumping on the steep valley sides indicated the possible dire consequences of any marked disturbance of the ground surface. For these reasons, we recommended against any seismic operations in the burnt area and this advice was accepted by both of the companies.

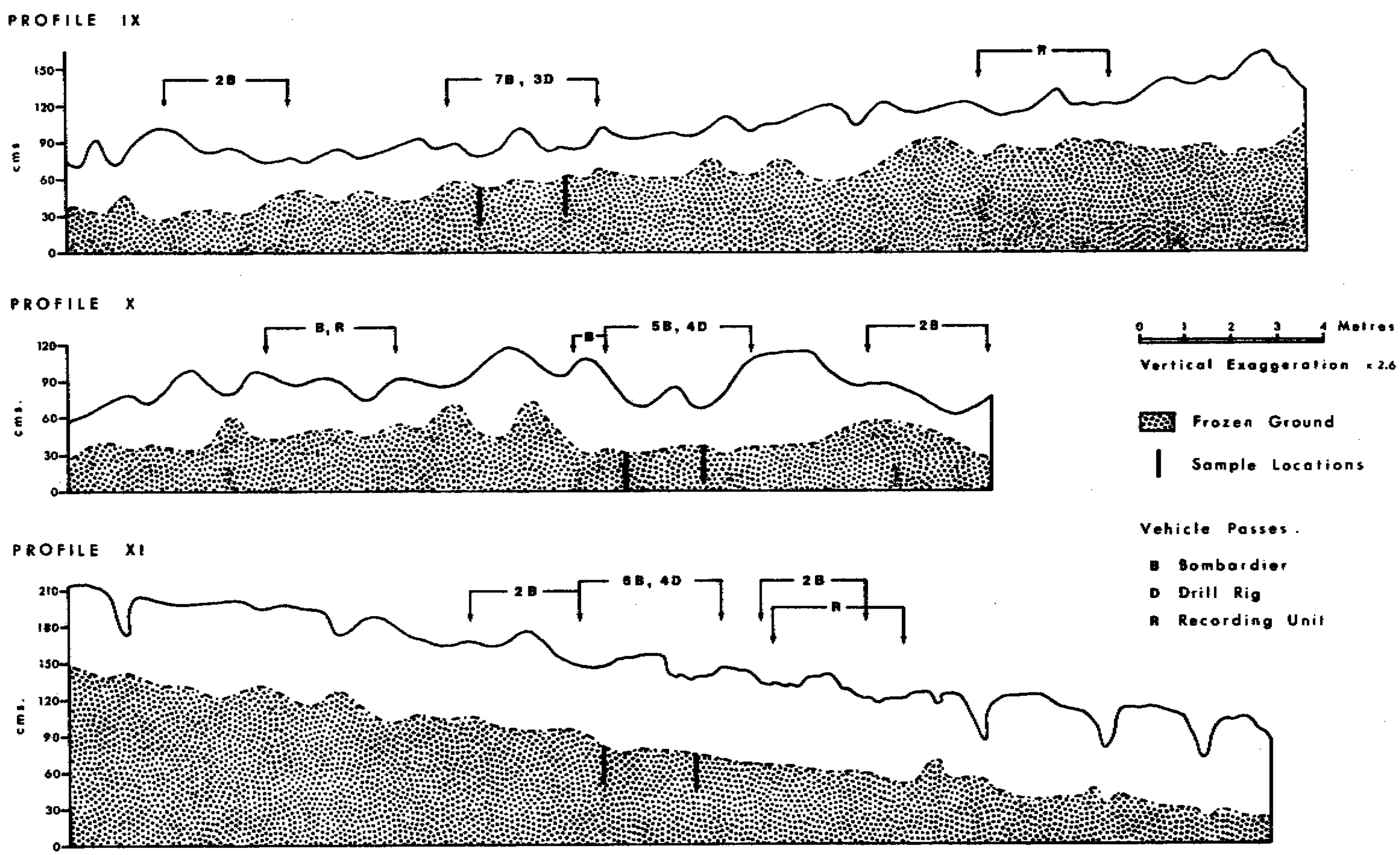
An aerial survey of the completed seismic programme, as shown in Figure 20, indicated that the general level of disturbance along most of the length of the lines was not appreciably different from that observed in the transect studies. One possible exception was the 'end spreads' of the lines where the vehicles returned along the same route. In one area, at the southeastern end of Line 141 (see Figure 20) there had been an unduly heavy concentration of vehicle passes and this had accentuated the degree of terrain damage. Since it was felt that the level of disturbance would probably be increased as a result of thermokarst subsidence, three profiles were established across the line to detect any subsequent long-term changes, and these are shown in Figure 30.

Profile IX was established at a point where the line traversed an area of well developed earth hummocks and mud boils, which averaged one to two metres across and 35-40 cms in height. Additional microrelief was provided by a number of prominent tussocks, up to 40 cms across and 30 cms in height, of the Sheathed Cotton-grass (Eriophorum vaginatum). Other vascular species, growing on the hummocks, included the Narrow-leafed

Figure 30

1971 SUMMER SEISMIC LINE

GULF – LINE 141 – PROFILES IX, X, XI



Labrador-tea (_Ledum palustre_ _ssp._ _decumbens_), Alpine Bearberry (_Arctostaphylos rubra_), Cloudberry (_Rubus chamaemorus_), Mountain Cranberry (_Vaccinium vitis-idaea_), Common Crowberry (_Empetrum nigrum_) and the Lapland Butterbur (_Petasites frigidus_). The Mountain Alder (_Alnus crispa_) and the Glandular Birch (_Betula glandulosa_) provided a sparse shrub cover, ranging from 0.5 to 1.0 metres in height. Many of the hummock surfaces were also mantled by extensive lichen mats (chiefly _Cetraria_ and _Cladonia_ species).

As Profile IX (Figure 30) shows, the two-way movement of vehicles, including passes of at least three drill rigs, one recorder and nine bombardiers, resulted in a marked depression of the ground surface in the form of several prominent ruts. Substantial quantities of organic material and mineral soil had been dislodged from the tops of some of the hummocks, and the track areas were noticeably wetter than the adjacent undisturbed terrain. In a few places along the line in this same area, pools of water, 10-12 cms deep, had accumulated in the floors of the tracks.

The second transect (Figure 30, Profile X) was established in similar terrain to that described above except that the hummock structures were slightly larger, being up to 1.5 metres across and 50 cms high. As Figure 30 (Profile X) shows, there was an even heavier concentration of traffic along this section of the line, and the most intensively used part of the route, the excessive number of vehicle passes had produced a rutted area 3-4 metres across and 50-60 cms deep. Considerable expanses of bare mineral soil were exposed along the floor and sides of the ruts, which were also much wetter than the relatively dry habitat of the undisturbed areas.

Profile XI was also established in the same general area, but whereas both Profiles IX and X were located on relatively flat upland surfaces, this transect was located on a gentle slope. Many of the hummocks in this site had developed into mud boils which were wider and lower than those in the other two transects, and mineral soil from the tops of these mud boils had been smeared along sections of the line. The primary reason for selecting this site, however, was the fact that minor quantities of water were slowly moving along some of the tracks and the configuration of the ground surface was established to determine if there is any subsequent erosion by surface runoff.

Since Line 141 was the first to be completed in the programme, it was possible to use these observations to modify or control the number of passes along other similar sections of line. In some cases, almost all of the shot holes along the end-spreads were drilled by a single rig, thereby reducing the required number of passes of the heaviest vehicle to two. Where this was not feasible, the vehicles were requested not to follow the same route on the return journey.

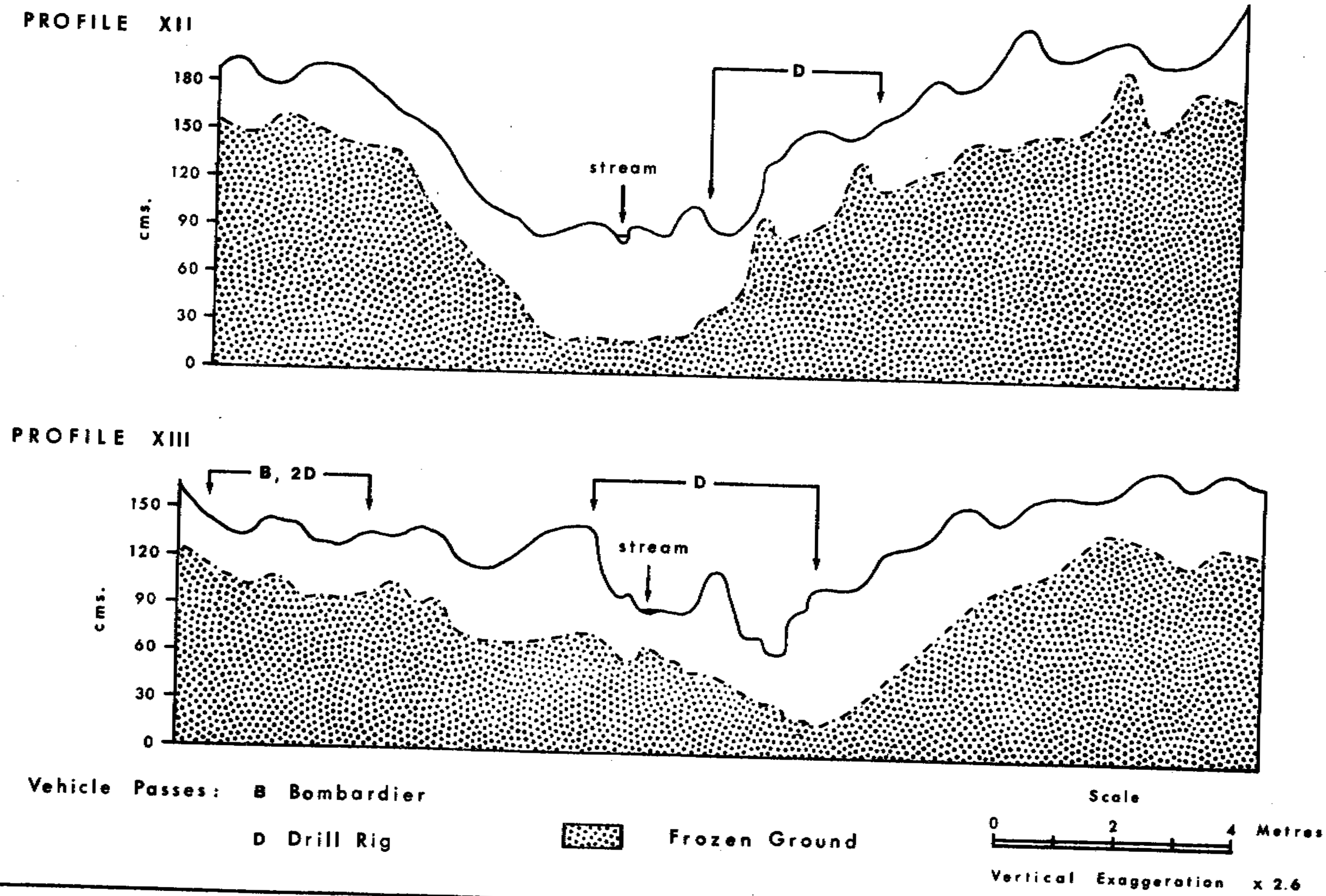
The majority of the stream crossings involved in the seismic programme were extremely well executed with little or no damage to either the banks or bed of the stream. The one major blemish on this record occurred along the access route used to move the vehicles to the northwest end of Line 146. At one point along this access road, one drill rig crossed one of the creeks and then attempted to move up the valley of a small tributary stream. The rig was not able to proceed too far before it became stuck in the soft ground and was compelled to back out again. Two profiles (Profiles XII and XIII) were surveyed across the disturbed area to see if there is any subsequent erosion by water moving along the tracks, and these profiles are shown in Figure 31.

As Figure 31 shows, the track area, covering a width of 2.5 to 3.0 metres was characterized by the development of prominent ruts, which in

Figure 31

1971 SUMMER SEISMIC OPERATIONS

ACCESS ROAD TO GULF LINE 146



places were 30-50 cms deep. Most of the vegetation cover had been destroyed in the rutted section, and the ground surface consisted of wet mud. Although there was not a great deal of water flowing in the tributary, a steady trickle had been diverted from its original course and was flowing down the tracks. It is difficult to comprehend why the operator even attempted to follow this route. The other drill rig moved along a nearby route used by the survey bombardier, and subsequently followed by the second rig, and, as Profile XIII shows, the disturbances along this alternative route were far less severe.

Finally, the access route to Line 146 also followed an old summer seismic line for a short distance and the degree of disturbance along this section was far more pronounced than when an entirely new route was selected. This again points to the need to qualify that section of the Land Use Regulations which encourages vehicle operators to follow existing lines wherever possible.

WINTER SEISMIC OPERATIONS

Seismic operations in most of the Western Canadian Arctic are primarily restricted to the winter months, and most of the studies of the types of terrain disturbance associated with these operations have been conducted in the form of a post-mortem or after-the-event investigations in the following, or even later, summers. The limitations of this method of study are that, while they do permit an approximate determination of the relative magnitude of the terrain damage, they do not yield any information on the immediate or short-term, as opposed to the long-term, effects of the disturbance, nor do they allow a ready evaluation of the causal factors involved. These limitations are compounded by the difficulties encountered in obtaining necessary background information on the seismic programmes, in terms of the terrain conditions, types of vehicles used, the number of passes of each type, and the level of disturbance associated with individual vehicles. The implications are that this method of investigation can, at best, provide some index as to whether or not the amount of damage conforms to acceptable levels; but the research has only limited value in terms of being able to predict the effects of future operations, or to suggest how the operational procedures can be modified to minimize the level of disturbance to the tundra. This type of information can only be obtained by either experimental manipulations of plots which attempt to reproduce the type of damage incurred, or better still, by on-site research and observations during an actual winter seismic operation.

This section of the report covers studies embracing both the on-site and 'post-mortem' methods of investigation. The first part includes some comments based on observations, largely qualitative, of a winter seismic operation in the Mackenzie Delta area, and the second part describes the terrain disturbances associated with the first winter seismic operations on Banks Island.

Caribou Hills Area.

In February, 1971, Gulf Oil Canada Limited, in cooperation with Globe Party #3, provided an opportunity to study and observe their winter seismic operation in the Caribou Hills area near to Reindeer Station. Unfortunately, the limited time available for the field investigations, combined with difficulties in the scheduling of the operations at the same time, resulted in the observations being restricted to qualitative assessments.

Two transects were established in the undisturbed terrain across the proposed route of one of the seismic lines. One of these transects was located on a bare upland surface from which most of the snow had been removed by the wind, and the second was situated in the floor of a depression where the snow cover was as much as one metre thick. Each profile was surveyed to provide details of the configuration of the ground surface and the thickness of the snow cover, and this procedure was repeated immediately following the passage of two bulldozers used to clear the snow off the line. Since the bulldozers did not arrive until the day that we were scheduled to return south, and there would be no opportunity to record the effects of the passages of other vehicles in the seismic operations, no additional research was performed on these transects. Furthermore, in the case of the upland site the substrate was composed of frozen gravel, in which no appreciable terrain damage is to be anticipated, and in the lowland area several centimetres of snow remained on the ground surface, as a compact layer, after the two vehicles had moved through.

Surveys of the completed seismic lines showed that in localized areas the snow cover had been completely removed and the ground surface had been disturbed. Observations of the movements of all the vehicles in the seismic programme also showed that the blade of the bulldozer, despite having shoes attached, was responsible for most of the damage to the terrain. Although the use of these vehicles may be essential to winter operations, it is questionable as to whether or not they need to blade away as much of the snow cover along the lines. In this respect, it may be worthwhile to encourage further research to develop a type of geophone that can provide good seismic records through the snow layer.

Banks Island.

Two major factors hindered a comprehensive survey of the terrain disturbances associated with the seismic operations completed on Banks Island, during the winter of 1970-71, by Elf Oil Exploration and Production Canada Limited, and Deminex (Canada) Limited. Firstly, the information provided to us in map form outlined the original proposed seismic operations for each company, and not the work which was actually completed. This was particularly significant in the case of Elf's programme in which many of the lines were not completed, and also in Deminex's programme where a number of changes occurred. Secondly, the logistical support provided in the form of a Twin Otter equipped with floats, was for this survey far from adequate. This aircraft is of only limited value for such surveys, due to the speed and altitude at which it must operate, and its extremely restricted versatility with respect to landing at the disturbed sites. Since a major part of our observations had to be made from elevations of several hundred feet above the ground surface, a Helio-Courier, equipped with tundra tyres, was chartered from Nahanni Air Services Ltd., to facilitate observations from much lower altitudes, and landings at any sites which appeared to exhibit signs of more severe environmental disturbance.

Fortunately, our task was made considerably easier due to the assistance of Mr. Andrew Carpenter, President of the Banks Island Trappers' Association, and Mr. Douglas Urquhart, Territorial Game Officer, Sachs Harbour. Both of these people had carried out numerous observations of the actual seismic operations during the winter, and had recorded any sites where environmental disturbances appeared to be most severe.

Although detailed ground inspections were only conducted at three sites, there is little doubt that the terrain disturbances associated with the winter seismic operations on Banks Island are negligible. Considerable difficulty was experienced in locating many of the lines and, even then, it was virtually impossible from the air to follow the lines for any appreciable distances. In many instances, the locations of the shot holes, or more precisely the sticks used as shot point markers, provided the only real clues to the existence of the seismic lines. This was particularly noticeable on the drier, upland areas which possess a scant vegetation cover. In the lower, wetter areas, the lines were somewhat easier to detect, but even in these areas there were few examples of any marked disturbance of the terrain.

Equal difficulty was encountered in locating the seismic lines on the ground. Ground inspections were made in the vicinity of Elf shot point #1385, located at approximately longitude 124° 20'W and latitude 73° 10'N. Several parallel tracks, occupying a total width of about 10 metres, were examined in a relatively flat, lowland area of somewhat restricted drainage. The site was characterized by the development of low hummocks and mud boils, with a maximum microrelief of about 10-15 cms. The only surface expression of the tracks consisted of occasional minor depressions, less than 5-10 cms deep, and there was no evidence of any mineral soil being exposed by other than natural means (i.e. the bare surfaces of the mud boils). Comparative measurements of the thickness of the active layer in the disturbed and adjacent undisturbed areas revealed no appreciable differences. In both areas the depth of thaw ranged from 25-30 cms beneath vegetated surfaces to 60-65 cms under the bare mineral soil. The vegetation of the site was dominated by prostrate willow, cotton-grass, sedges, avens and mosses. Disturbance or damage to the vascular species was minimal to non-existent. In the inter-hummock depressions, some of the mosses had been dissected by the vehicle tracks and could be easily dislodged, but the greater availability of moisture in these depressions will probably promote the regeneration and recovery of this moss layer.

Immediately to the south of the above site, the seismic line traversed a better-drained, upland area which was characterized by a greater predominance of mud boils. Approximately 55 per cent of the ground surface consisted of exposures of bare mineral soil. There was virtually no topographic expression of the vehicle tracks across this area and the depth of thaw, 65-70 cms, was identical in the 'disturbed' and the undisturbed terrain. The vegetation cover, principally *Dryas*, was no greater than 45 per cent, and of this, 50-65 per cent consisted of attached dead leaves that could easily be dislodged by foot. Any disturbance of such vegetation mats would probably be difficult in winter, when frozen and covered with snow. However, considering that this type of community is representative of a major portion of the area in which the winter seismic operations were conducted, the importance of the vegetation in stabilizing soil structure and moisture conditions, and the ease with which the vegetation can be removed during the summer, it is imperative that these facts are not overlooked if applications are made for summer seismic operations.

These ground inspections of the sites substantiated the conclusion that winter seismic operations had resulted in a negligible disturbance of the terrain. During discussions with the local residents, however, frequent mention was made of an instance, last February, when a bulldozer was 'lost' in the vicinity of the Big River. Apparently the operator had inadvertently moved into, or close to, the waterfowl sanctuary whilst attempting to locate the starting point of a seismic line; and the disturbance was considered to be extensive. Despite the assistance of Mr. Carpenter and Mr. Urquhart, considerable difficulty was encountered in locating the site which proved to be at approximately longitude 123° 55' W and latitude 72° 28' N, close to the north bank of the Big River. The seismic line, at this point traversed an alluvial terrace mantled by a fairly continuous vegetation cover of Dryas hummocks. Although the imprint of the vehicle tracks was slightly more pronounced than that described in the previous sites above, the most obvious effect of the disturbance appeared to be a suppression of the growth of the Dryas resulting in a higher proportion of dead leaves along the tracks.

The primary concern of the residents, however, was not the seismic line, but a patch of ground that had been disturbed by the tight turning action of a bulldozer. Although this had resulted in the local removal of 5-10 cms of material, exposing mineral soil, the level of damage should be considered to be minor. Since the subsurface materials at this point consist of well-drained sand and gravel, any further accentuation of the damage is most improbable. The presence of new leaves and shoots on damaged willows, and vegetative shoots on the sedges, further indicates that a reasonably rapid recovery of at least some of the vegetation is to be anticipated. Despite the minor nature of the disturbance at this site, there appeared to be a number of other instances where individual vehicles apparently had moved randomly across the tundra adjacent to the seismic lines. Although none of these trails has had a markedly deleterious effect upon the terrain, there would appear to be no logical necessity for such additional movements and, in future operations, it would seem that they might possibly be eliminated without adversely affecting the efficiency of the seismic operation.

There is little difficulty in accounting for the negligible disturbance encountered along the seismic lines. Doubtless, both companies have, for the most part, made a concerted effort to minimize any adverse effects of their operations on the tundra. Apart from the care which was obviously exercised in the general operation of the vehicles, the sinuous nature of the lines reflects an attempt to minimize any damage, by moving, as far as possible, along the drier, upland sites. Movement along these upland areas, with their scant vegetation cover, has restricted the amount of disturbance since it is the vegetative layer which usually exhibits the more obvious signs of damage. The high percentage of bare ground further implies that there will be minimal alterations to the thermal regime of the active layer and, consequently, limited possibilities of any future accentuation of the disturbance along the lines due to thermokarst subsidence. The wide spacing of the seismic lines also serves to minimize any unaesthetic qualities of the operation. These factors, together with the monitoring influence of the residents of Sachs Harbour have, cumulatively, resulted in operations which establish what can be done on Banks Island. It is to be hoped that these same factors will assure that any future operations will at least maintain the same high standards. The dangers of complacency should be self-evident since the neglect of any one of the above factors could only serve to increase the amount of terrain disturbance. In this respect it should be noted that, due to the more severe environmental conditions, any level of disturbance will probably take as long to recover as a more severe form of disturbance in the delta area to the south.

As mentioned previously the locations of the shot holes, or shot point markers, frequently provided the easiest means of tracing the seismic lines. However, it appears that some of the shot holes are not being filled in, as stipulated in the regulations (e.g. Elf shot point #1385 was open to a depth of 55 cms and shot point #1393 to a depth of more than 1.5 metres). Wooden marker sticks and shot wire were also left lying on the ground and could have been removed with comparative ease.

Despite the continued presence of a member of the Banks Island Trappers' Association on each operation, piles of garbage, presumably marking the positions of campsites, were observed at at least six sites. It was gathered, however, from discussions with some of the people at Sachs Harbour, that several prolonged storms had occurred during the winter with the result that garbage could have been obscured by snow and not noticed when the camp was moved. Since the Land Use Regulations are quite explicit with respect to the disposal of garbage it is suggested that the companies be requested to clean up these sites as quickly as possible.

The Elf Oil Company winter road from the staging area at Johnson Point to the site of the seismic operations is approximately 45 miles in length. The amount of care and thought involved in the selection of the route, to follow as much of the higher ground as possible, is reflected in the negligible disturbance along the route and the consequent difficulty in tracing it from the air. The only major exception to this pattern occurred where the winter road intersected the most easterly of the north-south seismic lines. Here, an inordinate number of separate tracks made it difficult to establish the real position of the road. The trace of the road also seemed to be more prominent where the route involved an oblique traverse of a slope. This can possibly be attributed to the fact that in such locations the weight of the vehicle is unevenly distributed on the tracks. This problem can possibly be alleviated in the routing of subsequent winter roads (and seismic lines) by following paths which run directly up or down a slope wherever the gradient permits.

The Deminex winter road from the staging area at Herbert Point was almost impossible to detect over much of its length, indicating negligible disturbance of the terrain.

The staging area at Johnson Point was extremely clean and tidy and provided an excellent example of how a base camp can be operated. The principal exception to this pattern occurred where a tracked vehicle had moved along a line between the dynamite storage sheds and airstrip after the ground had started to thaw. As a result of this movement, paralled ruts, up to 70 cms across and up to 30 cms deep (including 20 cms of water) had been formed in a number of wet areas. The depth of thaw beneath the imprint of the tracks averaged 48 cms, compared to an average depth of 68 cms in adjacent undisturbed areas, suggesting that the position of the frost table had already been lowered by approximately 10 cms. The vegetation in the water within the tracks was still alive, however, and had obviously not suffered extensive damage as a result of the compression and partial submergence. This solitary example apart, there appeared to have been no excessive use of vehicles outside the immediate camp area.

The staging area at Herbert Point for the Deminex operation was only inspected from the air, and also appeared to be clean and tidy, except for a large number of shot point marker sticks which were scattered over the ground on the east side of the camp.

<u>Storkerson Bay Rig Site</u>. In July, 1971, we were informed that a site had been selected, near the southern end of Storkerson Bay, for the location of the first well to be drilled on Banks Island. It was also

understood that the precise area of the rig site had been marked out on the ground and that an access route had been similarly marked for the movement of the rig and camp from a staging point on the coast. This movement was scheduled to take place in early August. Since this schedule appeared to represent an excellent opportunity to become involved in additional on-site research, we returned to Banks Island to conduct surveys of the undisturbed terrain conditions and record the effects of the vehicles to be used in the transportation of the rig. Due to unforeseen circumstances, the barges transporting the rig did not arrive while we were at the site. Most of the pin flags, used to mark the line of the access route, had also been removed by the wind, and even though it was eventually possible to reconstruct the position of the proposed road, it was felt that the route along the coast, from the staging area to the start of the road was such that it would be virtually impossible to use. The observations at Storkerson Bay were therefore restricted to six profiles of the undisturbed terrain conditions across the proposed rig site. These profiles will, in the future, permit an evaluation of the terrain disturbances incurred as a result of the drilling operations.

SUMMARY AND RECOMMENDATIONS

This final section of the report summarizes the findings of the summer research programme. It also includes some recommendations pertaining to the application of, and future research into, the Land Use Regulations with respect to the activities of the resource exploration industry in far northern Canada. In interpreting these comments, it is imperative to remember that the limited sample sizes, the inability to establish the pre-disturbance terrain conditions with any real degree of accuracy, and the almost total absence of any vital information regarding the operating conditions and amounts and types of vehicular traffic involved, seriously limit the usefulness of some of the conclusions.

The investigations of the sites of winter road operations show that the destruction of the vegetation cover and surface microrelief forms has produced a predictable increase in the thaw depths and ground temperatures beneath the disturbed areas as compared to the adjacent undisturbed terrain. This obliteration of the surface microrelief has also led to more uniformity in the thaw penetrations in the damaged areas, and if the recovery process is to include the development of these features, this will involve a much longer time period than that required to re-establish a continuous vegetation cover. The field observations suggest that the ice road method of construction is much more effective than the snow packing technique in limiting the level of terrain disturbance, but additional research is necessary to determine more precisely the number of years that the same access route should be used. Data from the quadrat studies in the Shingle Point area indicate that, in comparison to the undisturbed terrain, the re-use of the road produced a relative increase in the thickness of the active layer of almost 27 per cent, which compares with an increase of slightly less than 21 per cent in the winter road which was used for only one year's operations. This difference, of less than 6 per cent, may be too insignificant to warrant a consideration of the restriction of the use of an access route to only one year, but it remains to be seen whether Dr. Lambert's vegetation studies reveal any more appreciable differences. In terms of the general appearance of the two winter roads at Shingle Point, however, there is no doubt that these access routes should not be used for more than two years' operations. The extreme form of damage exhibited by the winter road at Sitidgi Creek demonstrates what can happen when the surface organic layer is finally destroyed to a point where pronounced thermokarst subsidence is initiated. The sequence of events associated with the activities of the resource exploration industry in the Sitidgi Creek area, particularly as related to the crossing of the open water of the creek in winter, also indicates that there is a need for improvements in the planning procedures used to select the routes for the winter roads.

The investigations of summer seismic lines, from one to nine years old, and those made during an actual summer seismic programme demonstrate conclusively that, in certain areas at least, and with the adoption of suitable operational techniques, the terrain disturbances associated with these operations need not result in any serious damage to the tundra. Indeed, the negligible amount of terrain disturbance revealed in the 1971 seismic operations suggests that there are in fact certain merits in scheduling summer programmes. Most of the disruption of the ground surface was in fact due to a compression of the organic layer and this ability of the terrain to undergo slight deformation in response to the weight of the vehicles may produce less damage than the abrasive effects of vehicles on the same terrain when it is frozen solid. Similarly, the supple nature of the vegetative cover, and the shrub layer in particular, in the summer allows it to withstand the passages of vehicles with fewer adverse effects than in the winter months. The on-site investigations also confirmed that, for the most part, the real problem with respect to cross-tundra movements in the summer thaw period is the maximum number of vehicle passes that the ground surface can tolerate before the degree of disturbance begins to exceed acceptable levels. Even with the use of a stationary base camp, an excessive number of vehicle passes along the same route is possible and, unless additional future research indicates otherwise, it appears that no more than two of the heavier vehicles (e.g. drill rigs or recording unit) should be encouraged to follow the same tracks.

The terrain disturbances associated with the 1970-71 winter seismic operations of Elf Oil Exploration and Production Canada Limited, and Deminex (Canada) Limited, on Banks Island are negligible. The minimal nature of the disturbance reflects a combination of factors including (a) the efficiency of each company's operations, (b) the careful selection of routes for both the seismic lines and the winter roads, and (c) the continued presence of a local resident during the actual operations. However, closer scrutiny is apparently necessary in certain aspects of the operations, particularly with respect to a curtailment of any unnecessary movements of vehicles over the tundra, the filling in of shot holes and garbage disposal.

The following tentative recommendations are made with regard to the application of, and future research into, the Land Use Regulations as applied to the operations of the resource exploration industry in the tundra regions of far northern Canada.

1. Winter roads, constructed by using conventional snow packing techniques, should not be used for more than two consecutive winters' operations.

2. The ice road method of building winter roads results in less damage to the terrain than the snow packing method of construction, and a wider adoption of this method should be

encouraged in general, and particularly when there is a scant snow cover or where it is definitely intended to use the same access route for two consecutive years.

3. There is a need to consider more thoroughly the section of the Land Use Regulations which encourages vehicle operators to follow existing lines, trails or rights-of-way wherever possible. In most cases the accentuated damage along the old line is much more severe than the level of disturbance that would be incurred in following a new route across previously undisturbed terrain.

4. The extreme form of damage associated with the late passage of vehicles along the Gulf ice road indicates that there is also a need for a stricter control, through the issuance of specific permits, of all cross-tundra movements of vehicles. The rights of individual companies to restrict the movements of other companies along routes for which they have the prime responsibility should also be firmly established.

5. If the Land Use Regulations are to have any real meaning, severe penalties must be levied against any blatant violations of these regulations.

6. Summer seismic operations in the Mackenzie Delta area need not result in any serious damage to the terrain, but no summer seismic work should be permitted on any recently burnt-over areas of the tundra.

7. The revegetation of any disturbed areas, resulting from summer seismic operations, will probably be enhanced if the work is

performed during the early part of the summer (e.g. late June and July), thereby facilitating some recovery of the vegetation during the remainder of the summer, rather than in the following year.

8. The level of disturbance associated with summer seismic operations is intimately related to the number of heavier vehicles moving along the same route, and rather than encourage a concentration of such traffic within a 33-foot width of the tundra, it would appear to be advisable to promote a dispersion of this vehicular activity.

9. On-site research, conducted during actual operations, provides the only means of recording the precise nature and extent of the terrain disturbance, the causal factors involved, and the collection of data that can be applied immediately to minimize the damage to the tundra in future land use operations. The advantages of this method of study are such that a concerted effort should be made to seek the further cooperation of the resource exploration industry in promoting this type of research as much as possible.

10. Where 'after-the-event' or ' post-mortem' investigations of terrain disturbances are the only feasible method of study, there is an immediate and compelling need to establish a comprehensive data bank system which should include exact maps of the operations, and details of the numbers and types of vehicles used, number of passes and tonnages involved, as well as any relevant information (e.g. depth of snow cover) pertaining to the operating conditions under which the work was performed.

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