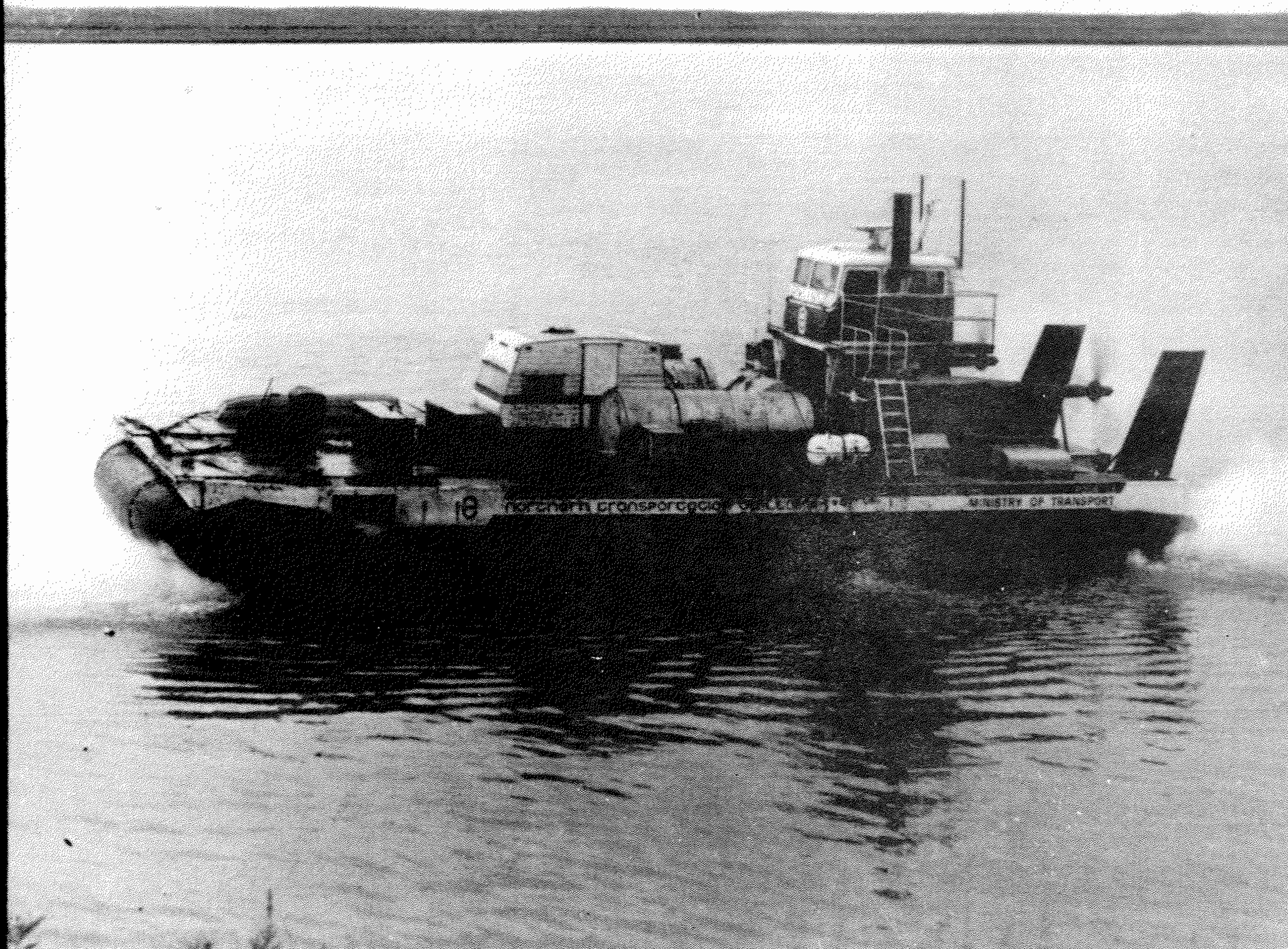
Environment Canada / Environnement Canada
Forestry Service / Service des Forêts

Voyageur air cushion vehicle trials on the Mackenzie Delta: Environmental effects two years later

by S. C. Zoltai



Information Report NOR-X-146
December 1976

northern forest research centre
edmonton, alberta

VOYAGEUR AIR CUSHION VEHICLE TRIALS ON THE MACKENZIE DELTA:

ENVIRONMENTAL EFFECTS TWO YEARS LATER

BY

S.C. ZOLTAI

INFORMATION REPORT NOR-X-146
DECEMBER 1976

NORTHERN FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE
ENVIRONMENT CANADA
5320 - 122 STREET
EDMONTON, ALBERTA, CANADA
T6H 3S5

Zoltai, S.C. 1976. Voyageur Air Cushion Vehicle trials on the Mackenzie Delta: Environmental effects two years later. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-146.

ABSTRACT

Tests were conducted in 1973 with a prototype Voyageur Air Cushion Vehicle on the Mackenzie Delta in lowland and upland tundra conditions. Reassessment in 1975 showed no damage or change in the vegetation or in the thawed layer on the lowland tundra trial courses. On the upland tundra some vegetation damage was recorded and the organic mat was torn in a few instances. Thawed layer thickness on the trial courses increased by 20-25%, probably the result of reduced albedo. The increased thawing did not lead to terrain subsidence.

RESUME

En 1973, on effectua des essais d'un prototype de véhicule sur coussin d'air, de marque Voyageur, dans le delta du Mackenzie. Il l'essaya sur des placettes dans la basse toundra et en toundra à haute altitude. Selon des examens faits en 1975, la végétation et la couche de sol dégelé dans les placettes en basse toundra n'avaient pas changé ou été endommagées. Sur la toundra à haute altitude, la végétation avait subi quelque dommage et le tapis de matière organique était parfois déchiré. L'épaisseur de la couche de sol dégelé dans les placettes avait augmenté de 20 à 25%, à cause probablement de l'albedo réduit. Ce dégel accru ne produisit pas d'affaissement du sol.

ERRATUM

Photos appearing on pages 16 and 17 were inadvertently interchanged. The photo on page 17 is Figure 6, and the one on page 16 is Figure 7.

Preface

On the Mackenzie Delta in 1973, environmental tests were carried out in lowland and upland tundra with the Voyageur 002 air cushion vehicle. Results were reported in the TDA report "Environmental Assessment, Bell Voyageur 002", July 1975.

To assess possible permanent damage, TDA provided funds and requested that Environment Canada reexamine the terrain over which the initial tests had been conducted. This was done in the summer of 1975 by Mr. S.C. Zoltai, Environment Canada.

In the following report, the state of the vegetation as observed immediately after the 1973 tests is compared with the condition of the vegetation as observed two years later.

Contents

1.	**Introduction**	1
1.1	General	1
1.2	Methods	1
2.	**Results**	3
2.1	Permanent Sample Plots, Site 3, Lowland Tundra	3
2.2	Permanent Sample Plots, Site 6, Upland Tundra	3
2.3	Trial Courses, Lowland Tundra	3
2.4	Trial Courses, Upland Tundra	6
2.5	Statistical Treatment of Data	6
3.	**Discussion**	7
3.1	Depth of Thaw	7
3.1.1	Active Layer Thickness	7
3.1.2	Variations in Active Layer Thickness	7
3.2	Effects on Vegetation	7
3.2.1	Damage to Plants	7
3.2.2	Change in Thermal Qualities	7
3.2.3	Change in Composition	7
3.3	Visual Impact	8
4.	**Conclusions**	9
	References	10

Tables

Table 1	Summary of trials by Voyageur A.C.V. (1973)	2
Table 2	Thickness of active layer and culm height of Carex on disturbed and control permanent sample plots, lowland tundra	4
Table 3	Thickness of active layer on disturbed and control permanent sample plots, upland tundra	4
Table 4	Summary of the impact of Voyageur Air Cushion Vehicle trials	5

Figures

Figure 1	Location of the control permanent sample plot in relation to the trial courses	11
Figure 2	Trial Courses 6, 8, 9, and 10 on the lowland tundra, viewed from the air	12
Figure 3	Ground view of the disturbed sample plot on the lowland tundra	13
Figure 4	Aerial view of Trial Courses 15, 16, and 17	14
Figure 5	Detached and redistributed Cetraria cucullata thallus	15
Figure 6	Alder shrub split at the base of stem	16
Figure 7	Disturbed upland tundra vegetation	17
Figure 8	Aerial view of Trial Course 2 on the lowland tundra	18
Figure 9	Aerial view of Trial Course 3 on the lowland tundra	19
Figure 10	Aerial view of part of Trial Course 7 on the lowland tundra	20
Figure 11	Linear depression in the vegetation on a seismic line	21
Figure 12	Land-water interface on Trial Course 9	22
Figure 13	Half of an alder shrub torn out by the ACV, with disrupted ground surface	23

1. Introduction

1.1 General

In August, 1973, a series of tests was conducted with an Air Cushion Vehicle (ACV) to assess the impact of multiple passes on the terrain, vegetation, and avifauna under Low Arctic conditions. The vehicle used in the tests was the prototype ACV, Voyageur, weighing about 16 tonnes (t) when empty and up to 40 t when fully loaded. This ACV has a ground clearance of about 10 cm and develops far less pressure (0.023 kg/cm^2 or 0.33 psi) than an average person standing on the ground (approx. 0.2 kg/cm^2 or 3 psi).

The tests were conducted on the southern part of Richards Island in the Mackenzie Delta region of the Northwest Territories under both lowland and upland tundra conditions. In the lowland tundra, sedge dominated with patches of low (about 1 m) willow. In the upland tundra, dwarf (less than 10 cm) heath shrubs, mosses, and lichens formed the dominant vegetation, with scattered low (about 1 m) alder and willow shrubs. In addition, tests were made on land-water interfaces along the shores of small ponds having both floating and emergent vegetation. The trials included single and multiple passes (20 passes) at different speeds under diverse weather conditions and with varying load weights (Table 1). Maneuvers such as stationary hover and pirouette were also performed.

The immediate effects on the vegetation and avifauna were monitored during and after the tests. Damage to vegetation was slight, except where the vehicle had become lodged in shrubs. On the upland sites, lichens were extensively dislodged and redistributed by the vehicle. The effects on the land-water interface and on the avifauna were also slight, but repeated and sustained operations could cause disruption of the terrain, vegetation, and fauna.

The specifications of the ACV, the trials, their locations, site conditions, and immediate effects have been fully reported (Slaney & Co. 1973, Vols. I-III). The report also included recommendations for the avoidance of sensitive areas, operational procedures, and vehicle design improvements to lessen the adverse impact on the environment.

In September, 1975, a reassessment of the ACV trial site was carried out to determine whether significant long-term terrain and vegetation changes had been induced by the trials. The results of the reassessment are presented in this report.

1.2 Methods

The procedures listed below were adopted for the reassessment.

- Permanent Sample Plots (PSPs): measuring the depth of thaw at 25 randomly selected points on each PSP, duplicating the method used in 1973; measuring Carex culm heights at 25 points on each lowland PSP; estimating displaced lichens at five points on the upland tundra.

- Inspecting the apparent courses at the most extensive trial sites on the lowland and upland tundra sites by walking and observing the entire length of Trial Courses 6, 8, 9, 10 (Site 3), including the aquatic sites, and Trial Courses 13, 14, 15, 16, 17 (Site 6), and documenting any visible changes.

- Aerial inspection of the other sites, with ground spot checks.

All trial courses except Trial 1 were located and inspected from the air. Trial Course 1 was located along the shore of a branch of the Mackenzie River.

A number of circumstances prevented a more comprehensive reassessment of the present conditions:

- the cardinal directions of the PSPs were erroneously reported. The directions clearly stated (Slaney & Co. 1973, Vol. II, App. 12) that the control PSP on the upland tundra area (Site 6) was located west of Trial Course 16. It was found, however, that the westerly PSP was disturbed, and the other PSP, lying east of Trial Course 16, was not disturbed. Aerial inspection established beyond doubt that the PSP east of Trial Course 16 was undisturbed and, therefore, was the control PSP (Fig. 1).

- the method of vegetation assessment used in 1973 was not repeatable. In each 20 m x 20 m PSP, there were 25 randomly placed .2-m^2 quadrats. An attempt at duplicating this method on the upland site yielded entirely different proportions of plants and even a number of previously unreported species on both the disturbed and control PSPs. It was felt that the original methodology was not sensitive enough for monitoring the changes that might have occurred.

- although the trial courses were visible from the air, their boundaries were very indistinct or even invisible on the ground. This made it impossible to conduct a ground inspection of the trial courses. Additional complications were presented by the numerous older seismic lines crossing the trial courses at both the lowland and upland sites.

All these uncertainties could have been avoided had the bearings of the trial courses been given, or if the courses had been marked by stakes.

Physiography	Site	Trial course number	Number of passes	Speed (km/h)	Load (t)
Lowland Tundra	1	1	20	52	29
	5	2	1	30	30
	2	3	1	58	30
	3	6	20	51	29
	4	7	1	32	39
	3	8	20	20	38
	3	9*	20	73	37
	3	10	1	73	37
Upland Tundra **	6	13	1	26	29
	6	14	1	43	29
	6	15	20	38	29
	6	16*	20	46	28
	6	17	20	29	28

Table 1. Summary of trials by Voyageur Air Cushion Vehicle

Data from Slaney & Co. (1973), Vol. 2, App. 1.

* Permanent Sample Plots (PSP).

** Comments: There had been considerable precipitation the day before the trials.

Note: Trials 13 and 14 were on the same course as Trials 16 and 17.

Trials 4 and 11: shut down for 30-75 min.

Trials 5 and 12: stationary hover for 6 min.

2. Results

2.1 Permanent Sample Plots, Site 3, Lowland Tundra

The PSPs at Site 3 are located on a large unpatterned fen which had about 10 cm of standing water at the time of the 1975 study. The soils are Fibric Organo Cryosols (Anon. 1973) which have developed in fibric sedge fen peat, with the permafrost table at about 55 cm. The vegetation is dominantly Carex aquatilis, with minor components of Equisetum arvense and Eriophorum angustifolium. There are thickets of Salix pulchra growing to a height of about 75 cm in the area, but not on the PSPs.

Trial Course 9 on which the disturbed PSP is located had been subjected to 20 passes by the ACV. This course was still visible from the air (Fig. 2), but it was not discernible on the ground (Fig. 3). A close inspection of the ground showed that many old Carex blades were lying flat and aligned in the same direction. This was probably caused by the blast of air issued from the ACV. The height of culms (flowering stems) of living Carex aquatilis was the same on both the control and disturbed plots (Table 2).

The thickness of the active layer was slightly greater under the disturbed PSP than under the control plot (Table 2). However, the active layer under the control plot was somewhat thinner in 1975 than it had been in 1973, probably due to different weather in these years. An estimate of expected thickness was made based on the 1973 control and disturbed plots. This estimate showed that the active layer thickness had increased by 1.4 cm or 2.5 percent under the disturbed plot in 1975. As well, the standard deviation was more than twice as high on the disturbed plot than on the undisturbed plot indicating that the active layer became more uneven in thickness after disturbance.

2.2 Permanent Sample Plots, Site 6, Upland Tundra

Site 6 is located on a low plateau elevated some 10 m above the level of the nearby Mackenzie River. The soils are Brunisolic and Gleisolic Turbic Cryosols (Anon. 1973), having developed on imperfectly to poorly drained loamy till-like material. The northern end of the test area grades into a high center polygon area with thick peat deposits. The peat on the PSPs is less than 20 cm thick, and thickest in the more poorly drained depressions. There are a few earth hummocks, some with a naturally bare center which exposes the mineral soils. Earth hummocks are generally associated with high ice content immmediately below the permafrost table (Zoltai and Tarnocai, 1974). The active layer is about 25 cm thick, consisting of cryoturbed materials.

The vegetation consists mainly of dwarf heath shrubs (Vaccinium vitis-idaea, V. uliginosum, Arctostaphylos rubra, Ledum palustre ssp. decumbens, Cassiope tetragona and Empetrum nigrum). Tussock-forming Carex bigelowii and Eriophorum vaginatum ssp. spissum are locally common. The ground is almost completely covered with moss and lichens (Cetraria cucullata, C. nivalis, and C. islandica, Cladonia spp., Alectoria sp., Polytrichum commune, Dicranum cf. fuscum). Low Betula glandulosa shrubs are common, and scattered higher (up to 1 m) Alnus crispa and Salix glauca occur.

The trial courses were well visible from the air (Fig. 4). On the ground, signs of disturbed vegetation were everywhere. The most common evidence was the occurrence of displaced lichens, mainly Cetraria cucullata thalli (Fig. 5). A check of five small (10 cm x 10 cm) random plots showed that about 10 percent of the thalli on the disturbed plot was displaced. These thalli did not differ in appearance from the undisturbed ones, but many had landed upside down or in small pools of water, so their viability was questionable. Broken, displaced alder and willow shrubs were further evidence of damage. Alders appeared to be more susceptible to breakage than willows. Most breakage occurred near the root collar, resulting in a split main stem (Fig. 6). Small clumps of dense Dicranum (cf. fuscescens) cushions were torn up and displaced. Some Carex tussocks were also split and uprooted, and the uprooted portions were dead (Fig. 7).

Attempts to determine change in vegetation composition were not successful as the original survey quadrat locations (Slaney & Co. 1973, Vol. II, App. 2) could not be duplicated. A comparison of the disturbed and control plots did not indicate either invasion of the disturbed site by new species or proliferation of an already present species.

The active layer was thicker under the disturbed plot than under the control plot (Table 3). In 1973, the reverse had been true. As on the lowland tundra, the active layer on the control plot was not as thick in 1975 as it had been in 1973. The active layer on the disturbed plot increased by 6.4 cm or 24 percent, based on the predictive technique previously described. The active layer thickness had been more irregular on the control plot in 1973, but, by 1975, the disturbed plot was much more irregular than the control plot. The standard deviation in the active layer thickness measurements under the disturbed plot was nearly twice as high than for the control plot (Table 3).

2.3 Trial Courses, Lowland Tundra

The observations on the impact of the Voyageur trials are summarized in Table 4. Overflight of the area, as indicated in the original report (Slaney & Co. 1973, Vol. II), revealed no visible traces of the trial course. This site is subject to annual flooding by the river, making a distinction between flood water, ice damage, and ACV effects almost impossible.

Trial Course 2, subjected to a single pass by the ACV at low speed, was still clearly visible from the air (Fig. 8). The terrain and vegetation were similar to

	Control			Disturbed		
	Ave. cm	Range cm	St. Dev'n	Ave. cm	Range cm	St. Dev'n
Carex culm height	57.0	52-75	6.224	56.7	40-72	6.527
Active layer thickness, 1973*	58.3	55-60		57.7	55-60	
Active layer thickness, 1975	53.8	52-57	1.241	54.6	48-60	2.885
Active layer, if no disturbance**				53.2		

Table 2. Thickness of active layer and culm height of Carex on disturbed and control permanent sample plots, lowland tundra.

* Data from Slaney & Co. (1973), App. 2.

** Had there been no disturbance, the relationship between active layer thicknesses in 1973 and 1975 on disturbed plots should have been the same as the relationship between 1973 and 1975 active layer thicknesses on control plots. The relationship can be expressed as:

$$\frac{\text{Active layer, control, 1973}}{\text{Active layer, control, 1975}} = \frac{\text{Active layer, disturbed, 1973}}{\text{Active layer, disturbed, 1975}}$$

By solving the equation for Active layer, disturbed, 1975, the thickness of 53.2 is obtained. This figure shows the thickness of the active layer on the disturbed plot which would be expected in 1975 if no disturbance had taken place.

	Control			Disturbed		
	Ave. cm	Range cm	St. Dev'n	Ave. cm	Range cm	St. Dev'n
Active layer thickness, 1973*	32.7	20-50		26.6	20-40	
Active layer thickness, 1975	24.8	21-32	2.677	26.2	19-45	4.971
Active layer, if no disturbance				20.2		

Table 3. Thickness of active layer on disturbed and control permanent sample plots, upland tundra.

* Data from Slaney & Co. (1973), App. 2.

Physiography	Trial course number	Visual Impact		Impact on Vegetation	Impact on Terrain
		Air	Ground		
Lowland Tundra	1	NV*	-	None	None
	2	V	-	None	None
	3	V	-	None	None
	6	V	NV	None	None
	7	V	NV	None	None
	8	NV	NV	None	None
	9	V	NV	None	None
	10	BP	NV	None	None
Upland Tundra	15	V	BP	**	***
	16	V	BP		
	17	V	BP		

Table 4. Summary of impact of Voyageur Air Cushion Vehicle trials.

* Visual impact rating (Abele, 1975):

NV: not visible

BP: barely perceptible

V: visible

** 10 percent lichen thalli dislocated; some shrubs, sedges and mosses torn and killed.

*** Active layer increased by 24 percent; minimal surface scuffing.

Course 9 where no evidence of damage was found. At trial Course 3, traversed once by the ACV at high speed, the path of the vehicle was still plainly visible (Fig. 9). No ground inspection was made as the effects are probably indiscernible on the grassy ground covered by shallow water. Trial Course 7 had been traversed by the Voyageur once at low speed but with near capacity load. The path of the vehicle remained clearly visible on the grassy area, but not on the low willow shrub area (Fig. 10). A brief ground inspection of this site revealed no effects on either the grassy or shrub areas.

Trial Courses 6, 8, and 9 had been traversed by the Voyageur 20 times each at various speeds (Table 1). Trial Course 10 had been traversed only once at high speed. The disturbed permanent sample plot is located on Trial Course 9. Trial Courses 6, 9, and 10 were visible from the air, but Course 8 was not discernible (Fig. 2). All trial courses were walked to detect any signs of disturbance, but, as in the case of the PSPs, none were found. Shrubs and grasses were examined enroute; the only noticeable effect was a tendency for the old, dead sedge blades to be aligned parallel to the trial course. By contrast, an older seismic line crossing Trial Course 10 showed a readily discernible linear groove in the vegetative mat of living and dead vegetation (Fig. 11). There was no difference in active layer thickness between the disturbed seismic line and the nearby area. Inspection of the aquatic sites and land-water interface sites, located on Trial Course 9, revealed no changes in appearance or in the composition of the vegetation (Fig. 12).

2.4 Trial Courses, Upland Tundra

Trial Courses 15, 16, and 17 had been subjected to 20 passes each by the Voyageur at low to moderate speeds (Table 1). All trial courses were clearly visible from the air (Fig. 4), but far less distinct on the ground. The kind of vegetation disturbance noted at the upland tundra PSP occurred on all the disturbed upland trial courses. The estimate of 10 percent displaced lichens appeared valid for all courses. Damaged shrubs, mainly Alnus crispa, were split at the base of the stem, and were occasionally found torn out of the ground. Approximately 10 percent of the alder shrubs showed this sort of damage. In addition, numerous dead willow and alder shrubs which had been broken off at or below ground level were scattered about. Many of these may have been dead at the time of the trials. Split Carex tussocks and detached chunks of Dicranum were also found, but far less commonly.

Only one instance of terrain damage directly attributable to ACV passage was noted. Half of an alder shrub was torn out of the ground (Fig. 13), resulting in a disrupted organic mat and a slight hollow some 15 cm deep where water had accumulated. No noticeable depression in the permafrost table appeared under the disturbed spot, and all active layer depths were within the natural variations in the neighbouring areas.

A few earth hummocks were found, some of which had bare patches on the elevated centers. These bare patches were due to natural processes in actively heaving soils and not to scalping by the ACV.

2.5 Statistical Treatment of Data

Statistical treatment of data relating to changes between 1973 and 1975 was not possible because a) the 1973 observations were available only as averages; b) differences in average 1973 active layer thickness between the control and disturbed sites were relatively large (e.g. 19 percent greater on the control plot); and c) extraneous factors caused a decrease in active layer thickness on the control plot, as shown by the 1973-1975 measurements.

The variations in 1975 active layer thickness measurements were subjected to a test for equality of variances. This variance-ratio or F-test (Husch, 1963) showed that the variations between the measurements on lowland tundra disturbed and control sites were significant at the 2 percent level, and on the upland tundra sites at the 10 percent level.

3. Discussion

3.1 Depth of Thaw

The timing of the thaw depth measurements taken in 1973 in relation to the vehicle trials is not known. Presumably all the measurements were made within a few days of the trials. The seasons in which measurements were taken in 1973 and 1975 were compatible (mid-August vs. mid-September), yielding comparable results.

3.1.1 Active Layer Thickness

The active layer thickness on both the lowland and upland tundra sites was less in 1975 than in 1973, undoubtedly the result of cool weather in 1975. This phenomenon obscured the effect of the ACV trials on thaw depth. The data (Table 2) show that the thickness of the active layer on the disturbed plot on the upland tundra immediately after the disturbance in 1973 was almost the same as in 1975. However, since the depth of the thaw on the control plot in 1975 was much decreased from the 1973 level, there should have been a similar reduction of thaw on the disturbed area if the Voyageur trials had no effect on the active layer. This did not occur. Instead, the active layer thickness increased some 24 percent on the disturbed plot in the upland tundra. On this basis, the ACV appears to have had an effect on the thawing activity.

On the lowland tundra, the change in the thaw depth on the disturbed plot was negligible because the site was covered by about 10 cm of free water. Water is a good conductor of heat and readily dissipates any local effects on the vegetation (changes in insulating qualities, reflectance, and absorbance of radiation, etc.). This finding is compatible with results of ACV tests on lowland sites in Alaska (Abele, 1975) where the increase in the depth of thaw was less than 1 percent after 2 years.

The coincidence of decreasing thaw depth due to climate and increasing thaw depth due to disturbance cancelled any net changes on the upland tundra in 1975. Should the weather patterns revert to those in 1973 within a few years, a thickening of the active layer will occur on the ACV tracks, and the release of water from the upper part of the permafrost will be inevitable. If the release of the water is gradual, allowing the drainage of surplus water, no serious thermokarst development should follow on the upland test site. If the drainage is impeded, thermokarst will probably develop.

3.1.2 Variations in Active Layer Thickness

The measurements taken in 1975 show that the thickness of the active layer is more variable on the disturbed plots than on the control plots. On the lowland tundra, the standard deviation (Table 2) is nearly one and a half times higher on the disturbed plot than on the control plot. On the upland tundra, the standard deviation for the disturbed site is nearly twice as high as on the control site. The F-tests show that, in both cases, the variances of the two sets of data should be considered significant.

The greater variations in thickness of active layer on both disturbed plots as compared to the control plots is probably due to the disturbance. On the lowland tundra, the differential flattening of the vegetation may have changed the insulating qualities to some degree, allowing deeper thawing in some spots and less thawing in others. On the upland tundra, the uneven redistribution of vegetation and debris probably resulted in the same effect.

3.2 Effects on Vegetation

The observed effects of the ACV fall into three categories: damage to individual plants, change in vegetation influencing the thermal qualities of the site, and change in species composition.

3.2.1 Damage to Plants

Plants were damaged on the upland tundra, but not on the lowland tundra. Dry lichens are very brittle and can be readily damaged, but moist lichens are supple and hardier. There had been considerable precipitation on the upland tundra the day before the ACV trial (Slaney & Co. 1973, Vol. II), so the lichens were moist and relatively more resistant to breakage when traversed by the Voyageur. In spite of these favorable conditions, lichens, especially Cetraria culcullata, were dislodged and redistributed by the vehicle. The fate of the dislodged lichens is not known, but it is unlikely that ACV operations will promote a greater lichen cover as suggested by the original study (Slaney & Co. 1973, Vol. II).

Some vascular plants were also broken or killed outright by the ACV. Alder appeared to be more prone to damage than willow, while the low shrubs sustained no apparent damage.

3.2.2 Change in Thermal Qualities

The minor vegetation disturbance on the lowland tundra was sufficient to cause increased unevenness in the thickness of the active layer, but not severe enough to cause an increase in the average thaw depth. On upland tundra there was some damage to the organic mat, but it was not sufficiently severe to account for the increased thawed layer. The displacement and redistribution of lichens visibly reduced the light reflectance of the surface, resulting in an increased absorption of solar radiation and a reduced albedo rate. This effect may well be responsible for the increased thickness of the active layer. Because lichens grow very slowly, the original albedo will not be attained for decades to come. Unfortunately, the albedo was not measured during the establishment or reassessment of the trials.

3.2.3 Change in Composition

No change in species composition was observed in the lowland tundra, but, on the upland site, the attached lichens had decreased by about 10 percent. The Voyageur disturbance produced no radical change in the floristic environment and did not allow either the invasion of new species or the expansion of those already present.

3.3 Visual Impact

The ACV paths are well visible from the air on both the lowland and upland sites. On the ground, the ACV path on the lowland tundra is imperceptible, and, on the upland tundra, only the practiced eye can note the uprooted, broken, or dislodged bits of vegetation that mark the path of the vehicle.

On lowland tundra sites in Alaska, it was found that the ACV path was readily visible from the air, but barely visible on the ground (Abele, 1975). Often the direction of travel influenced the signature of the path. In the Voyageur trials on the lowland tundra, the sedge blades were bent in one direction by a single pass and repeatedly rearranged by multiple passes. This may explain why single pass paths are more visible from the air than the multiple pass paths (cf. Figs. 8-10 with Fig. 2).

4. Conclusions

The following conclusions are only valid for the conditions encountered; no extrapolation can be made for substantially different terrain and vegetation types or operating conditions:

- the terrain and vegetation at the lowland tundra site were not susceptible to damage by the ACV, but some lasting changes were induced on the upland tundra.
- the lowland tundra vegetation showed no damage or change after 20 passes of the ACV.
- twenty ACV passes on the upland tundra resulted in dislodgement and redistribution of lichens. The vascular plants sustained some damage, mainly breakage of tall shrubs.
- disruption of organic mat after 20 ACV passes was minimal on the upland site and did not occur on the lowland site. Only in one instance was the organic mat torn by the ACV on the upland tundra site. This did not result in subsidence after 2 years.
- on the upland tundra site, the depth of thaw under the disturbed site increased 24 percent in 2 years over that of the undisturbed area.
- on both lowland and upland tundra, the thickness of the active layer became more uneven on the disturbed plots, probably due to changes in the insulating qualities of the surface.
- terrain damage caused by the greater depth of thaw could not be evaluated because of the generally reduced depth of thaw in 1975.

References

Abele, G. 1975. Effects of hovercrafts, wheeled and tracked vehicle traffic on tundra. 16th Muskeg Res. Conf., Montreal 1975. In press.

Anon. 1973. Tentative classification system for Cryosolic Soils. Proc. 9th Meeting, Can. Soil Surv. Comm., Saskatoon. pp. 350-357.

Husch, B. 1963. Forest mensuration and statistics. Ronald Press Co., New York. 474 pp.

Slaney, F.F. & Co. 1973. Environmental effects assessment, Voyageur Air Cushion Vehicle. Environ. Can., Environ. Prot. Serv. 3 vols.

Zoltai, S.C. and Tarnocai, C. 1974. Soils and vegetation of hummocky terrain. Environ. -Soc. Prog., North. Pipelines, Task Force North. Oil Develop. Gov. Can. Rep. 74-5.

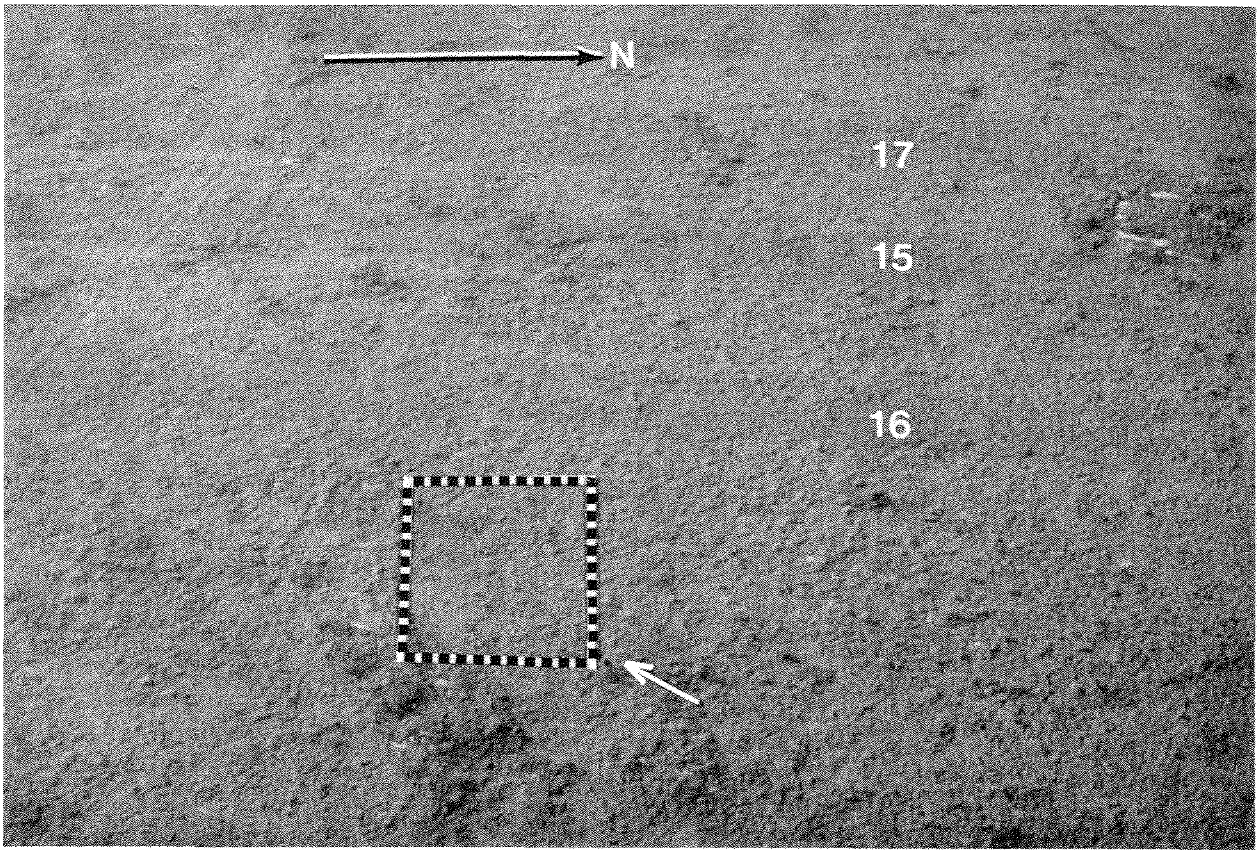


Figure 1. Location of the control permanent sample plot in relation to Trial Courses 15, 16, and 17. Small arrow points to persons on the NE corner of the control plot; approximate outline of control plot is shown by dotted line.

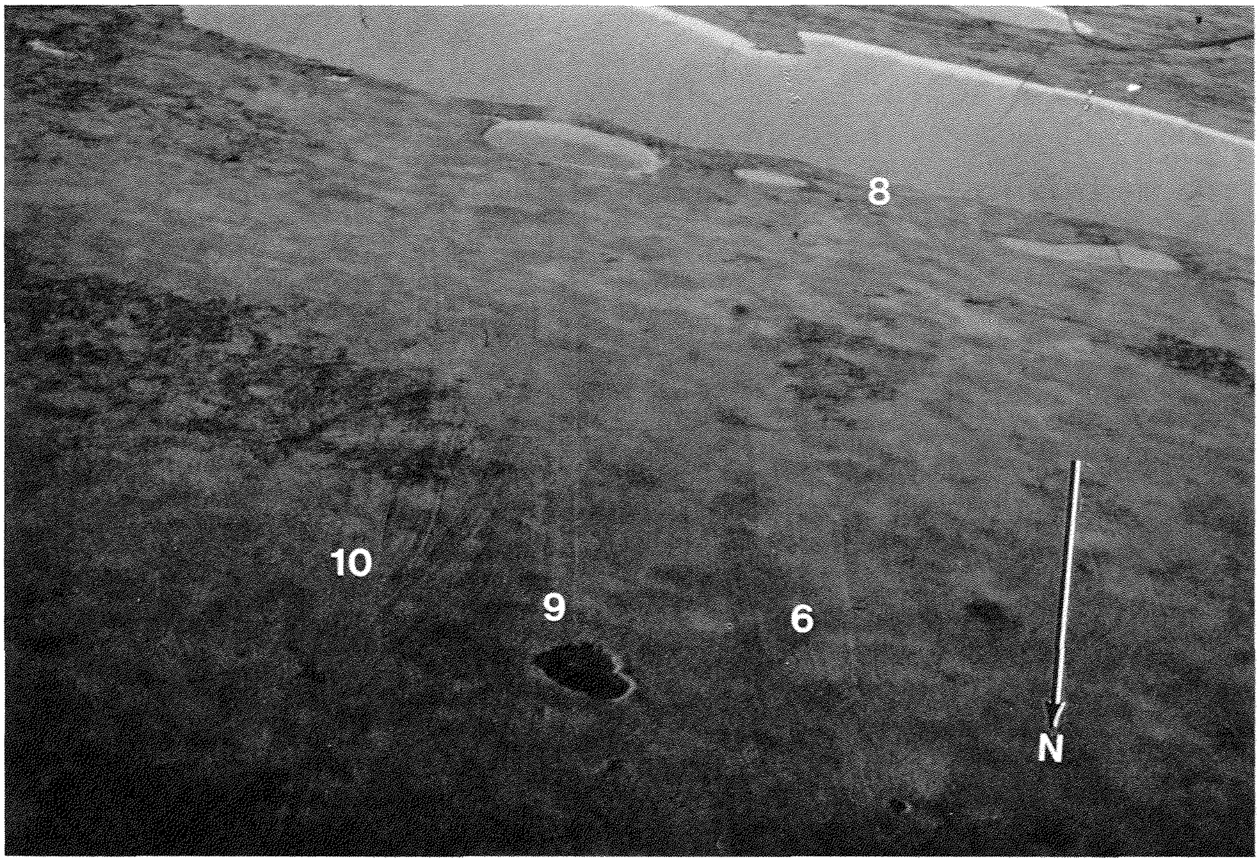


Figure 2. Trial Courses 6, 8, 9, and 10 on the lowland tundra, viewed from the air.


Figure 3. Ground view of the disturbed sample plot on the lowland tundra.

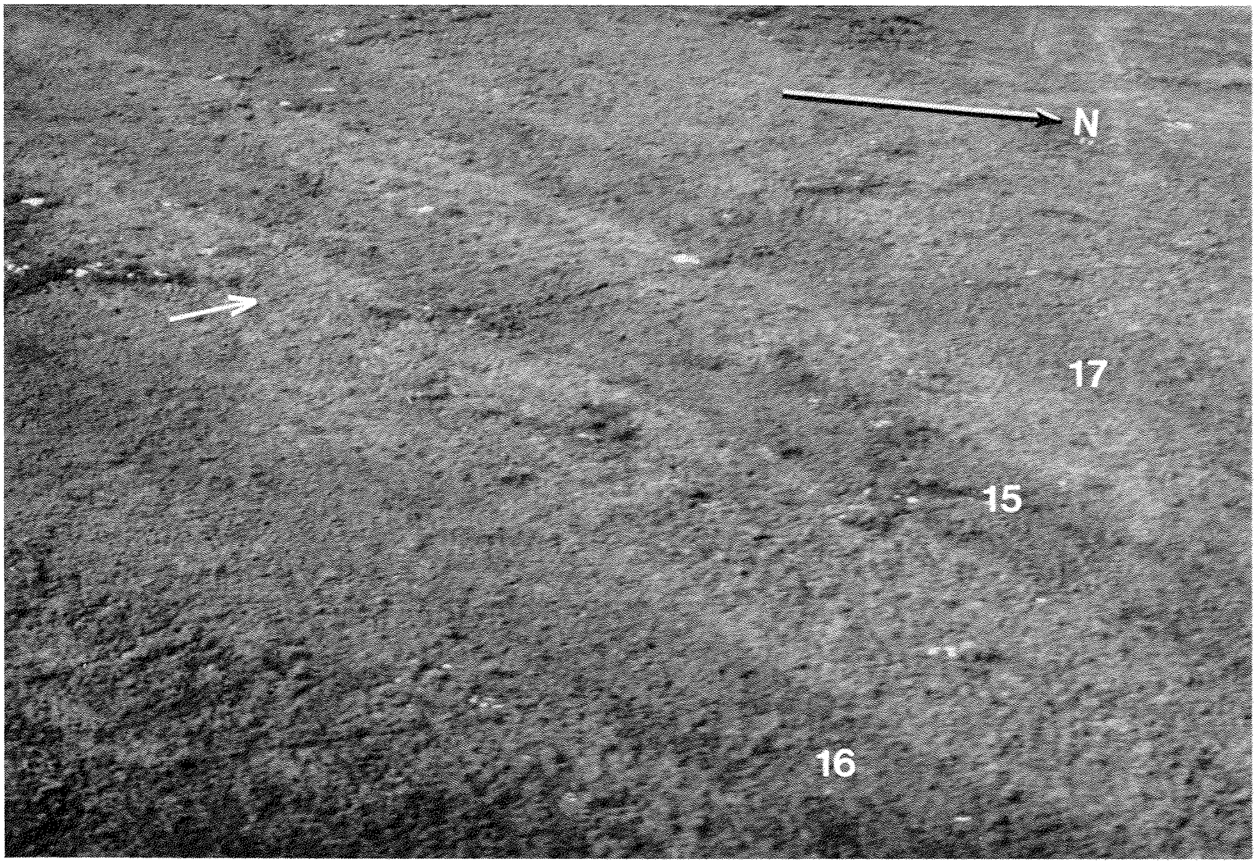


Figure 4. Aerial view of Trial Courses 15, 16, and 17. Note vehicle tracks on seismic line at small arrow.

Figure 5. Detached and redistributed Cetraria cucullata thallus at tip of pen.

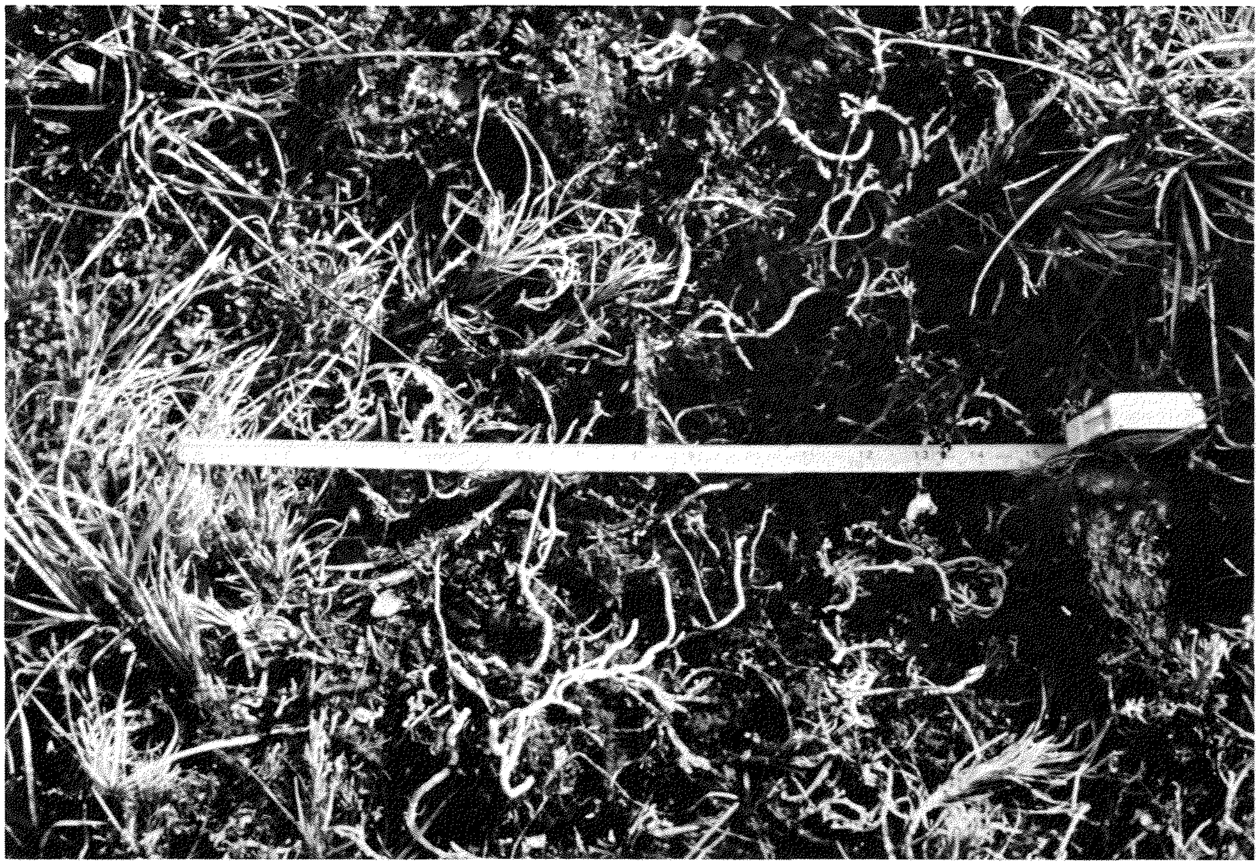


Figure 6. Alder shrub split at the base of stem. The shrub was flagged in 1973.

Figure 7. Disturbed upland tundra vegetation. Note torn and dead Carex at the tip of tape and displaced lichen below the tape near the 13-in. mark. The tape case is resting against a chunk of uprooted Dicranum.

Figure 8. Aerial view of Trial Course 2 on the lowland tundra.

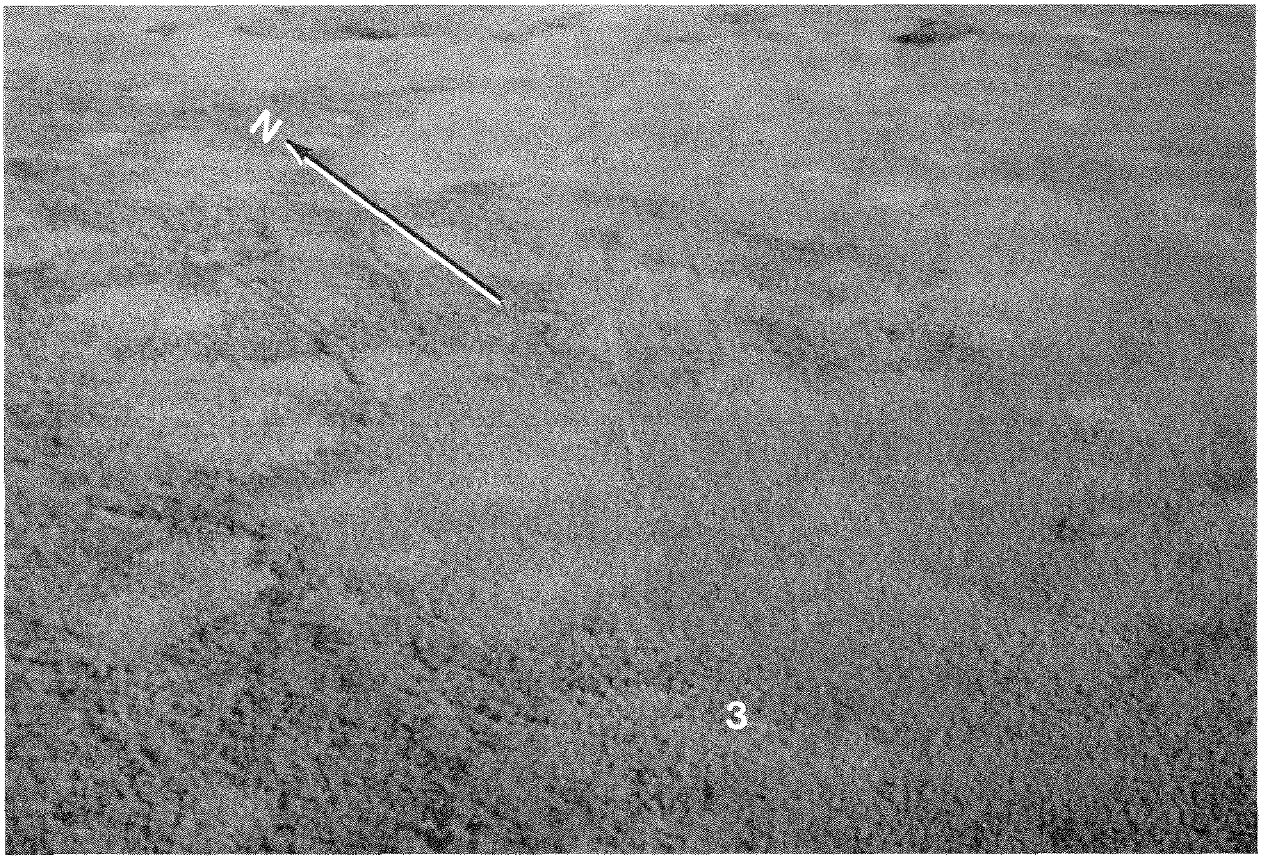


Figure 9. Aerial view of Trial Course 3 on the lowland tundra.

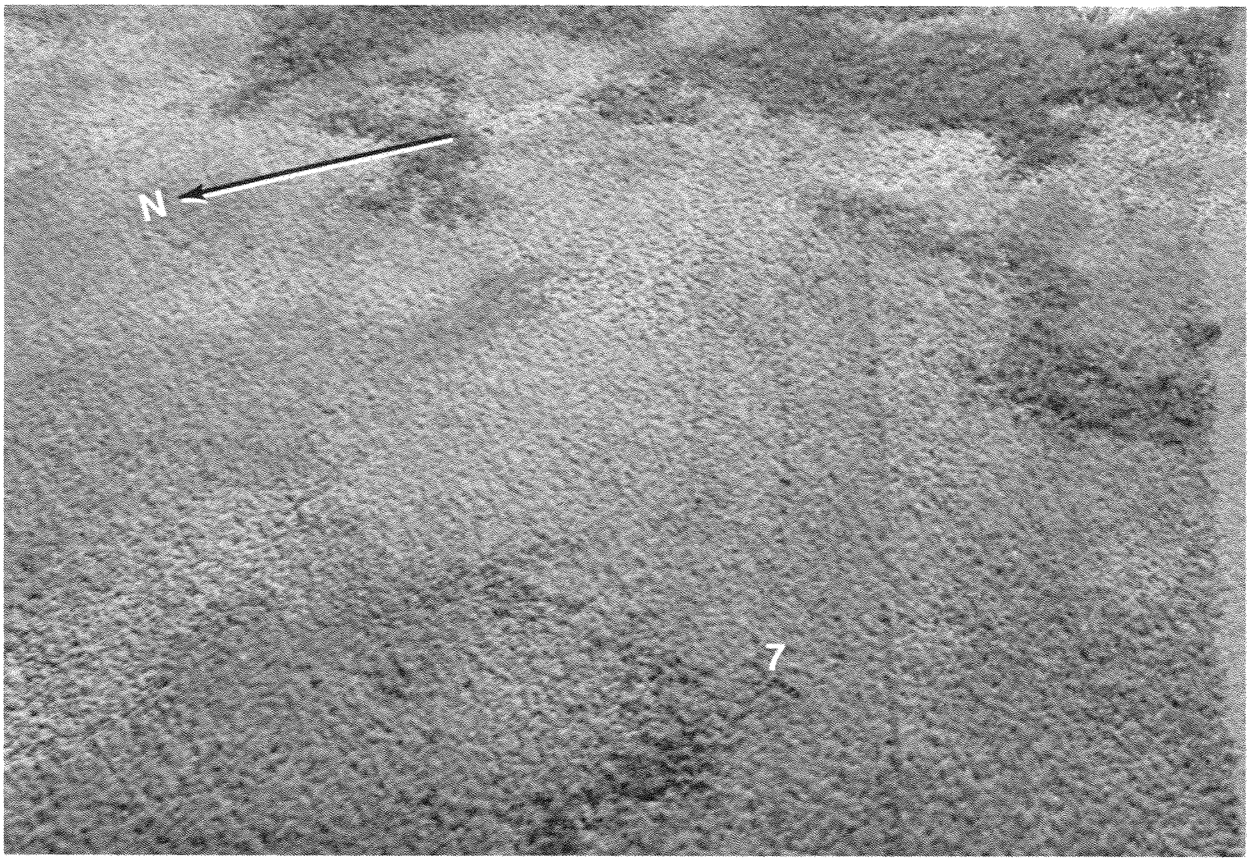


Figure 10. Aerial view of part of Trial Course 7 on the lowland tundra.

Figure 11. Linear depression in the vegetation on a seismic line.

Figure 12. Land-water interface on Trial Course 9.

Figure 13. Half of an alder shrub torn out by the ACV, with disrupted ground surface.