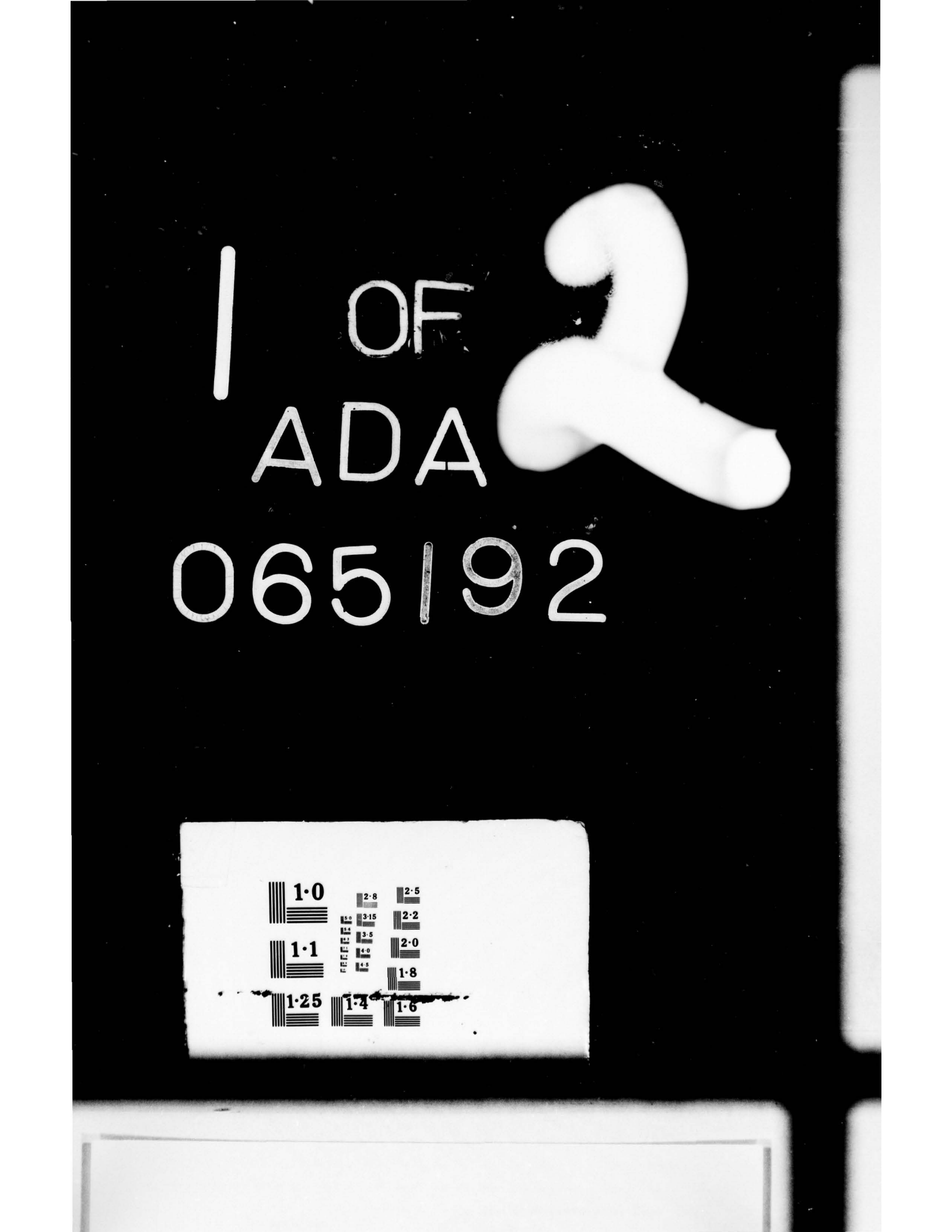
AD-A065 192 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 15/7
TUNDRA DISTURBANCES AND RECOVERY FOLLOWING THE 1949 EXPLORATORY--ETC(U)
DEC 78 D E LAWSON, J BROWN, K R EVERETT

UNCLASSIFIED CRREL-78-28 NL

1 OF 2
ADA 065192


1 OF 2
ADA
065192

LEVEL II
DDC
RECEIVED
MAR 5 1979
D

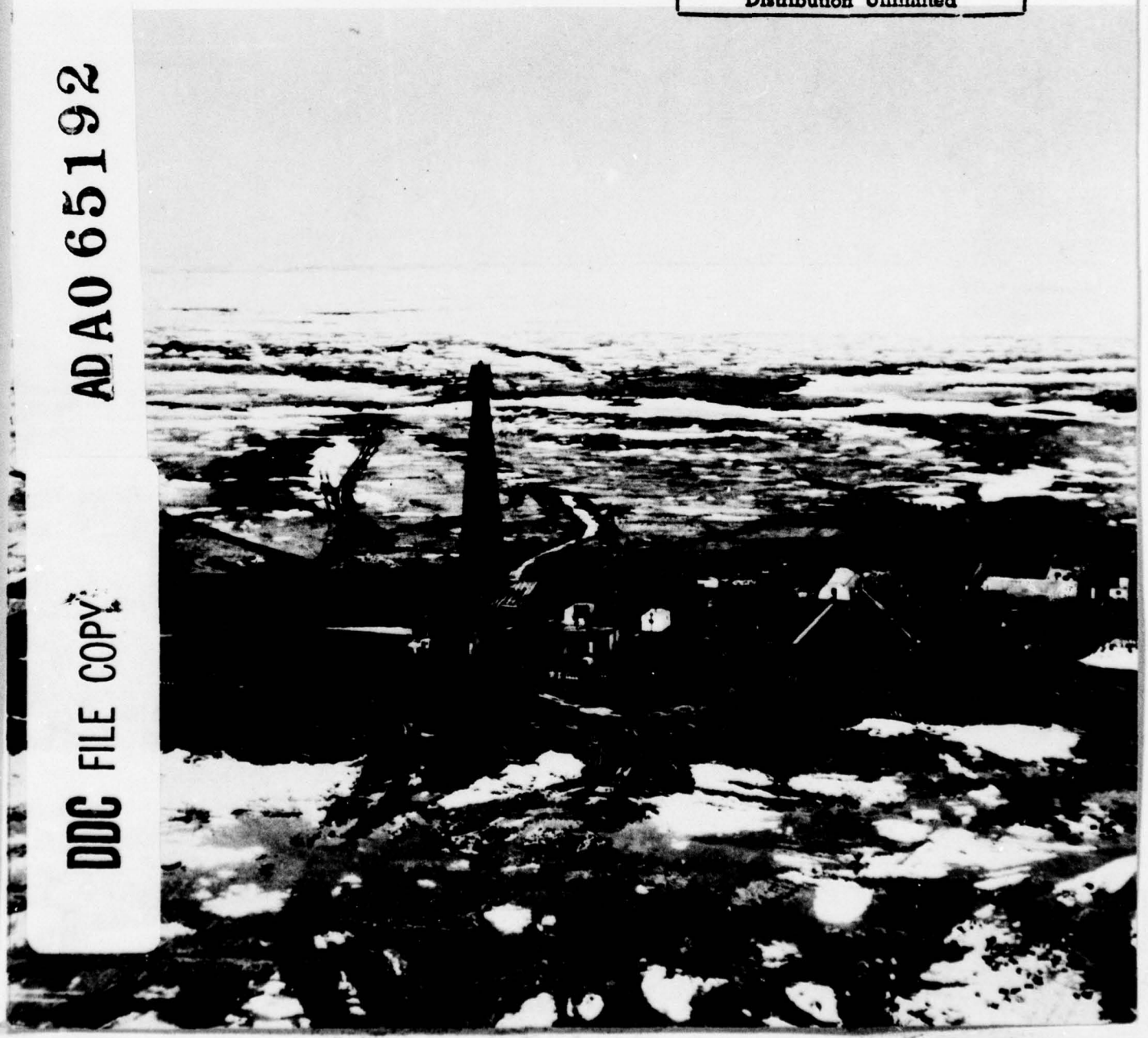
CRREL

REPORT 78-28

Tundra disturbances and recovery following the 1949 exploratory drilling, Fish Creek, Northern Alaska

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

AD A065192
DDC FILE COPY



For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Cover: *Oblique aerial photograph of Fish Creek Test Well No. 1 in 1949 (view west). Drill rig with canvas enclosure is in the center. Bulldozed and multiple pass trails extend away from the site, and two drainage ditches in the center drain the area into debris-littered ponds in the foreground. Camp Creek is in the background. (Photograph provided by U.S. Navy.)*

(12)

CRREL Report 78-28

Tundra disturbances and recovery following the 1949 exploratory drilling, Fish Creek, Northern Alaska

D.E. Lawson, J. Brown, K.R. Everett, A.W. Johnson,

V. Komárková, B.M. Murray, D.F. Murray and P.J. Webber

December 1978

ACCESSION for
NTIS White Section
DDC Buff Section
UNANNOUNCED
JUSTIFICATION
BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

DDC
RECEIVED
MAR 5 1979
D

Prepared for
U.S. GEOLOGICAL SURVEY
By

DEPARTMENT OF THE ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
CORPS OF ENGINEERS
HANOVER, NEW HAMPSHIRE 03755

79 02 28 126

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: CRREL Report 78-28
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:

4. TITLE *(and Subtitle)*: TUNDRA DISTURBANCES AND RECOVERY FOLLOWING THE 1949 EXPLORATORY DRILLING, FISH CREEK, NORTHERN ALASKA

5. TYPE OF REPORT & PERIOD COVERED:

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): D.E. Lawson, J. Brown, K.R. Everett, A.W. Johnson, V. Komárková, B.M. Murray, D.F. Murray and P.J. Webber

8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire 03755

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: DA Project 4A161102AT24, Scientific Area 02, Work Unit 002

11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Geological Survey, Washington, D.C.

12. REPORT DATE: December 1978

13. NUMBER OF PAGES: 91

14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*:

15. SECURITY CLASS. *(of this report)*: Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

Partially funded by the Directorate of Facilities Engineering, Office, Chief of Engineers.

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Arctic regions
Environmental effects
Oil pollution
Permafrost
Tundra
Vegetation

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A 1949 drill site in the Naval Petroleum Reserve Number 4, Alaska, the Fish Creek Test Well 1, was examined in August 1977 to determine the disturbance caused by drilling activities and to analyze the response and recovery of the vegetation, soils, permafrost, and surficial materials to that disturbance. Man-made disturbances include bladed and unbladed vehicular trails, a winter runway, excavations, pilings, remains of camp structures, steel drums and other solid waste, and hydrocarbon spills. The most intense and lasting disturbance to the vegetation, soils, and permafrost resulted from bulldozing of surface materials, diesel fuel spills, and trails developed by multiple passes of vehicles. Thermokarst subsidence and thermal erosion, caused by increased thaw of permafrost due to disturbance,

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

037 100

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

20. Abstract (cont'd)

resulted in the development of a hummocky topography and water-filled depressions at the drill site. Some ice wedges disturbed in 1949 are still melting. Soil disturbance ranges from minor modification to complete destruction of the soil morphology. The effects of hydrocarbon spills are still detectable in the soils. Little of the original vegetation remains in the intensely disturbed area, such as around the drill pad where a grass-dominated community prevails. After 28 years, the vegetation cover is closed over most mesic sites, shallow wet sites are well vegetated, and xeric sites, areas of diesel fuel spills and areas of severe erosion remain mostly bare. Pioneering plant species on bare, disturbed areas are members of mature vegetation assemblages from the undisturbed tundra which have high reproductive and dispersal capacities. A hypothetical model of natural revegetation and vegetation recovery is proposed. Vascular plants, bryophytes, and lichens were collected from the Fish Creek site area for the first time. Recommendations on cleanup and restoration of sites are presented.

PREFACE

This report was prepared by Dr. Daniel E. Lawson, Research Physical Scientist, and Dr. Jerry Brown, Chief, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory; and by Dr. Kaye R. Everett of the Institute of Polar Studies, Ohio State University; Dr. Albert W. Johnson of San Diego State University; Barbara M. Murrary and Dr. David F. Murray of the Institute of Arctic Biology, University of Alaska; and Dr. Vera Komárková and Dr. Patrick J. Webber of the Institute of Arctic and Alpine Research, University of Colorado.

This study was performed in cooperation with and primarily funded by the U.S. Geological Survey (USGS). Additional funding was provided by DA Project 4A161102AT24, *Research in Snow, Ice and Frozen Ground*, Scientific Area 02, *Cold Regions Environmental Interactions*, Work Unit 002, *Cold Regions Environmental Factors*.

Paul Sellmann of CRREL and Dr. Stephen Young of the Center for Northern Studies technically reviewed this report.

The authors wish to express their appreciation to the following individuals and organizations. Dr. Max Brewer and Dr. George Gryc of the USGS provided considerable encouragement and assistance throughout the planning and execution of the study. Husky Oil Co., primary contractor for current exploration in the National Petroleum Reserve, Alaska, provided excellent logistic support. John Schindler of Husky Oil's Anchorage Office and Dr. Val Zadnik, USGS, Reston, Virginia, were extremely helpful in providing information. The study was facilitated by the presence of several on-going CRREL projects along the haul road and the Yukon River. Field parties associated with these Federal Highway Administration, Department of Energy and CRREL projects along the road were used at Fish Creek. Methods, results and experience developed from these studies and research funded by the National Science Foundation were employed.

The information developed from the Fish Creek site is being disseminated in conjunction with the US-USSR Environmental Protection Agreement's project *Protection of Northern Ecosystems*. As part of that project, reports and information on the introduction of plant species onto disturbed tundra sites are being exchanged with organizations based in Leningrad, Moscow, Norilsk, Yakutsk, and Magadan. A set of vascular plants collected on the site is being exchanged between the University of Alaska Herbarium (ALA) and the Komarov Botanical Institute in Leningrad (LE) where there is both an intense interest and expertise in the Alaskan arctic flora.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

CONTENTS

	Page
Abstract	i
Preface	iii
Summary	viii
Introduction (J. Brown)	1
Location and background	1
Study objectives	1
The site (D.E. Lawson, J. Brown and K.R. Everett)	3
History	3
Regional and local setting	3
Types of disturbance	7
Disturbance of permafrost, massive ground ice, and surficial materials (D.E. Lawson and J. Brown)	14
Introduction	14
Methods	16
Discussion and conclusions	17
Soils and their reaction to impact and hydrocarbon spills (K.R. Everett)	25
Soils	25
Anthropogenically disturbed soils	26
Summary	29
Floristics of the disturbances and neighboring locales (A.W. Johnson, B.M. Murray and D.F. Murray)	30
Introduction	30
Vascular plants	30
Bryophytes and lichens	31
Description of disturbance and recovery	31
Discussion and conclusions	39
Geobotanical mapping, vegetation disturbance and recovery (V. Komárková and P.J. Webber)	41
Introduction	41
Methods	41
Description of mapping units	42
Predisturbance site status	46
Present site status	46
Analysis of disturbance	47
Proposed model of revegetation and vegetation recovery	48
Conclusions	49
Recommendations for future research (D.E. Lawson, J. Brown, K.R. Everett, A.W. Johnson, V. Komárková, B.M. Murray, D.F. Murray and P.J. Webber)	52
Cleanup recommendations for the Fish Creek site	52
Restoration of new work areas	52
Specific research recommendations	53
Literature cited	54
Photo credits	56
Appendix A. Results of pollen analyses (P.J. Webber)	57
Appendix B. Morphologic descriptions for selected soil profiles from Fish Creek site (K.R. Everett)	61
Appendix C. Alphabetical list of taxa of vascular plants collected at Fish Creek site (D.F. Murray)	67

Page

Appendix D. Alphabetical list of bryophytes and lichens collected at Fish Creek site (B.M. Murray) 69
Appendix E. Vascular plant composition and percentage cover in relevés representative for the Fish Creek mapping units (V. Komárková and P.J. Webber) 75
Appendix F. Selected environmental variables for relevés representative for the Fish Creek mapping units 81

ILLUSTRATIONS

Figure

1. Location map of NPRA and the Fish Creek site 2
2. Location map of the study area 4
3. Fish Creek camp, 7 September 1949 5
4. Oblique aerial view of Fish Creek camp on 28 April 1949 5
5. Thawing moss for insulation, Fish Creek camp on 18 April 1949 6
6. Map of the Fish Creek site showing distribution of debris and other disturbances ..... facing pg. 7
7. Aerial photograph of the Fish Creek site obtained in 1977 from which the disturbance map was constructed 9
8. Aerial photograph of Fish Creek site taken in 1948 prior to disturbance 10
9. Bladed trail with berm 11
10. Bladed trail without berm 11
11. Multiple pass vehicle trails in center and left foreground of photo 11
12. Single pass vehicle tracks near Camp Creek 11
13. Individual drums, some crushed, scattered randomly on ground surface 11
14. Groups of drums 11
15. Scattered wood, wood stack, individual drums, and a large drum pile litter the surface to the north of the drill pad 12
16. Concrete drill pad with pile supports, on and off that pad 12
17. Photo of debris from drill pad 12
18. Oblique aerial photograph showing several large wood piles with other debris 12
19. Typical diesel fuel spill on 28 July 1977 13
20. Isolated crude oil spills from rusted drum in seasonal shallow pond 13
21. Beaded drainage, Camp Creek 15
22. Trough formed by thermokarst subsidence due to man-induced disturbance above ice wedges 15
23. Bladed trail with berm piles 15
24. Cross section across Camp Creek 17
25. Water depth in beads measured in Camp Creek, 29-30 July 1977 18
26. Profiles and cross sections along trench of bladed trail 19
27. Ice wedge uncovered from beneath vehicular trail 20
28. Sketch of vertical profile through the ice wedge 20
29. Aerial photograph of Fish Creek camp area, with location of 100 × 100-m area indicated by four dots 21
30. Detailed map of types of disturbance and the location of subsidence caused by melting of ice wedges 22
31. Topographic map of 100 × 100-m grid 23

Figure		Page
32.	Composite graph of thaw depths measured in 100 × 100-m grid on 30 July 1977	24
33.	Thaw depth variations with relative intensity of disturbance	24
34.	Idealized cross section of the principal landform units and their associated soil profiles at Fish Creek site	25
35.	Compression of surface by tracked vehicle, 27 July 1977	27
36.	Schematic cross section of soil from track pictured in Figure 35	27
37.	Hydrocarbon spills typical of main drill area at Fish Creek	28
38.	General aspect of 55-gal. drum dump areas peripheral to main drill site	28
39.	Bladed trail from the Fish Creek camp area to Camp Creek, 28 July 1977	32
40.	Turfy berm on the edge of trail shown in Figure 39	32
41.	Thermokarst pond in bladed trail west of drill site occupied by almost pure stands of *Carex aquatilis* with lesser amounts of *Eriophorum angustifolium* and *Eutrema edwardsii*	33
42.	Base area at site 2 adjacent to trail of Figure 41 covered by a gray-white precipitate on the surface	33
43.	Debris field at site 3 covered by scattered drums, boards, etc.	34
44.	Site 3	34
45.	Coke bottle nearly overwhelmed by vegetation at site 4	35
46.	Pile of about 100 drums, two to three high in the center, on high-centered polygon at site 5	35
47.	"Luxuriance effect" of drums resulting in increased plant growth at site 5	35
48.	Elongate stack of drums in two rows at site 6	35
49.	Diesel fuel spill on sandy substrate at site 7	36
50.	Diesel fuel spill at site 8 with *Eriophorum scheuchzeri* and *Arctagrostis latifolia* cover of about 10%	37
51.	Scattered drums on high-centered polygon between two small lakes at site 9	37
52.	Scattered drums on low-centered polygon where damage was minimal, site 10	37
53.	Widely scattered drums on low-centered polygons with little effect on vegetation, site 11	37
54.	Hydrocarbon spill, probably diesel fuel, located in area formerly occupied by *Carex aquatilis* at site 11	38
55.	Site 12 consists of partly collapsed stack of barrels	38
56.	South side of drums at site 12 with complete vegetation cover, including *Salix pulchra*	38
57.	Drums on low-centered polygons with increased wet meadow species between them site 13, view north	38
58.	Low-centered polygon area where growth is suppressed, apparently due to oil spillage, at site 14	39
59.	Predisturbance vegetation of the Fish Creek test well site, 1948	facing pg. 42
60.	Vegetation of the Fish Creek test well site, August, 1977	following Fig. 59
61.	Mapping unit 2, one of the most extensive, includes areas dominated by *Eriophorum vaginatum* ssp. *spissum* tussocks	43
62.	Low-centered polygons are common; these landforms usually support upland tundra on rims and *Carex aquatilis* marsh in centers and troughs	43
63.	*Salix rotundifolia*-dominated snowpatch vegetation occurs in the lee of elevated ridges, bluffs, and streambanks	44

Figure Page

64. *Cassiope tetragona spp. tetragona*-dominated communities are found in snowpatches with shorter duration of snow cover than the *Salix rotundifolia* communities 44
65. Subhygric communities dominated by *Salix* and *Carex* taxa occupy less well-drained sites than mapping unit 2 both on flat upland surfaces and in drained lake basins 44
66. *Carex aquatilis* ssp. *stans*-dominated marshes are common along streams, on lake edges, in low-centered polygon centers, and in high-centered polygon troughs 45
67. *Salix rotundifolia* is the most important plant in the vegetation occupying disturbed snowpatch sites at Fish Creek, but few other plants associated with natural snowpatch vegetation are present 45
68. Successional snowpatch vegetation is limited to the extensively damaged area near the creek neighboring the test well site 46
69. Detailed map of vegetation in the area immediately adjacent to the Fish Creek Drill site, 1977 ..... facing pg. 46
70. The chain of events subsequent to surface disturbance of tundra vegetation ..... facing pg. 48

TABLES

Table

I. Daily maximum and minimum temperatures for North Slope sites, 26-30 July 1977 7
II. Classification and description of disturbances 8
III. Hydrocarbon contaminants from selected spills at Fish Creek site 28
IV. Key to vegetation mapping units 42

SUMMARY

During 1949, the Fish Creek Test Well 1 was drilled in the Naval Petroleum Reserve Number 4 as a stratigraphic test. The drill site has been unoccupied since that time. This study examined the disturbance caused by drilling activities and analyzed the response and recovery of the vegetation, soils, permafrost, and surficial materials to that disturbance.

The Fish Creek site (70°18'36"N, 151°52'40"W) lies 28 km south of Atigun Point and 26 km southwest of the westernmost branch of the Colville River. Equipment was freighted from Barrow to this site beginning on 31 January 1949, with camp construction beginning on 15 March and ending on 15 April. Drill rig construction began on 1 April. The well was spudded on 17 May and the full depth of the hole (2140 m) attained on 13 August. A production test was run from 10 September to 25 October. Site abandonment took place shortly after this time.

The terrain of the Alaskan Arctic Coastal Plain, upon which the Fish Creek site is located, is flat to gently rolling and dominated by oriented lakes and drained lake basins. Permafrost occurs beneath the entire region; at the drill site it apparently extends about 180 m below the surface. Fine to medium sand of the Meade River Unit of the Gubik Formation of Quaternary Age underlies the Fish Creek site. The near-surface portion of this sediment has been reworked by eolian, fluvial, and lacustrine processes. Poorly drained to undrained lake basins surround the site. A mixture of high- and low-centered polygons of low relief cover the drill site surface, whereas large, low-centered polygons dominate the lake basins.

Man-made disturbances on the Fish Creek site include bladed and unbladed vehicular trails, a winter runway, excavations, pilings, remains of camp structures, steel drums and other solid waste, and hydrocarbon spills. The intensity of disturbance decreases generally with distance from the drill pad. Vehicular trails and tracks resulted in the greatest areal extent of damage. The most lasting effects on the vegetation, soils, and permafrost appear to be bulldozing of surface materials for trails and excavations, diesel fuel spills, and trails developed by multiple passes of vehicles.

Disturbances at the Fish Creek site have resulted in degradation of the ice-rich permafrost. Analysis of the effects of natural thermal erosion in Camp Creek (unofficially named) indicate that massive ground ice (excess ice) extends to a minimum depth of 6 to 7 m beneath the site. Because the permafrost contains excess ice, mainly in the form of ice wedges, increased thaw due to disturbance has caused thermokarst subsidence and, in some cases, thermal erosion. Thermokarst processes have in turn resulted in the development of a hummocky topography (maximum relief about 2 m) and water-filled depressions in the immediate area of the drill site and along trails extending from the site. Partly vegetated thaw ponds and troughs containing freshly slumped materials indicate that melting of ice wedges triggered by the 1949 disturbance is still occurring. Thaw depths measured in a 100 × 100-m area around the drill pad suggest that thaw varies with the intensity of disturbance. Intensely disturbed areas (heavily trafficked or bladed) are thawed to a mean depth of 53 cm. Less intensely disturbed and undisturbed areas are thawed to a mean depth of 32 cm. This similarity suggests that thermal equilibrium and partial recovery may have taken place in those areas.

The soils at the drill site are tentatively placed in two taxonomic orders: Entisols (psamments and, provisionally, fluvents and aquents) and Inceptisols (aquepts and ochrepts). Histosols occur in the general area of the drill site, but they could not be examined in detail. Disturbances have resulted in the complete destruction of soil morphology in some areas. Soil horizons have been weakly reestablished in disturbed areas over the last 28 years, although soils that were severely compressed by vehicles retain a compressed morphology.

The effects of hydrocarbon spills of limited extent are still detectable chemically in the affected soils. Diesel fuel spills produced the most severe and lasting impact causing destruction of the vegetation and thaw beneath the spill to about twice its normal depth. Little recovery of the vegetation has occurred in 28 years.

One hundred eighty-seven collections of vascular plants representing 158 taxa and about 500 collections of bryophytes and lichens were made from the Fish Creek site area. These collections, the first from the region, are housed at the University of Alaska Herbarium. Significant northward extensions of range of the vascular plant species *Carex atrofusca, C. marina, C. rupestris, C. williamsii, Betula nana, Arctous alpina, Empetrum nigrum, Vaccinium uliginosum,* and *Erigeron humilis* are recorded, with minor extensions of *Carex vaginata, Potentilla hookeriana, Andromeda polifolia, Utricularia vulgaris,* and *Taraxacum phymatocarpum* also recorded. A probable new species in the moss genus *Barbula* and two species previously unreported for Alaska, the moss *Didymodon acutus,* and the hepatic *Lophozia collaris,* were found on the berm of a bladed trail.

The flora of the disturbed Fish Creek site and the undisturbed surrounding tundra differ only in frequency of occurrence and abundance of each species. For example, *Ceratodon purpureus, Leptobryum pyriforme, Psilopilum cavifolium, gemmiferous Pohlia spp.,* and other mosses were more abundant at the drill site than in the undisturbed tundra. Weathered lumber, pilings, rotting canvas, turf over concrete pads and cement bags, 55-gal. steel drums, and areas of hydrocarbon spills provide anomalous substrates for mosses and lichens. A limited number of etiolated vascular plants are found on these substrates.

Considerable disturbance to the plant communities, ranging from complete and presumably permanent disruption to relatively minor effects, occurred during occupation of the Fish Creek site. The most intense disturbances, such as those from concentrated vehicle traffic or bladed trails, significantly altered the vegetation. Areas with altered moisture relationships have been revegetated by species different from those in the predisturbance vegetation. Less intense disturbances have been substantially ameliorated in the last 28 years.

The invasion of plant species on bare, disturbed areas repeatedly showed pioneers on wet substrates to include *Eriophorum vaginatum, Saxifraga cernua, S. nelsoniana, Juncus castaneus, J. biglumis, Draba lactea, Alopecurus alpinus, Stellaria laeta, Eriophorum angustifolium, Carex aquatilis* and *Eutrema edwardsii,* on drier substrates, *Arctagrostis latifolia, Poa arctica, Hierochloe alpina, Luzula arctica, L. confusa, L. wahlenbergii* and *Trisetum spicatum* soon dominate disturbed soils. Shrubby species are rarely seen as pioneers. Each of the above species has a high reproductive and dispersal capacity, either by seeds or vegetative propagules. These pioneering species are members of mature vegetation assemblages in the undisturbed tundra. Pioneering hepatics, mosses, and lichens are also members of the mature vegetation.

The predisturbance vegetation and the present vegetation were examined, mapping units defined, and maps of the vegetation in 1948 and 1977 constructed. Little of the original vegetation remains in the intensely disturbed area surrounding the drill pad. Vegetation in this area is now a grass-dominated community

(*Arctagrostis latifolia, Poa arctica, Poa rigens (alpigena), Luzula confusa*). Areas of vehicular disturbance adjacent to Camp Creek support *Salix rotundifolia* snowpatch communities. Thermokarst troughs are dominated by pure stands of *Carex aquatilis* ssp. *stans* and *Eriophorum angustifolium* ssp. *subarcticum*.

Vegetation response varies with the intensity and type of disturbance. Vegetation cover is closed over most mesic sites after 28 years. Shallow wet sites are also vegetated. Xeric sites, areas of diesel fuel spills, and areas of severe erosion remain mostly bare today. The rates of natural revegetation and vegetation recovery following disturbance at the Fish Creek site are comparable to those found elsewhere in the Arctic.

Secondary communities of "weedy" tundra plants, such as *Braya humilis*, which are a minor component of the undisturbed tundra vegetation, develop first on disturbed areas, but the replacement of these secondary communities by the natural communities of the undisturbed tundra may have begun. Less disturbed areas show a partial cover of the primary communities.

A hypothetical model of natural revegetation and vegetation recovery, based in part on this study, is proposed. The intensity of disturbance, amount of ground ice, and site moisture are the primary factors controlling revegetation and recovery. Each pathway in the model represents a specific state of each of these factors.

The Fish Creek site and similar sites in the Arctic should be used to study in detail the impact of man-made disturbance on the vegetation, soils, permafrost, surficial geology, and aquatic environment and their recovery after disturbance. Specific recommendations for cleanup, restoration and future research are provided.

TUNDRA DISTURBANCES AND RECOVERY FOLLOWING THE 1949 EXPLORATORY DRILLING, FISH CREEK, NORTHERN ALASKA

D.E. Lawson, J. Brown, K.R. Everett, A.W. Johnson,
V. Komárková, B.M. Murray, D.F. Murray and P.J. Webber

INTRODUCTION

J. Brown

Location and background

During the period 1944 to 1953, 36 test wells were drilled within the Naval Petroleum Reserve Number 4* (Reed 1958) (Fig. 1). The region covered by those activities included the Arctic Coastal Plain and Foothills Provinces of the Arctic Slope. The entire region is located in the zone of continuous perennially frozen ground (permafrost) and covered by tundra vegetation. During the period of petroleum exploration, considerable localized impacts to the surface terrain occurred as a result of the year-round ground access to the sites and a general unawareness of long-term and future environmental concerns. Hok (1969) assessed the persistence of vehicular trails throughout much of NPRA. The present study was undertaken to examine in detail the nature of tundra response to disturbance and the recovery of the tundra at one drill site after an elapsed period of 28 years.

The Fish Creek site (Fig. 1) was briefly visited on 2 August 1976 by M.C. Brewer (USGS—NPRA), J. Brown, and G. Abele (CRREL) during a helicopter reconnaissance of winter trails. During that visit and in subsequent discussions it was proposed that the Fish Creek site should be investigated in summer 1977 for the following reasons:

1. Since abandonment in 1949, the site had not received additional human modifications. Therefore, nearly a three-decade record of natural terrain and vegetation responses existed.

2. The site constituted one of the few remaining ones which had not yet been cleaned up as part of the present NPRA activities (U.S. Navy 1977). Therefore, there was an urgency to visit the site prior to cleanup in order to document precleanup conditions and provide recommendations on the value of the site for additional long-term research on tundra recovery.

3. A number of interdisciplinary scientists familiar with the Arctic Coastal Plain environment were available in northern Alaska to undertake the initial investigation. In addition, logistics from the Husky Oil Co. base camp at Lonely, 90 km to the northwest, would also be available.

This report presents the results of field site investigations undertaken during the period 25 to 31 July 1977. Recommendations on followup studies and some related environmental research activities within the NPRA are also provided.

Study objectives

The broad objectives of the Fish Creek investigation were: 1) to document the environmental disturbances to and recovery from the 1949 activities, 2) to interpret these observations in a regional context, and 3) to provide recommendations on cleanup and future research activities at Fish Creek and other tundra sites where opportunities exist to further the knowledge of tundra response to disturbance

*Redesignated National Petroleum Reserve in Alaska (NPRA) by the Naval Petroleum Reserves Production Act of 3 April 1976, the abbreviation NPRA will be used hereafter.

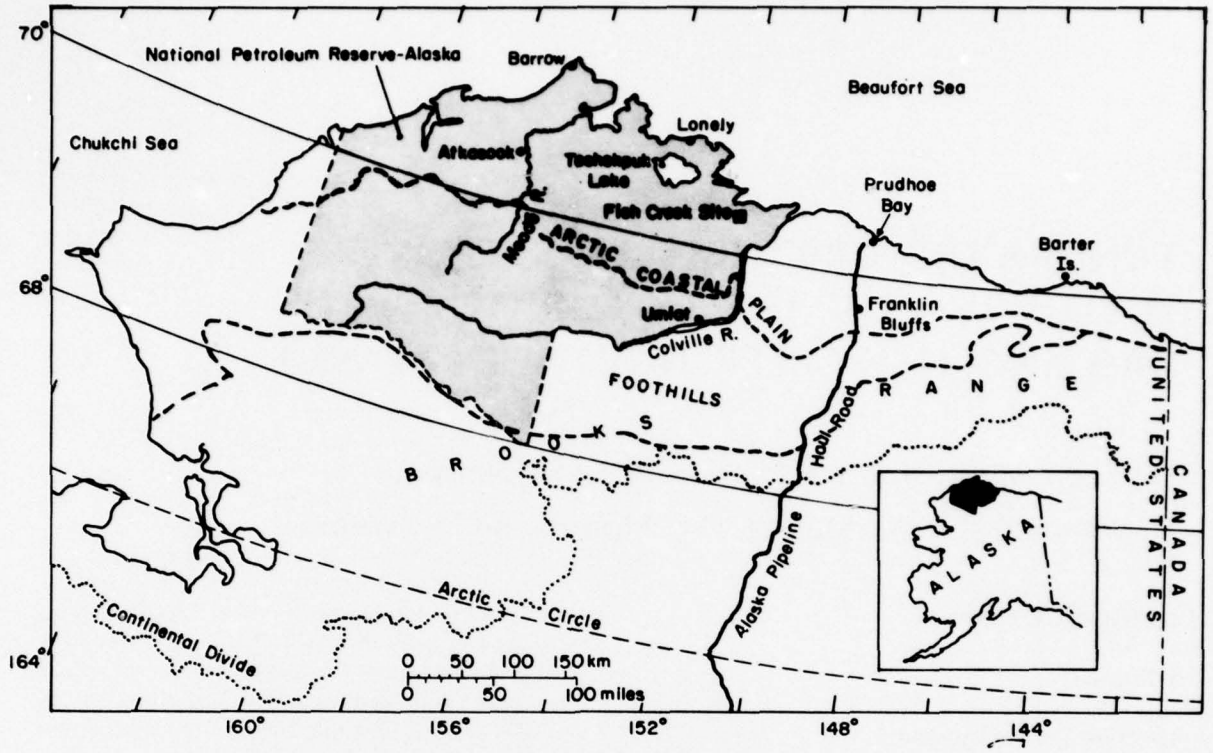


Figure 1. Location map of NPRA and the Fish Creek site. The boundaries of the Arctic Coastal Plain and Foothills Provinces are shown.

and recovery. These analyses attempted to determine the extent of impact of drilling activities at the site and the response and recovery of the natural systems to that impact.

For purposes of this report, the term "disturbance" includes environmental impacts and responses that are either irreversible or recoverable over a long period of time. The irreversible responses include phenomena triggered by man, such as thermal erosion and thermokarst (Mackay 1970), and those caused by natural changes such as climate. "Recovery" constitutes the biological, pedological, and geological attributes and processes that return the system to some subjective approximation of its original condition. In this study, recovery is synonymous with natural restoration (Johnson and Van Cleve 1976). No artificial means of restoration, such as application of fertilizers or seeds, were used at Fish Creek. Therefore, recovery observed is due to natural processes.

THE SITE

D.E. Lawson, J. Brown and K.R. Everett

History

The Fish Creek Test Well 1 (70°18'36"N, 151°52'40"W) was drilled near the Fish Creek oil seep (Fig. 2) during 1949 as a stratigraphic test (Reed 1958). It is located 28 km south of Atigaru Point and 26 km southwest of the westernmost branch of the Colville River (Fig. 1). Equipment for camp construction and drilling, weighing 2239 metric tons, was freighted from Barrow to the Fish Creek site between 31 January and 4 April 1949 using 14 tractor-trains. Camp construction began on 15 March and was completed by 15 April. Unlike most camps constructed in NPRA prior to this time, the buildings at Fish Creek were set on short pilings and connected by boardwalks (Fig. 3). Eleven hundred and ten pilings, which ranged in length from 1.5 to 6.1 m, were driven into the tundra using a steam point and driver. Buildings included 10 Jamesway huts, two Quonset huts, five wanigans and a canvas-covered garage. Areas adjacent to camp buildings were bulldozed clear of snow and, in some cases, of the vegetation cover and uppermost soil layer (Fig. 4). A winter runway was also constructed adjacent to the camp, although its location on the ground was no longer obvious in 1977. Sections of the vegetation mat were thawed and used for insulation in construction (Fig. 5), the remainder of the material was piled into berms around the margin of the site (Fig. 4). Drill pad and rig construction took place from 1 April to mid-May, and the well was spudded on 17 May using a National 50 rig (cover photograph). The full depth of the hole (2140 m) was attained on 13 August. The upper 920 m of the hole was then redrilled to perform a production test that began on 10 September and ended on 25 October, yielding a total of 444 barrels of crude oil. Approximately 30 workers occupied the site until it was closed shortly after 25 October 1949. Surface support vehicles and equipment on site included Caterpillar D-6 and D-8 tractors with blades, 2 weasels, a T-9 crane (cherry picker), a Northwest crane, and an LVT for trips to the coast.

During the period of occupancy, water was hauled to the site in a water wanigan (capacity, 9464 liters) by a D-8 tractor with blade. The initial water source was a lake 1.0 km from the site, but after ice breakup, the small creek near the site (unofficially named "Camp Creek" during the 1977 study) was used (Fig. 2). Consumption of water totaled 3,615,070 liters, requiring an estimated 380 trips on bladed and unbladed trails across the tundra. Buildings were equipped with plumbing facilities, including a hot water boiler. Wastewater was piped from the camp area through insulated and heated pipes.

The above information is based on Navy records, now archived at the U.S. Geological Survey, Menlo Park, California (U.S. Navy 1949). Figures 3-5 are reproduced from those records.

Regional and local setting

The Fish Creek site is located on the Alaskan Arctic Coastal Plain. The terrain varies from flat to gently rolling and is dominated by large oriented lakes and drained lake basins (Sellmann et al. 1975). Well-drained dune ridges separate poorly drained and undrained depressions. Permafrost underlies the entire region, its thickness ranging from about 150 to 650 m (Péwé 1975). At the Fish Creek site, resistivity and temperature surveys done in 1949 suggest that permafrost extends about 180 m beneath the drill pad (U.S. Navy 1949). The active layer thickness is less than 1.5 m in well-drained areas and less than 0.5 m in poorly-drained areas (Williams et al. 1977).

This region is underlain by the unconsolidated, marine Meade River Unit of the Gubik Formation of Quaternary Age (Black 1964). In the immediate area of the Fish Creek site, this unit consists of 20 m of well-sorted, fine to medium quartz sand with some chert and few accessory minerals (U.S. Navy 1949). Bluffs over 25 m high along Fish Creek, 5 km to the south, expose these sediments (Fig. 2). Shales, siltstones, and sandstones of Cretaceous Age underlie the Gubik Formation (Robinson and Collins 1959).

The surface of the Meade River Unit consists primarily of well-sorted fine to medium sand of eolian origin (Williams et al. 1977). Dune deposits containing abundant quartz with minor accessory minerals are massive to stratified with

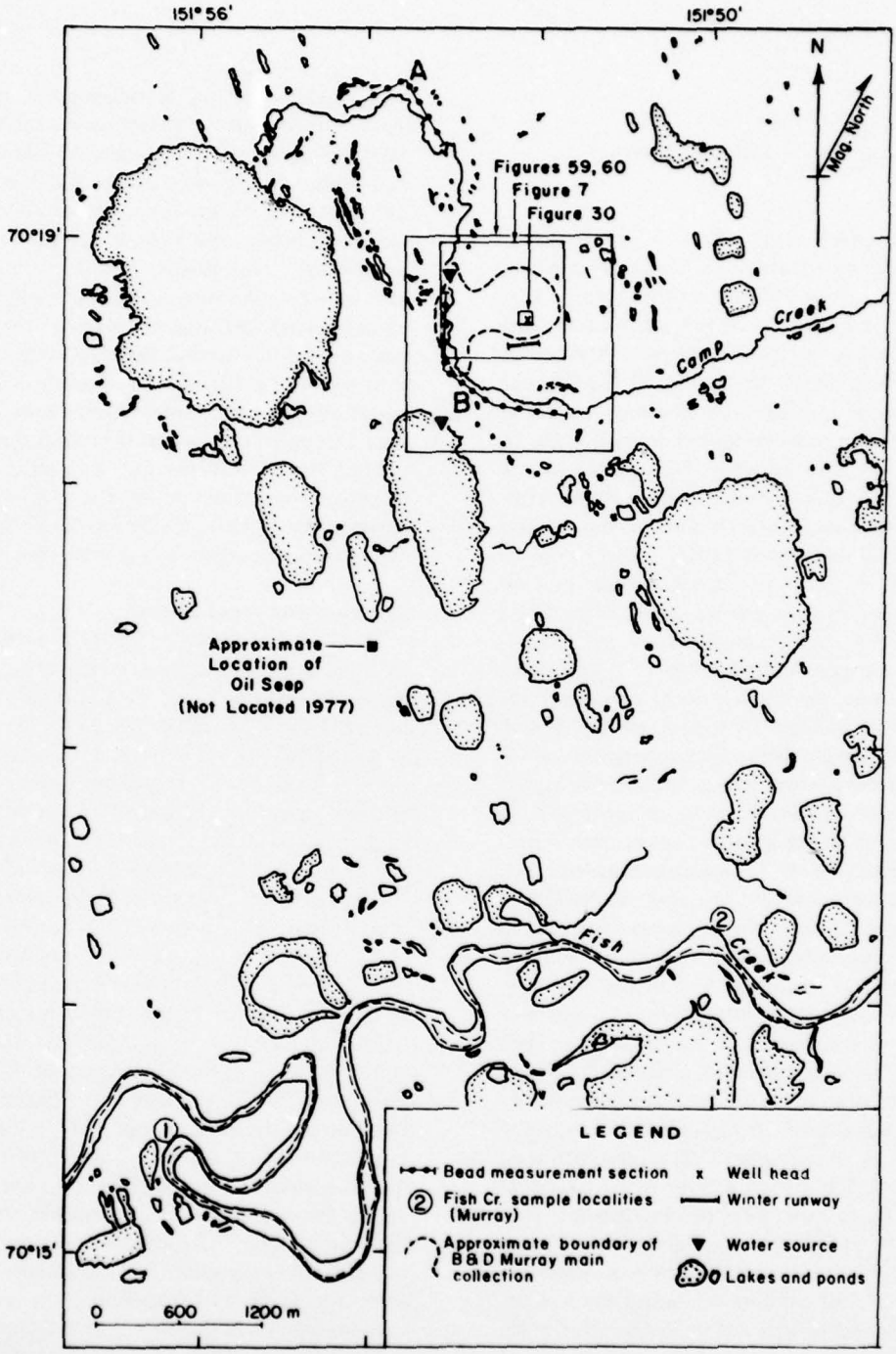


Figure 2. Location map of the study area. Location of Figures 6, 30, 59 and 60, the Murrays' main collection area, and bead measurement sections are shown.

Figure 3. Fish Creek camp, 7 September 1949. Jamesway huts on short pilings were connected by boardwalks; 55-gal. drum piles in center of photo. Quonset hut used for mess hall is in left center of photo (U.S. Navy 1949).

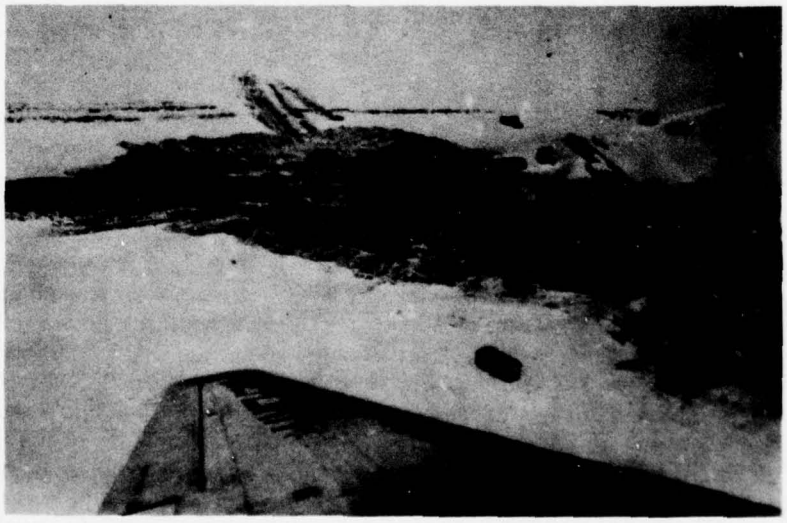


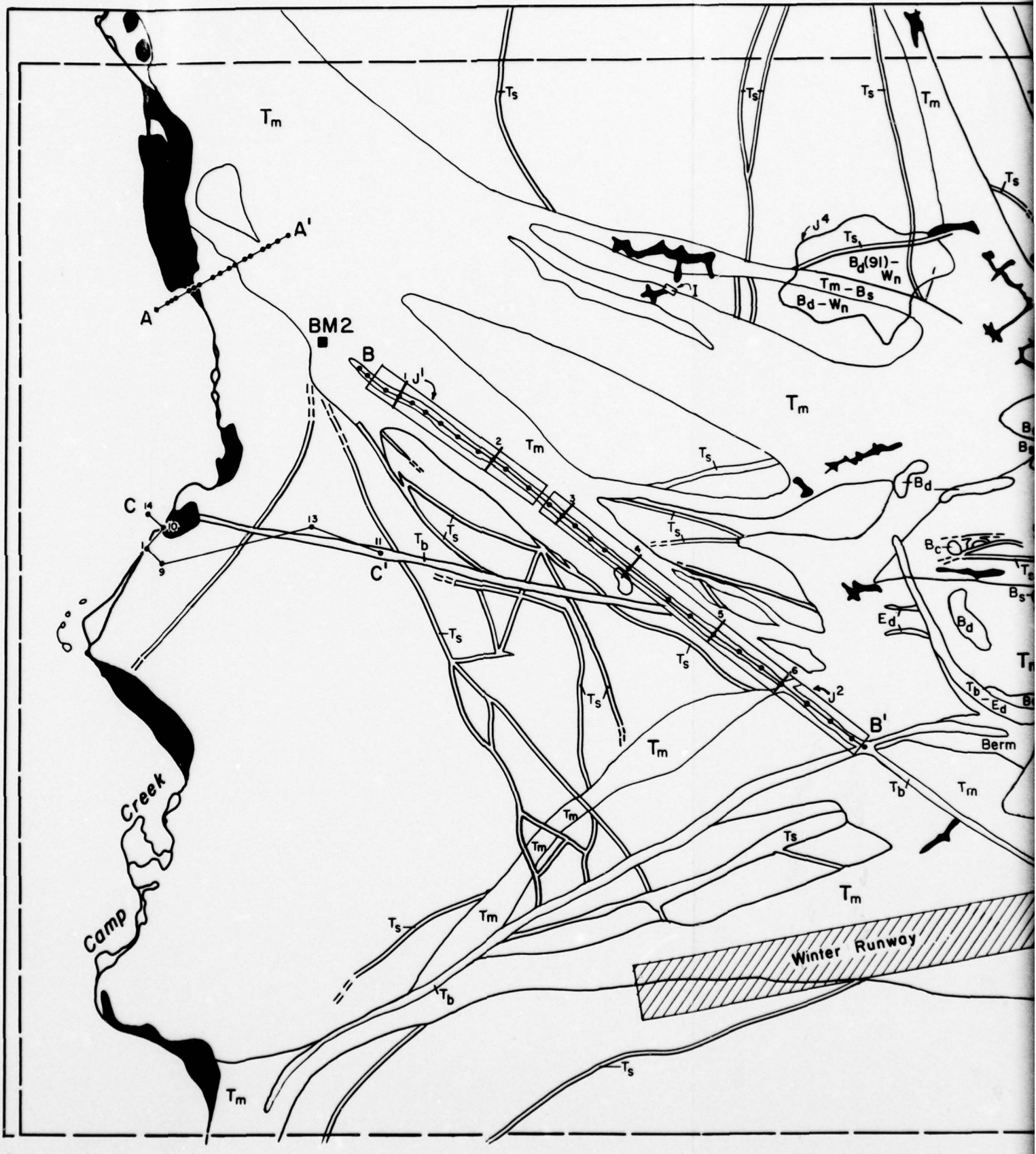
Figure 4. Oblique aerial view of Fish Creek camp on 28 April 1949. Bulldozed berms consisting of sediment and snow surround the camp. Bulldozed trails and drainage ditches, camp buildings, stacks of lumber, and several vehicles are also shown (U.S. Navy 1949).

Figure 5. Thawing moss for insulation, Fish Creek camp on 18 April 1949 (U.S. Navy).

large-scale cross bedding in places (Williams et al. 1977). These surface materials have been reworked by fluvial processes (Black 1951), and recently by lacustrine processes through the thaw-lake cycle (Britton 1967). This cycle consists of repetitive stages of lake formation and drainage. It is the primary process of surface modification resulting in active erosion of basin margins that may then cause lake drainage or coalescence of adjacent lakes. In the vicinity of the drill site, there are a number of large thermokarst lakes that are drained and partly drained. Drained lakes contain large (10- to 12-m) low-centered polygons, orthogonal and nonorthogonal in shape. The partly drained lakes are characterized by numerous basin-concentric peat ridges separated by sedge fens, many with well-developed string bogs. A number of these lake basins contain one or more low (several-meter-high) mounds, which are believed to be hydrostatic in orgin and possess well-developed high-centered polygons. Headward erosion by the small beaded stream, Camp Creek, appears responsible for the drainage of at least two of the lakes.

Intervening primary land surfaces and ridges of stabilized sand dunes occur several meters above the lake bottom lowlands. It was on such a surface that the Fish Creek test was drilled in 1949. These surfaces are covered by low relief, high-centered polygons or, more commonly, by a mixture of both high- and low-centered polygons. The extent of natural thermokarst suggests these surfaces are in transition from a low-centered polygon terrain to one dominated by high-centered polygons. Tussock tundra is the characteristic vegetation of high-centered polygons, whereas low-centered polygons display a range of vegetation across each polygonal element (center, rim, and trough).

The Fish Creek area was virtually unknown prior to 1977 in terms of vegetation, floristics, soils, and climate. Comparable inland coastal sites which have been studied include Atkasook to the west (Batzli and Brown 1976) and a narrow zone along the TAPS haul road to the east (Brown and Berg 1977). Summers at Fish Creek are apparently warmer and more comparable to Atkasook than to those of the coastal climates at Barrow, Lonely, Prudhoe Bay or Barter Island (Brown et al. 1975). Daily maximum and minimum temperatures (°C) for several days during 1977 are listed in Table 1.


A
A'
B
B'
C
C'
BM2
J1
J2
J3
J4
Tm
Ts
Tb
Bd(91)-Wn
Tm-Bs
Bd-Wn
Bd
Bc
Bs
Ed
Tb-Ed
Berm
Winter Runway
Camp Creek

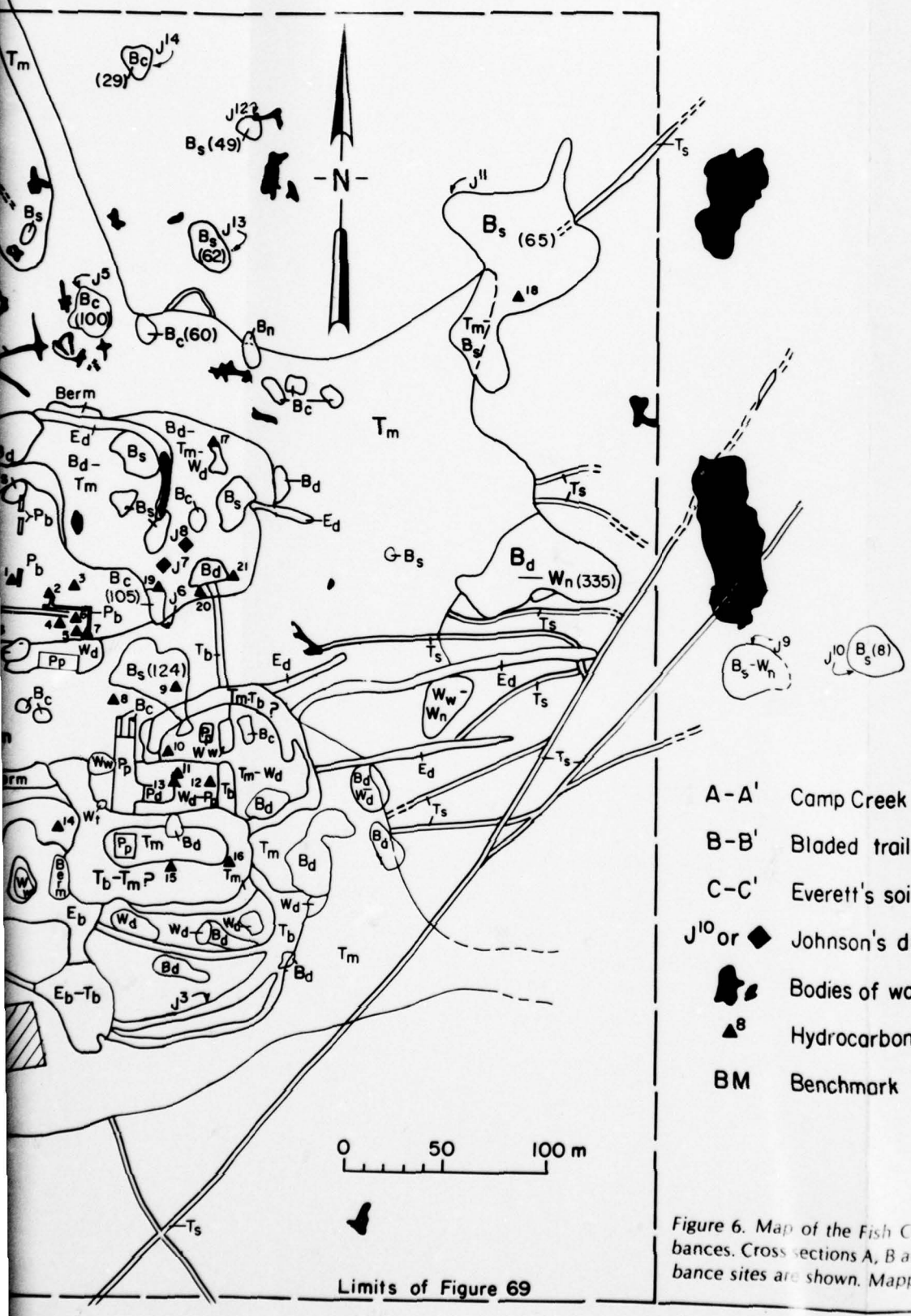
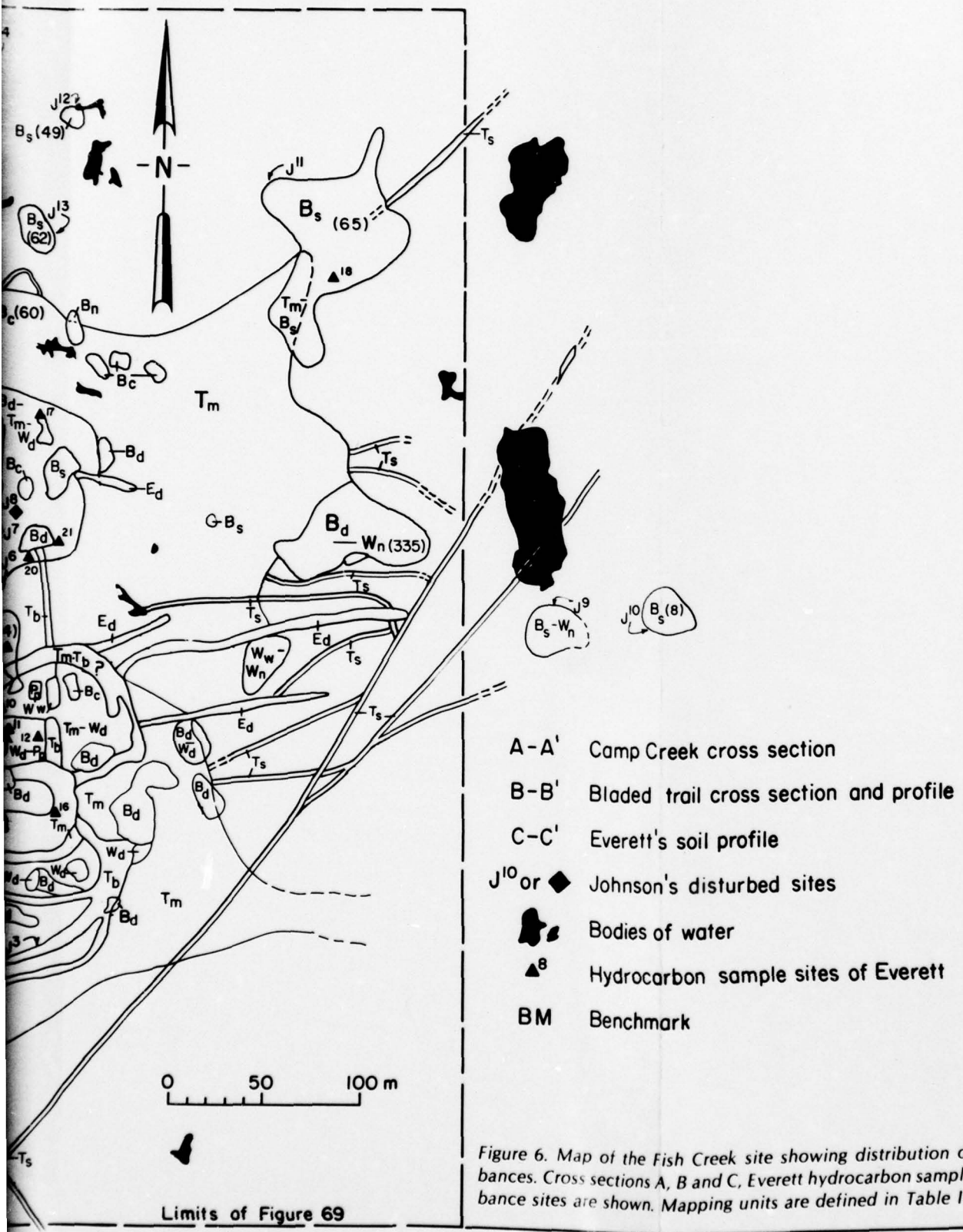


Figure 6. Map of the Fish Creek site showing distribution of debris and oth
bances. Cross sections A, B and C, Everett hydrocarbon sample sites, and Johns
bance sites are shown. Mapping units are defined in Table II.



A-A' Camp Creek cross section

B-B' Bladed trail cross section and profile

C-C' Everett's soil profile

J^{10} or ◆ Johnson's disturbed sites

Bodies of water

▲8 Hydrocarbon sample sites of Everett

BM Benchmark

Figure 6. Map of the Fish Creek site showing distribution of debris and other disturbances. Cross sections A, B and C, Everett hydrocarbon sample sites, and Johnson disturbance sites are shown. Mapping units are defined in Table II.

Table I. Daily maximum and minimum temperatures (°C) for North Slope sites, 26-30 July 1977.

Location	26 July		27 July		28 July		29 July		30 July	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Atkasook	5	12	4	24	9	22	11	26	18	25
Barrow	1	3	1	6	2	13	7	18	6	17
Lonely	1	4	2	4	4	11	8	16	5	17
Fish Creek*	1	8	-	18	6	26	6	21	4	20
Prudhoe	2	6	1	7	3	23	10	23	8	18
Franklin Bluffs	0	15	3	24	10	21	11	19	5	18

*Shielded minimum-maximum thermometer mounted on a post, temperatures at other sites from standard shelters.

Types of disturbance

The type and location of the major man-made disturbances on the Fish Creek site are presented in Figure 6; study sites are also indicated. This map was prepared by D.E. Lawson using a vertical aerial photograph taken on 21 August 1977 after field investigations were completed. Field notes and sketches drawn in the field were used to construct this map. Figure 7 is the 1977 aerial photograph from which the map was constructed. For comparison, the 1948 aerial photograph of the preconstruction condition of the site is shown in Figure 8. The disturbances are classified and described briefly in Table II, and specific types of disturbance are illustrated photographically in Figures 9-20.

Comparison of the aerial photograph of the Fish Creek site taken prior to construction in 1948 (Fig. 8) with that taken in 1977 (Fig. 7) shows that disturbance is most intense immediately surrounding the drill pad and generally decreases in intensity, except along the major vehicular trails, with distance from the camp area. Disturbances in Figure 7 have primarily resulted from the development of a hummocky topography and polygonal depressions that are filled with water, and from similar changes along the linear vehicle trails which extend from the site. In terms of area impacted by a given process, vehicular tracks and trails caused the greatest extent of damage to the surface.

The preliminary results of this study suggest that the processes which cause the most lasting effects on the vegetation, soils, and geology of the Fish Creek site are, in order of importance: blading of the surface materials for trails and excavations, diesel spills, and multiple pass trails. These results are discussed in the following sections.

Table II. Classification and description of disturbances.

Trails and runways

T_b *Bladed with berm.* Prominent, nearly straight trench-like depression. Floors nearly level, vegetation covered, generally between 0.5 and 0.75 m below surrounding surface except deeper in water-filled thermokarst pits. Berms less than 0.5 m above surrounding surface generally vegetation-covered, sporadic-wind abraded areas near crest. Pronounced signature on air photographs (Fig. 9).

T_d *Bladed with a ditch only.* In most respects similar to T_b. Lack of berm probably the result of marginal slump into trench (Fig. 10).

T_m *Multiple pass trails.* Anastomosing, commonly partially superimposed, parallel tracks. In upland tundra surface compression is generally <10 cm. Thermokarst subsidence is a common adjunct in areas of polygonized tundra especially where track crosses ice wedge intersections or runs parallel to the wedges. Signatures on air photographs are variable (Fig. 11).

T_s *Single pass trails.* Isolated tracks. Surface compression generally <10 cm. Weak signature on air photographs tending to fade in wet areas (Fig. 12).

T_r *Winter runway.* Linear feature confined to relatively well-drained margins of drained lake. Airphoto signature variable and weak.

Excavations

E_b *Depressions with berm.* Irregular, flat-floored shallow basins. Vegetation cover is similar to that in T_b. Berm usually confined to one or two sides and rises to 1 m above floor. Berm composed mostly of scraped organic surface, generally grass-covered with a few bare spots.

E_r *Ripped trenches.* Narrow (±0.5-m) short linear ditch 0.5 to 1 m deep. Angular blocks of turf (overturned and commonly lacking vegetation) occur sporadically adjacent to ditch. Usually some marginal slumping.

E_d *Drainage ditches.* Either linear or curvilinear features extending from drill area to adjacent drained lake basin. Similar to T_b areas but may be wider (±4 m). Usually have prominent and discontinuous berms up to 1 m high (Fig. 18).

Steel drums (55 gal.)

B_d *Dispersed as individuals.* Individuals scattered randomly (2 to 10 m between drums), commonly peripheral to drum stacks, in drained lake basin, or distributed along shoreline by seasonally high water. Usually lying on their sides (Fig. 13).

B_s *Dispersed in small groups.* Defined groups of 10-100 drums several meters apart. Probably represent collapsed drum stacks and, if erect, supports for former storage platforms (Fig. 14).

B_c *Collected and stacked.* Well-defined stacks of drums (several to a hundred or more). Drums piled 3 to 4 high, 2 to 4 drums wide and up to 20 drums in length (Fig. 15).

Pilings and structures

P_d *Concrete drill pad.* Concrete drilling pad approximately 15 × 7 m, elevated about 1 m above local tundra surface. Generally flanked by P_p (Fig. 16).

P_p *Piles.* Creosoted wooden pilings extending 0.5 to 1.5 m above local tundra surface. Generally in a grid form with individuals 1 to 2 m apart. Served as platform supports. Most probably extend 1 or more meters into permafrost (Fig. 16, 17).

P_b *Boardwalks.* Discontinuous lath-like wooden walkways 0.5 to 0.75 m above the local tundra surface. Such features rest on pile supports P_p or drums and have well-defined signatures on aerial photographs. Scattered boards and barrels are commonly associated (Fig. 17).

Other soilid waste

W_n *Nondegradable (bottles, cans, waste).* Areas with diffuse boundaries covering up to several hundred square meters and commonly associated with dispersed barrels B_d, B_s or wood stacks W_w (Fig. 17, 18).

W_w *Wood stacks.* Conical or elliptical piles 1 to 2 m high and covering up to 70 m² (Fish Creek) of broken and whole construction lumber. Prominent features from the air. May be associated with B_d, W_d or W_r (Fig. 18).

W_d *Scattered wood.* Individual pieces dispersed randomly on the landscape, commonly associated with B_d, P_p and W_n (Fig. 15, 16).

W_c *Canvas tarps.* Individual canvas tarps associated with W_w or occurring sporadically on the tundra (commonly around pilings and structures). Vegetation may protrude through tears but is absent beneath.

W_m *Landing mats, sheet iron or other metal objects.* Landing mats commonly occur as scattered pieces on the tundra. May also occur associated with B_s or P_p as storage platforms or in stacks associated with W_n.

Spills and effluents

S_d *Diesel fuel.* Prominent irregular areas (0.1 to 10 m²) generally dark brown to black, occasional tufts of grass. Characteristic diesel fuel smell from coves just below surface, commonly around drum stacks and former generator areas (Fig. 19).

S_{cc} *Crankcase oil.* Prominent small areas (0.6 to 1.4 m²) commonly black or greyish-black in color. Strong odor of weathered oil on warm days. Generally free of vegetation but *Senecio* sp. may be common.

S_c *Crude oil.* Uncommon. Confined to the immediate area of leaking oil drums and to leaking 5-gal. cans on runway. Faint odor of crude oil at shallow depth below surface (Fig. 20).

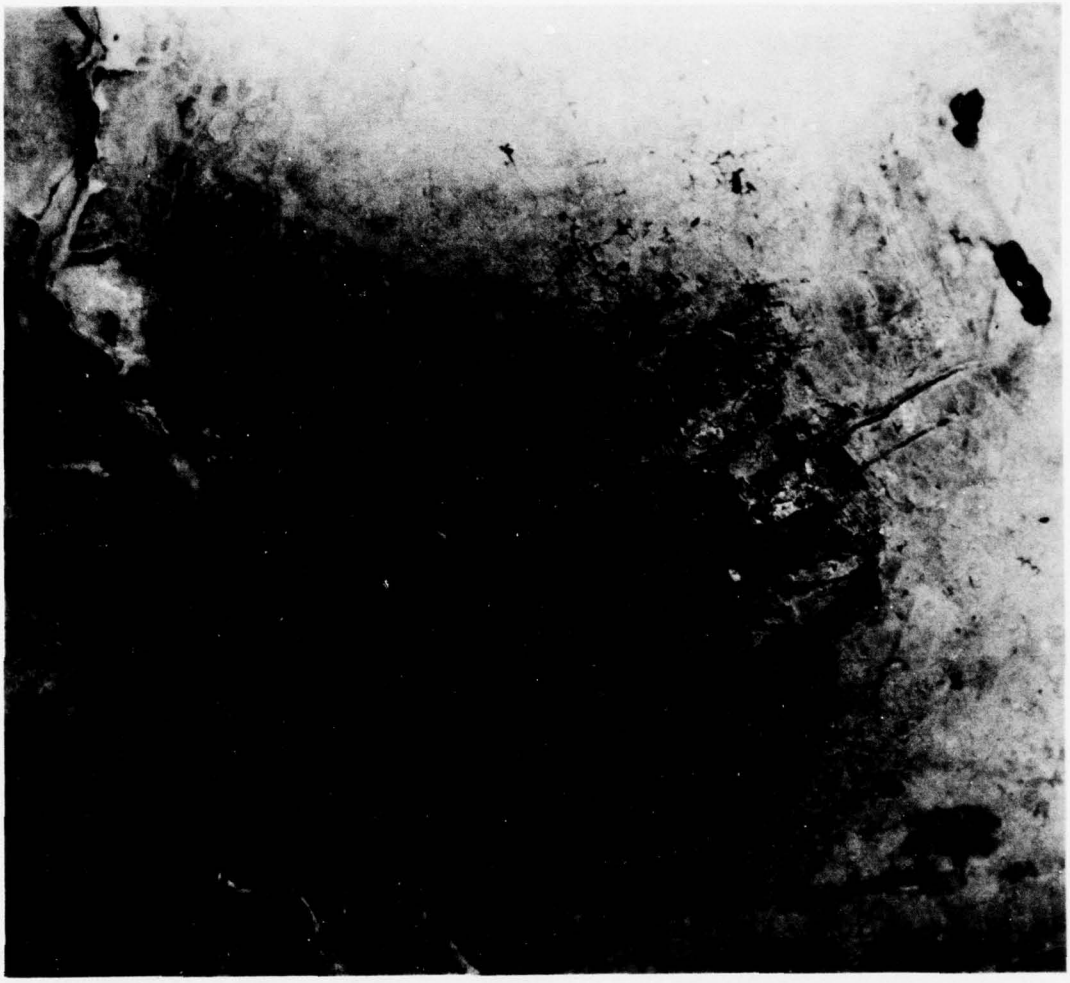


Figure 7. Aerial photograph of the Fish Creek site obtained in 1977 from which the disturbance map (Fig. 6) was constructed (photo obtained by J. Mellor, University of Alaska, 21 August 1977).

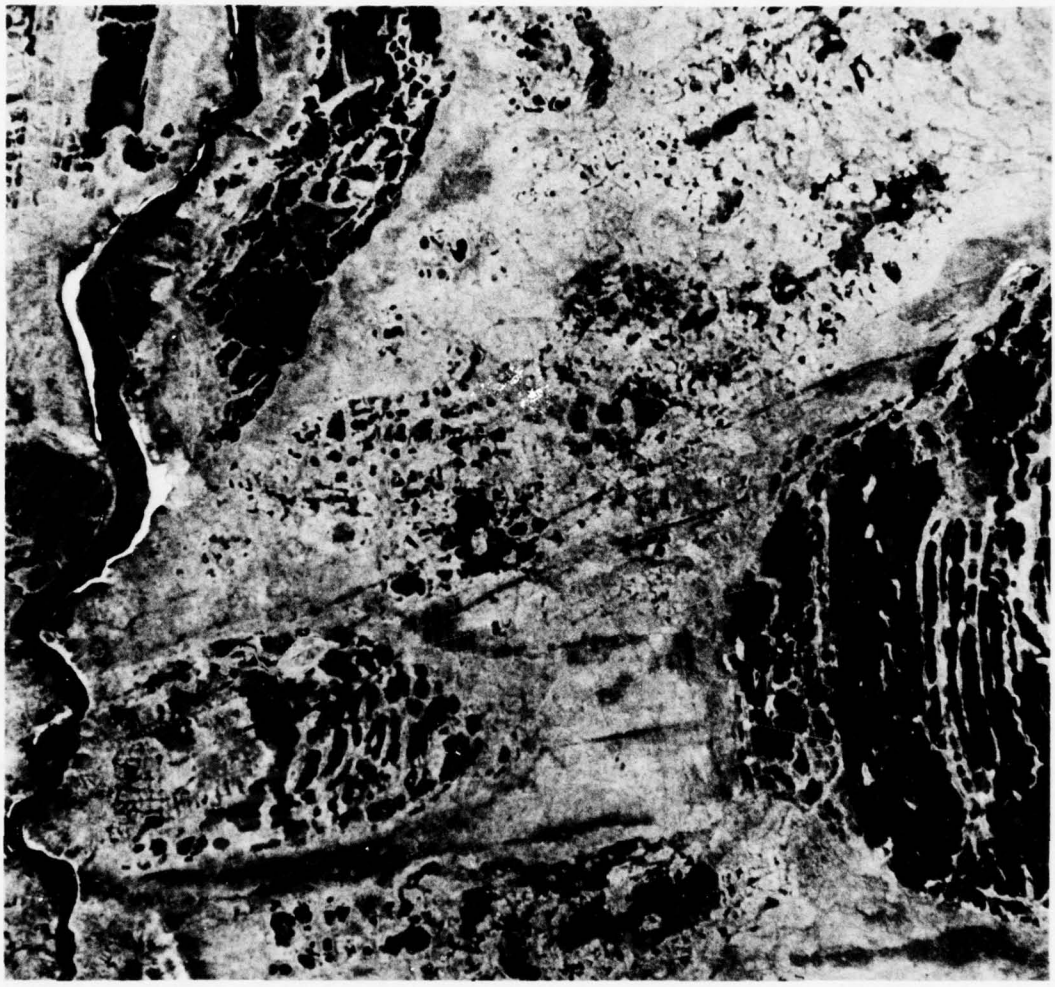


Figure 8. Aerial photograph of Fish Creek site taken in 1948 prior to disturbance (BAR-74-029, 10 July 1948).

Figure 9. Bladed trail with berm (T_b). A small thermokarst pit occurs near photo center. Vegetation cover is extensive. View northeast.

Figure 10. Bladed trail without berm (T_d). Large thermokarst pond adjacent to 0.4-m scale. Lack of berm may be due to consolidation and marginal slumping. View east.

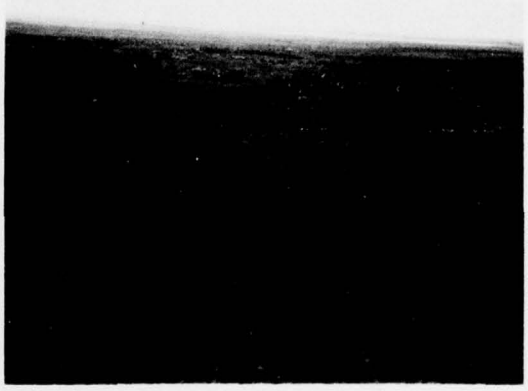


Figure 11. Multiple pass vehicle trails (T_m) in center and left foreground of photo. Steel drum stacks and groups, and other debris occur in background.

Figure 12. Single pass vehicle tracks (T_s) near Camp Creek. Tracks depressed generally less than 10 cm. View north.

Figure 13. Individual drums (B_d), some crushed, scattered randomly on ground surface. Man-induced thermokarst trough in center. Groups of drums in background.

Figure 14. Groups of drums (B_s). Dark gray pattern marks wet areas of thermokarst origin. Single pass vehicle trails occur in foreground. View southeast.

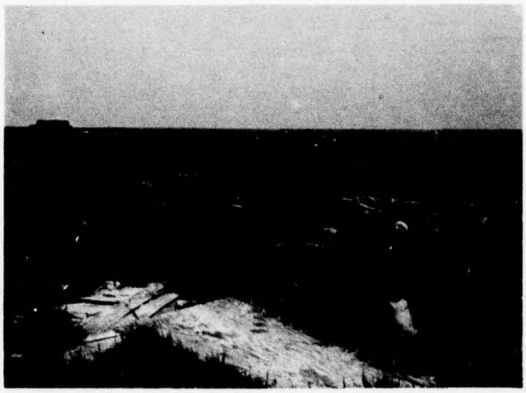


*Figure 15. Scattered wood (W_d), wood stack (W_w), individual drums (B_d), and a large drum pile (B_p) (left center of photo) litter the surface to the north of the drill pad. The predominant type of vegetation associated with disturbed sites at Fish Creek includes a number of grasses (*Arctagrostis latifolia, Poa arctica, Poa rigens*) which determine its physiognomy. Grasses do not dominate in the principal types of the surrounding natural vegetation. View north.*

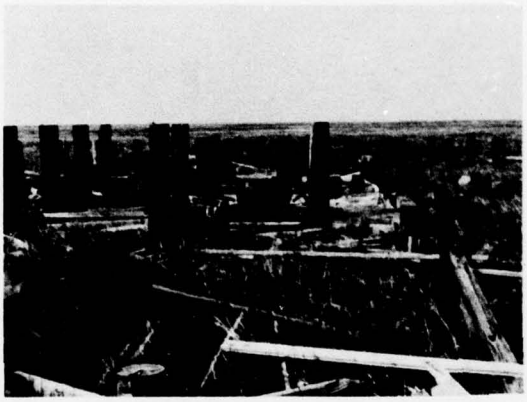


Figure 16. Concrete drill pad (P_d) with pile supports (P_p), on and off that pad. Wood, drums and other debris litter the surface. View west to Camp Creek.

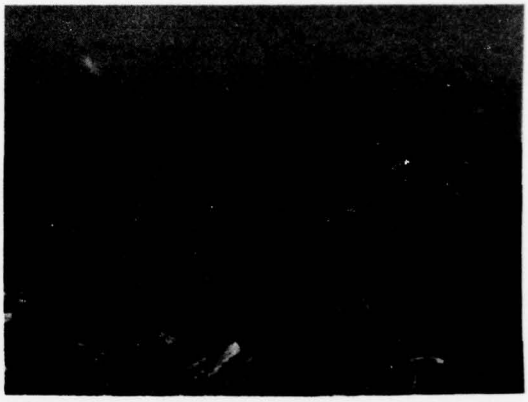


Figure 17. Photo of debris from drill pad. View north. Broken boardwalks (P_b), short pilings (P_p), cans and bottles (W_w), drums, and wood cover the surface. Dark areas mark wet thermokarst pits.

Figure 18. Oblique aerial photograph showing several large wood piles (W_w) with other debris. Wet bladed drainage ditch parallels left margin of photo; a second occurs in upper part of photo to right of wood stack. Carex aquatilis *ssp.* stans *and* Eriophorum angustifolium *ssp.* subarcticum *inhabit the bladed drainage ditches. View west to drill pad area.*

Figure 19. Typical diesel fuel spill (S_d) on 28 July 1977.

Figure 20. Isolated crude oil spills (S_c) from rusted drum in seasonal shallow pond. Spill probably occurred many years after site abandonment.

DISTURBANCE OF PERMAFROST, MASSIVE GROUND ICE, AND SURFICIAL MATERIALS

D.E. Lawson and J. Brown

Introduction

The Fish Creek drill site is located on tundra overlying unconsolidated sediments which, except for a thin active layer (0.2 to 0.8 m thick in late July 1977) at the surface, are perennially frozen. Perennially frozen ground or permafrost is reported to extend to approximately 180 m below the ground surface (U.S. Navy 1949). Widespread polygonal ground, the beaded stream that flows through the area (Fig. 21), and low pingos in the drained lake basins indicate the presence of substantial amounts of massive ground ice in the upper part of the permafrost.

Ice wedges, segregated ice, and pore ice were observed in the soils and near-surface sediments beneath the site. Pore ice, which originates by freezing of the soil and the water it contains in the unfrozen state, partly or completely fills cavities between the particles of sediment and acts as a cement binding these particles together. Segregated ice forms during the migration of water into sediments while they are freezing (Taber 1929, Mackay 1971); this ice may vary in size from small lenses and layers to large bodies that are tens of meters thick and hundreds of meters square in area. In contrast to pore and segregated ice, wedge ice develops after the sediments are frozen as the result of the thermal fracturing of the uppermost part of the permafrost and the infilling of these thermal contraction cracks by meteoric water (Leffingwell 1919, Lachenbruch 1962). A yearly cycle of cracking and infilling increases the dimensions of ice wedges, and the associated seasonal warming and heaving of the sediments in contact with the wedge ice produces a polygonal pattern on the surface. This pattern, however, only partly reflects the surface dimensions of the ice wedges and does not indicate their depth. As an extreme example, Lachenbruch (1966) reported near-surface permafrost composed of as much as 90% wedge ice. Similarly, buried ice wedges may also occupy large volumes (Brown 1969). Perennially frozen sediments containing excess ice, such as ice wedges and segregated ice, are considered supersaturated: they contain more water in the form of ice than the sediments could hold if the water were in the liquid state.

Because the formation of permafrost depends upon the temperature at the ground surface, processes that affect the thermal regime of the surface environment alter the permafrost significantly (e.g. Gold and Lachenbruch 1973). Usually, disturbance of the tundra surface raises the mean summer temperature at the ground surface and increases the depth of thaw (e.g. Brown et al. 1969, Mackay 1970, Viereck 1973). Loss of vegetation due to fire, removal of the upper soil layer by bulldozing, and compaction of the vegetation mat and upper soil layer by vehicles are examples of such disturbances. If the permafrost is supersaturated, the removal of this ice by in-situ melting results in thermokarst subsidence of the ground surface (Mackay 1970). The amount of subsidence that occurs can be equated to the quantity of ice lost by melting. If melting of the excess ice results from the flow of water over that surface, however, thermal erosion takes place. Both processes occur at the Fish Creek site (Fig. 22 and 23). Thus, the extent and activity of man-induced thermokarst subsidence at this site indicates the effect of disturbance after 28 years.

The intensity of disturbance caused by natural and man-induced thermokarst and thermal erosion is directly related to the depth and areal extent of excess ice in the upper part of the degrading permafrost. At the Fish Creek site, the distribution and volume of this ice are unknown, and the depth to which excess ice occurs may be limited. Brown and Sellmann (1973) reported that the average depth below which excess ice does not occur is about 8 m in silts at Barrow, Alaska. Massive ice was encountered, however, at depths exceeding 18 m in the Canadian

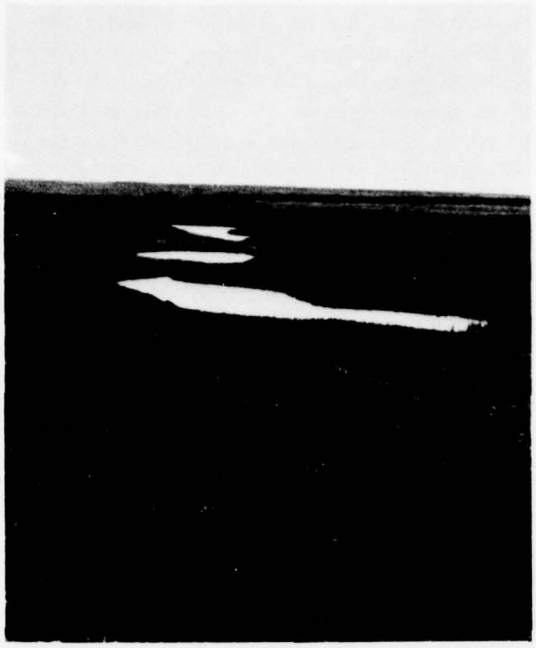


Figure 21. Beaded drainage, Camp Creek. Beads occupy depressions formed by melting of ice wedges; narrow, vegetation-filled channels connect individual beads.

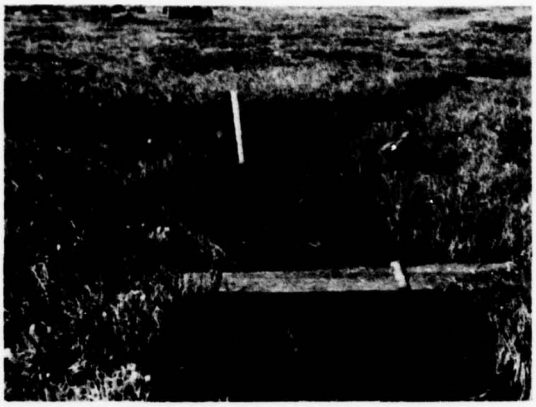


Figure 22. Trough formed by thermokarst subsidence due to man-induced disturbance above ice wedges. Scale (extending 0.8 m) stands at ice wedge intersection. Tipped pile right of pond indicates continued thawing and slumping of sediment, soil, and vegetation mat. Planking lies across the trough in foreground.

Figure 23. Bladed trail with berm piles. Disturbance resulted in thermal and fluvial erosion from runoff. Water flows from top to base of photo, where it enters Camp Creek valley over a small delta.

regions of the Arctic (e.g. Mackay 1966) and was also observed at depths in excess of 25 m north of the Brooks Range along the Trans-Alaska Pipeline. The percentage by volume of ice measured in sediments of the supersaturated zone ranges from about 40% to greater than 90% (e.g. Mackay 1966, 1970, 1971; Brown and Sellmann 1973; French 1974, 1975; Racine 1977). Black (1969) found that deposits of sand, silt, and silty-clay/silty peats of the Barrow unit of the Gubik Formation near Barrow, Alaska, contained 9% to 40%, 13% to 65% and 75% to 91% moisture by weight, respectively. Black (1969) concluded that ground ice in the Arctic Coastal Plain constitutes 30 to 60% of the upper 10 m of the permafrost. Sampling and drilling of the permafrost are required to determine precisely the volume and extent of excess ice beneath the Fish Creek site as well as the quantity of ice that has melted because of disturbance.

An estimate of the volume of excess ice and the lower limit of this excess ice in perennially frozen sediments can be made indirectly in some cases by examining areas of natural and man-induced thermokarst subsidence. Following surface disturbance by the passage of a vehicle or the removal of the uppermost layer of the tundra by bulldozing, permafrost degradation and preferential subsidence above ice wedges in the sediments beneath and adjacent to the disturbed zone take place (e.g. Mackay 1970, Rickard and Brown 1974, French 1975) (Fig. 10, 11, and 23). If it is assumed that no sediment is removed by other processes, the volume of the thaw ponds and troughs approximates the volume of ice melted from the ice wedge. Thus, an estimate of the volume of wedge ice contained in near-surface sediments to a depth equal to that of the thaw pond or trough can be calculated for a specific area if the location of all ice wedge polygons is known. The presence or absence of ice below the bottom of the ponds and troughs must, however, be determined by drilling.

The thaw lake cycle (Britton 1967) is a natural process that results in basin formation by melting of excess ice in the permafrost. Livingstone et al. (1958) estimated the volume of ice melted during the formation of East Oumalik Lake (69°50'N, 155°27'W), a thaw lake located about 154 km southeast of the Fish Creek site in the foothills of the Brooks Range. In order to make this estimate, they assumed that the volume of the thaw lake basin equaled the volume of ice lost by melting due to the thaw lake cycle and that the volume of sediment in the basin equaled the volume present prior to lake formation. They calculated that about 70% by volume of the upper 28 m of the permafrost at East Oumalik Lake consisted of excess ice.

Streams also induce thermokarst subsidence and thermal erosion. Streams that have eroded headward into coastal lakes and subsequently drained them are often characterized by shallow ponds connected by vegetated stream troughs (Fig. 23) and are referred to as beaded drainage (Hopkins et al. 1955). Beads occur in places occupied formerly by ice wedges, and thus their depth may indicate the lower limit of wedge ice. A topographic profile from upland surfaces across beaded streams may provide an estimate of the volume of ice removed from the near-surface sediment. This assumes, however, that headward erosion results primarily from thermal erosion and that little sediment is removed by hydraulic erosion. Estimation by this method therefore yields a maximum value for this volume.

In this preliminary study, the extent and condition of man-induced disturbance to the permafrost was qualitatively evaluated in the immediate vicinity of the drill site, and the volume and depth of excess ice removed by natural and man-induced thermokarst subsidence estimated at selected sites.

Methods

Topographic cross sections of the Camp Creek Valley and the trench of a bladed trail, together with point elevations in a 100 × 100-m grid around the drill pad, were measured using a self-leveling level. A reference mark (RM 20206) on the drill site was arbitrarily assigned an elevation of 17 m and used as a bench mark. The volume of excess ice lost by melting was computed graphically from the cross sections. The adjacent, apparently undisturbed surfaces were used as a plane of reference and the loss of sediment due to hydraulic erosion was considered negligible. The 100 × 100-m area was taped off as a grid at 20-m intervals. Disturbance and topographic maps of this area were drawn using this grid as a base map. Maps were refined by examining a 1977 aerial photograph obtained after the field work was completed. Depth of thaw was measured by probing to refusal with a 0.5-cm-diam metal probe. Beads and thaw ponds were sounded with a weighted line on the end of a rod to obtain water depths.

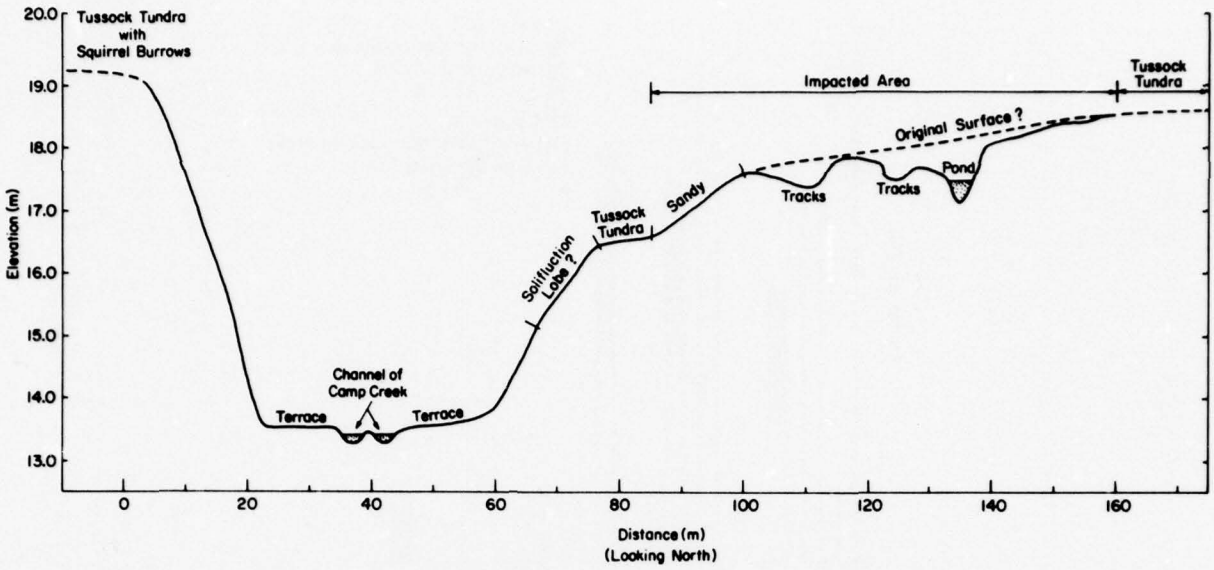


Figure 24. Cross section across Camp Creek. Ice-rich sediment about 6.75 m thick was removed by hydraulic and thermal erosion. Location shown on Figure 6.

Discussion and conclusions

The depth of beads in Camp Creek and a cross-sectional profile of the creek adjacent to the Fish Creek site (Fig. 24) were measured. The depth of beads upstream and downstream from the location of the cross section and the depth of the valley indicate that the depth to which excess ice has been removed is about 6 to 7 m (Fig. 25). Upstream (section A) in the presumably younger drainage, eight of the deeper beads averaged 1.5 m of water. Downstream (section B), 32 of the deeper beads averaged 1.3 m of water and ranged from 3 to 10 m wide and 4 to 11 m long. The size of beads measured in section B increased generally with increase in depth. The depth of the beads in the valley probably represents the minimum depths at which ice wedges occur, but analyses of stream processes and drilling in the valley bottom are required to determine if this depth is actually the lower limit of excess ice. Slump and collapse of the steep-walled banks of the beads downstream left undisturbed blocks of soil and vegetation on the pond bottoms, suggesting that excess ice may still be present in the valley sediments. These slumped materials indicate that lateral migration of the stream, apparently as the result of thermal erosion, hydraulic erosion or both, is still occurring. The undisturbed condition of the blocks of soil and vegetation suggest hydraulic erosion has little influence on stream migration.

From the cross-sectional profile, the quantity of ice and sediment removed by natural thermal and hydraulic erosion was estimated by assuming that the undisturbed tussock tundra represents the original surface into which Camp Creek was incised. The maximum depth from which both ice and sediment have been removed is approximated by the depth of the channel bottom, about 5.25 m. The area of the valley above the cross-sectional profile is approximately 230 m^3. This cross section is representative of a 70-m length of the creek valley upstream of its location. Thus, about 16,100 m^3 of sediment and ice has been removed from this part of the valley. If it is assumed on the basis of Black's (1969) estimate of the quantity of ice in the upper 10 m of permafrost in the Arctic Coastal Plain that 45% of this quantity represents ice, 7250 m^3 of ice was removed. Thus, 8850 m^3 of sediment was either removed from the area or underwent consolidation as the ice was removed.

As an example of man-induced thermokarst subsidence at the Fish Creek site, profiles of a trail formed by bulldozing and multiple passages of vehicles were obtained (Fig. 26). The elevations of the bottom of the trail, bottom of thaw ponds, original surface and standing water levels in the ponds, and thaw depths are shown. This trail crosses approximately 35 ice wedges between Camp Creek and the drill site. Each of these wedges has melted and formed thaw

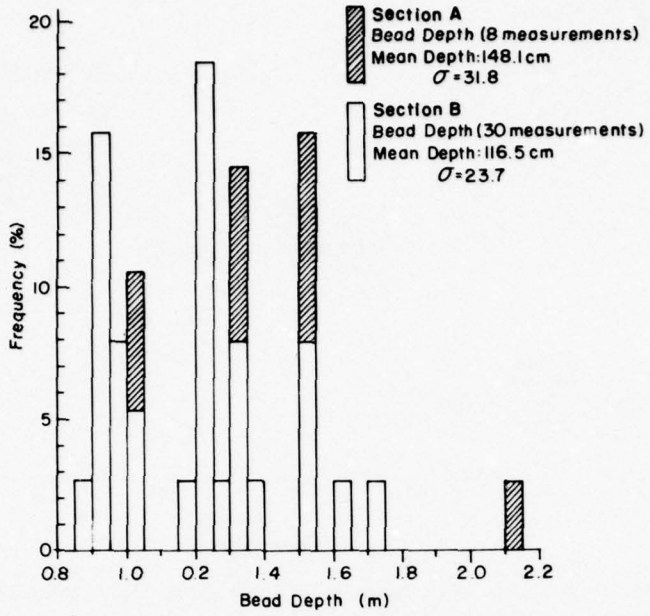
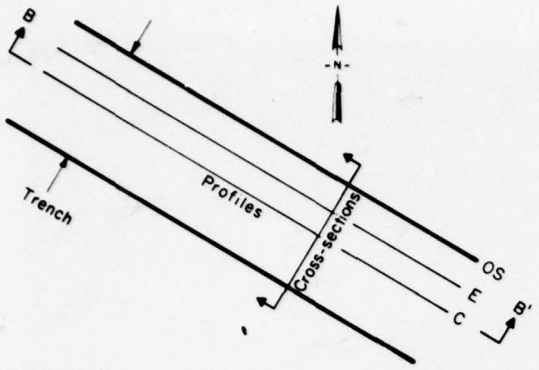


Figure 25. Water depth in beads measured in Camp Creek, 29-30 July 1977. Locations of measurements are shown in Figure 2.

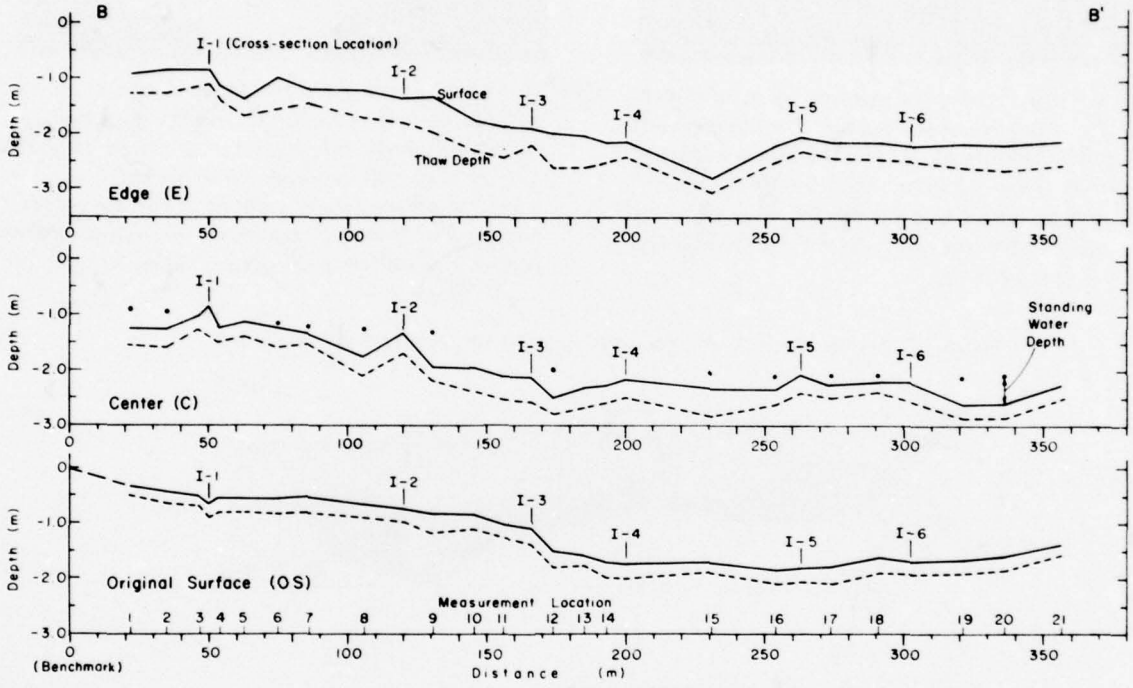
ponds of different dimensions and shapes that depend upon the angle at which the trail intercepted the underlying ice wedges. The elevation of the trench, including the bottom elevation of the thaw ponds, ranges from 0.5 to 1.2 m lower than the undisturbed surface adjacent to the measured sections. A bulldozed berm lies next to some parts of the trail. It is generally less than 0.5 m higher than the undisturbed surface. Slumping and wind erosion as well as normal consolidation of berm materials are probably responsible for the absence and reduced size of the berm along parts of the trial.

Characteristics of the shallow ponds in the flat-bottomed bladed trench suggest that they are in equilibrium with the seasonal thaw regime; however, the thaw depths suggest otherwise. Equilibrium is suggested by the complete vegetation cover and the stability of the sediments in the trench. Thaw depths in the adjacent undisturbed materials are, however, usually less than those beneath ponds and the bottom of the trench and may indicate that an increase in seasonal thaw is occurring. The thaw depth for 27 ponds averaged 30.7 cm (standard deviation σ = 8.5) excluding the water column and 47.4 cm (σ = 19.3) including the water column. The depth of thaw in the trench adjacent to the berm averaged 40.0 cm (σ = 12.7). The mean depth of thaw for the adjacent undisturbed sediment was 24.8 cm (σ = 4.1). The fact that excess ice was present in the Camp Creek valley to a depth of 6 to 7 m implies that ice wedges and lens ice remain beneath the thaw ponds and trench. Thus, if the thaw depth is still increasing, the bottom of the trench will continue to subside. Precise profiling is necessary to determine if subsidence is occurring. Shallow cores of the sediments beneath the trench are required to ascertain the amount and nature of residual ground ice in these materials.

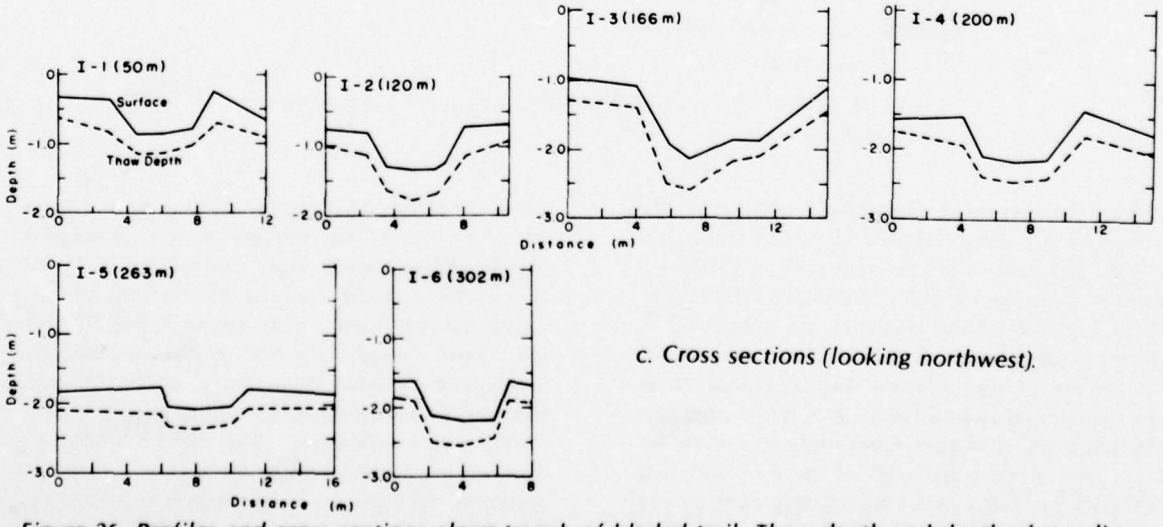
Partly vegetated troughs and ponds containing freshly slumped blocks of soil with vegetation indicate that melting of ice wedges triggered in 1949 is still taking place in some areas. In an area traversed several times by vehicles, excavation of the organic cover between two such thermokarst ponds uncovered a 2.3-m-wide, V-shaped ice wedge (Fig. 27). This wedge lies beneath a soil containing interstratified silts and organics (10 cm thick) and buried, decomposed organics (18 to 23 cm thick) (Fig. 28). Fine- to medium-grained, well-sorted sand lies along the lateral margins of the wedge. A thin layer of ice and a crack in the soil cover at the crest of the wedge suggest that it was active and growing



a. Location of profiles and cross sections.



b. Trench profiles (looking northeast).



c. Cross sections (looking northwest).

Figure 26. Profiles and cross sections along trench of bladed trail. Thaw depth and depth of standing water in thermokarst ponds are indicated. Location shown on Figure 6.

a. Flat-topped ice wedge exposed by hand trenching. Soil cover is about 30 cm. The thermokarst ponds in the foreground and the upper center of the photo resulted from vehicular disturbance of the surface above this ice wedge. Troughs were not observed in the undisturbed areas. Exposed scale is 0.85 m long.

b. Detailed view of dissected ice wedge. Black material (18-23 cm thick) overlying wedge is highly decomposed organics; stratified organic silt overlies this material. Well-sorted, medium sand lies on the lateral margins of the ice wedge. Sample of organic material for radiocarbon dating and pollen analysis was taken to right of scale above ice.

Figure 27. Ice wedge (2.3 m wide) uncovered from beneath vehicular trail.

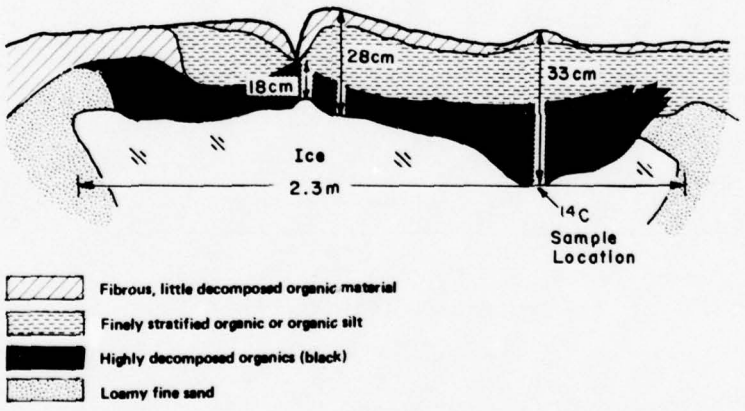


Figure 28. Sketch of vertical profile through the ice wedge (drawing by K.R. Everett).

before excavation. Decomposed organics lying above the ice were sampled for radiocarbon and pollen analyses. A whole peat sample yielded a radiocarbon age of 2020 ± 70 (DIC 970) B.P. The results of the pollen analyses are presented in Appendix A.

Permafrost degradation and seasonal thaw were analyzed in detail in a 100 × 100-m area surrounding the drill pad. Degradation is most intense south, west and east of the drill pad, but less intense north and immediately next to the pad (Fig. 29). The areas of intense disturbance are now wetter and appear dark gray in Figure 29. Thaw ponds and troughs which developed above melting ice wedges are largest in these areas. The troughs formed by melting of ice wedge polygons are readily apparent (Fig. 28 and 29). These troughs do not appear on photos taken prior to disturbance (Fig. 7) and are absent today in undisturbed areas adjacent to the Fish Creek site indicating that their formation resulted from disturbances caused by camp occupation. The types of disturbance and their location in the 100 × 100-m area are shown in

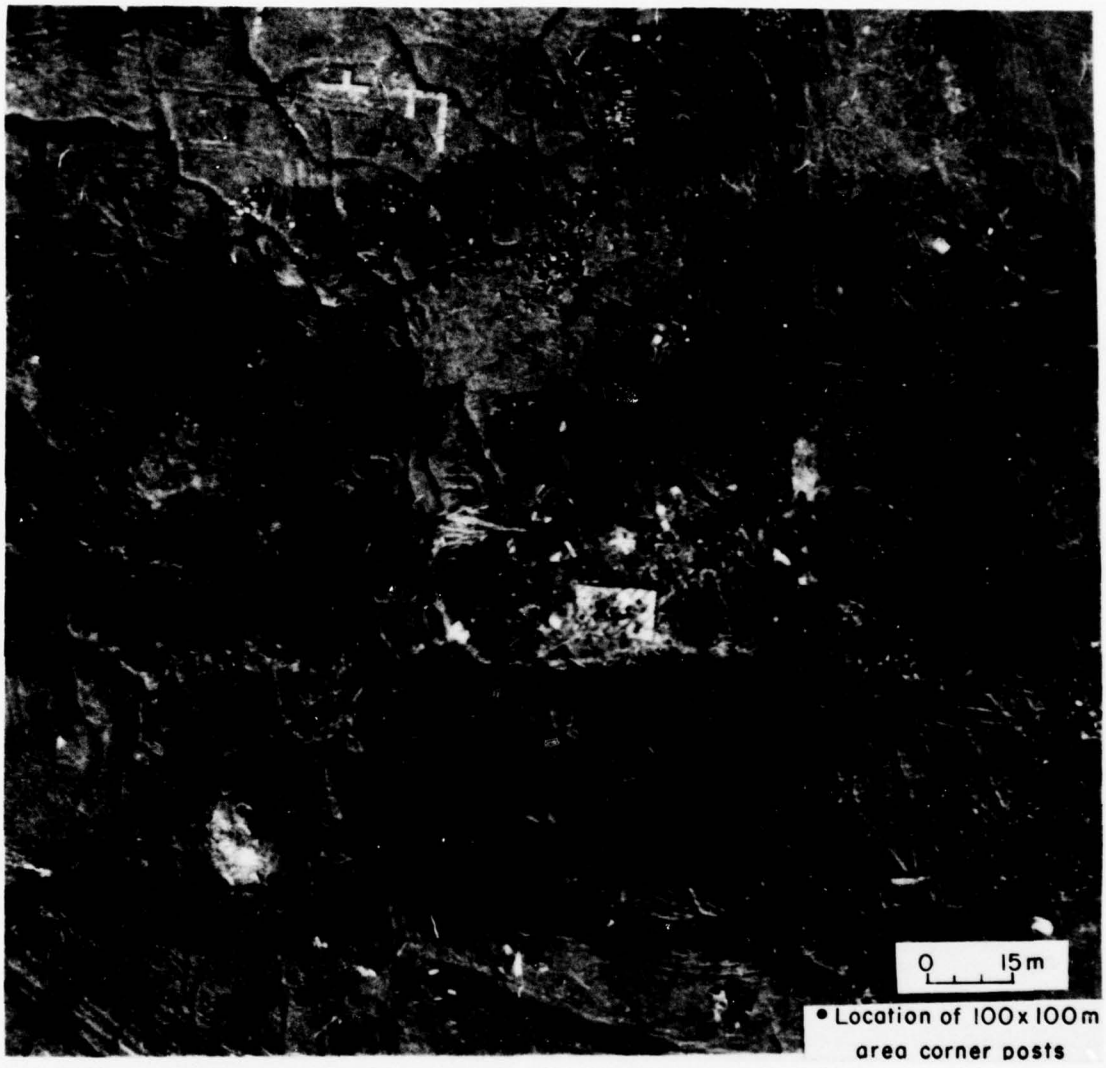


Figure 29. Aerial photograph of Fish Creek camp area, with location of 100 × 100-m area indicated by four dots. Extensive thermokarst subsidence above ice wedges forming the polygonal pattern on the photo and the resultant hummocky topography are evident. White rectangle in photo center is drill pad. (Photo by J. Mellor, University of Alaska, 21 August 1977.)

Figure 30. The most intense disturbance resulted from bulldozing, heavy traffic, or both. All other types of disturbance affect the permafrost but to a lesser degree.

The changes in relief in the 100 × 100-m area due to thermokarst are shown in Figure 31. Maximum relief across the site is about 2.0 m. The absence of thermokarst troughs and ponds on the 1948 aerial photograph (Fig. 8) and the relief observed in undisturbed areas of the tundra today (e.g. Fig. 27) suggest that relief in the 100 × 100-m area prior to disturbance was probably less than 0.5 m. In bulldozed areas and in those of heavy vehicular usage (e.g. just west of the drill rig pilings), the ground surface is hummocky and relief over short distances exceeds 1 m. Thaw ponds are generally less than 1 m deep. Berms appear reduced in height, probably as the result of melting of excess ice, consolidation of berm materials, and eolian erosion of the sand-size sediment of which they are composed.

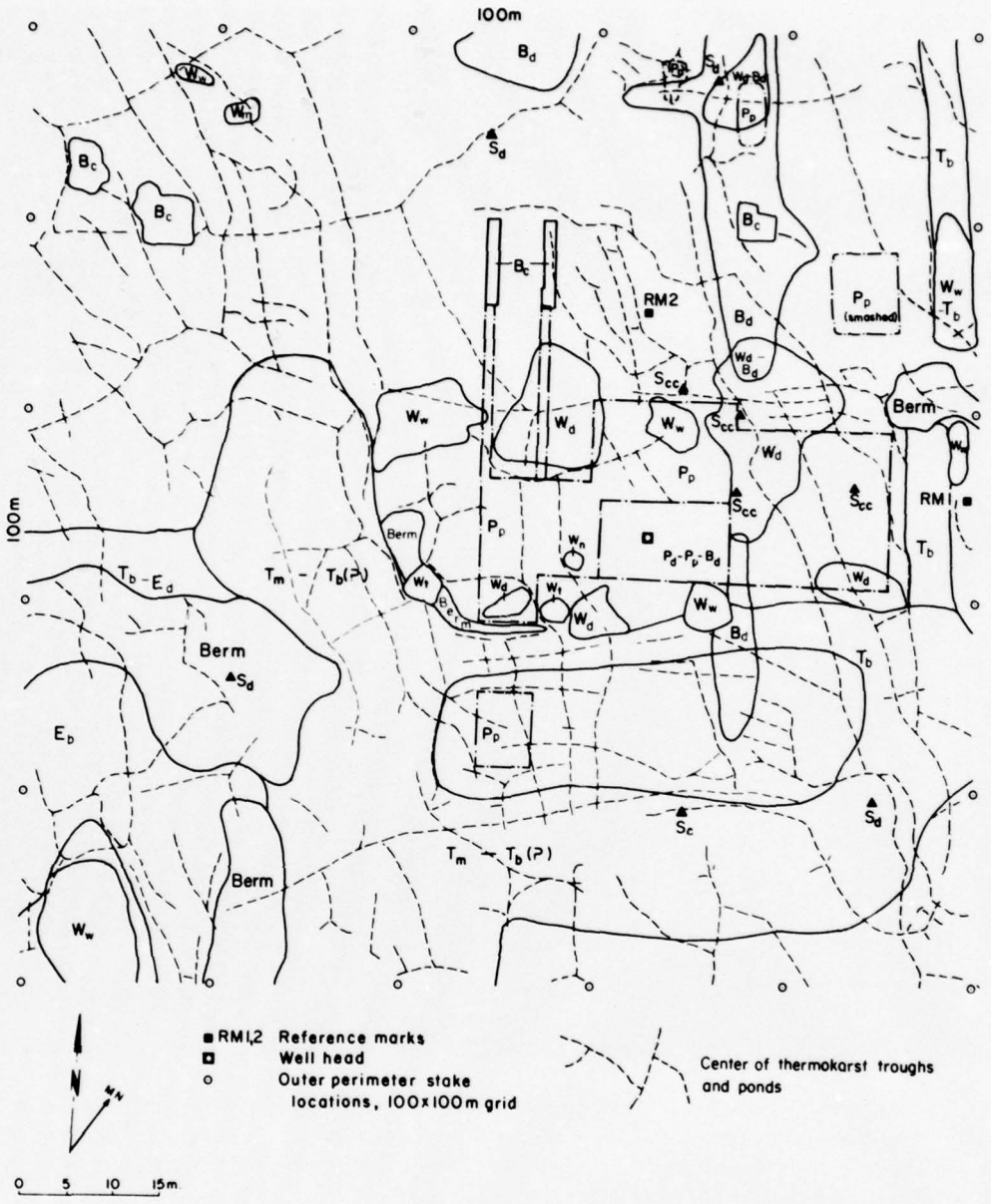


Figure 30. Detailed map of types of disturbance and the location of subsidence caused by melting of ice wedges. Map symbols are defined in Table I. Location of map shown on Figure 29.

Thaw depths measured at 69 points across the 100 × 100-m area (Fig. 31) range from 20 to 77 cm, with a mean depth of 36.8 cm (σ = 11.0) (Fig. 32). These values do not vary systematically across the area.

The depth of thaw is apparently related to the intensity of disturbance. Figure 33 shows the variation in thaw depths of: 1) thermokarst troughs in areas of light disturbance, 2) dry areas with light disturbance and without subsidence, 3) dry areas, including berms, with light disturbance and without subsidence that are adjacent to intensely disturbed areas, and 4) areas of intense disturbance (bladed, vehicular traffic) with or without subsidence. The average depth of thaw in areas of most intense disturbance is 53 cm, whereas less disturbed areas average about 30 cm. The average thaw in less disturbed areas

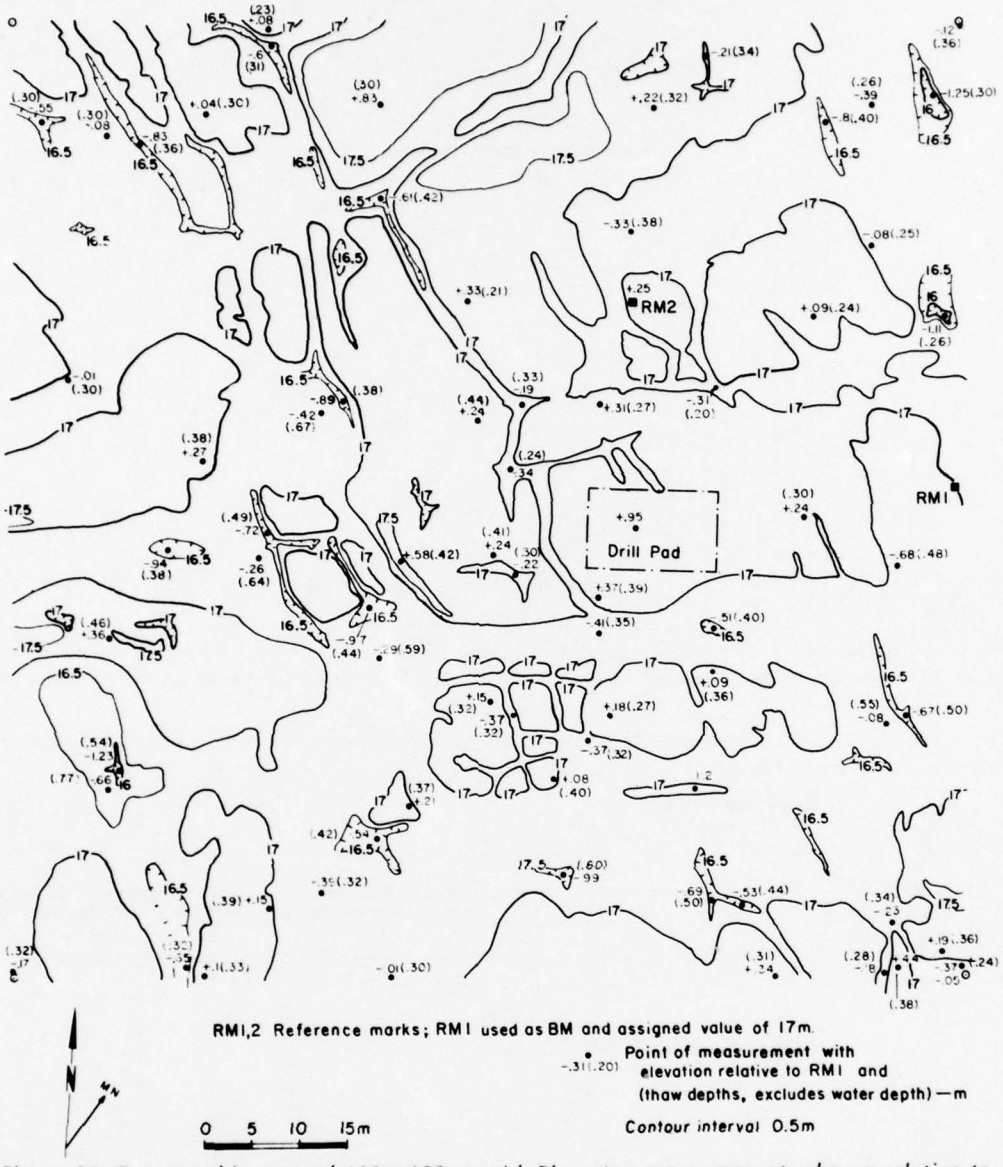


Figure 31. Topographic map of 100 × 100-m grid. Elevation measurements shown relative to bench mark (RM1) that was assigned an elevation of 17 m; thaw depths at each point are shown in parentheses (30 July 1977). Linear pattern reflects depressions formed by melting of ice wedges.

was comparable to that in undisturbed areas, suggesting that thermal equilibrium and partial recovery have occurred. The depth of thaw beneath troughs and ponds containing water plus the depth of the water in those depressions is approximately equal to the depth of thaw in adjacent sediments. This observation suggests that stagnant ponded water and saturated sediments are thermally similar.

The much larger thaw depths of intensely disturbed areas suggest that thermokarst subsidence may be continuing at a slow rate; however, precise profiling of the ground surface over a number of years is required to determine if subsidence is continuing.

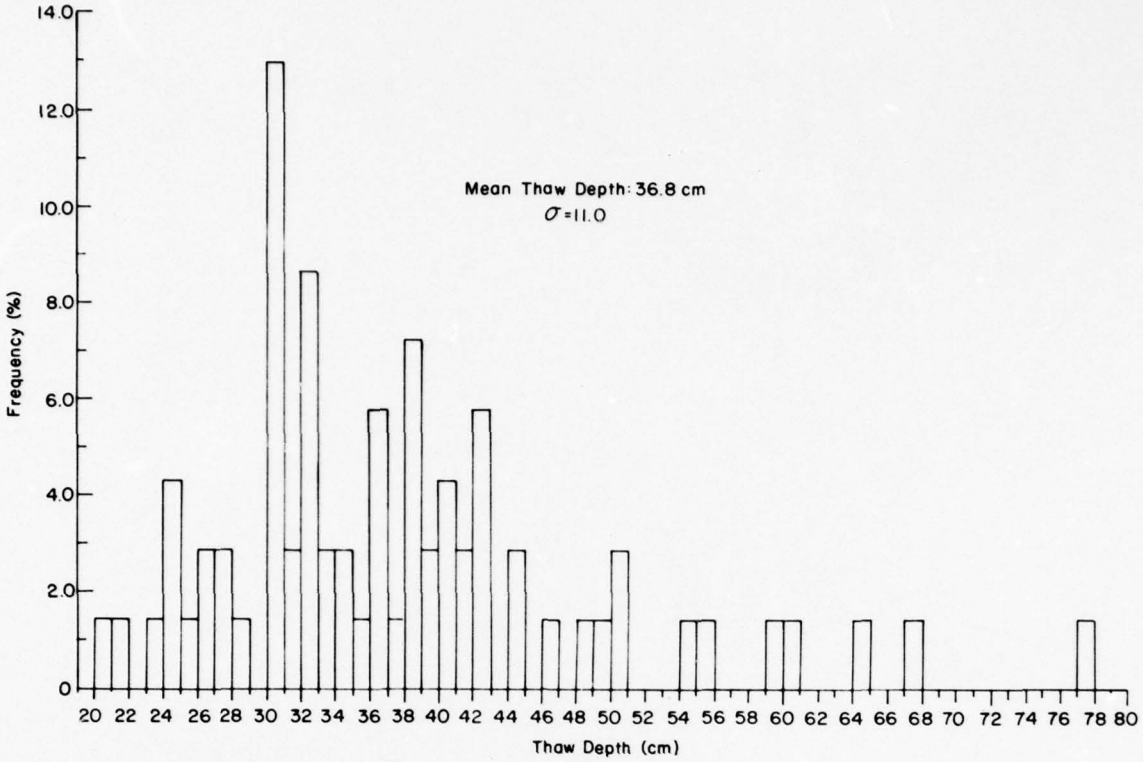
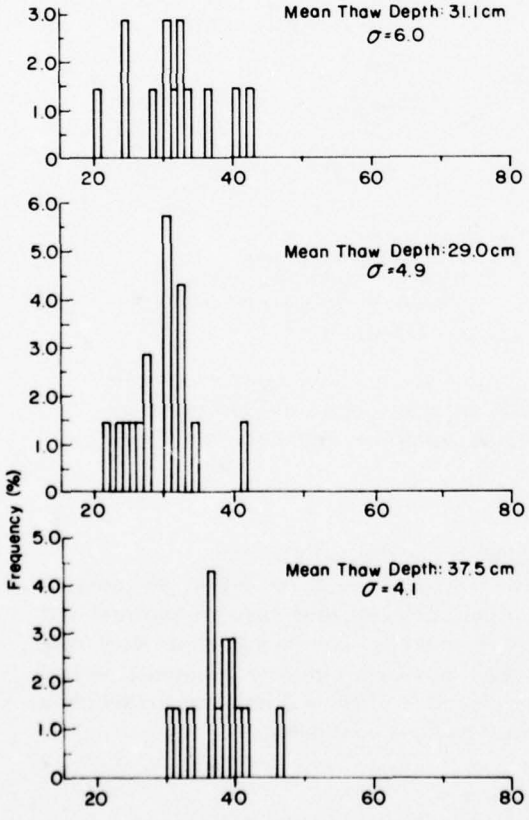


Figure 32. Composite graph of thaw depths measured in 100 × 100-m grid on 30 July 1977. Location of measurements is shown in Figure 31.



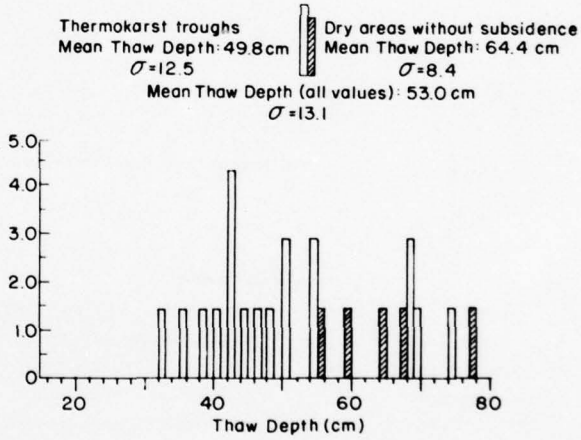


Figure 33. Thaw depth variations with relative intensity of disturbance. Thaw depths are largest beneath bulldozed areas that were subject to heavy vehicular traffic and some blading (D); smallest thaw depths occur in dry areas with less disturbance (A, B). Berms and dry areas adjacent to intense disturbances show increased thaw depths (LC).

SOILS AND THEIR REACTION TO IMPACT AND HYDROCARBON SPILLS

K.R. Everett

Soils

In view of the botanical, physiographic and geological similarities between the Fish Creek site and the more intensively studied Atkasook (Meade River) site, it is not surprising that there is considerable similarity in the soils as well. Taxonomically two and probably three soil orders can be recognized: Entisols, Inceptisols and perhaps Histosols (Soil Survey Staff 1975). The soil profiles referred to in the following discussion are described in Appendix B. Their locations are shown in Figure 7 and in the idealized cross section of Figure 34.

Entisols

These sandy textured mineral soils that display little or no morphologic or chemical differentiation (horizon development) are commonly found on hydrostatic blisters in many of the drained or partially drained lakes (profile 3, Fig. 34) and on active and recently stabilized sand dunes along Fish Creek, located about 5 km south of the drill site (Fig. 2). Soils, which are best described as Entisols because of their morphology, are found sporadically in frost scars on the primary land surfaces (profile 9).

The narrow, sedge-covered alluvial plain adjacent to Camp Creek has very immature soils with highly variable profile morphology. Casual inspection of their morphology as it is exposed in the stream bank would suggest that they are organic soils; however, in most cases, the organic materials are composed predominantly of living and dead roots of *Carex aquatilis* (profiles 14A and 14B, Fig. 34). Also, the organic content (expressed as percentage organic matter or organic carbon) of the soil is commonly too low (less than 18% organic carbon) to permit the soil to be classified as an organic soil (Histosol). Such soils are more realistically placed with the Entisols. These soils are not truly fluvents, as little sand has been added through successive flooding. Most of the sand is probably derived from the adjacent bluffs during winter as the result of wind erosion. The remainder may be introduced by snowbank sapping of the bluff during spring melt and thaw consolidation of bluff sediments as the stream valley expands laterally.

Inceptisols

This large and diverse group of mineral soils is well represented in the region and is the predominant type at the drill site. The Inceptisols, developed under tussock tundra on the high-centered polygons and in areas on the upslope side of the low bluffs bounding the

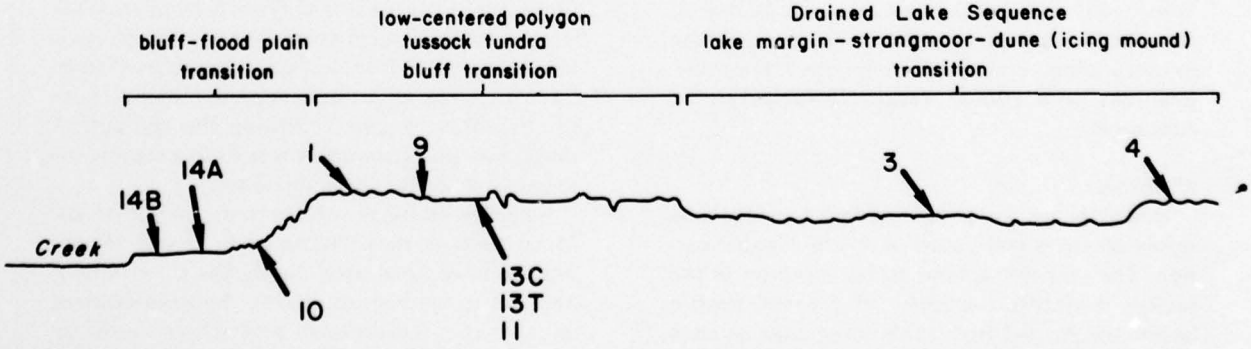


Figure 34. Idealized cross section of the principal landform units and their associated soil profiles at Fish Creek site. View north.

drained lakes and the streams, are represented by profile 4. These soils show characteristics similar to soils occupying similar topographic poisitions at Atkasook. Profile 13C typifies a substantial part of the drill site area occupied by low-lying, flat-topped polygons and low-centered polygons. Soils represented by profiles 4 and 13C belong to the Great Group of Pergelic Cryaquepts.

Soils immediately upslope from many escarpments and on the crests of old and stabilized dunes are sandy textured Inceptisols that belong to the Great Group of Cryocherpts (profile 1). There soils are moderately well-drained and display some of the most pronounced horizon development in the area. Areally they are quite restricted as are their counterparts at Atkasook. Highly disturbed soils with similar profiles occur beneath hummocky areas covered seasonally by snowbanks along the front of many bluffs.

Soils of the drained and partially drained lake basins do not show the primary characteristics of organic soils, although at many locations in the polygon centers and in the flat areas between the strings of aligned hummocks (stränges), they may have up to 20 cm of fibrous organic materials overlaying sands. The organic surface horizon, which may meet the taxonomic criteria for an organic soil, lacks sufficient thickness. Therefore, such soils are Inceptisols and designated as Histic Pergelic Cryaquepts. In other instances, the soil profile is similar to those of the Camp Creek flood plain (profiles 14A, 14B).

A relatively thick (18- to 36-cm), dark-colored surface horizon which contains substantial amounts of highly oxidized organic matter occurs on many stränges and pronounced polygon rims. This horizon, or epipedon, overlies frozen sands or, in some cases, fine gravelly sands. These soils are tentatively classified as Humic Pergelic Cryaquepts (profile 4). They are similar in morphology and share analogous microrelief positions with Humic Pergelic Cryaquepts at Atkasook.

Histosols

Histosols are those soils at Fish Creek whose upper 40 cm is composed of ≥12% organic carbon. They do not appear to be common in the region. A detailed analysis of the soil profile below the August frost table, especially at sites located in low-centered polygons on primary land surfaces (e.g. profile 13C), is required to determine their extent. Such an analysis may reveal that the upper 40 cm is mainly organic and that the mineral horizon is actually a thin and taxonomically allowable interruption. Hence, the soil of profile 13C would then be considered a Histosol rather than an Inceptisol.

Anthropogenically disturbed soils

Man's effects on the soils at Fish Creek (and in permafrost regions generally) appear to be of three types:

1. Impacts associated with tracked vehicles. These impacts commonly begin with compression of the organic surface horizon. The less decomposed the organic material, the more rapidly it will rebound. If the vehicle passage is repeated or if the vehicle is heavy (e.g. Caterpillar D-6 or larger), compression and compaction of the thawed mineral subhorizons occurs and may result in a permanent increase in density. Ponding or thaw consolidation of the soil and thermokarst may result.

Repeated vehicular movement eventually produces mechanical abrasion of the surface in addition to soil compression. The severity of abrasion is dependent upon the microrelief.

2. Blading of the active layer. Blading commonly results in complete destruction of the physical and morphologic characteristics of the soil. Following removal of the insulating active layer, rapid thaw consolidation of the underlying ice-rich soil occurs. Depending upon the regional slope, it may be accompanied by extensive hydraulic erosion.

3. The addition of foreign substances to the surface. The effects of foreign substances on the tundra depend upon the nature of the substance itself, the volume spilled, and the condition of the tundra surface at the time of spillage. Among the most common substances spilled on tundra are unrefined and refined hydrocarbons (crude oil and diesel fuel). The results of such spills may range from a slight, short-term disruption of vegetation to its complete removal. Loss of vegetation occurs following the spillage of diesel fuel and commonly results in a significant increase in active layer thickness.

Single or multiuse vehicle trails are numerous. Most, such as that illustrated in Figure 35, appear to have been used during the thaw period, and this usage has resulted in the development of sporadic thermokarst pits where trails intersect ice wedges. The surface compression seen in Figure 35 is represented diagramatically

Figure 35. Compression of surface (tussock tundra) by tracked vehicle, 27 July 1977. Scale is 0.75 m long.

in Figure 36 (also profile 13C and 13T). The principal effects appear to be compression and some thaw consolidation of the mineral B2 and A1b horizons. While the bulk density data for the upper horizons (O1 and A1) are not significantly different between the track and the nonimpacted surroundings, the increase in moisture in the track is probably significant. More samples would be required to substantiate this. Typical of most tracks, the soil profile remains essentially unaltered except for horizon thickness.

Figures 10, 11 and 12 illustrate the effect of repeated surface traffic by large tractors and sleds and of blading of the surface to permit easy movement of sledges on the frozen soil. Subsequent thaw consolidation of apparently homogeneous subsoil materials produced a relatively flat-floored depression in which soil development began anew. Profile 11 approximates the soils developed on the "flood plain," or subsidence plain, of Camp Creek. The micromorphology of the depression is different from that of the adjacent (primary) land surface. Thermokarst depressions exist but appear to be static and in adjustment with the depression.

Within the area of the drill site itself, blading of many square meters of the surface produced soil and surface characteristics similar to the bladed trail (Fig. 9). The bladed material was pushed into piles which now rise a meter or more above the depression. These materials constituted the original active layer with soils similar to profiles 13C and 4. Their elevated position and increased drainage permitted relatively rapid oxidation of the organic materials and the production of a thick organic-rich mineral soil with well-developed structure (profile 12).

Repeated vehicular impact on the sandy mineral soils of the bluff crest and face (Pergelic Cryochrepts — profile 1) completely destroyed their morphology. In the 28 years since impact, leaching, oxidation and limited accumulation of organic matter produced a soil (profile 10) similar to that of the stabilized frost scar (profile 9).

Hydrocarbon impacts

Hydrocarbon spills associated with the Fish Creek drill site are of three types: 1) crude oil, probably produced on site, 2) crankcase oil, and 3) diesel fuel. In the 100 × 100-m grid which encompasses most of the "working" drill site (Fig. 30), diesel spills account for 26 m² of the 44 m² affected by hydrocarbons. When spent drum dumps and other disposal sites beyond the 100 × 100-m grid are examined, an additional

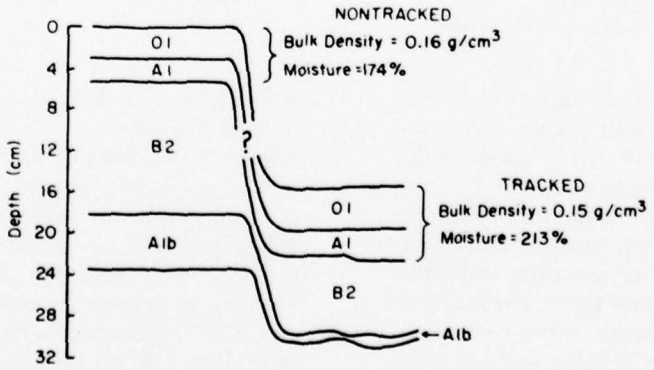


Figure 36. Schematic cross section of soil from track pictured in Figure 35.

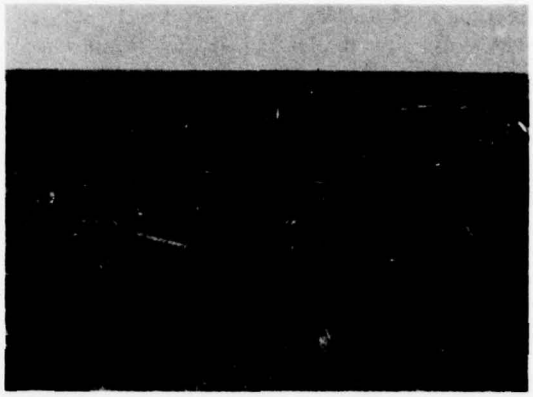


Figure 37. Hydrocarbon spills typical of main drill area at Fish Creek. Linear dark areas in foreground are crankcase spills. Area in near center ground is a diesel fuel spill.

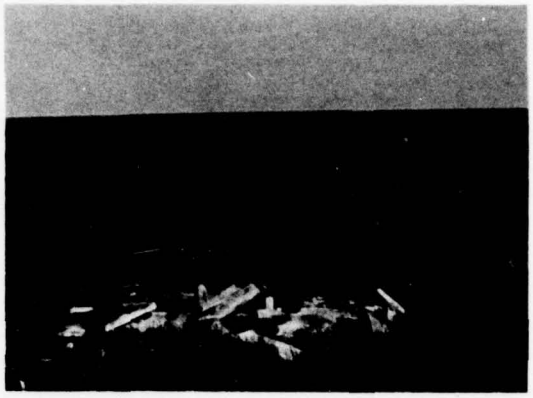


Figure 38. General aspect of 55-gal. drum dump areas peripheral to main drill site. Larger diesel fuel spills, up to 54 m², are associated with some drum piles.

Table III. Hydrocarbon contaminants (diesel fuel) from selected spills (1949) at Fish Creek site.*

Sample	Depth (cm)	Wt of soil extracted (g)	Wt of extract (g)	Extract (gram wt of soil)	Presence by gas chromatography	Color of extract
01	0-15	40.0	1.020	0.026	+ + +	orange
01	5-33	39.2	0.576	0.015	+ + +	orange
02	0-10	44.4	0.106	0.002	+	yellow
02	10-25	67.3	0.237	0.004	+ +	yellow
02	25-41	50.9	0.094	0.002	+ +	yellow
03	0-10	41.2	0.388	0.009	+ +	yellow
03	10-25	49.3	0.248	0.005	+ + +	orange
03	25-41	58.4	0.054	0.001	–	yellow

*Analyses performed by Alan Sexstone, University of Louisville, Louisville, Kentucky, November 1977.

All samples extracted for 4 hours with 250 ml diethyl ether in Soxhlett extractor.

+ + + heavy contamination
+ + contamination
+ some components present
– no resolvable components

area of approximately 112 m² is affected. Of this total, 100 m² is affected by diesel spills. The locations of hydrocarbon spills sampled for analysis are shown on Figure 6.

Most of the drill site spills are small (<10 m²) (Fig. 37). Those associated with drum dumps (Fig. 38) are larger; one of 50 m² was observed. Most of these spills are believed to be the result of leakage from the spent drums. A few spills, such as that pictured in Figure 20, apparently resulted from the decay of full or nearly full drums of crude oil. Some spills, such as that of Figure 11, probably occurred many years after abandonment of the site.

Most of the crude oil and crankcase spills, except in areas of heaviest impact, show some signs of significant vegetation recovery (some nearly complete). The areas of diesel spills, such as shown in Figure 19, show relatively little recovery of vegetation and significant depression of the permafrost beneath the spill. Soils in these areas still possess a strong odor of diesel fuel to depths of at least 40 cm. Thaw in some cases reached 70 cm, nearly twice the thaw in

adjacent unaffected areas. Eight samples from three diesel spill sites were collected and the ether extractable hydrocarbons were analyzed by gas chromotography; the results are summarized in Table III. These data, although incomplete, indicate that the refined fractions penetrate deeply and retain a toxic component for at least 28 years.

Summary

With respect to landform units, the soils of the Fish Creek site are generally comparable in morphology and site position to those of the Atkasook area. In both areas, the soils have developed in or on sandy textured mineral materials that are neutral to moderately alkaline in reaction. Near-surface organic horizons are slightly acidic. The Fish Creek soils have been tentatively placed within two taxonomic orders: Entisols (psamments, fluvents, and aquepts — the last two are provisional), and Inceptisols (aquepts and ochrepts). Soils representative of the order Histosols occur within the general area of the drill site but were not described because shallow drilling could not be done.

Disturbances associated with the test well drilling have resulted in complete destruction of soil morphology in some areas. Weak reestablishment of horizons has taken place in the last 28 years, especially in the better drained materials. Soils that were severely compressed during drilling operations still retain a compressed morphology. In a few instances, the scraping of organic horizons into mounds or ridges a meter or more in height resulted in increased drainage and oxidation of the organic materials. These soils have been placed in the humic subgroup of the aquepts.

The effects of the spilling of limited amounts of hydrocarbons, particularly diesel fuel, can still be detected within the affected soils.

FLORISTICS OF THE DISTURBANCES AND NEIGHBORING LOCALES

A.W. Johnson, B.M. Murray and D.F. Murray

Introduction

Plant succession in arctic areas is poorly understood for several reasons, among which are the relative inaccessibility of much of the landscape, the absence of large-scale and repeated disturbances such as fire and agriculture, the lack of long-term observations of permanent quadrats, and the lack of clearly defined groups of species characteristic of different stages in a sere. Some arctic investigators, starting with Griggs (1934), have pointed to the general weediness of the arctic flora as a basis for suggesting that the concepts of succession and climax may not apply to arctic areas in general, whereas others (e.g. Benninghoff 1963) have suggested that frost heaving prevents stability from occurring. Whether or not these generalizations have merit, the literature on plant succession in the Arctic is limited.

The Fish Creek drill site provides an opportunity to document plant succession on disturbed areas of known age. It is assumed that the Fish Creek site was undisturbed by man until it was occupied in early 1949 and that the period of disturbance was coincident with the relatively brief occupation of the site during 1949. Thus, the site can be used as an index of the natural recovery that can be expected in 28 years in regions with similar characteristics that suffer light to heavy disturbance.

Landscape changes in the Arctic can, for convenience, be categorized as follows:

1. Large-scale modifications which are related to major physiographic processes such as the draining of lakes, abandonment of stream channels and marine transgressions. The time scale involved here is of an order of magnitude of thousands of years for landscape change.

2. Medium-scale changes which result from erosion and deposition, and catastrophic events such as overgrazing, fires, floods, and soil/ice melting. The time scale involved for changes in the landscape at this scale is probably hundreds of years.

3. Small-scale changes which result from animal disturbance, annual frost heaving, plant senescence, vehicle passage, and other disturbance on a microtopographic scale. The time scale for recovery is probably measured in tens of years.

The impact of man on landscapes in the Arctic belongs mostly to types 2 and 3. Whether medium-scale or small-scale changes occur is probably based on the degree to which the equilibrium between the atmosphere and the soil/ice interface is upset. For example, if this equilibrium is seriously changed such that large-scale melting of ice occurs, a type 2 change will probably take place. Although artificial draining of lakes, modification of stream gradients, or alteration of drainage channels can set in motion type 1 changes in the Arctic, they are uncommonly set in motion by man.

Vascular plants

A total of 187 collections of vascular plants representing 158 taxa were made by D.F. Murray from the immediate vicinity of the Fish Creek Test Well 1, from the environs beyond the area of disturbance, and from two sites several kilometers apart on the bluffs of Fish Creek (Fig. 2). Appendix C lists taxa identified at these sites. These collections are now part of the permanent collection at the University of Alaska Herbarium.

Although our knowledge of the flora of the Arctic Coastal Plain is improving, maps of plant distribution prepared by Hultén (1968) show no information for the region southeast of Teshekpuk Lake. Some surrounding areas have been well collected: sites at Barrow, Meade River (Atkasook), Ikpikpuk River, Colville River and on the Colville River delta have been studied. Most of the taxa collected at Fish Creek in 1977 are quite expected and fall within the ranges outlined by Hultén. This collection fills a gap in our knowledge of the distribution of flora on the Arctic Coastal Plain.

This study also provides new information on the range of certain plant species. Minor northward extensions of range are recorded for *Carex vaginata, Potentilla hookeriana, Andromeda polifolia, Utricularia vulgaris,* and *Taraxacum phymatocarpum.* Significant extensions northward are recorded for *Carex atrofusca, C. marina, C. rupestris, C. williamsii, Betula nana, Arctous alpina, Empetrum nigrum, Vaccinium uliginosum,* and *Erigeron humilis. Puccinellia andersonii* is a poorly known taxon in Alaska, its determination is therefore tentative.

Bryophytes and lichens

Approximately 500 collections of bryophytes and lichens were made by B.M. Murray from the immediate vicinity and environs of Fish Creek Test Well 1 and from the sandy bluffs of Fish Creek a few kilometers to the south (Fig. 2). Most specimens were taken from the disturbed site. Appendix D lists the mosses and lichens collected at the Fish Creek site that have been identified. Some collections require further work or study by specialists, especially the moss families *Bryaceae* and *Mniaceae* and the genus *Dicranum.* Collection numbers follow the species name and are preceded by S if they came from the Fish Creek Test Well 1 site, by C if they were from the general area around the site, and by B if from the sandy bluffs of Fish Creek. Some species were collected at sites examined by A.W. Johnson, and these are indicated by the initials AWJ and the site number. Also, brief notes describe the habitats where each species was found. These collections, the first from the area, are housed in the University of Alaska Herbarium.

Specimens obtained from the immediate environs show that the flora of the Fish Creek site is similar to that of the surrounding undisturbed tundra. Only the frequency of occurrence and the abundance of species differ between disturbed and undisturbed sites. Mosses such as *Ceratodon purpureus, Leptobryum pyriforme, Psilopilum cavifolium* and gemmiferous *Pohlia* spp. were more abundant on the Fish Creek site than in the surrounding tundra.

Several unique substrates and habitats at the Fish Creek site support lichens and mosses but only a limited number of etiolated vascular plants. Moss mats, consisting primarily of *Pohlia* spp., *Bryum* spp. and a few hepatics that are shade-tolerant, occurred beneath piles of drums. This soil is enriched because the drum piles have obviously provided shelter for ptarmigan, microtines and foxes. Lumber, pilings, concrete pads, cement bags, rotting canvas, and airplane fabric provide substrates different from those of the natural environment. Most species of moss and lichen found on such materials also occur on soil, organics, or the bark of shrubs in the surrounding tundra. One lichen, *Cetraria orbata* (App. C), has previously been postulated as being adventive on felled utility poles on Amchitka Island (Weber et al. 1969). If this is true, then this lichen is probably the only adventive species at the Fish Creek site.

The following is a list of mosses and lichens found on the anomalous substrates that resulted from the operations at the Fish Creek site.

On weathered wood: *Campylium arcticum, C. stellatum, Ceratodon purpureus, Alectoria* sp., *Caloplaca* spp., *Cetraria orbata, C. pinastri, C. sepincola, Parmelia olivacea.*

On airplane fabric (moist): *Bryum* spp., *Ceratodon purpureus, Drepanocladus revolvens, D. uncinatus, Oncophorus wahlenbergii, Pohlia cruda, Tetraplodon paradoxus, Peltigera lepidophora.*

On rotting canvas: *Bryum* spp., *Calliergon giganteum, Campylium arcticum, Ceratodon purpureus, Drepanocladus uncinatus, Leptobryum pyriforme.*

On turf over the concrete pad and on cement bags: Anastrophyllum minutum, Bryoerythrophyllum recurvirostrum, Bryum sp., *Campylium stellatum, Ceratodon purpureus, Distichium capillaceum, Leptobryum pyriforme, Tortula ruralis.*

In drums in refuse piles: *Campylium stellatum, Leptobryum pyriforme, Caloplaca stillicidiorum.*

On bare soil containing spilled oil: *Bryum* sp., *Ceratodon purpureus, Leptobryum pyriforme.*

Description of disturbance and recovery

Disturbed areas thought to be more or less typical of the Fish Creek site were chosen subjectively by A.W. Johnson for analysis. The following information was recorded: 1) probable predisturbance vegetation, 2) nature of disturbance, 3) present species composition, and 4) present species cover. D.F. Murray and B.M. Murray also collected plants concurrently on the same sites. Photographs were taken of all sites, many of which appear in this report. The location of the disturbed sites is shown in Figure 6.

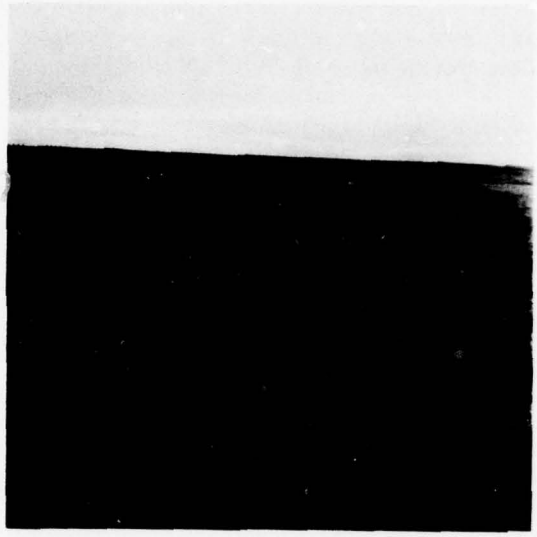


Figure 39. Bladed trail from the Fish Creek camp area to Camp Creek, 28 July 1977. Site 1, view east.

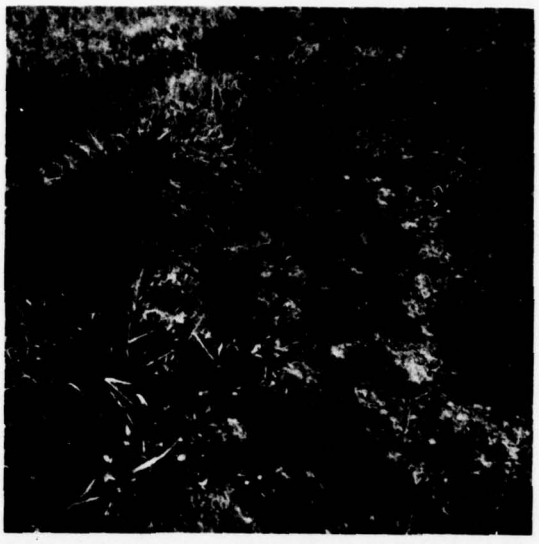


Figure 40. Turfy berm on the edge of trail shown in Figure 39.

Site 1. Trail from Camp Creek to Fish Creek drill site

This site is a trail that was run over many times by heavy tracked vehicles. The trail is about 1 m below the surrounding vegetation, which primarily consists of sedge tussocks on high-centered polygons (Fig. 39). The upper rim of the resulting trough or trench is typically covered with *Carex aquatilis* (75%), with smaller amounts (usually less than 5% each) of *Chrysosplenium tetrandrum, Cerastium beeringianum, Poa alpigena, Arctagrostis latifolia, Salix lanata* ssp. *richardsonii, Salix glauca, Juncus biglumis, Eutrema edwardsii, Bistorta plumosa, Cardamine digitata, Stellaria laeta, Astragalus alpinus* and *Juncus castaneus*. Rarely, tussocks of *Eriophorum vaginatum* had become established on these rims. Some of these tussocks have been invaded by *Vaccinium vitis-idaea*.

On the banks of the trough, an assemblage of plants adapted to somewhat drier conditions occurs (Fig. 40). On these sites, *Arctagrostis latifolia* dominates and is accompanied by *Salix lanata, Equisetum arvense, Carex aquatilis, Trisetum spicatum, Hierochloe alpina, Cerastium beeringianum, Papaver lapponicum, Salix phlebophylla, Oxytropis arctica, Bistorta plumosa, Bistorta vivipara, Saxifraga nelsoniana, Luzula arctica* and *Salix reticulata*. The sides of the trench are by no means uniform from place to place and considerable variation in the vegetation exists.

The bottom of the trail is wet except along the ridge bordering Camp Creek where it comes upon higher and drier ground. In a few places between this ridge and the Fish Creek drill site, the bottom of the trail contains plants typical of open standing water, such as *Utricularia vulgaris, Hippuris vulgaris, Ranunculus pallasii* and *Arctophila fulva*. On somewhat drier areas, *Eriophorum angustifolium* may form nearly pure stands covering up to 100% of the area. *Dupontia fisheri, Carex aquatilis, Saxifraga cernua, Draba lactea* and *Ranunculus gmelinii* occur in amounts of less than 5% each. Some areas with deep thermokarst subsidence and standing water contain no rooted emergent species.

Site 2. Trail from Camp Creek to Fish Creek drill site

At a point approximately 100 m west of the Fish Creek drill site, the trail goes through a lower, wetter, sedge meadow. In this area trail banks and bottoms are covered by almost pure stands of *Carex aquatilis* with lesser amounts of *Eriophorum angustifolium* and *Eutrema edwardsii*. Many open water areas occur in the bottom of the trail, and it is here that the true aquatic plants are most common (Fig. 41).

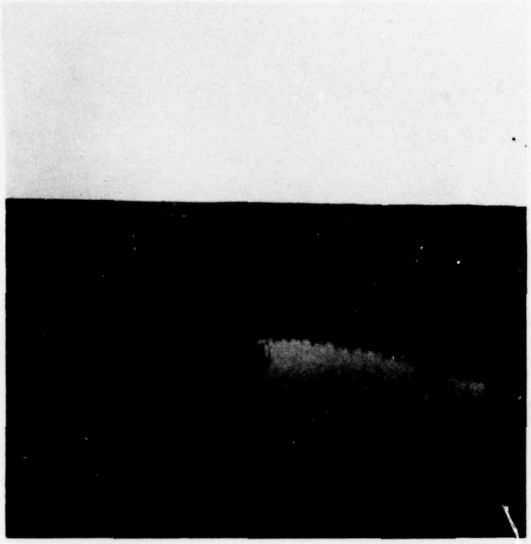


Figure 41. Thermokarst pond in bladed trail west of drill site occupied by almost pure stands of Carex aquatilis *with lesser amounts of* Eriophorum angustifolium *and* Eutrema edwardsii. *Site 2, view west.*

Figure 42. Base area at site 2 adjacent to trail of Figure 41 covered by a gray-white precipitate on the surface.

Occasionally bare areas occur on the upper rims of the depressed trail. Some of the bare spots appear to be due to a dense, tough, and fibrous organic mat which is inhospitable to the establishment of plants. Some of the bare areas have a gray-white precipitate (salts?) on the surface. *Cochlearia officinalis* is common (Fig. 42).

Site 3. Debris field

This site is divided into a small upland portion and a larger, lower area adjacent to it. On the lower portion, drums are scattered randomly, covering about 25% of the surface. Although holes were punched in most of the drums, it does not appear that petroleum products were spilled. Scattered boards, wooden barrels, and other primarily wooden debris cover about 10% of the surface of the upper part (Fig. 43). The lower portion was probably covered by *Eriophorum* tussock heath on high-centered polygons, but it has been almost entirely replaced by species characteristic of other plant communities. The upper portion may have been a small sand dune superimposed on high-centered polygon terrain, as it is now drier and supports plants adapted to dry conditions. The upper portion of site 3 is covered by *Arctagrostis latifolia* (50%), *Poa arctica* (30%), *Luzula arctica* 1%), *Stellaria laeta* (1%), *Eriophorum vaginatum* (1%), *Luzula wahlenbergii* (1%), *Luzula confusa* (1%), *Salix phlebophylla* (1%), *Salix rotundifolia* (1%), and scattered individuals of the following: *Bistorta plumosa, Senecio congestus, Deschampsia caespitosa, Senecio atropurpureus, Poa malacantha, Trisetum spicatum, Saxifraga nelsoniana* and *Hierochloe alpina* (Fig. 44). On the lower portion, the cover of *Arctagrostis latifolia* is reduced to 5%, while *Eriophorum vaginatum* (5%), *Luzula confusa* 10%), and *Carex bigelowii* (5%) are indicative of the wetter nature of the site. Other species which are present in trace amounts include *Poa arctica, Bistorta plumosa, Hierochloe alpina, Senecio atropurpureus, Luzula arctica, Saxifraga nelsoniana, Equisetum arvense, Stellaria laeta, Cassiope tetragona, Ledum decumbens, Vaccinium vitis-idaea* and *Saxifraga cernua*. Bare soil accounted for about 5% of the area.

The effects of the oil drums on the composition and vigor of certain species can be seen rather clearly in this site. In deep shade under drums, *Stellaria laeta* and *Saxifraga cernua* are common and often etiolated. Against the north sides of drums *Cassiope tetragona* is present, probably associated with the later melting of snow. *Ledum decumbens* and *Vaccinium vitis-idaea* grow only on the south sides of the drums. Against the flat drum ends, particularly those

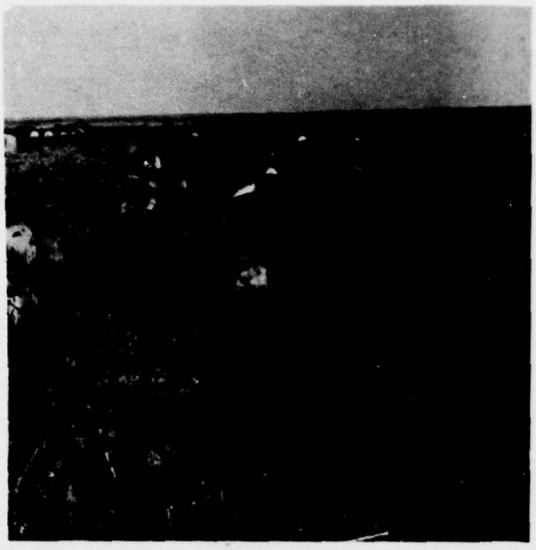


Figure 43. Debris field at site 3 covered by scattered drums, boards, etc.

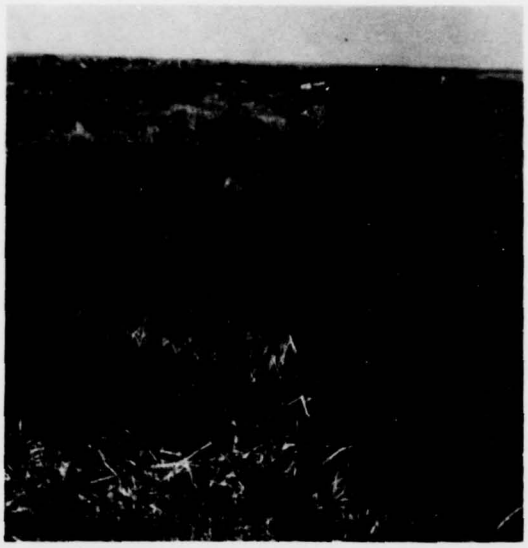


Figure 44. Site 3. Arctagrostis latifolia, Poa arctica, Luzula wahlenbergii, Luzula confusa, Salix phelobophylla and Salix rotundifolia dominate the upland part of this site.

facing west or southwest, *Salix glauca* and *S. pulchra* show vigorous, taller growth. Between drums, particularly those which are 1 m or less apart, bare soils can be seen, but where plants occur, they tend to be taller, etiolated, and somewhat "behind" in their phenology from those not under the influence of the drums.

Site 4. Drum field

Site 4 is covered by 91 steel drums scattered over an area of about 10,000 m^2. A few small groups of drums are present. In addition to the drums, the area has served as a general dumping ground for cans, bottles and wooden objects, most of which are scattered throughout the area. It is probable in this case that the drums were used as collectors of the refuse, hauled to this site, and the material they contained dumped. This site is an area of high-centered polygons which were not badly disturbed during the dumping activity. The general character of the vegetation has probably not changed since the camp was occupied. Around a few of the drums, bare areas occur, possibly due to spills of diesel oil. The plants now growing on the site are those normally associated with high-centered polygons, species that do well on disturbed soils are not abundant.

This site is interesting in that many of the cans, bottles, and wooden objects have been nearly overwhelmed by plant growth (Fig. 45). In general, it appears that from 25 to 75 mm of vertical growth has occurred since 1949. The disturbance in this case was probably relatively light.

Site 5. Drum field

Site 5 includes a compact stack of about 100 drums piled haphazardly two or three high in the center (Fig. 46). The drums were placed on a high-centered polygon which probably included the typical tussock-heath vegetation on the center and wetter vegetation dominated by *Carex aquatilis* and *Eriophorum vaginatum* in the troughs. West of the edge of the stack, for a distance of about 2 m, the vegetation is dominated by *Arctagrostis latifolia, Luzula arctica, Luzula confusa* and *Poa arctica*. The cover of these species is complete. Plants near the drums show a "luxuriance effect," probably because of infrared radiation reflected from the drums and reduced wind effects (Fig. 47). As noted in many other sites, willows, primarily *Salix pulchra*, and dwarf birches (*Betula nana*) may grow as tall as 1 m against the ends of the drums. *Saxifraga cernua* and *S. nelsoniana* are common between and under the shaded edges

Figure 45. Coke bottle nearly overwhelmed by vegetation at site 4.

Figure 46. Pile of about 100 drums, two to three high in the center, on high-centered polygon at site 5.

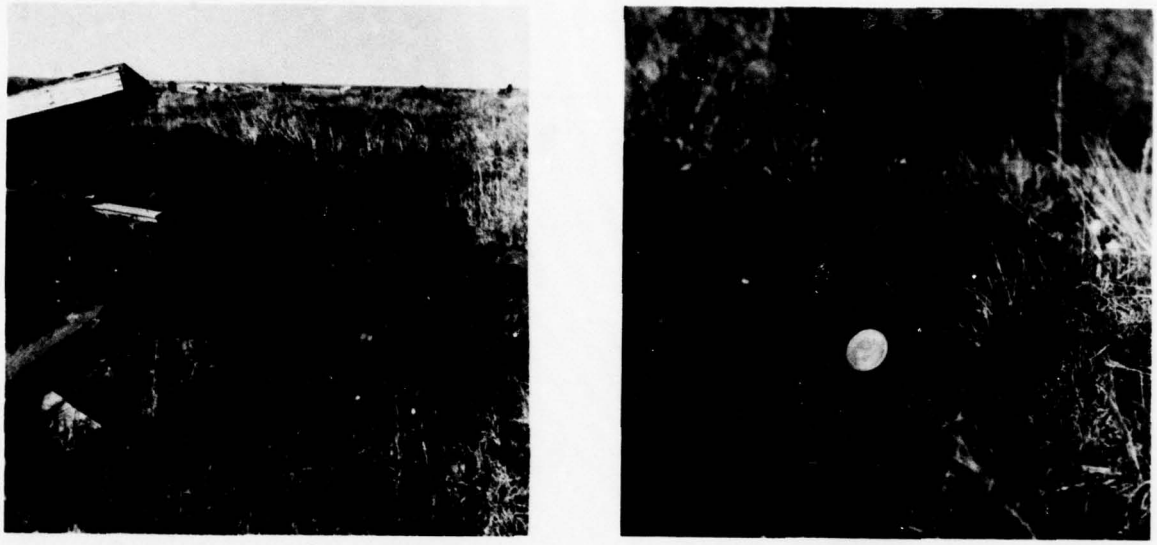
Figure 47. "Luxuriance effect" of drums resulting in increased plant growth at site 5.

Figure 48. Elongate stack of drums in two rows at site 6.

of drums. It is probable that a strong fertilizer effect occurs around the drums because rodents and their predators commonly use these areas for cover.

Site 6. Drum field

This site includes an elongate stack of drums which have been piled in two rows and up to four drums high, with a total of about 120 to 150 drums in the stack (Fig. 48). The predisturbance vegetation was probably sedge tussock heath on high-centered polygons. The drums lie across two troughs which are still occupied by *Carex aquatilis* and *Eriophorum angustifolium*. East of the drums, plant cover is complete, with the following species noted: *Eriophorum vaginatum* (10%), *Carex aquatilis* (40%), *Arctagrostis latifolia* (10%), *Salix pulchra* (10%), *Eriophorum*



a. General view showing absence of vegetation and well-defined spill margin.

b. Closeup of spill margin showing rapid loss of vegetation. Coin for scale.

Figure 49. Diesel fuel spill on sandy substrate at site 7.

scheuchzeri (1%), *Carex bigelowii* (5%) and traces of *Saxifraga nelsoniana, Eutrema edwardsii, Saxifraga hirculis, Poa arctica, Luzula arctica, Eriophorum angustifolium* and *Saxifraga cernua*. On the west side of the drums, the same mixture of species occurs with the major difference being that *Arctagrostis latifolia* dominates the vegetation close to the drums. The luxuriance effect previously mentioned was observed here, particularly on the west side of the drums.

Site 7. Diesel fuel spill

This small area, measuring about 9 m^2, is an apparent diesel fuel spill on a sandy substrate (Fig. 49a) with a noticeable smell of oil. The plant cover of about 5% consists of *Arctagrostis latifolia, Dupontia fisheri, Poa arctica, Carex aquatilis* and a single-headed *Eriophorum (E. scheuchzeri?)*. The *C. aquatilis* shows a transition from upright plants at the edge of the spill to stunted and contorted plants on the spill (Fig. 49b). Plants both on and off the spill were in flower.

Site 8. Diesel fuel spill

This apparent fuel spill measures about 16 m^2. Plant cover is about 15% with the following species recorded: *Arctagrostis latifolia* (5%), *Eriophorum scheuchzeri* (5%), *Poa arctica* (3%), *Festuca brachyphylla* (2%) and traces of *Luzula confusa, Eriophorum angustifolium, Carex aquatilis* and *Eriophorum vaginatum* (Fig. 50).

Site 9. Drum field

This area was located on a small high-centered polygon between two small lakes (Fig. 51). Wood and metal debris covered about 20% of the area, but apart from the physical presence of the debris, not much damage was done to the vegetation. Plant cover included *Eriophorum vaginatum* (40%), *Ledum decumbens* (25%), *Carex bigelowii* (5%), *Salix pulchra* (5%), and traces of *Luzula confusa, Senecio atropurpureus, Betula nana, Pedicularis langsdorffii* and *Stellaria laeta*. Moss cover devoid of higher plants was about 5%.

Site 10. Drum field

Site 10 is located on a small low-centered polygon. Eight oil drums are scattered over the area and damage is light (Fig. 52). The polygon ridges are covered by *Eriophorum vaginatum* (30%), *Ledum decumbens* (10%), *Vaccinium vitis-idaea* (1%), *Carex bigelowii* (20%), and *Betula nana* (5%). Traces of *Cassiope tetragona, Senecio atropurpureus* and *Empetrum nigrum* are also present. The polygon centers are dominated by *Carex aquatilis* (80%), and *Eriophorum angustifolium* (20%), *Andromeda polifolia, Juncus biglumis, Pedicularis langsdorffii* and *Salix*

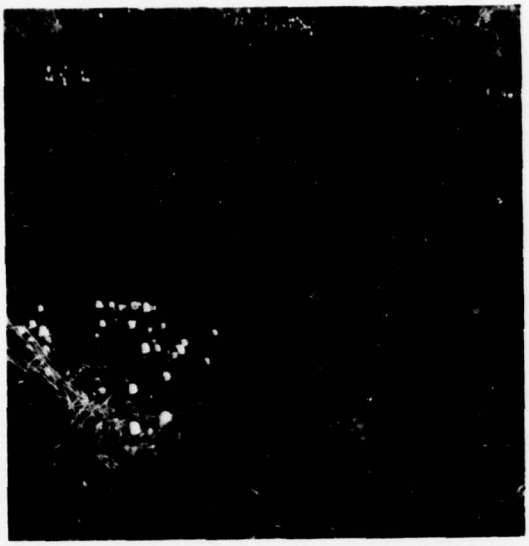


Figure 50. Diesel fuel spill at site 8 with Eriophorum scheuchzeri *and* Arctagrostis latifolia *cover of about 10%.*

Figure 51. Scattered drums on high-centered polygon between two small lakes at site 9. Little damage occurred to the vegetation here. View east.

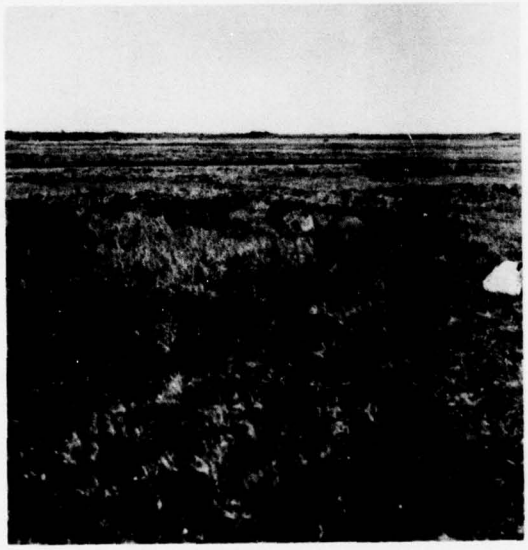


Figure 52. Scattered drums on low-centered polygon where damage was minimal, site 10.

Figure 53. Widely scattered drums on low-centered polygons with little effect on vegetation, site 11.

reticulata occur in trace amounts. *Chrysosplenium tetrandrum* was found in one oil drum.

Site 11. Drum field

This area of low-centered polygons is covered by 65 drums scattered in the centers of the polygons (Fig. 53). Except for the physical presence of the drums, no effects on the composition of the vegetation were observed, except as follows. Near two drums a hydrocarbon-soaked area occurs in what had apparently been *Carex aquatilis* meadow. No plants are growing there today (Fig. 54). A strong odor of oil, probably diesel fuel, is present in the soil.

Figure 54. Hydrocarbon spill, probably diesel fuel, located in area formerly occupied by Carex aquatilis *at site 11.*

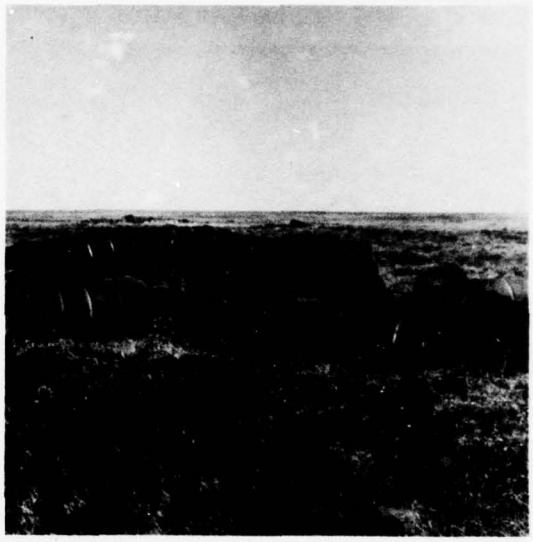


Figure 55. Site 12 consists of partly collapsed stack of barrels. Vegetation cover is only 20% on the north side of the drums.

Figure 56. South side of drums at site 12 with complete vegetation cover, including Salix pulchra.

Figure 57. Drums on low-centered polygons with increased wet meadow species between them, site 13, view north.

Site 12. Drum field

This site includes 49 drums arranged east-west in two rows, with scattered drums around the rows (Fig. 55). The vegetation had been typical sedge tussock heath on high-centered polygons. A pronounced north-south effect is seen here; the north side of the drums exhibits no more than 20% cover by vascular plants, but the rest of the area is covered by mosses and hepatics. The vascular plants include *Arctagrostis latifolia, Saxifraga nelsoniana* and *Eutrema edwardsii*. On the south side of the drums, the cover consists entirely of vascular plants, which include *Salix pulchra* (Fig. 56), *Carex aquatilis, Eriophorum angustifolium, Saxifraga cernua, Saxifraga nelsoniana* and *Poa arctica*. No evidence of spilled oil was seen.

Figure 58. Low-centered polygon area where growth is suppressed, apparently due to oil spillage, at site 14. Carex aquatilis *on margins of "spill."*

Site 13. Drum field

Sixty-two drums are located in an area of low-centered polygons, primarily on the polygon ridges. The only noticeable effect of these drums is that of a slight increase in wet meadow species between and around them (Fig. 57). Drums placed closely together generally suppress the growth of all plants.

Site 14. Drum field

This site consists of a large low-centered polygon partially covered by 29 oil drums. The vegetation of the low centers is primarily (80%) composed of *Carex aquatilis* and a single-headed *Eriophorum (russeolum?).* Apparently, oil leaked from the drums subsequent to their being placed in the polygon, because the plants around the drums are suppressed and the surface has an oil-soaked appearance (Fig. 58). Plant cover has been reduced to less than 10% around the southern group of 7 drums, and to about 50% around the northern group of 22 drums.

Discussion and conclusions

During the relatively short time that the Fish Creek drill site was occupied, considerable disturbance, due primarily to vehicular traffic, occurred to the plant communities of the area. The physical disturbance resulting from construction and occupation of the Fish Creek site spanned a broad spectrum of vegetation impacts ranging from complete and permanent disruption to relatively minor effects. For example, many of the vehicle tracks still evident have not broken the surface of the organic mat and, apart from constituting scars visible primarily from the air, apparently did not change the vegetation significantly. Where vehicular traffic was concentrated, however, compression of the vegetation and soil, melting of buried ice, thermokarst subsidence, and thermal and mechanical erosion substantially interrupted the otherwise continuous vegetation cover. In addition to these effects, spills of various petroleum products have had serious and long-lasting inhibiting influences on the vegetation (K.R. Everett, this report).

A generalization that emerges from most studies of arctic plant ecology is that, within discrete areas, species distributions reflect a moisture gradient. Relatively little evidence is available from the Arctic that suggests the occurrence of "conditioning" changes of soils, which Crocker and Major (1955) demonstrated at Glacier Bay for succession on recently exposed substrates. It should be noted that little effort has been directed at this problem in the Arctic. Although it has been shown that *Vaccinium vitis-idaea* and *Ledum decumbens* grow from the tops and sides of *Eriophorum vaginatum* tussocks, for example, neither of these shrubby species requires *E. vaginatum.* The relationship is probably an indirect one in which the latter creates a moisture regime favored by the shrubs. At least among the higher plants, little evidence suggests direct relationships among the species. An exception is the probable hemiparasite status of some species in the genus *Pedicularis.* Thus, nearly any species from the vascular flora finds newly exposed soils within its growth requirements, if the moisture characteristics of the site are also within its tolerances.

Despite this observation, however, it is evident from the Fish Creek study that invasion of species on bare substrates is not a random phenomenon. Certain species are repeatedly seen as pioneers in these areas. On wet substrates at Fish Creek, *Eriophorum vaginatum, Saxifraga cernua, S. nelsoniana, Juncus castaneus, J. biglumis, Draba lactea, Alopecurus alpinus, Stellaria laeta, Eriophorum angustifolium, Carex aquatilis* and *Eutrema edwardsii* are frequent invaders. On drier substrates *Arctagrostis latifolia, Poa arctica, Hierochloe alpina, Luzula arctica, L. confusa, L.*

wahlenbergii and *Trisetum spicatum* soon dominate disturbed soils. On the other hand, most shrubby species such as *Vaccinium* spp., *Ledum decumbens, Cassiope tetragona, Betula nana* and *Salix* ssp. are rarely seen as pioneers.

Why some species in the Arctic play a pioneer role and others do not probably relates to their reproductive and dispersal capacities. The species listed above are either those that seed heavily or have superior vegetative reproductive systems. The rushes are, in general, examples of the former and the sedges of the latter. All pioneer species are members of mature vegetation assemblages; indeed some, like *Eriophorum augustifolium, E. vaginatum* and *Carex aquatilis,* dominate the vegetation over large parts of the Arctic. Others, like various species of *Draba, Saxifraga* and *Luzula*, are relatively inconspicuous in the mature vegetation and become abundant only when disturbance allows their temporary ascendancy. Such fluctuating abundance suggests different competitive abilities among these species.

This discussion does not consider the role in succession of hepatics, mosses, and lichens. The observations by B.M. Murray on these groups suggest the importance of different species among them as pioneers on anthropogenic habitats, as well as their roles in more mature vegetation.

The observations on plant succession at Fish Creek support the following tentative conclusions:

1. The most intense (type 2) disturbance has significantly changed predisturbance vegetation both quantitatively and qualitatively. In those cases where moisture relationships have been substantially altered, the sites have been recolonized by species different from those believed to have characterized the predisturbance vegetation. Where chemical pollution of the site occurred, or on dry sites, the vegetation has been slow to recover, either because of toxic effects or because moisture relationships of the soils have been modified.

2. Less intense (type 3) disturbances have been substantially ameliorated in the 28 years of recovery. In most cases, simple removal of drums, wood and other objects would enable more or less complete recovery of the disturbed areas.

3. Invasion of disturbed sites is primarily by those species which have a high reproductive and dispersal capacity, either by seeds or other vegetative propagules.

4. Plants that behave as pioneer species on disturbed areas of the Fish Creek site belong to the mature vegetation; some of them become temporarily more abundant on disturbed sites than usual in more mature habitats. Although a group of often-encountered opportunistic species occurs, it is not clearly segregated from the species dominating the mature vegetation.

GEOBOTANICAL MAPPING, VEGETATION DISTURBANCE AND RECOVERY

V. Komárková and P.J. Webber

Introduction

Preliminary geobotanical investigations provide a test for hypotheses and methods arising from investigations at Atkasook (Komárková and Webber 1977) and along the Haul Road (Batzli and Brown 1976, Brown and Berg 1977). The Fish Creek area was found to be similar, floristically and vegetationally, to the Meade River area near Atkasook, Alaska, enabling review and utilization of the mapping vegetation units developed there. The Meade River flora belongs to Young's zone 3 or is perhaps transitional between his zone 3 and 4 (Young 1971, Komárková and Webber 1977); the flora in the Fish Creek area belongs to the arctic floristic zone 3 of Young. A qualitative comparison of similar habitats in the Meade River and Fish Creek areas indicates that the composition of these two floras is almost identical — of the 106 vascular plants identified in the Fish Creek relevés, only four do not occur at Meade River. Both areas belong to the low arctic tundra subzone of Alexandrova (1970), and although landforms and vegetation types are similar, they appear to be somewhat less distinctly differentiated at Fish Creek than at Meade River. This lack of distinction may reflect different overall age and surface history in these two areas. It is interesting to note that the flora and vegetation of the Meade River area extend this far east. Based on our experience along the Yukon River-Prudhoe Bay haul road, it seems probable that this vegetation and landform-substrate complex disappears just east of the Fish Creek, west of the Colville River.

Methods

The response and recovery of vegetation to the original disturbance at the Fish Creek site was studied by comparing the predisturbance and present vegetation status. A predisturbance vegetation map of the site was based on 1948 black and white aerial photography. A map of the present site status was based on the 1977 black and white aerial photography and on our field survey. The vegetation present at the site and in the immediate vicinity was mapped onto recent aerial photographs while in the field. Subsequently, this field map was compared with the predisturbance aerial photographs. It was concluded that no observable changes in the distribution of the mapping units occurred in the area of undisturbed vegetation surrounding the test well site between 1948 and the time of our field survey. Our field notes were transferred onto the predisturbance photograph, and the map was then extended into the undisturbed area.

The present vegetation mapping units were developed by the authors for the Meade River area near Atkasook during the Research on Arctic Tundra Environments (RATE) project (Batzli and Brown 1976). Most of the units employed at the Fish Creek site appear on a small-scale (1:20,000) Atkasook vegetation map, while some units from a large-scale (1:6,600) Atkasook vegetation map are also included. Descriptions of each mapping unit, the mapping method, and the mapping unit naming procedure will appear along with these two Atkasook maps (Komárková and Webber, in prep.).

In general, the present mapping method corresponds to Kuchler's comprehensive method of vegetation mapping (Kuchler 1967). A combination of floristical and physiognomical delimitation of the mapping units was employed. The mapping units 3, 4 and 7 represent vegetation complexes associated with low-centered polygons, high-centered polygons, and strangmoors.

The vegetation was described according to the Braun-Blanquet method of vegetation analysis (Westhoff and Van der Maarel 1973). Any vegetation sample, or relevé, consists of a cover estimate for each plant taxon present in a subjectively selected, uniform vegetation stand. A representative relevé illustrates the plant composition of each mapping unit and its environment. More relevés are used when a mapping unit consists of several distinct vegetation types.

Table IV. Key to vegetation mapping units.

Descriptions	
I. a Water bodies, may have sparse emergent vegetation	Mapping unit 9
b Terrestrial surfaces with noticeable vegetation cover	II
II. a High center polygons present	Mapping unit 3
b Low center polygons present	Mapping unit 4
c None of these landforms present	III
III. a Lichens abundant	IV
b Lichens rare	V
IV. a Evergreen dwarf scrubs and lichens dominant	Mapping unit 1
b *Eriophorum vaginatum* ssp. *spissum* tussocks dominant	Mapping unit 2
V. a Grasses abundant	Mapping unit 10
b Grasses rare	VI
VI. a Vegetation of habitats with high moisture, bryophytes usually abundant	VII
b Vegetation of snowpatch habitats, bryophytes rarely abundant	Mapping unit 5
VII. a Shrubs and sedges dominant, amount of moisture lower	Mapping unit 6
b Shrubs subordinate, amount of moisture higher	VIII
VIII. a Marshes with elevated "strings"	Mapping unit 7
b Marshes without elevated "strings"	Mapping unit 8

The nomenclature of vascular plants follows Löve and Löve (1975) in the majority of cases. In Appendix E, well-known synonyms (Hultén 1968) are given in parentheses.

Description of mapping units

The key presented in Table IV serves to distinguish between the various mapping units. A description of each mapping unit, which includes the environmental and landform setting of the units, their relative cover and a comparison with the Meade River units, follows. The plant composition of relevés representative of the mapping units is detailed in Appendix E and selected environmental variables are given in Appendix F. The maps of vegetation of the Fish Creek site in 1948 and 1977 are presented in Figures 59 and 60.

Mapping unit 1 — evergreen dwarf scrub, ridge

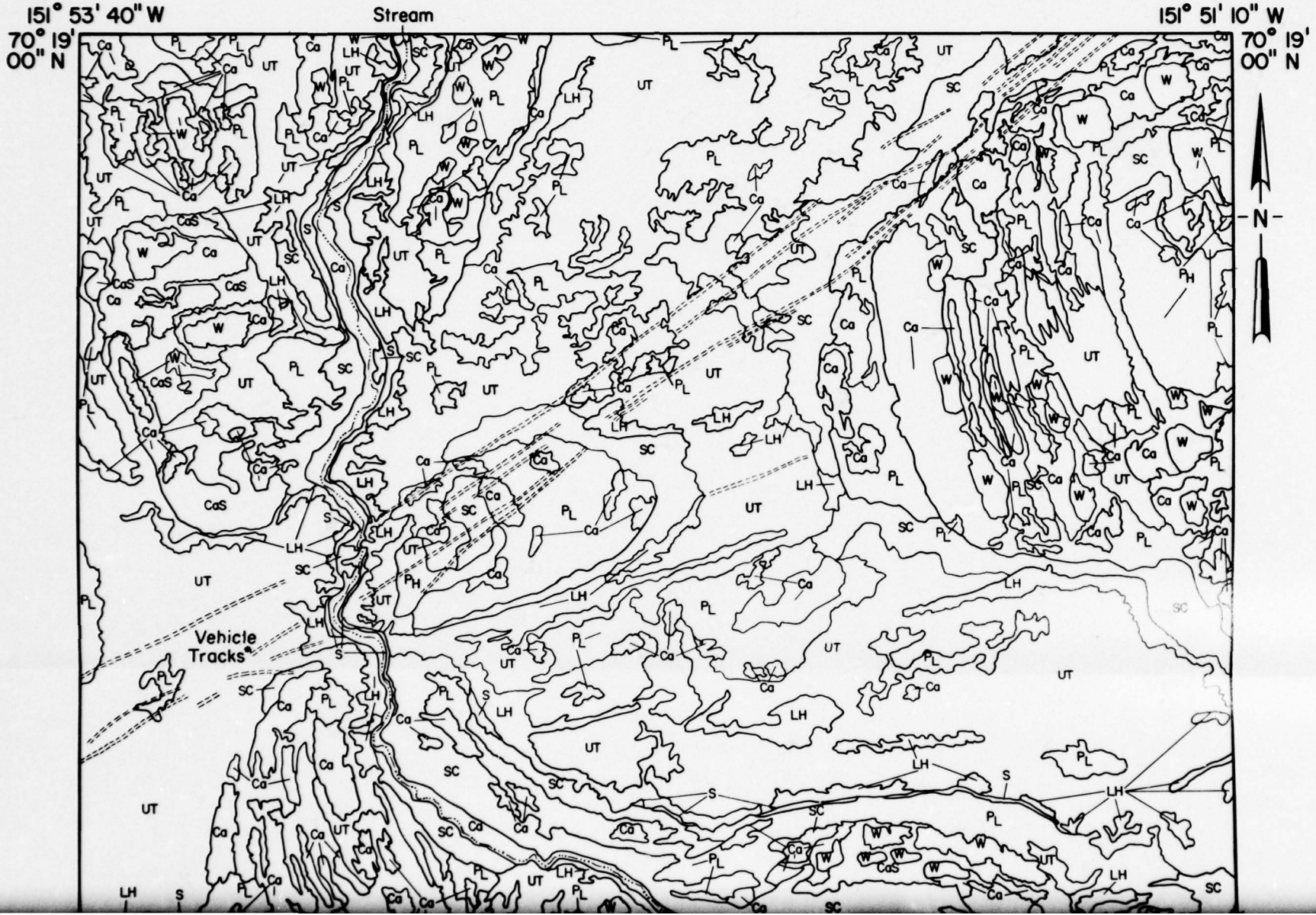
The vegetation cover of these communities is mainly composed of evergreen dwarf scrubs and lichens. They are found on elevated, generally xeric ridges and bluffs that surround former and present lake basins and streambeds. Two distinct vegetation types can be distinguished within this mapping unit (fewer than in the Meade River, Atkasook area): a xerophilous *Dryas integrifolia* ssp. *integrifolia*-dominated community (relevé 6) and a hummocky community dominated by *Cassiope tetragona* ssp. *tetragona*, *Salix phlebophylla*, and *Dryas integrifolia* ssp. *integrifolia* (relevé 9). These communities intergrade with those of mapping unit 2 in many places. The extent of mapping unit 1 communities in the Fish Creek area is limited. Additional habitats occupied by this mapping unit in the Meade River area, which are not present at Fish Creek, include stabilized dunes.

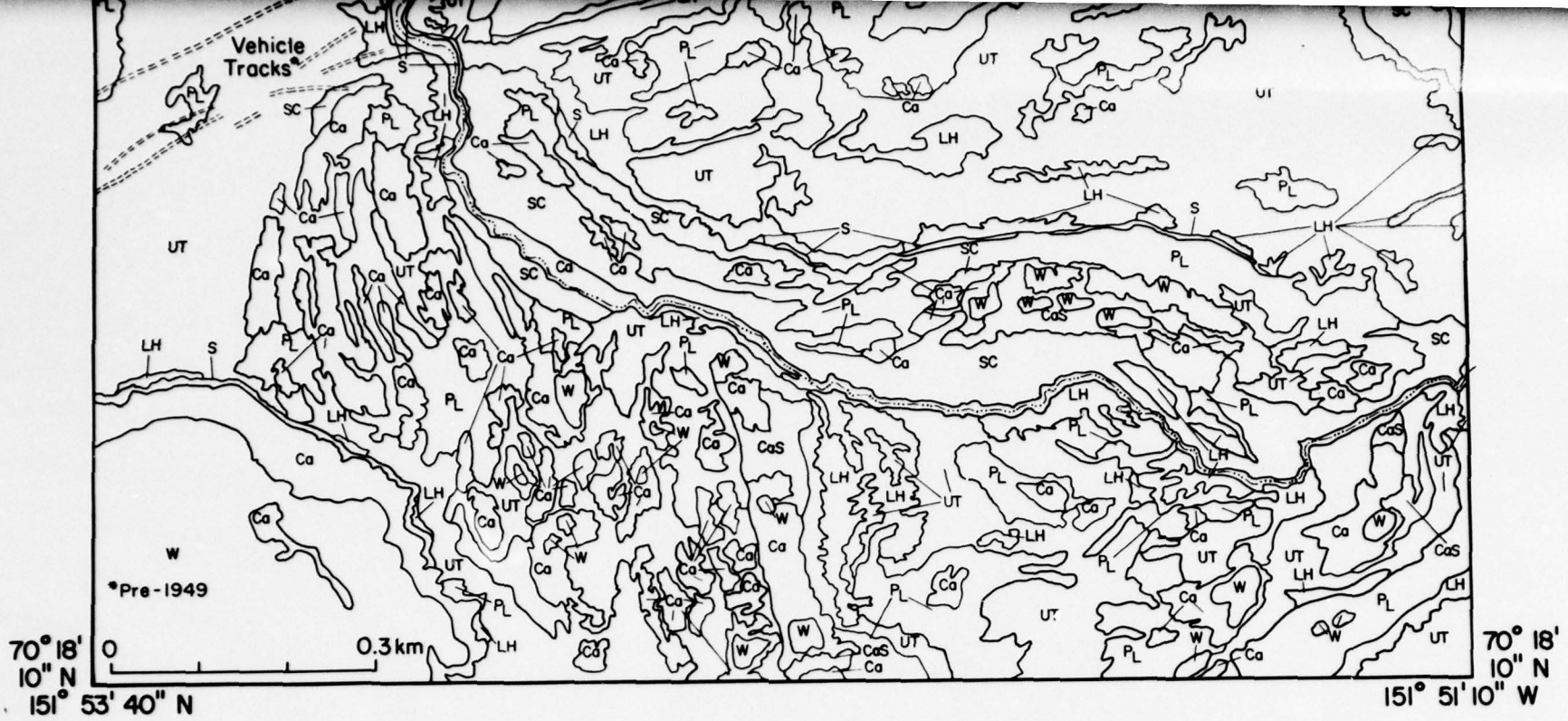
Mapping unit 2 — seasonal short grass, upland

This mapping unit has a considerably more uniform plant composition throughout the study area than other Fish Creek mapping units. Tussocks formed by *Eriophorum vaginatum* ssp. *spissum* are the most conspicuous feature of these communities (Fig. 61) which cover large areas on flat, well-drained surfaces at Meade River and at Fish Creek. Lichens reach high cover among the *Eriophorum* tussocks. Along with *Carex aquatilis* marshes, this mapping unit covers a large percentage of the Fish Creek site.

Mapping unit 3 — vegetation complex, high-centered polygon

This mapping unit is defined by the presence of high-centered polygon landforms, which at Fish Creek are found on elevated features in the center of drained lake basins or drainage areas. For example, an icing mound in the northeast corner of the predisturbance vegetation map (Fig. 59) is covered by high-centered polygons. A few high-centered polygons also occur along creekbanks. Vegetation on high-centered polygons is composed of approximately 85% upland tundra (mapping unit 2) communities on polygon rims and centers, and 15% marsh (mapping unit 8) communities in the troughs. High


151° 53' 40" W
70° 19' 00" N
Stream
151° 51' 10" W
70° 19' 00" N
N
Vehicle Tracks
UT
SC
LH
PL
Ca
W
S
CaS
PH



LH Evergreen dwarf scrub, ridge

UT Seasonal short grass, upland

P_H Vegetation complex, high-centered polygon

P_L Vegetation complex, low-centered polygon

S Evergreen and deciduous dwarf scrub, snowpatch

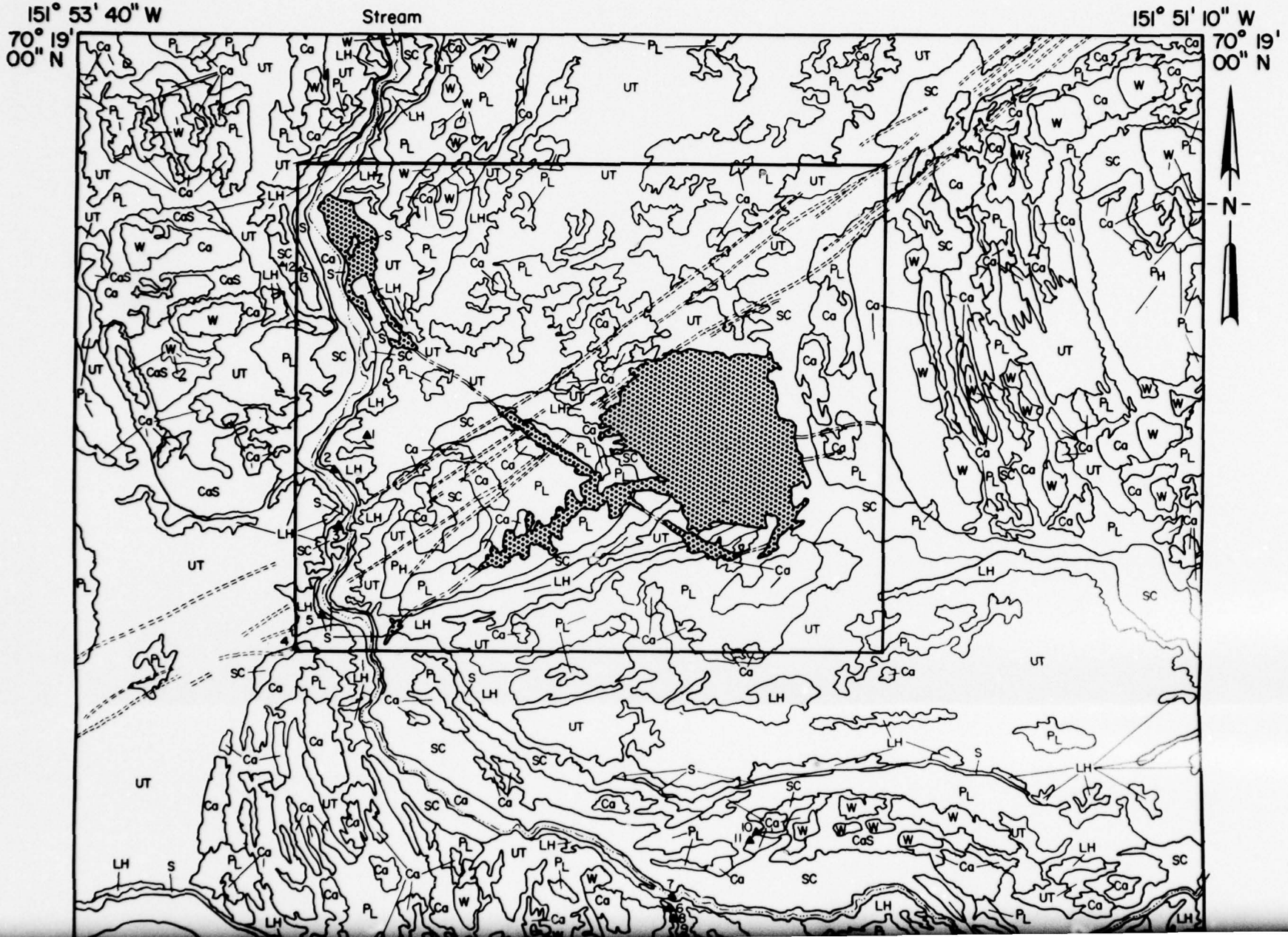
SC Deciduous shrub savanna, lowland

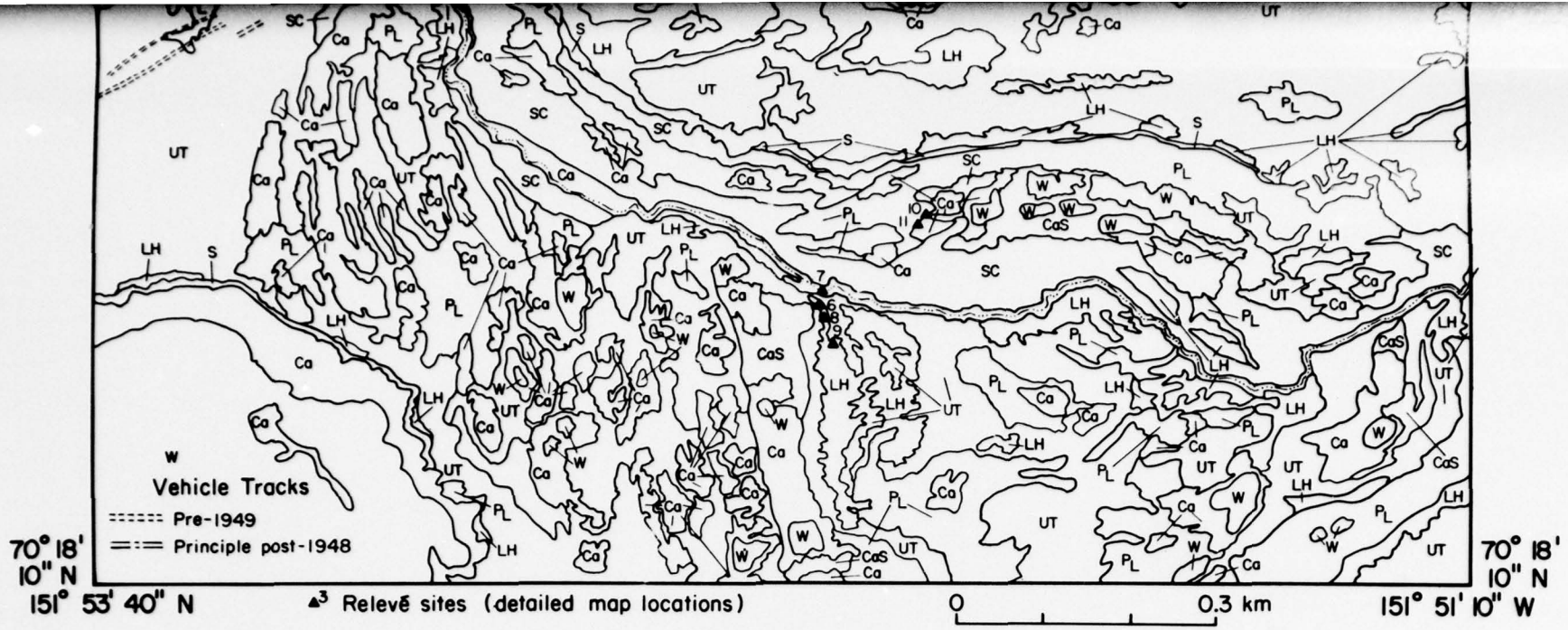
CaS Deciduous shrub savanna, stränge in strangmoor

Ca Seasonal short grass, marsh

W Water

Figure 59. Predisturbance vegetation of the Fish Creek test well site, 1948. Mapping units are described in Table IV.


151° 53' 40" W
Stream
151° 51' 10" W
70° 19' 00" N
70° 19' 00" N
N



LH Evergreen dwarf scrub, ridge

UT Seasonal short grass, upland

P_H Vegetation complex, high-centered polygon

P_L Vegetation complex, low-centered polygon

S Evergreen and deciduous dwarf scrub, snowpatch

SC Deciduous shrub savanna, lowland

CaS Deciduous shrub savanna, stränge in strangmoor

Ca Seasonal short grass, marsh

W Water

Man-disturbed ground

Figure 60. Vegetation of the Fish Creek test well site, August, 1977. Mapping units are described in text.

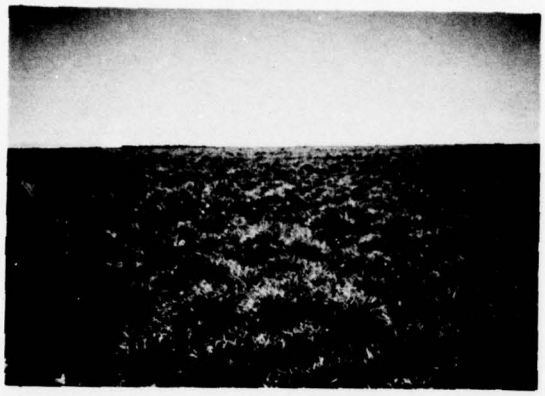


Figure 61. Mapping unit 2, one of the most extensive, includes areas dominated by Eriophorum vaginatum *ssp.* spissum *tussocks.*

Figure 62. Low-centered polygons are common; these landforms usually support upland tundra on rims and Carex aquatilis *marsh in centers and troughs (mapping unit 4).*

center polygons are similar in vegetation composition and limited in extent at both Fish Creek and Meade River.

Mapping unit 4 — vegetation complex, low-centered polygon

Like the preceding mapping unit, this unit is defined by the presence of a landform, in this case, low-centered polygons (Fig. 62). The mosaic of vegetation types supported by low-centered polygons usually consists of about 75% marsh (mapping unit 8) communities in polygon centers and troughs, and 25% upland tundra (mapping unit 2) communities on elevated polygon rims. Occasionally in habitats with a large amount of moisture, vegetation of mapping unit 6 occurs on the rims. Low center polygons are distributed in a variety of flat, hygric habitats both in drained lake basins and uplands. At Fish Creek and Meade River, this mapping unit covers a large percentage of the mapping area.

Mapping unit 5 — evergreen dwarf scrubs, deciduous dwarf scrub, snowpatch

Snowpatches are small in areal extent in the low arctic landscape of Meade River and Fish Creek. However, arctic snowpatches support several distinct vegetation types, probably as the result of the steep environmental gradient of the duration of snow cover. Two snowpatch communities which are most important at Fish Creek include a community dominated by *Salix rotundifolia* (relevé 2, Fig. 63) which occurs in the longer-lasting snowpatches and a community dominated by *Cassiope tetragona* ssp. *tetragona* (relevé 5, Fig. 64). Snowpatch communities are found frequently on inclined streambanks and on the lee side of elevated ridges and bluffs.

Mapping unit 6 — deciduous shrub savanna, lowland

This mapping unit occupies lowland areas that may be polygonized. The stands are usually dominated by *Salix pulchra* and *Carex aquatilis* spp. *stans* (relevé 4, Fig. 65), but stands with *Salix lanata* ssp. *richardsonii* and *Carex bigelowii* ssp. *bigelowii* (relevé 13) are also common. At Meade River and Fish Creek this mapping unit is relatively large in extent. With respect to the disturbance at Fish Creek, it appears that communities with *Salix pulchra* and *Carex aquatilis* ssp. *stans* develop or replace partially destroyed communities on disturbed surfaces if the moisture increased as the result of disturbance. Some of the communities in this unit near the test well site may be secondary.

Figure 63. Salix rotundifolia-dominated snowpatch vegetation occurs in the lee of elevated ridges, bluffs, and streambanks (mapping unit 5).

Figure 64. Cassiope tetragona ssp. tetragona-dominated communities are found in snowpatches with shorter duration of snow cover than the Salix rotundifolia communities (mapping unit 5).

Figure 65. Subhygric communities dominated by Salix and Carex taxa (mapping unit 6) occupy less well-drained sites than mapping unit 2 both on flat upland surfaces and in drained lake basins.

Mapping unit 7 — vegetation complex, strangmoor

Strangmoors develop in poorly drained habitats around lakes and in drained lake basins. Their vegetation is usually composed of two different communities. *Carex aquatilis* marsh (mapping unit 8) covers most of the surface of a strangmoor (85%), whereas the elevated "strings" of these bogs support a community dominated by *Salix pulchra, Carex aquatilis* ssp. *stans,* and *Sphagnum* ssp. (15% of the surface, relevé 10). Strangmoors cover a small percentage of the area at Fish Creek and at Meade River.

Mapping unit 8 — seasonal short grass, marsh

These communities are found in the shallow marshes of polygon centers and troughs, of high-centered polygon troughs, on lake edges, and along streams. Their plant composition varies with the moisture and nutrient status of the marshes. Several distinct vegetation types

Figure 66. Carex aquatilis *ssp. stans-dominated marshes (mapping unit 8) are common along streams, on lake edges, in low-centered polygon centers, and in high-centered polygon troughs.*

Figure 67. Salix rotundifolia *is the most important plant in the vegetation occupying disturbed snowpatch sites at Fish Creek, but few other plants associated with natural snowpatch vegetation are present.*

are recognized, the three vegetation types represented here are: the most common *Carex aquatilis* ssp. *stans*-dominated community (Fig. 66), which occurs in polygon centers and on lake margins (relevé 11), the *Carex aquatilis* ssp. *stans*-dominated streamside community (relevé 3), and the relatively rare *Juncus* and *Carex* taxa-dominated marsh community (relevé 12). Mapping unit 8 covers a high percentage of the area of Fish Creek and Meade River.

Mapping unit 9 — water

The water mapped in the Fish Creek area belongs to lakes and ponds; the streams are too narrow to be mapped at this scale. *Arctophila fulva* occurs in shallow water in some of the lakes.

Mapping unit 10 — seasonal short grass, deciduous dwarf scrubs, man-disturbed ground

This mapping unit represents all disturbance-associated vegetation in the study area. The subordinated types and successional stages distinguished within this vegetation are too small in extent to be mapped individually.

The main components of the predominant type of disturbance-associated vegetation occuring in mesic habitats on the Fish Creek site are grasses (*Arctagrostis latifolia, Poa arctica,* and *Poa rigens*) which are less common in the surrounding natural tundra vegetation (relevé 15, Fig. 15). The disturbed area at Fish Creek covered by this vegetation is today limited to the immediate vicinity of the drill pad. Similar vegetation was observed in areas disturbed for a comparable length of time in the Meade River area and elsewhere in the Arctic (e.g. Hernandez 1972a, 1972b, 1973, Younkin 1973, Druzhinina and Zharkova in press, Matveyeva in press, Yurtsev and Korobkov in press, Komárková and Webber in prep.). *Salix pulchra* and *Carex aquatilis* ssp. *stans*-dominated communities may develop in disturbed sites if the moisture is increased as a result of disturbance.

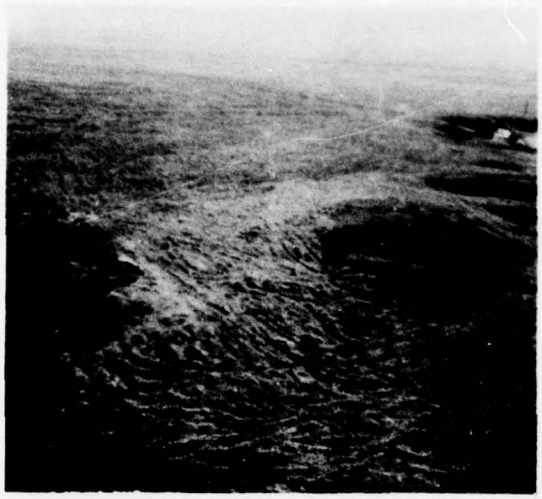


Figure 68. Successional snowpatch vegetation is limited to the extensively damaged area near the creek neighboring the test well site.

Natural revegetation of disturbed snowpatches in the last 28 years has resulted in the development of a mostly continuous vegetation cover in which *Salix rotundifolia* is the predominant plant (relevé 14, Fig. 67). *Salix rotundifolia* is also dominant in one snowpatch community (relevé 2, Fig. 63), but few other snowpatch-associated plants occur in this successional vegetation. Successional snowpatch vegetation does not occur at the well site but is evident at sites of extensive damage near Camp Creek (Fig. 68). On the drill site (Fig. 19, 41), pure stands of *Carex aquatilis* ssp. *stans* and *Eriophorum angustifolium* ssp. *subarcticum* grow in troughs and other disturbed wet habitats, possibly of thermokarst origin. *Salix pulchra* colonizes a number of habitats associated with deep vehicle tracks.

Several conspicuous vegetation types occur at the Fish Creek site, but they were too small in extent to be mapped. Two important types are described below.

Seasonal short grass, arctic ground squirrel mound

Arctic ground squirrel mounds represent habitats and support vegetation distinctly different from others in the Arctic. The mounds are elevated above the surrounding surfaces, they usually occur on elevated bluffs and ridges. The mound habitats are xeric and wind-exposed. Snow cover is shallow and short in duration, but depth of thaw is greater than in most other arctic habitats. Continuous activity of arctic ground squirrels during the growing season prevents development of a continuous vegetation cover and increases the available nutrient supply. The vegetation on these mounds is different from the man-disturbed sites, although it also consists of plants occurring in the natural tundra vegetation. The most common plants at the Fish Creek mounds include *Polemonium boreale* ssp. *boreale, Poa glauca,* and *Koeleria asiatica* (relevé 8).

Seasonal open submerged meadow, stream

This type of predominantly submerged vegetation occurs in the creek close to the drill site. *Sparganium hyperboreum* and *Hippuris vulgaris* are the most important vascular plants (relevé 7). This vegetation type was observed in the Meade River area.

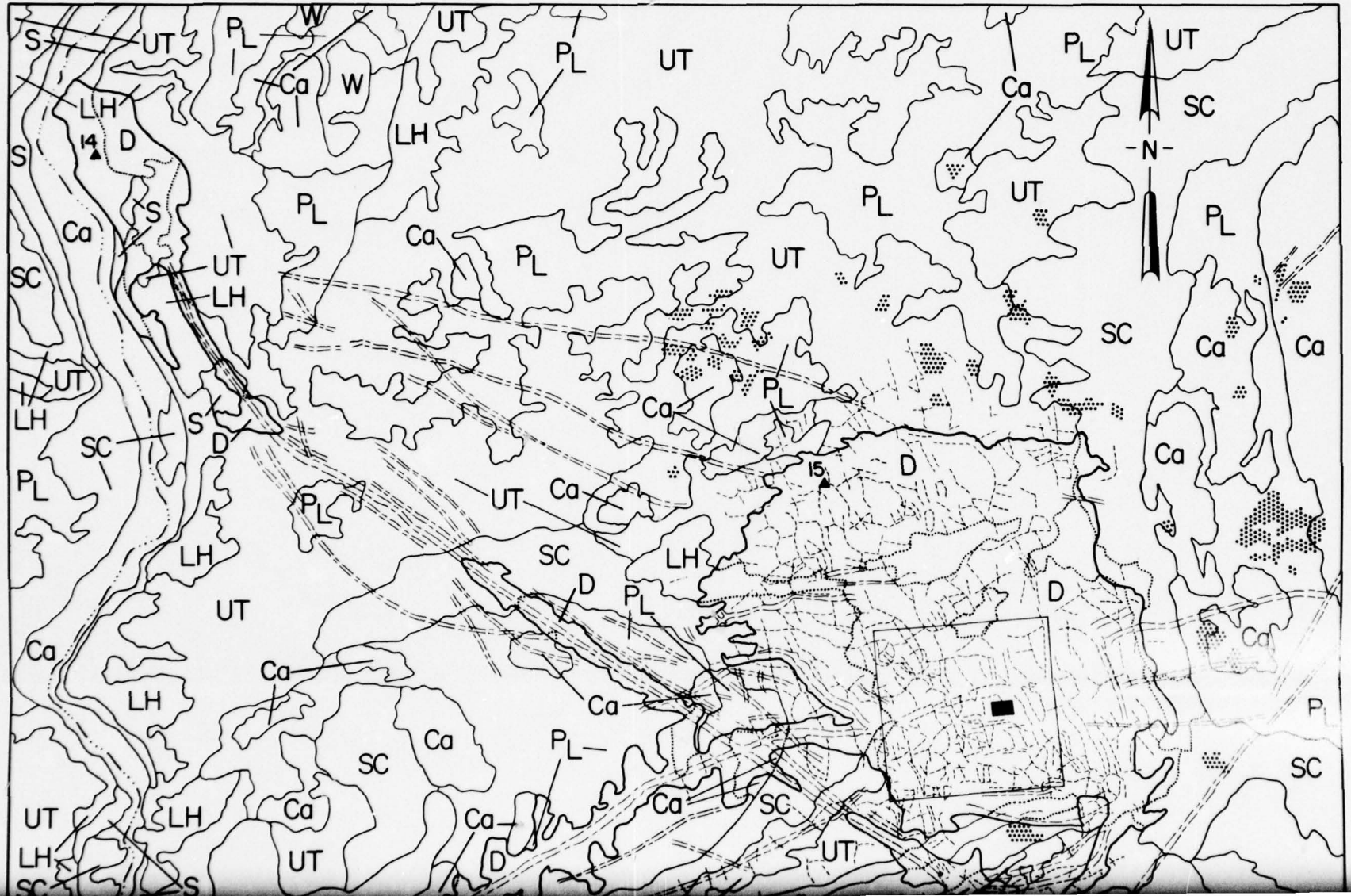
Predisturbance site status

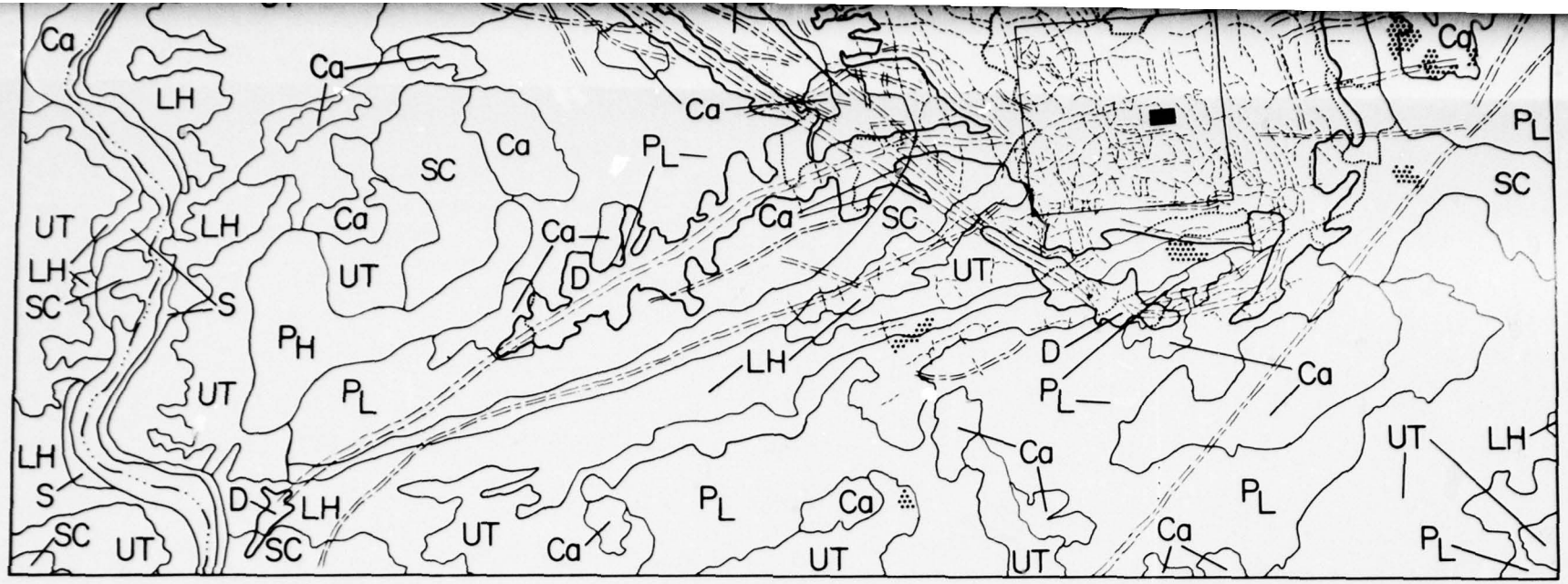
The predisturbance black and white aerial photographs and vegetation map (Fig. 59) indicate the site had been little disturbed prior to 1949. Only occasional vehicle tracks crossed the area.

There is no evidence that the predisturbance vegetation types were different from the vegetation types in the area surrounding the site today. The vegetation types assumed to have occurred on the Fish Creek site and in its close vicinity prior to disturbance include: a large area of upland tundra (mapping unit 2), which was also present on the low-centered polygon rims (mapping unit 4) and on the high-centered polygon centers (mapping unit 3); *Salix, Carex* subhygric meadow (mapping unit 6) in shallow depressions on the edges of the drained lake basin and in its center, *Carex aquatilis* marsh (mapping unit 8) in the low-centered polygon centers and troughs, in the high-centered polygon troughs and in larger ponds; and lichen heath (mapping unit 1) on elevated, relatively xeric ridges. Additional sites disturbed at the time of construction and operation are located by the creek where both mapping unit 1 and 5 communities occurred prior to the disturbance, snowpatches were not represented at the drill site.

Present site status

The current status of the undisturbed vegetation surrounding the site (Fig. 60) appears to be unchanged since the 1949 activities, except for


S
UT
W
PL
Ca
LH
D
14
SC
-N-
15



LH Evergreen dwarf scrub, ridge

UT Seasonal short grass, upland

PH Vegetation complex, high-centered polygon

PL Vegetation complex, low-centered polygon

S Evergreen and deciduous dwarf scrub, snowpatch

SC Deciduous shrub savanna, lowland

Ca Seasonal short grass, marsh

W Water

D Man-disturbed ground

Sites of intensive disturbance

Thermokarsting

Stream

Multiple pass post-1948 vehicle tracks

Pre-disturbance mapping unit boundaries

Oil well drilling pad

▲15 Relevé sites

Square indicates grid location

Figure 69. Detailed map of vegetation in the area immediately adjacent to the Fish Creek Drill site, 1977. Location shown on Figures 6 and 60. Square locates 100 × 100-m grid of Figure 30.

several additional vehicle tracks made prior to site occupation. The extent of the damage caused by drilling activities is mainly limited to the area in the immediate vicinity of the test well and to the area between the drill site and Camp Creek (Fig. 69).

The vegetation of the disturbed site has been included in one mapping unit simply for the purpose of mapping; however, a variety of disturbances of varied intensity and habitat resulted in many different vegetation responses at the site. A detailed investigation will be necessary to analyze these responses; some of these have been discussed previously in *Floristics of the Disturbances and Neighboring Locales*.

The vegetation response varies with the intensity and type of disturbance throughout the site. For instance, crude oil and fuel spill sites show today as bare surfaces, bryophyte-covered surfaces, and closed vegetation cover. Whether these results are due to the differences in environmental conditions or the type and quantity of spilled substance remains to be evaluated. Minor effects of tracks included compression of the vegetation cover and accelerated removal of litter and standing dead plants. Some surfaces disturbed mechanically are still bare today (mostly xeric sites), whereas others show continuous vegetation of variable composition. The degree of thermokarst development influences vegetation succession due to the deepening and warming of the active layer.

The drum and wooden debris piles create several interesting effects by providing new microclimates and niches. On the south sides of wooden boxes and drums, dwarf shrubs become tall and erect. Between drums and under abandoned wooden walkways, shading is increased and herbaceous plants become etiolated. Such microsites serve to increase the floristic diversity of the region. Debris such as strips of wood and metal and wire cables become overgrown by plants and organic accumulation.

Analysis of disturbance

No overall change of landforms at the site of the Fish Creek disturbance was apparent in the field or on the predisturbance (Fig. 59) and postdisturbance (Fig. 60) vegetation maps. The changes are apparent only at a more detailed scale (Fig. 69).

Comparison of the distribution of vegetation units on the site prior to and following disturbance shows that the vegetation units on the site prior to disturbance occur at the site margin today. Little of the original vegetation, however, remains in the intensively disturbed area. Mapping units 1, 2, and 6, which were the main vegetation mapping units at the site prior to the disturbance, do not occur there today. A fair correspondence exists between the present distribution of these units (except for mapping unit 1) along the margins of the disturbed site and their distribution on the site prior to the disturbance. Several patches of mapping unit 1 vegetation at the site margin could not be located. The vegetation of mapping unit 1 and perhaps some areas of mapping unit 2 may have been replaced by xeric to mesic stands of *Salix pulchra, Carex bigelowii* ssp. *bigelowii,* and *Carex aquatilis* ssp. *stans*. The stands of *Carex aquatilis* marshes located close to the site are similar in extent today as prior to disturbance.

The primary vegetation type at the site is a grass-dominated community which has been described previously under mapping unit 10. This vegetation type developed in places formerly occupied by mapping units 1, 2, and 6 and possibly, in a few instances, in previous *Carex aquatilis* marshes. Many small wet habitats on the site today are, apparently, the result of disturbance and thermokarst development. They are now vegetated by *Carex aquatilis* ssp. *stans, Eriophorum angustifolium* ssp. *subarcticum*, and a few other plants. Hernandez (1973) reported that *Arctophila fulva* and *Carex aquatilis* colonized wet sites, originally bladed to permafrost, on summer seismic lines in the Tuktoyaktuk Peninsula region, Northwest Territories. It appears that the degree of thermokarst development following disturbance was noticeably less in the well-drained, relatively xeric sites, which were occupied by the lichen heath ridges covered with mapping unit 1 vegetation prior to disturbance.

The old drained lake basin or drainage area between the drill site and the creek was only partly disturbed; hence, most of its vegetation is probably similar to that prior to disturbance. Grass-dominated, disturbance-associated vegetation developed in places previously occupied by low-centered polygons and communities from mapping units 6 and 8. Shrubby communities dominated by *Salix pulchra* develop on the sides of multiple-pass vehicle tracks.

The sandy disturbed site located by Camp Creek supports a type of disturbance-associated

vegetation not located on the drill site. This vegetation develops only in disturbed snowpatches (mapping unit 10) and its development depends on continued snowpatch conditions after disturbance (Matveyeva 1977). It does not occur in habitats occupied by other mapping units prior to disturbance. The disturbance in mesic habitats by the creek was limited, whereas the damage to mapping unit 1 communities was more extensive. However, no disturbance-associated vegetation developed in the xeric habitats. They remain largely bare except for occasional clumps of several pioneering plants, most of which occur in the disturbance-associated vegetation at the drill site.

Vegetation cover is closed over most of the mesic sites after 28 years, but xeric sites and other special cases, such as areas of diesel fuel spills, remain bare today. Shallow wet sites, which developed as a result of the disturbance, are usually well vegetated today. Vegetation cover in successional snowpatches is intermediate between that in the xeric and mesic sites.

In general, the disturbance at the drill site appears to have resulted in a greater uniformity of environmental conditions (mainly moisture), landforms, and vegetation than existed prior to disturbance. This change may be the result of leveling of much of the surface during camp construction and drilling.

Proposed model of revegetation and vegetation recovery

Figure 70 depicts a hypothetical sequence of events which may follow surface disturbance of tundra vegetation in the absence of further disturbance and significant climatic and other environmental changes (after Webber and Ives 1978). Ultimately a stable vegetation is formed, but it will not be an exact replica of the original communities because of climatic variations and the time necessary to develop the natural tundra. Also, the present tundra vegetation may be a relict of more favorable climatic conditions of the past, and thus may not be in equilibrium with the present climate (Webber and Ives 1978).

Each pathway of natural revegetation and vegetation recovery in Figure 70 (A-H) characterizes a specific set of environmental conditions. These environmental conditions are defined primarily by the intensity of disturbance, amount of ground ice near the surface, and site moisture, which are the primary factors controlling natural revegetation and vegetation recovery of tundra vegetation (e.g. Matveyeva 1977, Hok 1971, Brown et al. 1969, Kevan 1971, Rickard and Brown 1974). In the presence of intermediate or more complex conditions, the succession probably proceeds on a combination of pathways.

The proposed sequence of revegetation and recovery is summarized below.

Pathways A and B

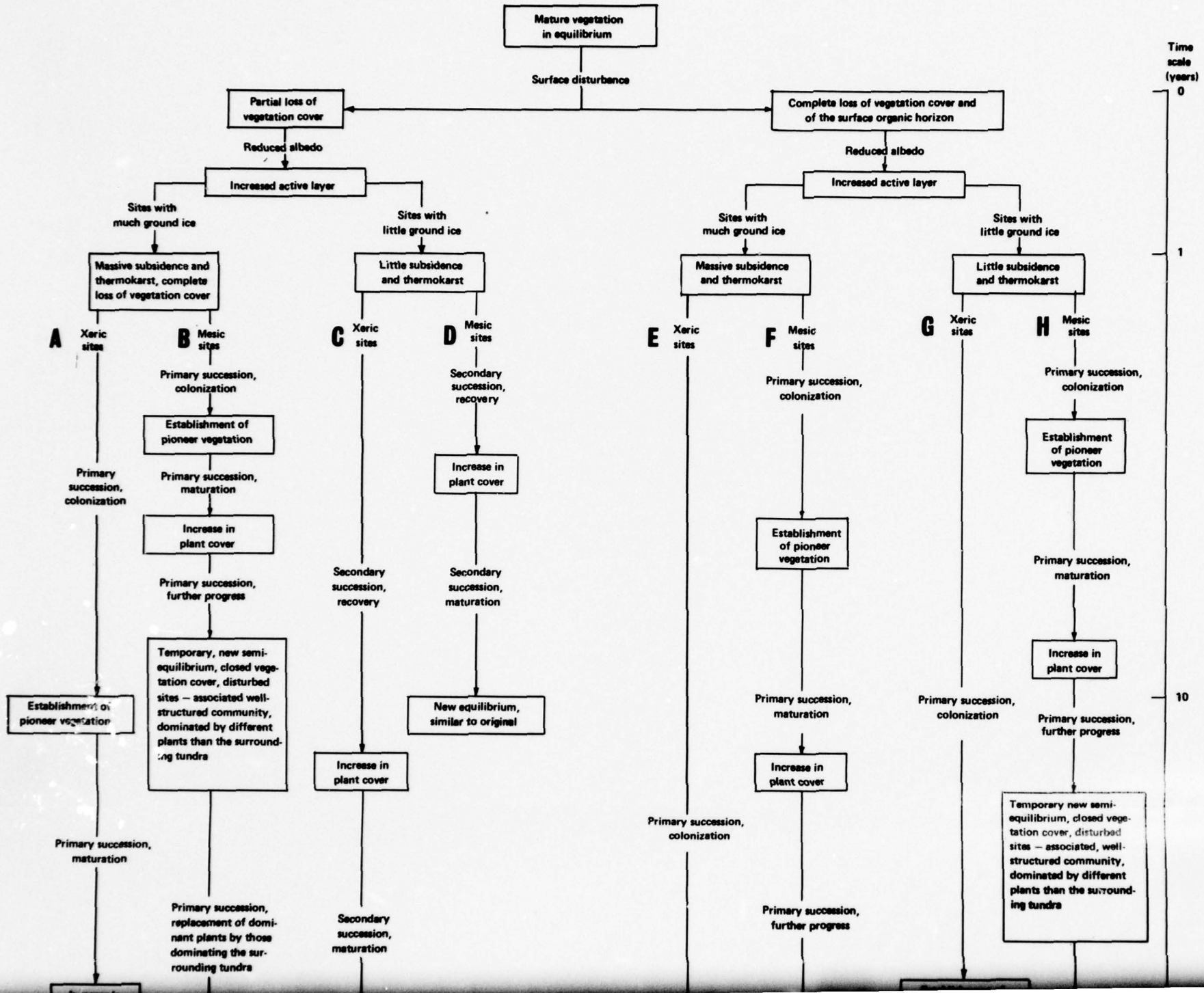
Partial loss of vegetation cover occurs on sites with much ground ice. Massive subsidence and thermokarst result in complete loss of vegetation. The organic surface horizon may be lost during subsequent erosion; in this case, the vegetation succession will follow the same pathways (E, F) as when the vegetation cover and surface organic horizon are lost in the presence of ground ice. If the organic horizon is preserved the primary succession in mesic sites temporarily results in a semiequilibrium disturbance-associated plant community and, finally, in an equilibrium community, possibly related to the original community. The time necessary to reach this new equilibrium is considerable, but always shorter in the presence of the preserved organic surface horizon than in its absence (pathways E and F), providing that the site moisture conditions remain unchanged. The equilibrium is reached earlier in mesic (pathway B) than in xeric sites (pathway A).

Pathways C and D

Partial loss of vegetation cover on mesic sites with little ground ice (pathway D) results in secondary succession, recovery, increased plant cover, maturation and a vegetation equilibrium similar to the original. The length of time needed for the recovery depends upon the severity of the vegetation loss. The recovery is delayed in xeric sites (pathway C).

Pathways E and F

Complete loss of vegetation cover and the organic surface horizon and further disturbance by surface subsidence and thermokarst in the presence of much ground ice are the least favorable circumstances for natural revegetation and vegetation recovery. The processes and sequence of events are the same as for pathways A and B, but the time necessary to reach the final stage is considerably longer in both mesic (pathway E) and xeric (pathway F) sites. Denuded


Mature vegetation in equilibrium
Surface disturbance
Partial loss of vegetation cover
Complete loss of vegetation cover and of the surface organic horizon
Reduced albedo
Reduced albedo
Increased active layer
Increased active layer
Sites with much ground ice
Sites with little ground ice
Sites with much ground ice
Sites with little ground ice
Massive subsidence and thermokarst, complete loss of vegetation cover
Little subsidence and thermokarst
Massive subsidence and thermokarst
Little subsidence and thermokarst
A Xeric sites
B Mesic sites
C Xeric sites
D Mesic sites
E Xeric sites
F Mesic sites
G Xeric sites
H Mesic sites
Primary succession, colonization
Establishment of pioneer vegetation
Primary succession, maturation
Increase in plant cover
Primary succession, further progress
Temporary, new semi-equilibrium, closed vegetation cover, disturbed sites – associated well-structured community, dominated by different plants than the surrounding tundra
Primary succession, replacement of dominant plants by those dominating the surrounding tundra
Primary succession, colonization
Establishment of pioneer vegetation
Primary succession, maturation
Primary succession, colonization
Establishment of pioneer vegetation
Primary succession, maturation
Increase in plant cover
Primary succession, further progress
Temporary new semi-equilibrium, closed vegetation cover, disturbed sites – associated, well-structured community, dominated by different plants than the surrounding tundra
Secondary succession, recovery
Increase in plant cover
Secondary succession, maturation
Secondary succession, recovery
Increase in plant cover
Secondary succession, maturation
New equilibrium, similar to original
Primary succession, colonization
Primary succession, maturation
Increase in plant cover
Primary succession, further progress
Primary succession, colonization
Primary succession, maturation
Increase in plant cover
Primary succession, further progress
Time scale (years)
0
1
10

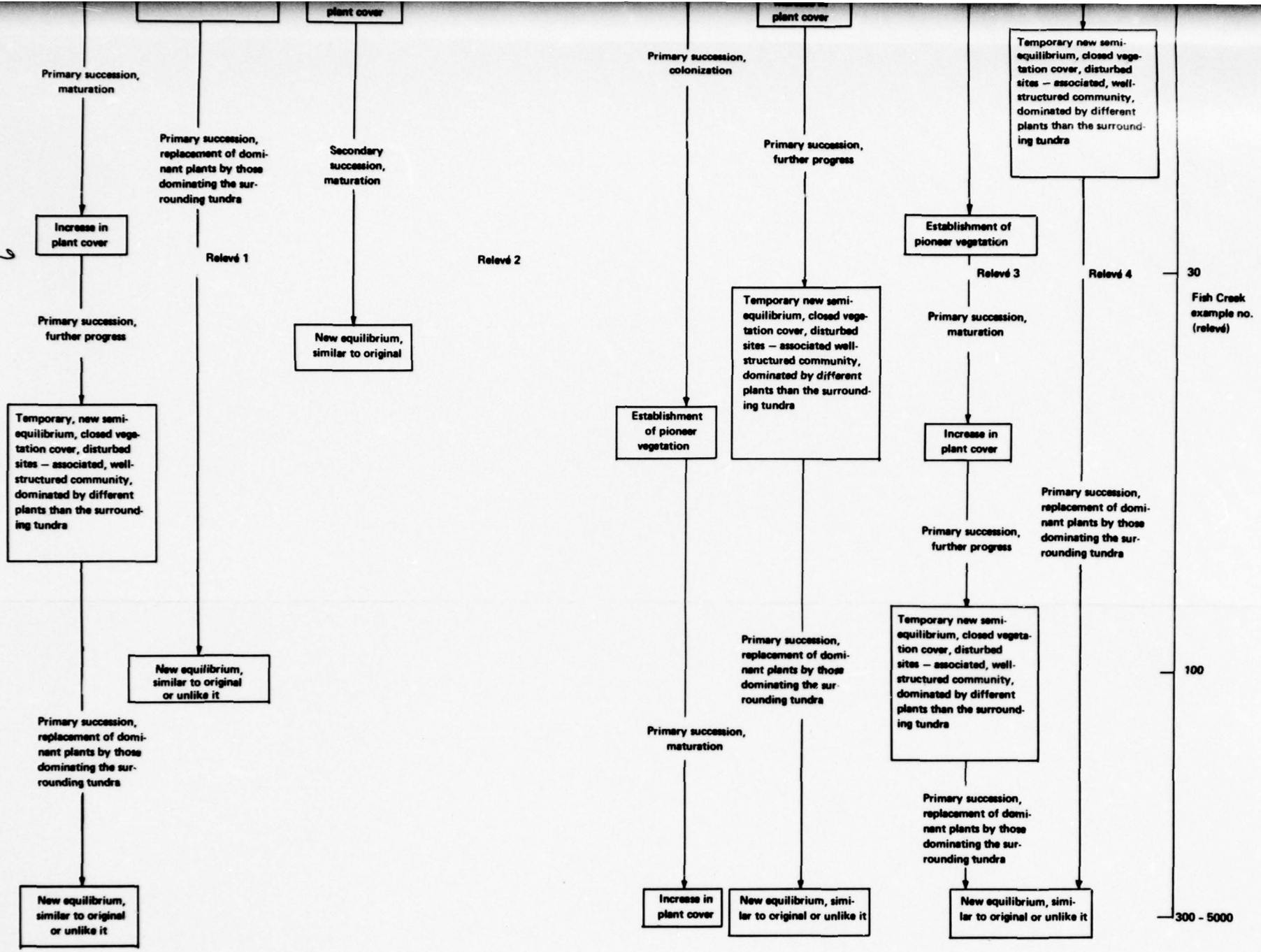


Figure 70. The chain of events subsequent to surface disturbance of tundra vegetation. Based primarily on the Fish Creek site data as well as data from the Atkasook, Alaska, area and from the Yukon River–Prudhoe Bay Haul Road.

xeric sites may never be revegetated by natural processes.

Pathways G and H

Removal of the vegetation cover and of the surface organic horizon occurs on sites with little ground ice. The length of time necessary for natural revegetation and vegetation recovery is shorter than for areas of massive subsidence and thermokarst (pathways E and F) but longer than in areas where the organic horizon is preserved (pathways A and B). The processes and the sequence of events are the same as pathways A and B. The recovery is delayed in xeric sites (pathway G) in comparison with mesic sites (pathway H).

The following is a list of vascular plants and an estimate of their percentage cover to illustrate each stage of revegetation and vegetation recovery at the Fish Creek site (+ indicates less than 1%).

1. Vegetation that was in a multiple pass trail where tussocks had been comminuted by the vehicle tracks; this list corresponds to mapping unit 2 with the addition of plants characteristic of disturbance or pioneer situations (see mapping unit 10): *Eriophorum vaginatum* ssp. *spissum* (40), *Ledum palustre* ssp. *decumbens* (5), *Stellaria edwardsii* (5), *Carex bigelowii* ssp. *bigelowii* (3), *Luzula confusa* (3), *Poa arctica* (2), *Polytrichum juniperinum* (2), *Salix phelbophylla* (2), *Salix pulchra* (2), *Aulacomnium turgidum* (1), *Bistorta plumosa* (1), *Cassiope tetragona* ssp. *tetragona* (+), *Luzula arctica* (+), *Saussurea viscida* (+), *Tephroseris atropurpurea* (+), *Vaccinium vitis-idaea* ssp. *minus* (+).

2. Vegetation that may be partly disturbed and recovered, with secondary succession: *Salix pulchra* (50), *Eriophorum vaginatum* ssp. *spissum* (30), *Salix reticulata* (3), *Arctagrostis latifolia* (4), *Carex aquatilis* ssp. *stans* (3), *Poa arctica* (3), *Bistorta vivipara* (2), *Betula nana* ssp. *exilis* (2), *Bistorta plumosa* (1), *Stellaria laeta* (+), *Pyrola grandiflora* ssp. *grandiflora* (+).

3. Vegetation in subxeric, completely scraped trails over mapping unit 1: *Dryas integrifolia* ssp. *integrifolia* (30), *Astragalus alpinus* var. *alpinus* (5), *Parrya nudicaulis* ssp. *septentrionalis* (5), *Poa glauca* (5), *Equisetum arvense* (3), *Carex bigelowii* ssp. *bigelowii* (2), *Draba cinerea* (2), *Erigeron eriocephalus* (2), *Poa arctica* (2), *Salix reticulata* (2), *Salix rotundifolia* (2), *Arctagrostis latifolia* (1), *Festuca brachyphylla* (1), *Papaver radicatum* ssp. *radicatum* (1), *Salix lanata* ssp. *richardsonii* (1), *Silene acaulis* ssp. *arctica* (1), *Trisetum spicatum* ssp. *spicatum* (1), *Carex fuliginosa* ssp. *misandra* (+).

4. Disturbance-associated plant community (dominant in most disturbed sites at Fish Creek), relevé 15: *Arctagrostis latifolia* (30), *Poa arctica* (25), *Poa rigens* (15), *Stellaria edwardsii* (8), *Carex bigelowii* ssp. *bigelowii* (5), *Salix reticulata* (5), *Luzula confusa* (3), *Bistorta plumosa* (2), *Eriophorum angustifolium* ssp. *subarcticum* (2), *Carex aquatilis* ssp. *stans* (2), *Saxifraga cernua* (2), *Luzula arctica* (1), *Saxifraga nelsoniana* (1), *Trisetum spicatum* ssp. *spicatum* (1), *Salix glauca* ssp. *acutifolia* (1), *Salix phlebophylla* (1), *Draba alpina* (+).

The relationships between the intensity of disturbance, amount of ground ice, and the moisture of the site are considerably more complex than depicted in Figure 70. The sequence of events shown in the diagram assumes constant environmental conditions; that is, a mesic site remains mesic during the entire process of vegetation recovery. In reality, these conditions are changing as the result of the conditions, processes, and stages involved. For instance, the degree of subsidence and thermokarst after the thaw of permafrost influences site moisture. Thick organic layers in peaty sites may become dry and the reestablishment of plants is therefore delayed (Deneke et al. 1975).

Several other factors not included in Figure 70 influence events following surface disturbance. Strang (1973) found in the Mackenzie Valley that thawed material tended to remain in place on slopes of less than 5%, whereas a combination of thermal and mechanical erosion resulted from removal of vegetation and organic layers on slopes steeper than 5%. The season of the disturbance may be important. For instance, Hok (1969) and Hernandez (1973) reported that vegetation is more susceptible to disturbance in summer than in winter. Bellamy et al. (1971) pointed out that wet sedge meadows are affected by a single pass of a tracked vehicle in summer.

Conclusions

Primary succession in mesic sites results, in 28 years, in secondary communities of "weedy" tundra plants (native plants associated with disturbed sites). The "weedy" plants are minor in occurrence in tundra vegetation. These communities will probably be replaced by normal tundra communities at a later stage of succession.

Colonization of disturbed sites at Fish Creek is assumed to occur in two stages similar to those described by Lambert (1972). The first stage involves habitation by secondary weedy plants, and the second, reestablishment of the natural community through gradual expansion of undisturbed vegetation.

Only the first stages of replacement of secondary "weedy" communities by plants dominant in the surrounding natural vegetation were, however, observed at the Fish Creek site. Several plants dominant in the surrounding natural vegetation (*Salix pulchra, Eriophorum vaginatum* ssp. *spissum, Carex aquatilis* ssp. *stans*) were found established in and possibly replacing the grass-dominated, disturbance-associated vegetation, but their cover was low. In disturbed sites with an extensive cover of these plants, the extent of disturbance was small.

These secondary "weedy" communities were observed elsewhere in the Arctic. Equivalent communities occur in most of the disturbed sites associated with coal mining and dwellings near Atkasook, Alaska (Komárková and Webber, in prep.) Mining was discontinued in 1944 and grass-dominated, disturbance-associated communities have developed near the mine since that time. *Poa rigens* and *Poa arctica* show a high cover there and at Fish Creek, although *Arctagrostis latifolia* is important only at Fish Creek and *Elymus mollis* ssp. *villosissimus* only at Atkasook. Secondary shrubby communities (dominated by *Salix alaxensis* ssp. *alaxensis, S. lanata* ssp. *richardsonii,* and *S. glauca* ssp. *acutifolia*) associated with a riverbank habitat (absent a. Fish Creek) are also present at the Atkasook site.

Bliss and Wein (1972a) and Hernandez (1972a, 1972b) observed that the native plants *Calamagrostis canadensis, Arctagrostis latifolia, Chamaenerion angustifolium,* and *Tephroseris palustris* ssp. *congesta* pioneer natural disturbances in the Mackenzie Delta region. According to Hernandez (1973), summer seismic lines, bladed to permafrost in 1965 in the Tuktoyaktuk Peninsula region, Northwest Territories, show natural plant recolonization. *Arctagrostis latifolia, Calamagrostis canadensis, Poa arctica,* and *Luzula confusa* are among the most typical and abundant plants on disturbed upland mesic sites. They occur in the surrounding natural tundra as single culms and compose less than 1% of the total vegetation cover (Hernandez 1972a, 1972b, 1973, Younkin 1973). This distribution is also found on the Fish Creek site. Similarly, dwarf scrubs, although abundant in the surrounding communities, were rarely observed in the secondary communities in the Tuktoyaktuk Peninsula region and at Fish Creek.

Many plants of Fish Creek also occur in anthropogenic habitats in the Vorkuta region in the Siberian Arctic (Druzhinina and Zharkova 1977), on the western Taimyr Peninsula (Matveyeva 1977) and on the southeastern Chukotka Peninsula (Yurtsev and Korobkov 1977). As in the Alaskan Arctic, a group of almost obligate apophytes occurs on disturbed sites throughout the Siberian Arctic, and some plants (e.g. *Artemisia tilesii, Poa rigens, P. arctica, Arctagrostis latifolia, A. arundinacea*) occur in these sites in both areas. Secondary communities are common in the Vorkuta region because the disturbance is widespread, and as with Fish Creek, these are dominated by grasses (Druzhinina and Zharkova 1977). Matveyeva (1977) found plants typical of zonal associations practically absent in the recovering vegetation cover of intrazonal communities, again this is similar to Fish Creek. The source of the vegetation cover of the Taimyr disturbed sites are herb-grass communities from south-facing riverbanks because moisture and thermal conditions in the soil of the disturbed and riverbank sites are similar.

The successional stages at the Fish Creek crude oil spill sites are similar to those reported by Deneke et al. (1975) for natural oil seeps at Cape Simpson, Alaska. Pioneer mosses and lichens are followed by clumps of *Carex* and *Eriophorum* and finally by an *Arctagrostis* community. Deneke et al. (1975) concluded that the revegetation of spill areas is governed primarily by moisture availability because it leaches hydrocarbons. Plice (1948) determined that the degree of soil saturation by the spilled substance is inversely related to soil moisture, but is also dependent on the amount of the spilled substance, topography, and soil texture.

The rates of natural revegetation and vegetation recovery following surface disturbance at Fish Creek are comparable to those found elsewhere in the Arctic. Secondary succession or recovery from nondisruptive damage is frequently quite complete after 5 to 10 years in the Arctic (Webber and Ives 1978). According to Johnson (1969), disturbed areas are invaded within five years, whereas in areas of thermokarst subsidence, irreversible destruction of

tundra may occur. Some sites with high ice content, thermokarst subsidence, and erosion have not been revegetated after 20 years (Hok 1969). Comparable sites at Fish Creek include those with severe erosion on xeric surfaces and those covered by diesel fuel spills. Trails up to 10 years old resulted in a reduction of plant cover from 95-100% to about 5% with little evidence of reinvasion (Bliss and Wein 1972b). Andreev (1972) reported that, in the Siberian Far Northeast, hummocky marsh *Carex-Eriophorum* tundras are restored approximately 8 to 10 years after disturbance by different plant communities. Hernandez (1974) concluded that plant establishment on exposed mineral soil in low shrub-heath communities usually begins during the first summer after disturbances and that ground cover is about 50% within 6 to 10 years.

RECOMMENDATIONS FOR FUTURE RESEARCH

D.E. Lawson, J. Brown, K.R. Everett, A.W. Johnson, V. Komárková, B.M. Murray, D.F. Murray and P.J. Webber

Cleanup recommendations for the Fish Creek site

The following recommendations were made following the Fish Creek study.

1. Accomplish removal of barrels and other debris with minimum surface disturbance and disruption of vegetation.

2. Stockpile barrels and debris outside the 100 × 100-m grid and establish permanent corner posts with red flagging for future reference.

3. Leave partially buried wood, canvas, and metal in place (if not conspicuous) in order to provide long-term reference for organic matter accumulation and growth rate of plants. Leave in place the cable that stretches from the drill site across the bladed trail to Camp Creek.

4. Leave representative clusters of barrels as shelter for enhanced vegetation growth and microclimate studies. Three sets of barrels on the northeast side have been flagged with red tape and these should be left for long-term observations of willow growth.

5. Do not level or modify any mounds or debris. Leave the site topography as is.

6. Leave the four wooden piles that are flagged with red tape on the present drill pad for reference.

Restoration of new work areas

During the course of the Fish Creek study, several sandy work pads located elsewhere in the NPRA and which were used in 1976 and 1977 were visited. These sites provide an opportunity to follow natural revegetation and terrain modification employing natural materials and processes. The following recommendations are intended to explore these possibilities without impairing long-term restoration of these sandy sites by the use of domestic seed mixtures that are not likely to succeed.

1. Shape and slope the edge of work pads onto the tundra surface in order to encourage the development of a natural moisture gradient. Fill in mud pits located on the pad with available sand.

2. Avoid the use of domestic seeds or hay mulches for revegetation. The preliminary results of this study suggest that natural revegetation will occur in a relatively short period of time where adequate moisture exists. If some revegetation seems necessary for short-term visual enhancement or to reduce wind erosion of sandy pads, experimental plantings with the following dune species, which have excellent root binding capabilities, are recommended:

Willow cuttings:	Grasses as small clones:
Salix alaxensis	*Poa arctica*
Salix niphoclada	*Festuca rubra*
Salix glauca	*Leymus (Elymus) mollis*
	Bromopsis pumpelliana
	Carex obtusata

These plantings should be watered frequently during at least the first growing season.

Vegetation

The Fish Creek site and other drill sites in NPRA should be used to study natural revegetation and vegetation recovery following disturbance. These studies will be extremely valuable for developing an understanding of the processes involved in the arctic tundra following disturbance. Few sites exist which were disturbed at some known time and remain without further disturbance. None have been subject to intensive research. Documentation available on Fish Creek activities can be utilized to reconstruct in detail the kind, intensity, and duration of disturbances in habitats at the site. These investigations have two main objectives and benefits: 1) a prediction of the response to disturbance of arctic tundra ecosystems in different environmental settings with time, and 2)

recommendations for artificial revegetation and restoration of man-disturbed environments. A long-term biological monitoring study at the Fish Creek site would contribute significantly to an understanding of long-term changes in arctic tundra ecosystems.

Soils

Soil development on disturbed areas of the Arctic has not been documented. A quantitative analysis of soil formation with time could be conducted at Fish Creek and at other disturbed sites. Features at the Fish Creek site (e.g. the buried cable and pilings) can be used as markers to monitor rates of organic accumulation under different site conditions.

Microbiological and soil chemical analyses of diesel fuel spill areas should also be conducted to determine the current biological-chemical state of the soil. Fertilizer amendments designed to stimulate microbial recolonization could be added to selected subareas as a precursor to natural revegetation, a process largely ineffective at the diesel fuel spill areas over the last 28 years.

Permafrost and surficial geology

The effect of disturbance on surface and subsurface materials and processes in the Arctic is poorly understood. Few well-documented data sets and analyses exist on thermokarst and thermal erosion in the Alaskan Arctic. A quantitative analysis of the type, rate, and extent of disturbance-induced processes should be made at Fish Creek, other previously disturbed sites, and future drill sites. In particular, the effect of disturbance on permafrost, massive ground ice, and predisturbance surficial processes should be evaluated. Shallow drilling to ascertain ground ice types and distribution needs to be performed before and after the thaw season. This research should be integrated with the analyses of soil, aquatics, and vegetation.

Aquatic environment

Although our investigations did not include the response and recovery of tundra ponds, the long-term response of the aquatic ecosystem to oil and other hydrocarbon spills should be examined at Fish Creek.

Specific research recommendations

Some specific recommendations for future research are:

1. Observe the vegetation and permafrost response to cleanup at early PET 4 sites and at newly established sites in NPRA.
2. Establish rates of accumulation of organic matter over debris such as the cable, wood, tarps, and barrels.
3. Examine natural succession from the 1949 investigation to post-cleanup conditions at Fish Creek.
4. Conduct plant population studies of enhanced Fish Creek habitats in disturbed areas.
5. Evaluate the effect and fates of old crude oil and diesel spills on terrestrial and aquatic habitats.
6. Evaluate the reestablishment and rate of development of natural soils after 30 years.
7. Estimate the quantity of ice removed by thermokarst development and thermal erosion following disturbance at Fish Creek.
8. Develop regional extrapolations for surface protection and for mapping of terrain sensitivity and recoverability by examining and monitoring other early PET 4 sites and new sites in NPRA.
9. Observe vegetation and soil thaw response to recent snow roads and trails in the vicinity of new drill pads.

LITERATURE CITED

Andreev, V.N. (1972) Study of anthropogenic effects on tundra vegetation in connection with the general trend in tundra biome development. *Proceedings, Fifth Symposium on Biological Problems of the North*, Magadan, p. 173-179. CRREL Draft Translation 557, 1976, 12 p.

Alexandrova (Aleksandrova), V.D. (1970) The vegetation of the tundra zones in the USSR and data about its productivity. In *Productivity and Conservation in Northern Circumpolar Lands* (W.A. Fuller and P.G. Kevan, Eds.), International Union Natur., Morges, Switzerland, Publ. NS 16, p. 93-114.

Batzli, G.O. and J. Brown (1976) RATE — the influence of grazing on arctic tundra ecosystems. *Arctic Bulletin*, vol. 2, p. 153-160.

Bellamy, D., J. Radforth and N.W. Radforth (1971) Terrain, traffic and tundra. *Nature*, vol. 231, p. 429-432.

Benninghoff, W.S. (1963) Relationships between vegetation and frost in soils. In *Proceedings, First Int. Conf. on Permafrost*, National Academy of Sciences, Washington, D.C., p. 9-12.

Black, R.F. (1951) Eolian deposits of Alaska. *Arctic*, vol. 4, p. 89-111.

Black, R.F. (1964) Gubik formation of Quaternary age in northern Alaska. U.S. Geological Survey Professional Paper 302-C, p. 59-91.

Black, R.F. (1969) Thaw depressions and thaw lakes: A review. *Biuletyn peryglacjalny*, vol. 19, p. 131-150.

Bliss, L.C. and R.W. Wein (1972a) Ecological problems associated with arctic oil and gas development. *Proceedings, Canadian Northern Pipeline Research Conference*, National Research Council of Canada, Associate Committee on Geotechnical Research, Technical Memorandum 104 (NRCC 12498), p. 65-77.

Bliss, L.C. and R.W. Wein (1972b) Changes to the active layer caused by surface disturbance. National Research Council of Canada, Technical Memorandum 103, p. 37-47.

Britton, M.E. (1967) Vegetation of the arctic tundra. In *Arctic Biology* (H.P. Hansen, Ed.), Oregon State University Press, p. 3-64.

Brown, J. (1969) Buried soils associated with permafrost. In *Symposium on Pedology and Quaternary Research*, University of Alberta, p. 115-127.

Brown, J. and R. Berg (1977) Environmental engineering investigations along the Yukon River-Prudhoe Bay Haul Road, Alaska. Annual Report to FHWA, 15 July 1977, CRREL.

Brown, J. and P.V. Sellmann (1973) Permafrost and coastal plain history of Arctic Alaska. Arctic Institute of North American Technical Paper No. 25, p. 31-47.

Brown, J., R.K. Haugen and S. Parrish (1975) Selected climatic and soil thermal characteristics of the Prudhoe Bay region. In *Ecological Investigations of the Tundra Biome in the Prudhoe Bay region, Alaska* (J. Brown, Ed.), Biological Papers of the University of Alaksa, Special Report no. 2, p. 2-11.

Brown, J., W. Rickard and D. Vietor (1969) The effect of disturbance on permafrost terrain. CRREL Special *Report 138*. AD 699327.

Crocker, R.L. and J. Major (1955) Soil development in relation to vegetation and surface age at Brady Glacier, Alaska. *Journal of Ecology*, vol. 43, p. 427-448.

Deneke, F.J., B.H. McCown, P.I. Coyne, W. Rickard and J. Brown (1975) Biological aspects of terrestrial oil spills: USA CRREL oil research in Alaska, 1970-1974. CRREL Research Report 346.

Druzhinina, O.A. and Yu.G. Zharkova (in press) On the study of plant communities of anthropogenic habitats in the area of the Vorkuta industrial center region. Biological Papers of the University of Alaska.

French, H.M. (1974) Active thermokarst processes, Eastern Banks Island, Western Canadian Arctic. *Canadian Journal of Earth Sciences*, vol. 11, p. 785-794.

French, H.M. (1975) Man-induced thermokarst, Sachs Harbour airstrip, Banks Island, Northwest Territories. *Canadian Journal of Earth Sciences*, vol. 12, p. 132-144.

Fosberg, F.R. (1967) Classification of vegetation for general purposes. In *IBP Handbook Number 4: Guide to the Checksheet for IBP Areas* (G.F. Peterken, Ed.), International Biological Programs. Oxford: Blackwell Publisher, p. 73-120.

Gold, L.W. and A.H. Lachenbruch (1973) Thermal conditions in permafrost-a review of North American literature. In *Proceedings Second International Conference on Permafrost, North American Contribution*. National Academy of Sciences, Washington, D.C., p. 3-25.

Griggs, R.F. (1934) The problem with arctic vegetation. Washington Academy of Sciences, vol. 24, p. 153-175.

Hernandez, H. (1972a) Surficial disturbance and natural plant recolonization in the Tuktoyaktuk Peninsula region, N.W.T. M.S. thesis (unpublished), University of Alberta, Edmonton, Alberta.

Hernandez, H. (1972b) Surface disturbance and natural plant recolonization in the Mackenzie Delta region. In *Botanical Studies of Natural and Man-Modified Habitats in the Eastern Mackenzie Delta region and the Arctic Islands* (L.C. Bliss and R.W. Wein, Eds.), Department of Indian Affairs and Northern Development, Ottawa, Canada. ALUR Report 71-72, p. 143-174.

Hernandez, H. (1973) Natural plant recolonization of surficial disturbances, Tuktoyaktuk Peninsula region, Northwest Territories. *Canadian Journal of Botany*, vol. 51, p. 2177-2196.

Hernandez, H. (1974) Possible effects on vegetation of the proposed gas pipeline from Prudhoe Bay, Alaska, and the Mackenzie Delta, to Alberta. Research Reports, vol. IV, Environmental impact assessment of the portion of the Mackenzie gas pipeline from Alaska to Alberta. Environmental Protection Board, Winnipeg, Manitoba, p. 37-68.

Hok, J.R. (1969) A reconnaissance of tractor trails and related phenomena on the North Slope of Alaska. U.S. Department of Interior, Bureau of Land Management, 66 p.

Hok, J.R. (1971) Some effects of vehicle operation on Alaskan arctic tundra. M.S. thesis (unpublished), University of Alaksa, Fairbanks.

Hopkins, D.M., T.N.V. Karlstrom et al. (1955) Permafrost and ground water in Alaska. U.S. Geological Survey Professional Paper 264F, p. 113-146.

Hultén, E. (1968) *Flora of Alaska and neighboring territories*. Stanford, California: Stanford University Press, 1008 p.

Johnson, L. and K. Van Cleve (1976) Revegetation in arctic and subarctic North America: A literature review. CRREL Report 76-15, 32 p.

Johnson, P.L. (1969) Arctic plants, ecosystems and strategies. *Arctic*, vol. 22, p. 341-355.

Kevan, P.G. (1971) Vehicle tracks on high arctic tundra: An 11-year case history around Hazen Camp, Ellesmere Island, N.W.T. Hazen No. 41, Ottawa, 17 p.

Komárková, V. and P.J. Webber (1977) Annotated list of vascular plants from the Meade River area near Atkasook, Alaska. RATE (Research on Arctic Tundra Environments) Report, U.S. Arctic Research Program, Division of Polar Programs, National Science Foundation (unpublished).

Komárková, V. and P.J. Webber (in prep) Two low arctic vegetation maps of the Meade River area near Atkasook, Alaska.

Kuchler, A.W. (1967) *Vegetation mapping*. New York: Ronald Press, 472 p.

Lachenbruch, A.H. (1962) Mechanics of thermal contraction cracks and ice-wedge polygons in permafrost. Geological Society of America Special Paper 70.

Lambert, J.D.H. (1972) Plant succession on tundra mudflows: Preliminary observations. *Arctic*, vol. 25, p. 99-106.

Leffingwell, E. de K. (1919) The Canning River region, northern Alaska. U.S. Geological Survey Professional Paper 109, 251 p.

Livingstone, D.A., K. Bryan, Jr. and R.G. Leahy (1958) Effects of an arctic environment on the origin and development of fresh-water lakes. *Limnology and Oceanography*, vol. 3, p. 192-214.

Löve, Á. and D. Löve (1975) Cytotaxonomical atlas of the arctic flora. Cramer, Vaduz, 598 p.

Mackay, J.R. (1966) Segregated epigenetic ice and slumps in permafrost, Mackenzie Delta area, N.W.T. *Geographical Bulletin*, vol. 8, p. 59-80.

Mackay, J.R. (1970) Disturbance to the tundra and forest tundra environment of the western Arctic. *Canadian Geotechnical Journal*, vol. 7, p. 420-432.

Mackay, J.R. (1971) The origin of massive icy beds in permafrost, western Arctic coast, Canada. *Canadian Journal of Earth Sciences*, vol. 8, p. 397-422.

Matveyeva (Matveeva), N.V. (in press) An attempt to compile a list of plants inhabiting natural and anthropogenical disturbances of tundra cover: Western Taimyr, the settlement of Kresty. Biological Papers of University of Alaska.

Péwé, T.L. (1975) Quaternary geology of Alaska. U.S. Geological Survey Professional Paper 835, 145 p.

Plice, M.J. (1948) Some effects of crude petroleum on soil fertility. *Soil Science*, vol. 13, p. 413-416.

Racine, C.H. (1977) Tundra disturbance resulting from a 1974 drilling operation in the Cape Espenberg Area, Seward Peninsula, Alaska. Report to U.S. Department of Interior, National Park Service. Center for Northern Studies, Wolcott, Vt., 47 p.

Reed, J.C. (1958) Exploration of Naval Pertroleum Reserve No. 4 and adjacent areas, northern Alaska, 1944-53. Part 1: History of the exploration. U.S. Geological Survey Professional Paper 301, 192 p.

Rickard, W.E. and J. Brown (1974) Effects of off-road vehicles on the tundra landscape. *Environmental Conservation*, vol. 1, p. 55-62.

Robinson, F.M. and F.R. Collins (1959) Core test, Sentinel Hill area and test well, Fish Creek area, Alaska. U.S. Geological Survey Professional Paper 305-I, p. 501-521.

Sellmann, P.V., J. Brown, R.I. Lewellen, H. McKim and C.J. Merry (1975) The classification and geomorphic implications of thaw lakes on the Arctic Coastal Plain, Alaska. CRREL Research Report 344, 21 p.

Soil Survey Staff (1975) Soil taxonomy, Soil Conservation Service, USDA, Agriculture Handbook No. 436, 754 p.

Strang, R.M. (1973) Studies of vegetation, landform and permafrost in the Mackenzie Valley: Some case histories of disturbance. Environmental-Social Committee Northern Pipelines, Task Force on Northern Oil Development, Report No. 73-14, 49 p.

Taber, S. (1929) Frost heaving. *Journal of Geology*, vol. 37, p. 428-461.

U.S. Navy (1949) Fish Creek Test Well No. 1: Drilling, engineering and geologic completion reports, Naval Petroleum Reserve No. 4. Bureau of Yards and Docks, U.S. Geological Survey, Menlo Park, California.

U.S. Navy (1977) Final environment impact statement — continuing exploration and evaluation of Naval Petroleum Reserve No. 4. Naval Petroleum and Oil Shale Reserves, Washington, D.C., 2 volumes.

Viereck, L.A. (1973) Ecological effects of river flooding and forest fires on permafrost in the taiga of Alaska. In *Proceedings, Second International Conference on Permafrost, North American Contribution*, National Academy of Sciences, Washington, D.C., p. 60-67.

Webber, P.J. and J.D. Ives (1978) Recommendations concerning the damage and recovery of tundra vegetation. *Environmental Conservation*, vol. 5, no. 3, p. 171-182.

Weber, W.A., J.A. Erdman and H. Krog (1969) Annotated list of lichens. In *Vegetation of Amchitka Island, Aleutian Islands, Alaska* (H.T. Shacklette et al., Eds.), U.S. Geological Survey Professional Paper 648, 66 p.

Westhoff, V. and E. van der Maarel (1973) The Braun-Blanquet approach. In *Handbook of Vegetation Science* (R. Tuxen, Ed.), Part 5, *Ordination and Classification of Communities* (R.H. Whittaker, Ed.). Junk, The Hague, p. 617-726.

Williams, J.R., W.E. Yeend, L.D. Carter and T.D. Hamilton (1977) Preliminary surficial deposits map of National Petroleum Reserve — Alaska. U.S. Geological Survey Open File Report 77-868.

Young, S.B. (1971) The vascular flora of St. Lawrence Island with special reference to floristic zonation in the arctic regions. *Contributions from the Gray Herbarium*, vol. 201, p. 11-115.

Younkin, W.E. (1973) Autecology studies of native species potentially useful for revegetation, Tuktoyaktuk region, N.W.T. In *Botanical Studies of Natural and Man-Modified Habitats in the Mackenzie Valley, Eastern Mackenzie Delta Region and the Arctic Islands* (L.C. Bliss and R.W. Wein, Eds.), Department of Indian Affairs and Northern Development, Ottawa, Canada. ALUR Report 72-73-14, p. 45-76.

Yurtsev, B.A. and A.A. Korobkov (in press) An annotated list of plants inhabiting sites of natural and anthropogenic disturbances of tundra cover: Southeasternmost Chukchi Peninsula. Biological Papers of University of Alaska.

PHOTO CREDITS

The photograph in Figure 9 was taken by D.F. Murray. Figures 16, 17, 19, 20, 21, 35, 37 and 38 were photographed by K.R. Everett, Figures 39 to 58 by A.W. Johnson, and Figures 62 to 68 by V. Komárková. All other photos are from CRREL files.

APPENDIX A. RESULTS OF POLLEN ANALYSES (P.J. WEBBER).

Table AI. Percentage pollen data from just above an excavated ice-wedge, from recent moss polsters and from soil samples at the Fish Creek site.

Landform	*Upland*		*Lowland*	*Snowpatch*	*Strangmoor*	*Ridge (profile 3)*		*Upland (profile 4)*			*Man-disturbed ground (profile 12)*		
Source	*Ice-wedge*	*Aulacomnium polster*	*Sphagnum/ Aulacomnium polster*	*Rhacomitrium/ Hylocomium polster*	*Sphagnum polster*	*Soil 0-2.5 cm*	*Soil 2.5-6.0 cm*	*Soil 0-2.5 cm*	*Soil 2.5-6.0 cm*	*Soil 6.5-8.0 cm*	*Soil 0-6.5 cm*	*Soil 6.5-10.5 cm*	*Soil 10.5-16.5 cm*
Coniferous trees													
Larix	–	1	3	6	3	–	–	–	–	–	–	–	–
Picea	3	1	–	1	–	–	15	0.5	0.5	1	1	3	1
Pinus	1	1	–	–	–	7	–	–	–	–	–	–	1
Woody dicotyledons													
Alnus	13	13	17	11	16	7	27	7	14	11	14	23	29
Betula	76	7	36	15	10	48	15	78	71	73	53	47	39
Ericaceae	13	89	5	34	–	4	3	11	14	20	29	57	23
Myrica	1	1	–	–	–	–	–	2	1	1	2	–	–
Rubus	–	–	1	–	–	–	–	2	2	1	1	–	–
Salix	2	52	22	16	44	4	18	3	2	5	13	16	18
Herbaceous dicotyledons													
Artemisia	0.5	–	1	1	–	–	–	–	–	–	–	4	–
Asteraceae	–	2	1	5	–	–	3	0.5	1	–	1	1	1
Brassicaceae	0.5	–	–	–	–	–	–	–	0.5	–	–	–	3
Caryophyllaceae	–	–	–	–	–	–	–	0.5	–	–	–	–	–
Rosaceae	0.5	1	4	12	8	4	15	1	1.5	1	1	–	–
Saxifragaceae	–	–	1	7	4	4	–	0.5	–	–	–	–	–
Monocotyledons													
Cyperaceae	81	83	111	56	79	111	170	21	74	55	119	163	142
Poaceae	1	21	13	23	11	19	6	2	2	1	9	5	8
Pteridophytes and mosses													
Filicales	–	–	–	1	–	7	–	0.5	1	0.5	3	–	–
Lycopodium	–	–	1	1	–	–	–	1	0.5	3	–	–	–
Selaginella	–	–	–	–	–	–	–	–	–	3	–	–	–
Sphagnum	1	1	1	1	–	4	15	–	0.5	–	1	1	1

Table AII. Percentage pollen data based on all pollen taxa.

Landform	Upland		Lowland	Snowpatch	Strangmoor	Ridge (profile 3)		Upland (profile 4)			Man-disturbed ground (profile 12)		
Source	Ice-wedge	Aulacomnium polster	Sphagnum/ Aulacomnium polster	Rhacomitrium/ Hylocomium polster	Sphagnum polster	Soil 0-2.5 cm	Soil 2.5-6.0 cm	Soil 0-2.5 cm	Soil 2.5-6.0 cm	Soil 6.5-8.0 cm	Soil 0-6.5 cm	Soil 6.5-10.5 cm	Soil 10.5-16.5 cm
Coniferous trees													
Larix	–	+	1	3	2	–	–	–	–	–	–	–	–
Picea	2	+	–	1	–	–	5	+	+	1	+	1	+
Pinus	1	+	–	–	–	3	–	–	–	–	–	–	+
Woody dicotyledons													
Alnus	6	5	8	6	9	3	9	6	7	8	6	7	11
Betula	39	3	17	8	6	21	5	58	37	40	21	15	15
Ericaceae	7	33	2	18	–	2	1	9	8	10	11	18	9
Myrica	1	+	–	–	–	–	–	1	1	1	1	–	–
Rubus	–	–	+	–	–	–	–	1	1	1	+	–	–
Salix	1	19	10	8	25	2	6	3	1	3	5	5	7
Herbaceous dicotyledons													
Artemisia	+	–	+	1	–	–	–	–	–	–	–	1	–
Asteraceae	–	1	+	3	–	–	1	+	1	–	+	+	+
Brassicaceae	+	–	–	–	–	–	–	–	+	–	–	–	1
Caryophyllaceae	–	–	–	–	–	2	–	+	–	–	–	–	–
Rosaceae	+	+	2	7	4	2	5	1	1	1	+	–	–
Saxifragaceae	–	–	–	4	2	–	–	+	–	–	–	–	–
Monocotyledons													
Cyperaceae	42	30	51	29	44	49	59	16	39	32	47	51	53
Poaceae	1	8	6	12	6	8	2	1	1	1	4	2	3
Pteridophytes and mosses													
Filicales	–	–	–	1	–	3	–	+	1	+	1	–	–
Lycopodium	–	–	+	–	–	–	–	1	+	1	+	–	–
Selaginella	–	–	–	–	–	–	–	–	–	–	+	+	–
Sphagnum	1	+	+	1	–	2	5	–	+	–	+	+	+

Table AIII. Absolute pollen data based on numbers of grains per gram over dry weight of the original material (see Table AI).

Landform	*Upland*		*Lowland*	*Snowpatch*	*Strangmoor*	*Ridge (profile 3)*		*Upland (profile 4)*			*Man-disturbed ground (profile 12)*		
Source	*Ice-wedge*	*Aulacomnium polster*	*Sphagnum/ Aulacomnium polster*	*Rhacomitrium/ Hylocomium polster*	*Sphagnum polster*	*Soil 0-2,5 cm*	*Soil 2.5-6,0 cm*	*Soil 0-2.5 cm*	*Soil 2.5-6,0 cm*	*Soil 6.5-8.0 cm*	*Soil 0-6.5 cm*	*Soil 6.5-10.5 cm*	*Soil 10.5-16.5 cm*
Coniferous trees													
Larix	–	255	557	1127	247	–	–	–	–	–	–	–	–
Picea	1764	255	–	188	–	–	155	504	451	1241	274	1410	530
Pinus	504	255	–	–	–	23	–	–	–	–	–	–	530
Woody dicotyledons													
Alnus	6300	3317	3156	2066	1318	23	280	7553	12632	16553	3843	10807	15376
Betula	38553	1786	6684	2817	823	149	155	79055	64064	88973	14547	22083	20677
Ericaceae	6552	22710	928	6385	–	11	31	11581	13084	22347	7960	26781	12194
Myrica	504	255	–	–	–	–	–	2014	1353	1655	549	–	–
Rubus	–	–	186	–	–	–	–	2014	2256	2483	274	–	–
Salix	1260	13269	4085	3005	3623	11	186	3525	2256	6621	3568	7518	9543
Herbaceous dicotyledons													
Artemisia	252	–	186	188	–	–	–	–	–	–	–	1879	–
Asteraceae	–	510	186	939	–	–	31	504	1353	–	274	470	530
Brassicaceae	252	–	–	–	–	–	–	–	451	–	–	–	1591
Caryophyllaceae	–	–	–	–	–	11	–	504	–	–	–	–	–
Rosaceae	252	255	743	2254	659	11	155	1007	1804	1655	274	–	–
Saxifragaceae	–	–	186	1315	329	–	–	504	–	–	–	–	–
Monocotyledons													
Cyperaceae	40821	21179	20608	10516	6506	345	1739	21652	67222	70351	32663	76585	75287
Poaceae	756	5358	2414	4319	906	57	62	2014	2256	2069	2470	2349	4242
Pteridophytes and mosses													
Filicales	–	–	–	188	–	23	–	504	902	414	823	–	–
Lycopodium	–	–	186	188	–	–	–	1007	451	2483	274	–	–
Selaginella	–	–	–	–	–	–	–	–	–	–	274	470	–
Sphagnum	504	255	186	188	–	11	55	–	451	–	274	470	530

APPENDIX B: MORPHOLOGIC DESCRIPTIONS FOR SELECTED SOIL PROFILES FROM FISH CREEK SITE (K.R. Everett)

Profile 1

Pergelic Cryochrept

Topography	Upland-bluff adjacent to camp creek – slope angle ~0%.
Microrelief	Large diameter 8- to 10-m flat polygons with small (< 50-cm) diam low hummocks.
Drainage	Moderately well to well drained.
Vegetation	*Salix phlebophylla, Cassiope tetragona, Bistorta* sp., *Andromeda polifolia*, scattered *Carex* spp. Coverage 80%.
A1 0-4 cm	Dark reddish brown (5 YR 2.5/1)* organic fine sandy load (Fig. B1), friable, weak coarse sub-angular blocky structure, roots are common. Abrupt wavy/ruptic boundary.
A12 4-12 cm	Dark brown (7.5 YR 3/2) loamy fine sand, friable, weak medium sub-angular blocky structure, roots common. Abrupt wavy/ruptic boundary.
B21 12-19 cm	Dark brown (7.5 YR 4/4) medium sand, friable, structureless, roots few. Abrupt wavy boundary.
B22 12-24 cm	Olive brown (2.5 YR 4/4) medium to fine sand, friable, structureless, roots few. Abrupt wavy boundary.
BC/BCg 24-46 cm	Olive brown (2.5 YR 4/4) fine sand, sporadic small inclusions of black (10 YR 2/1) organic sand, friable, structureless, weak coarse dark yellowish brown (10 YR 4/4) mottles. Frost.

*Colors follow Munsell notation.

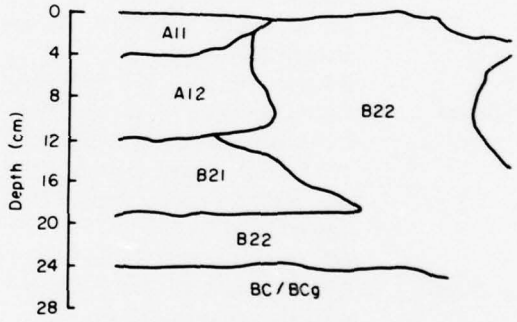


Figure B1. Soil Profile 1.

PRECEDING PAGE BLANK-NOT FILMED

Profile 3

Pergelic Cryaquept (provisional)

Topography	Low broad mounded area in drained lake basin, old sand dune area or hydrostatically uplifted area.
Microrelief	Low high-centered polygons (8- to 10-cm diam), trough depth 10 to 30 cm, small (<50-cm) hummocky polygonal cells (10-15 cm high).
Drainage	Moderately well-drained.
Vegetation	*Dryas integrifolia* mats, *Silene acaulis*, some scattered *Carex* ssp., and *cassiope tetragona* in troughs and inter-hummock cracks.
A1	Very dark brown (10 YR 2/2) organic loam, friable, weak medium granular structure, roots common. Abrupt ruptic boundary. pH 6.7,* organic carbon 16%.
C1 6-15 cm	Olive brown (2.5 Y 4/4) fine sand, friable, structureless, flecked with very dark greyish brown (10 YR 3/2) organic fine sand, roots common, pH 7.5, organic carbon 1%. Abrupt smooth boundary.
C2 15-38 cm	Olive brown (2.5 Y 4/4) fine sand, friable, structureless, sporadic fine inclusions of dark greyish brown (10 YR 3/2) organic material, roots few, pH 7.9, organic carbon 0.8%. Abrupt wavy boundary.
C3 38-71 cm	Olive brown (2.5 Y 4/4) fine sand, friable, structureless, roots absent, pH 8.0, organic carbon 1%.

Profile 4

Humic Pergelic Cryaquept

Topography	Flat area approximately 10 m from low ridge crest above string bog.
Microrelief	Well-developed sedge tussocks (*Eriophorum vaginatum?*) 15 cm+ high.
Drainage	Poorly drained.
Vegetation	*Eriophorum vaginatum* (?), *Salix phlebophylla, Salix* sp., mosses and lichens, scattered *Saussurea angustifolia, Bistorta* sp. and *Cassiope tetragona.*
Remarks	See Profile 9.
A1 0-6 cm	Dark brown (7.5 YR 3/2) organic fine sandy loam, friable, structureless or moderate medium granular structure, roots common, pH 6, organic carbon 11%. Abrupt wavy boundary.
AB 6-15 cm	Very dark greyish brown (10 YR 3/2) fine sandy loam mixed with dark brown (7.5 YR 3/2) organic loam and sporadic thin streaks of black (10 YR 2/1) organic material, friable, breaks to weak medium and coarse granular structure, roots common, pH 5.2, organic carbon 9%. Abrupt wavy boundary.
A1b 15-22 cm	Black (10 YR 2/1) highly decomposed (sapric) organic silt loam, friable, structureless, slight enmixture from AB horizon, pH 5.5, organic carbon 19%. Frost.

*Laboratory determination of pH in 1:1 soil/water mixture. Other pH values are field determinations in 1:5 soil/water mixture.

Profile 9

Taxonomically unassigned

Topography	Level area approximately 50 m back from stream bluffs and 150 m from camp.
Microrelief	Frost scar in transition area between reticulate microrelief (profile 1) and tussock/low-centered polygon microrelief (profile 4).
Drainage	Poorly drained.
Vegetation	Not recorded.
Remarks	Scar is apparently stable.
A1	Black (10 YR 2/1) organic silt,
0-3 cm	friable, weak fine granular structure, roots common, pH 5.1. Abrupt wavy to ruptic boundary.
B2 (?)	Dark brown (10 YR 3/3) very fine
3-10 cm	sand, friable, roots common, pH 5.8. Abrupt smooth boundary.
Cg	Dark greyish brown (2.5 Y 4/2) fine
10-41 cm	sand, friable, common fine distinct dark yellowish brown (10 YR 4/4) oxidation mostly between 10 and 18 cm, few roots, pH 5.4. Frost.

Profile 10

Pergelic Cryopsamment

Topography	Low solifluction bench area adjacent to Camp Creek.
Microrelief	Flat to rutted and uneven, 5-20 cm.
Drainage	Well-drained to moderately well-drained.
Vegetation	*Silene acaulis, Dryas intergrifolia,* scattered *Carex* sp. and grasses, sporadic coverage of other vascular plants. Coverage 20-80%.
Remarks	
A1	Black (10 YR 2/1) fine sand, friable,
0-3 cm	structureless, roots common, pH 7.4. Abrupt ruptic boundary (horizon is 9-10 cm thick in nonimpacted area).
B2	**Dark brown (10 YR 4/3)** fine sand,
3-9 cm	friable, structureless, roots few to absent, pH 7.9. Abrupt wavy to ruptic boundary.
C	Dark greyish brown (2.5 Y 4/2) fine
9-29 cm	sand, friable (some lenses of coarse and medium sand), moderate medium prismatic structure (cf. Meade River), pH 8.4.

Profile 11

Pergelic Cryaquent (provisional)

Topography	Thaw consolidated center of water haul road track (bladed) approximately 61 cm below surrounding unbladed tundra.
Microrelief	None present.
Drainage	Very poorly drained.
Vegetation	*Carex* sp., sporadic *Salix* sp. encroaching from sides.
Remarks	Bladed haul road (1949) – continuation of water haul road (profile 10)
Oi/C	Very dark greyish brown (10 YR 3/2)
0-2 cm	and very dark brown (10 YR 2/2) fibrous sedge fragments and roots in medium sand, pH 6.4, organic carbon 4%. Abrupt smooth boundary.
C1	Dark grey (5 Y 4/1) fine sand,
2-11 cm	wet, friable, weak diffuse dark grey (10 YR 4/1) mottles and strong prominent dark reddish brown (5 YR 3/4) oxidation rings around some roots, pH 6.6, organic carbon 0.3%. Abrupt smooth boundary.
IIC2	Dark grey (4 Y 4/1) fine sand, wet,
11-24 cm	friable, structureless, few strong prominent dark reddish brown (5 YR 2/4) oxidation rings around some roots, roots abundant, pH 6.8, organic carbon 0.3%. Abrupt smooth boundary.
IIIC3	Dark grey (5 Y 4/1) medium sand,
24+ cm	wet, friable, structureless. Boundary not observed as water fills pit to 20 cm. Frost at 71 cm.

Profile 12

Humic Pergelic Cryaquept

Topography	Mound built of bulldozed active layer material in 1949.
Drainage	Well- to moderately well-drained.
Vegetation	*Arctagrostis latifolia* 80% coverage.
Remarks	Sporadic salt concentrations on exposed surface.
A1 0-17 cm	Very dark greyish brown (10 YR 3/2) fine sandy loam, friable, medium and coarse subangular blocky structure, coarse roots abundant, pH 6.7, organic carbon 6%. Abrupt wavy boundary.
A12 17-27 cm	Dark brown (7.5 YR 3/2) fine sandy loam, friable, weak medium subangular blocky structure, roots abundant, pH 6.9, organic carbon 6%. Abrupt smooth boundary.
A13 27-42 cm	Black (10 YR 2/1) to very dark brown (10 YR 2/2) organic sapric, fine sand, friable, breaks to weak coarse subangular blocky structure, thin (½ cm) lens of yellowish brown (10 YR 5/4) fine sand, roots abundant, pH 6.5, organic carbon 11%. Frost.

Profile 13C

Pergelic Cryaquept (provisional)

Topography	Polygonized upland – appears to be degenerating.
Microrelief	Weakly developed high-centered polygons 8 to 10 m in diameter. 10 to 30 cm relief difference.
Vegetation	*Eriophorum vaginatum* tussocks.
Drainage	Poorly drained.
Remarks	See profile 13T.
O1 0-3 cm	Dark brown (7.5 YR 4/4) fibrous mat of moss and roots. Abrupt smooth boundary.
A1 3-5 cm	Black (10 YR 2/1) organic silt loam, friable, weak fine granular structure, roots abundant. At approximately 4 cm is a dark red (2.5 YR 3/6) band of oxidized iron. Abrupt smooth boundary.
B2 5-18 cm	Very dark grey (10 YR 3/2) fine sandy loam, friable, breaks to very weak medium subangular blocky structure, approximately 10% organic fragments, fine roots abundant. Abrupt smooth boundary.
A1b/Oe1 18-23 cm	Very dark brown (10 YR 2/2) hemic organic loam, 75% fibers that break down easily, roots common. Frost.

Profile 13T

Taxonomically unassigned

Microrelief	Approximately 15 cm below unaffected area.
Remarks	See profile 13 C. Tussocks appear to have been generally eliminated or if present still retain their compressed form. Profile includes a compressed tussock.
O1 0-4 cm	Dark yellowish brown (10 YR 3/4) fibrous organic (sedge) and very dark brown (10 YR 2/2) fibrous and granular organic matter. Abrupt wavy boundary.
A1 4-7 cm	Black (10 YR 2/1) organic silt loam, compact, somewhat friable, weak fine granular structure, few roots. Abrupt wavy boundary.
B2A/1b 7-15 cm	Very dark greyish brown (10 YR 3/2) fine sandy loam. Horizon corresponds approximately to 5- to 18-cm horizon of profile 13C. Lower 1 cm to 12-23 cm horizon. Frost.

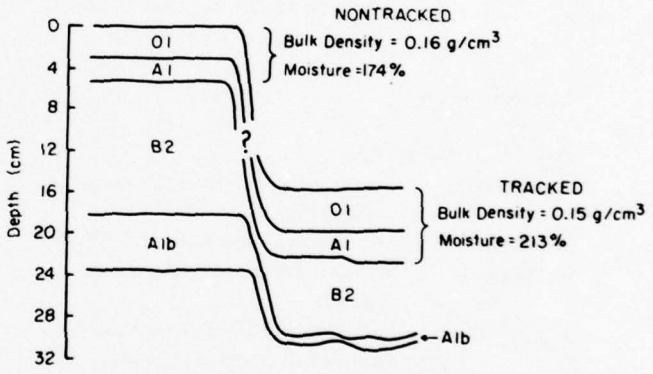


Figure B2. Soil Profile 13T. Compression due to vehicular traffic.

Profile 14A

Pergelic Cryofluvent (provisional)

Topography	Flood plain approximately 10 m from base of stream bluff.
Microrelief	None.
Drainage	Very poorly drained.
Vegetation	*Carex* sp.
Oi1 0-5 cm	Dark brown (10 YR 3/3) fibrous organic matter and roots, 30%+ fine sand, wet, friable. Abrupt smooth boundary.
Oi2(C2) 5-20 cm	Dark greyish brown (2.5 Y 4/2) coarse fibrous organic sand, fiber content 60% by volume, breaks down easily to <20% by volume, pH 5.4. Abrupt smooth boundary.
Oi3(C3) 18-46+ cm	Dark brown (2.5 Y 4/2) as above, weak fine platy structure, roots common. Boundary not observed due to flooding of pit. Frost estimated to 25 cm.

Profile 14B

Pergelic Cryofluvent (provisional)

Topography	See Profile 14A. Approximately 13 m from Camp Creek and about same distance from 14A.
Microrelief	None.
Drainage	Very poorly drained.
Vegetation	See Profile 14A.
Oi1 0-4 cm	Dark reddish brown (5 YR 3/2-2/2) coarsely fibrous organic, breaks down with difficulty. Abrupt smooth boundary.
C1 4-11 cm	Dark greyish brown (10 YR 4/2) coarsely fibrous organic sandy loam, fiber content 30% by volume, breaks down with difficulty to 10-20%, roots common, pH 5.3. Abrupt smooth boundary.
C2 11-17 cm	Dark greyish brown (2.5 Y 4/2) fibrous organic loam, fiber content 30%, breaks down with some difficulty to <10%, roots common, pH 5.4. Abrupt smooth boundary.
C3 17-23 cm	Dark greyish brown (2.5 Y 4/2) loamy fine sand, 15-20% fibrous organic matter, breaks down easily to <10%, roots few, pH 5.1. Abrupt smooth boundary.
C4(IIC4) 23-25 cm	Dark grey (5 Y 4/1) fine and medium sand, sedge fibers and few living roots <10% by volume, pH 5.6. Frost.

APPENDIX C: ALPHABETICAL LIST OF TAXA OF VASCULAR PLANTS COLLECTED AT FISH CREEK SITE (D.F. Murray)

Alopecurus alpinus Sm. ssp. *alpinus* 6588
Andromeda polifolia L. 6597
Androsace chamaejasme Host ssp. *lehmanniana* (Spreng.) Hult. 6605
Androsace septentrionalis L. 6626, 6663
Anemone parviflora Michx. 6618
Anemone richardsonii Hook. 6640
Antennaria alpina (L.) Gaertn. 6554, 6672
Arctagrostis latifolia (R.Br.) Griseb. ssp. *latifolia* 6538, 6692
Arctophila fulva (Trin.) Anderss. 6558
Arctous alpina (L.) Neid. 6608
Armeria maritima (Mill.) Willd. ssp. *arctica* (Cham.) Hult. 6621
Arnica frigida C.A. Meyer 6687
Artemisia arctica Less. ssp. *arctica* 6599
Artemisia borealis Pall. 6681
Artemisia tilesii Ledeb. ssp. *tilesii* 6670
Aster sibiricus L. 6686
Astragalus alpinus L. 6536
Astragalus umbellatus Bunge 6616
Betula nana L. ssp. *exilis* (Sukatsch.) Hult. 6516
Bistorta plumosa (Small) Greene 6546
Bistorta vivipara (L.) S.F. Gray 6572
Braya humilis (C.A. Meyer) Robins. ssp. *arctica* (Bocher) Rollins 6530, 6684
Bromopsis pumpelliana Scribn. ssp. *arctica* (Shear) Love & Love
Calamagrostis purpurascens R.Br. 6682
Caltha palustris L. ssp. *arctica* (R.Br.) Hult. 6701
Campanula uniflora L. 6638
Cardamine digitata Richards. 6584
Cardamine pratensis L. ssp. *angustifolia* (Hook.) Schulz 6634
Carex aquatilis Wahlenb. (including *C. stans* Drej.) 6537, 6604
Carex atrofusca Schkuhr 6649
Carex bigelowii Torr. (including *C. lugens* Holm.) 6526, 6559, 6594, 6600, 6648
Carex chordorrhiza Ehrh. 6602
Carex glareosa Wahlenb. ssp. *glareosa* 6574
Carex lachenalii Schkuhr 6573
Carex marina Dewey 6650
Carex maritima Gunnerus 6571, 6664
Carex membranacea Hook. 6614
Carex misandra Br. Br. 6529
Carex nardina E. Fries 6646
Carex rariflora (Wahlenb.) J.E. Sm. 6601
Carex rotundata Wahlenb. 6603
Carex rupestris Allioni 6697
Carex saxatilis L. ssp. *laxa* (Trautv.) Kalela 6575
Carex scirpoidea Michx. 6532
Carex vaginata Tausch 6586
Carex willamsii Britton 6613
Cassiope tetragona (L.) D. Don 6583
Castilleja caudata (Pennell) Rebr. 6693
Cerastium beeringianum Cham. & Schlecht. 6534, 6569
Chrysanthemum bipinnatum L. ssp. *bipinnatum* 6596, 6662
Chrysanthemum integrifolium Richards. 6653
Chrysosplenium tetrandrum (Lund) T. Fries 6542
Cochlearia officinalis L. ssp. *arctica* (Schlecht.) Hult. 6520, 6560
Comarum palustre L. 6625
Deschampsia cespitosa (L.) Beauv. 6632
Descurainia sophioides (Fisch.) Schulz 6661
Draba borealis DC. 6522
Draba cinerea Adams 6535, 6689
Draba corymbosa R.Br. ex DC. 6688
Draba glabella Pursh. 6690a
Draba lactea Adams 6521, 6577
Dryas integrifolia M. Vahl 6533
Dupontia fisheri R.Br. ssp. *fisheri* (= *D. pelligera* Rupr.) 6567
Empetrum nigrum L. ssp. *hermaphroditum* (Lange) Bocher 6611
Epilobium latifolium L. 6565
Equisetum arvense L. 6541
Equisetum variegatum Schleich. 6703
Erigeron eriocephalus J. Vahl 6620
Erigeron humilus Grah. 6669
Eriophorum angustifolium Honck. ssp. *subarcticum* (V. Vassiljev.) Hult. 6557
Eriophorum scheuchzeri Hoppe 6519, 6545, 6563
Eriophorum triste (T.Fr.) Hadac & Love 6691
Eriophorum vaginatum L. 6564
Eritrichum aretioides (Cham.) DC. 6673
Erysimum pallasii (Pursh) Fern. 6671
Eutrema edwardsii R. Br. 6423
Festuca baffinensis Polunin 6685
Festuca brachyphylla Schultes 6525
Festuca rubra L. ssp. *richardsonii* (R. Br.) Hult. 6589
Gastrolychnis apetala (L.) (Hook.) Tolm. & Kozh. 6561
Gentianella propinqua (Richards.) Gillett 6665
Hierochloe alpina (Sw.) Roem. & Schult. ssp. *alpina* 6552
Hierochloe pauciflora R.Br. 6595
Hippuris vulgaris L. 6641
Juncus arctica Willd. ssp. *alaskanus* Hult. 6677
Juncus biglumis L. 6657, 6676
Juncus castaneus Sm. ssp. *castaneus* 6543
Kobresia myosuroides (Vill.) Fiori & Paol. 6590
Kobresia sibirica Turcz. 6647
Koeleria asiatica Domin 6645, 6660
Ledum palustre L. ssp. *decumbens* (Ait.) Hult. 6582
Lupinus arcticus S. Wats. 6639
Luzula arctica Blytt 6550
Luzula confusa Lindeb. 6551
Luzula kjellmaniana Miyabe & Kudo 6549
Luzula wahlenbergii Rupr. ssp. *wahlenbergii* 6570
Lycopodium selago L. 6581
Minuartia rubella (Wahlenb.) Graebn. 6591
Oxyria digyna (L.) Hill 6652
Oxytropis arctica R.Br. 6544
Oxytropis borealis DC. 6666
Papaver lapponicum (Tolm.) Nordh. ssp. *occidentale* (Lundstr.) Knaben 6531
Papaver macounii Greene 6527, 6654
Parnassia kotzebuei Cham. & Schlecht. 6576
Parrya nudicaulis (L.) Regel ssp. *septentrionalis* Hult. 6637
Pedicularis capitata Adams 6617
Pedicularis langsdorffii Fisch. ssp. *arctica* (R.Br.) Pennell 6633
Pedicularis sudetica Willd. ssp. *albolabiata* Hult. 6598

Petasites frigidus (L.) Franch. 6636
Phippsia algida (Soland.) R.Br. 6518
Poa alpigena (E. Fries) Lindm. 6698
Poa glauca M. Vahl 6592, 6630
Poa malacantha Komarov 6517, 6566, 6628
Poa sp. 6667
Polemonium acutiflorum Willd. 6587
Polemonium boreale Adams ssp. *boreale* 6619
Potentilla hookeriana Lehm. ssp. *hookeriana*
Potentilla hyparctica Malte 6699
Puccinellia andersonii Swallen 6675
Pyrola grandiflora Radius 6606
Ranunculus gmelinii DC. 6696
Ranunculus nivalis L. 6700
Ranunculus pallasii Schlecht. 6578
Ranunculus pedatifidus Sm. ssp *affinis* (R.Br.) Hult. 6528, 6658
Rubus chamaemorus L. 6607
Salix alaxensis (Anderss.) Cov. ssp. *alaxensis* 6679
Salix arctica Pall. 6622, 6643
Salix brachycarpa Nutt. ssp. *niphoclada* (Rydb.) Argus 6680
Salix glauca L. var. *glauca* 6623, 6668
Salix lanata L. ssp. *richardsonii* (Hook.) Skvortz. 6539
Salix phlebophylla Anderss. 6556
Salix planifolia Pursh ssp. *pulchra* (Cham.) Argus var. *pulchra* 6540
Salix reticulata L. 6612
Salix rotundifolia Trautv. 6642
Saussurea angustifolia (Willd.) DC. 6651
Saxifraga caespitosa L. 6655
Saxifraga cernua L. 6585
Saxifraga hieracifolia Waldst. & Kit. 6624
Saxifraga hirculus L. 6553
Saxifraga nelsoniana D. Don 6548
Saxifraga nivalis L. 6694
Saxifraga rivularis L. (including *S. hyperborea* R. Br.) 6579
Senecio atropurpureus (Ledeb.) Fedtsch 6547, 6593 an unusual branched form
Senecio congestus (R.Br.) DC. 6568
Silene acaulis L. ssp. *acaulis* 6659
Sparganium hyperboreum Laest. 6702
Stellaria edwardsii R.Br. 6562
Stellaria laeta Richards. 6555
Taraxacum alaskanum Rydb. 6695
Taraxacum phymatocarpum J. Vahl 6683
Taraxacum sp. 6635, 6674
Tofieldia pusilla (Michx.) Pers. 6610
Trisetum spicatum (L.) Richt. ssp. *spicatum* 6524
Utricularia vulgaris L. ssp. *macrorhiza* (Le Conte) Clausen
Vaccinium uliginosum L. ssp. *microphyllum* Lange 6615
Vaccinium vitis-idaea L. ssp. *minus* (Lodd.) Hult. 6609
Valeriana capitata Pall. 6644
Wilhelmsia physodes (Fisch.) McNeill 6656, 6678

APPENDIX D: ALPHABETICAL LIST OF BRYOPHYTES AND LICHENS COLLECTED AT FISH CREEK SITE (B.M. Murray)

Bryophytes

Hepatics

(The hepatics were identified by H. Inoue, National Science Museum, Tokyo, Japan.)

Anastrophyllum cavifolium (Buch & Arnell) Lammes
(= *Lophozia cavifolia*)
S: 77-881, 897, 980
AWJ-3, 4, 9
Upland and high-centered polygons

Anastrophyllum minutum (Schreb.) Schust.
S: 77-868, 873, 927
AWJ-3
Under drums, boards and on turf over concrete pad.

Aneura pinguis (L.) Dum.
S: 77-829, 897, 904. C: 77-1045, 1046
AWJ-1, 4
On side of berm of bladed trail, in burrow area and in *Cassiope* heath near stream.

Anthelia juratzkana (Limpr.) Trev.
C: 77-1093, 1228, 1232
Stream bank.

Arnellia fennica (Gott.) Lindb.
C: 77-1060
Cassiope heath on ridge.

Blepharostoma trichophyllum (L.) Dum.
S: 77-794, 892, 904, 934, 980, 994, 1104. C: 77-1044, 1209
AWJ-4, 9, 12
Sheltered under drums and on tussocks, hummocks, heath, upland and polygons.

Cephalozia pleniceps (Aust.) Lindb.
S: 77-799, 895, 904, 1007. C: 77-1044.
AWJ-1, 4, 14
Top of berm of bladed trail, wet meadow and in heath near stream.

Cephaloziella arctica Bryhn & Douin
S: 77-1024
On bare sandy soil, oil spill area.

Diplophyllum taxifolium (Wahlenb.) Dum.
S: 77-897
AWJ-4
High-centered polygons.

Lophozia collaris (Nees) Dum.
S: 77-812
AWJ-1
On berm of bladed trail.
According to H. Inoue (*in litt.*, April 1978) this species is new to Alaska.

Lophozia ehrhartiana (Web.) Inoue & Steere (= *L. alpestris*)
C: 77-1046
Cassiope heath near stream.

Lophozia grandiretis (Lindb.) Schiffn.
S: 77-861, 973
AWJ-3, 8
Upland and berm at edge of bladed trail.

Lophozia heterocolpa (Thed.) M.A. Howe
C: 77-1229
Stream bank.

Lophozia opacifolia Culm.
S: 77-914. C: 77-1224.
AWJ-4
High-centered polygons and ridge.

Lophozia quadriloba (Lindb.) Evans
S: 77-915, 1023. C: 77-1231
AWJ-4, 9
High-centered polygons, wet sedge meadow, and stream bank.

Lophozia ventricosa (Dicks.) Dum.
C: 77-1210
Heath.

Lophozia ?wenzelii (Nees) Steph.
S: 77-973
AWJ-8
Berm at edge of bladed trail.

Mannia fragrans (Balbis) Frye & Clark
C: 77-1239. B: 77-1146, 1165
River banks and steep sandy bluff.

Marchantia polymorpha L.
S: 77-822, 845, 880, 990, 1024
AWJ-1, 3, 10
Bladed trail, wet sedge meadow, bare sandy soil in oil spill area.

Marsupella arctica (Berggr.) Bryhn & Kaal.
S: 77-811
AWJ-1
On berm of bladed trail.

Odontoschisma macounii (Aust.) Underw.
C: 77-1046, 1125
Cassiope heath near stream and center of low-centered polygon, wet sedge meadow.

Prelssia quadrata (Scop.) Nees
C: 77-1096
North-facing bank near stream.

Ptilidium ciliare (L.) Hampe
S: 77-786, 827. C: 77-1210, 1230
AWJ-1
Side of berm of bladed trail, among tussocks, heath, and stream bank.

Riccardia latifrons Lindb.
C: 77-1114
Wet sedge meadow.

Scapania degenii Schiffn. *ex* K. Muell.
S: 77-997
AWJ-12
Sedge tussock-heath on high-centered polygons.

Scapania parvifolia Warnst.
C: 77-1210
Heath.

Tritomaria quinquedentata (Huds.) Buch
S: 77-958, 994

AWJ-6, 12
Sedge tussock-heath on high-centered polygons.

Mosses

Aplodon wormskjoldii (Hornem.) R.Br.
S: 77-796
Bladed trail (AWJ-1, 2), in erosional ditch or melting ice-wedge.

Aulacomnium acuminatum (Lindb. & Arnell) Kindb.
C: 77-1027. B: 77-1190
Heath and bluff.

Aulacomnium palustre (Hedw.) Schwaegr.
S: 77-783, 806, 878, 885. C: 77-1066, 1081, 1100.
AWJ-3, 4
Wet sedge meadow, heath, sandy burrow area, berm of bladed trail (AJW 1, 2).

Aulacomnium turgidum (Wahlenb.) Schwaegr.
S: 77-779, 783, 786, 878, 884, 890, 977, 998, 1002.
C: 77-1120. B: 77-1190.
AWJ-3, 4, 9, 12, 13
Tussocks, wet sedge meadow, heath, bluff.

Barbula sp. nov.?
S: 77-813B, det. R.H. Zander, 1978
AWJ-1
On berm of bladed trail.
I have collected this taxon also in the Brooks Range near Galbraith Lake and the Alatna River.

Bartramia ithyphylla Brid.
C: 77-1059, 1161
Heath.

Brachythecium spp.
Several collections have not yet been identified.

Bryobrittonia longipes (Mitt.) Horton (= *B. pellucida*)
S: 77-849. B: 77-1163
AWJ-2
Wet meadow in bladed trail and low, periodically flooded river bank.

Bryoerythrophyllum recurvirostrum (Hedw.) Chen
S: 77-810, 815. C: 77-1088
AWJ-1
Berm and side of berm of bladed trail and rich grassy knoll with ground squirrel burrow.

Bryum spp.
Most *Bryum* collections have not yet been identified. Many are sterile and difficult to determine.

Bryum cryophilum Mårt.
S: 77-1010
AWJ-14
Wet meadow.

Calliergon spp.
Several collections have not been identified.

Calliergon giganteum (Schimp.) Kindb.
C: 77-944, 1092
In stream.

Calliergon richardsonii (Mitt.) Kindb. *ex* Warnst.
S: 77-855. C: 77-1105
Wet meadow, including bladed trail (AWJ-1).

Campylium arcticum Williams
S: 77-767, 854, 928. B: 77-1187
Wet meadow, including trail (AWJ-1) and on wood and rotting canvas.

Campylium stellatum (Hedw.) C. Jens.
S: 77-758, 853, 985, 1013, 1017. C: 77-1107, 1238
AWJ-10
Wet meadow, including bladed trail (AWJ-1, 2) and heath. In garbage dump and on concrete from cement bag dump at site.

Catoscopium nigritum (Hedw.) Brid.
C: 77-1115
Wet sedge meadow.

Ceratodon purpureus (Hedw.) Brid.
S: 77-756, 762, 766, 771, 874, 876, 880, 924, 925, 935, 964, 993, 1016. C: 77-1075, 1086
AWJ-3, 12
Frequent at Test Well on bare soil where oil was spilled and on various substrates (wood, airplane fabric, rotting canvas, turf over concrete, concrete); also in heath and rich grassy knoll with ground squirrel burrow.

Cinclidium spp.
Several collections have not yet been identified.

Cinclidium subrotundum Lindb.
S: 77-782, 787
Tussock and wet sedge meadow.

Cirriphyllum cirrosum (Schwaegr. *ex* Schultes) Grout
B: 77-1180
Bluff.

Climacium dendroides (Hedw.) Web. & Mohr
C: 77-945
Periodically flooded stream bank.

Conostomum tetragonum (Hedw.) Lindb.
C: 77-1041
Depression in heath.

Cyrtomnium
Collections have not yet been identified.

Desmatodon heimii (Hedw.) Mitt.
S: 77-816
Side of berm of bladed trail (AWJ-1, 2).

Dicranella crispa (Hedw.) Schimp.
S: 77-817
Side of berm of bladed trail (AWJ-1, 2).

Many *Dicranum* specimens have only been tentatively identified as yet and are not reported here.

Dicranum elongatum Schleich. *ex* Schwaegr.
C: 77-1077, 1225
Ridge and sedge-forb meadow.

Dicranum groenlandicum Brid.
S: 77-858, 893, 1022
AWJ-3, 4, near 9
Wet sedge meadows, often in *Sphagnum* hummock.

Dicranum scoparium Hedw.
S: 77-886
AWJ-4
Heath.

Didymodon cf. *acutus* (Brid.) K. Saito
S: 77-825, det. R.H. Zander, 1978
AWj-1
Side of berm of bladed trail.
This species has apparently not been reported for Alaska.

Distichium capillaceum (Hedw.) B.S.G.
S: 77-818, 831, 847, 1014. C: 77-1034, 1057, 1100.
B: 77-1129, 1148, 1180, 1182
Side of berm and wet meadow of bladed trail (AWJ-1, 2), heath, rich grassy knoll with ground squirrel burrow, and sandy bluffs and terraces. Also on concrete at cement bag dump.

Distichium hagenii Ryan *ex* Philib.
S: 77-824
Side of berm of bladed trail (AWJ-1, 2) at animal burrow.

Ditrichum flexicaule (Schwaegr.) Hampe
B: 77-1153
Sandy bluff.

Several *Drepanocladus* collections have not yet been identified.

Drepanocladus revolvens (Sw.) Warnst.
S: 77-764, 784, 839, 844, 894, 900, 899.
C: 77-1102, 1105, 1108, 1116. B: 77-1175
AWJ-4, 10
Wet sedge meadows, including bladed trail (AWJ-1, 2) and on airplane fabric.

Drepanocladus uncinatus (Hedw.) Warnst.
S: 77-761, 828, 923, 929, 991.
C: 77-947, 1072, 1213. B: 77-1188, 1190
AWJ-12
Stream bank, heath and bluff. At Test Well site in areas with animal droppings and burrows and on wood, airplane fabric, and wet canvas.

Encalypta alpina Sm.
S: 77-824
Side of berm of bladed trail (AWJ-1) in burrow area.

Encalypta procera Bruch
B: 77-1142, 1145, 1147
Steep sandy bluff.

Encalypta rhaptocarpa Schwaegr.
C: 77-1062, 1079. B: 77-1129, 1139
Heath and sandy burrow area and sandy bluff.

Fissidens osmundoides Hedw.
S: 77-987. C: 77-1069, 1113, 1122
AWJ-10
Wet sedge meadow and sedge-forb meadow.

Funaria arctica (Berggr.) Kindb.
S: 77-809, 826. B: 77-1197
On berm and side of berm of bladed trail (AWJ-1) in burrow area and in slump on sandy bluff.

Hylocomium splendens (Hedw.) B.S.G.
S: 77-886. C: 77-1026, 1050, 1070, 1073, 1202
AWJ-4
Heath.

Hypnum collections have not yet been identified.

Leptobryum pyriforme (B.S.G.) Wils.
S: 77-766, 795, 820, 840A, 930, 965, 1012, 1015.
B: 77-1193, 1199
AWJ-7
Wet meadow and berm of bladed trail (AWJ-1, 2) on soil at oil spill, in garbage drums, on concrete at cement bag dump, on wet and rotting canvas and on sandy bluff and in slump at bluff.

Meesia triquetra (Richt.) Aongstr.
S: 77-784, 835. C: 77-1105, 1117
Wet sedge meadow, including bladed trail (AWJ-1, 2).

Meesia uliginosa Hedw.
C: 77-1097
Wet meadow, center of low-centered polygon.

Mnium collections have not yet been identified.

Myurella julacea (Schwaegr.) B.S.G.
C: 77-1115
Wet sedge meadow.

Myurella tenerrima (Brid.) Lindb.
C: 77-1057
Heath.

Oncophorus wahlenbergii Brid.
S: 77-786, 894, 900, 986, 1008. C: 77-1069, 1101, 1119, 1227
AWJ-4, 10, 14
Tussocks, wet sedge meadow, sedge-forb meadow, and heath.

Orthothecium chryseum (Schwaegr. *ex* Schultes) B.S.G.
C: 77-1111
Hummock in wet sedge meadow.

Orthothecium strictum Lor.
B: 77-1181
Heath.

Paludella squarrosa (Hedw.) Brid.
C: 77-945, 946, 1235
Heath and periodically flooded stream bank.

One specimen of *Philonotis* from heath has not yet been identified.

Several specimens of *Pohlia* have not yet been identified.

Pohlia bulbifera (Warnst.) Warnst.
S: 77-870
AWJ-3
Under boards, much microtine sign.

Pohlia cruda (Hedw.) Lindb.
S: 77-760, 869B, 933
AWJ-3
Under barrels, some microtine sign and on airplane fabric.

Pohlia nutans (Hedw.) Lindb.
S: 77-779
In crack in melting ice-wedge polygon.

Pohlia proligera (Kindb. *ex* Limpr.) Lindb. *ex* Arnell
S: 77-869
AWJ-3
Under boards, much microtine sign.

Polytrichastrum alpinum (Hedw.), G.L. Smith
S: 77-830, 865, 913, 963, 1005
AWJ-3, 4, 6, 14
Side of berm of bladed trail (AWJ-1) near animal burrows and wet meadow.

Polytrichum commune s. lat.
C: 77-949
Periodically flooded stream bank.

Polytrichum hyperboreum R.Br.
S: 77-913, 963
AWJ-4, 6
Heath.

Polytrichum juniperinum Hedw.
S: 77-877, 999. C: 77-1078
AWJ-3, 12
Heath and sedge-forb meadow.

Polytrichum strictum Brid.
S: 77-864, 893
AWJ-3, 4
Heath, in depressions.

Psilopilum cavifolium (Wils.) Hag.
S: 77-798, 823, 879, 902, 942. B: 77-1192, 1198
AWJ-3, 4
Top and side of berm of bladed trail (AWJ-1, 2), under wood, on bluff and in slump. Frequent at Test Well site.

Rhacomitrium lanuginosum (Hedw.) Brid.
S: 77-886. C¾ 77-1026
AWJ-4
Heath.

Rhytidium rugosum (Hedw.) Kindb.
S: 77-884. C: 77-1026, 1071, 1089. B: 77-1189
AWJ-4
Dominant moss on rich grassy knoll with ground squirrel burrow, also in heath and on bluff.

Scorpidium scorpioiodes (Hedw.) Limpr.
S: 77-785. C: 77-943, 1092, 1098, 1099, 1110
Wet sedge meadow and in stream.

Sphagnum aongstroemii C. Hartm.
S: 77-774
Forming lawn in wet meadow.

Sphagnum balticum (Russ.) Russ. *ex* C. Jens.
S: 77-912
AWJ-4
Among tussocks in heath.

Sphagnum capillifolium (Ehrh.) Hedw. var. *tenellum* (Schimp.) Crum (= *S. capillaceum* var. *tenellum*)
S: 77-791, 901, 911, 979. C: 77-950, 954
AWJ-3, 9
On hummocks, centers of high-centered and ice-wedge polygons and on stream bank.

Sphagnum fimbriatum Hook. & Wils.
S: 77-907, 909, 1001, 1011, 1021. C: 77-1124, 1223
AWJ-4, near 9, 13, 14
Hummocks in wet sedge meadows and on ridge.

Sphagnum girgensohnii Russ.
S: 77-910, det H. Crum, 1978
AWJ-4
Hummock in wet sedge meadow

Sphagnum imbricatum Hornsch. *ex* Russ.
S: 77-776
Edge of tundra pool.

Sphagnum squarrosum Crome
S: 77-787, 790, 805, 1020
AWJ-near 9
On berm of bladed trail (AWJ-1, 2) and on hummocks in wet sedge meadow.

Splachnum sphaericum Hedw.
S: 77-841
On dung in bladed trail, wet meadow.

Splachnum vasculosum Hedw.
S: 77-8408
On dung in bladed trail, wet meadow.

Tetraplodon mnioides (Hedw.) B.S.G.
S: 77-887, 992. C: 77-1203
AWJ-4, 12
Heath.

Tetraplodon pallidus Hag.
S: 77-786, 840
AWJ-1, 2
On dung on tussock and in wet meadow of bladed trail.

Tetraplodon paradoxus (R.Br.) Hag.
S: 77-764, 778, 786, 840A
On dung on tussock and in wet meadow of bladed trail (AWJ-1, 2), also on airplane fabric and in crack of melting ice-wedge.

Thuidium abietinum (Hedw.) B.S.B.
C: 77-1050, 1081, 1089, 1200. B: 77-1179
Heaths and animal burrow areas.

Tomenthypnum nitens (Hedw.) Loeske
S: 77-840A, 842. C: 77-951, 1032, 1050, 1100, 1201, 1214. B: 77-1190
Wet meadow of bladed trail (AWJ-1, 2), heath, stream bank, bluff, and margin of low-centered ice-wedge polygon.

Tortella fragilis (Drumm.) Limpr.
C: 77-1118, 1205. B: 77-1178, 1183
Wet sedge meadow, heath, and bluff.

Tortula ruralis (Hedw.) Gaertn., Meyer & Scherb.
S: 77-927. C¼ 77-1085. B: 77-1128, 1143
On turf over concrete, rich grassy knoll with ground squirrel burrow, and sandy bluff and blowouts.

Lichens

Several ***Alectoria*** collections have not yet been identified.

Alectoria nigricans (Ach.) Nyl.
S: 77-899, 908. B: 77-1137
AWJ-4
Heath and sandy bluff.

Alectoria nitidula (Th. Fr.) Vain.
S: 77-899
AWJ-4
Heath.

Alectoria ochroleuca (Hoffm.) Mass.
S: 77-862, 889, 1004. C: 77-1031, 1067
AWJ-3, 4, 13
Heath and sedge-forb meadow.

Asahinea chrysantha (Tuck.) W. Culb. & C. Culb.
C: 77-1027
Heath.

Several *Caloplaca* collections have not yet been identified.

Caloplaca stillicidiorum (Vahl) Lynge
S: 77-937, 938
On board and on turf over oil drum.

Cetraria cucullata (Bell.) Ach.
S: 77-801, 862, 889, 924, 981, 1000, 1004.
C: 77-1029, 1065, 1067, 1071, 1218. B: 77-1143, 1185
AWJ-3, 4, 9, 12, 13, 14
Berm of bladed trail (AWJ-1, 2) heath, sedge-forb meadow, rich grassy knoll with ground squirrel burrow, bluff; also on wood at Test Well site.

Cetraria delisei (Bory *ex* Schaer.) Th. Fr.
C: 77-1042, 1220
Heath, in depressions.

Cetraria islandica (L.) Ach.
S: 77-802, 862, 886, 889, 924, 1000.
C: 77-1033, 1071, 1219
AWJ-3, 4, 12
On berm of bladed trail, heath, rich grassy knoll with ground squirrel burrow, also on wood at Test Well site.

Cetraria nivalis (L.) Ach.
C: 77-1029, 1217. B: 77-1186
Heath and bluff.

Cetraria orbata (Nyl.) Fink
S: 77-753A, determination verified by T.L. Esslinger.
On exposed board.
It is interesting that Weber, Erdman and Krog (1969) in reporting *C. ciliaris* (*C. orbata*) from Amchitka Island, said, "On a felled utility pole; possibly an adventive species introduced during World War II occupation."

Cetraria pinastri (Scop.) S. Gray
S: 77-754
On exposed board, totally sorediate thallus.

Cetraria sepincola (Ehrh.) Ach.
S: 77-753B, det. T.L. Esslinger.
On exposed board.

Cladina spp. which were very rare, have not been identified.

Most *Cladonia* collections have not yet been identified.

Cladonia chlorophaea (Floerke *ex* Somm.) Spreng.
S: 77-867
AWJ-3
Heath.

Cladonia elongata (Jacq.) Hoffm.
S: 77-921
AWJ-4
Heath.

Cladonia pleurota (Floerke) Schaer.
S: 77-972
AWJ-8
Berm of bladed trail (AWJ-1, 2).

Cladonia pocillum (Ach.) O. Rich.
S: 77-1025. C: 77-1058, 1083, 1090, 1208. B: 77-1159
Heath, bluff and burrow areas.

Coriscium viride (Ach.) Vain
S: 77-1019
In *Sphagnum fimbriatum* hummock, wet sedge meadow.

Cornicularia divergens Ach.
S: 77-1004. C: 77-1031, 1065
AWJ-13
Heath.

Dactylina arctica (Hook.) Nyl.
S: 77-862, 889, 981, 1000, 1004. C: 77-1067, 1071, 1218
AWJ-3, 4, 9, 12, 13, 14
Heath and sedge-forb meadow.

Dactylina ramulosa (Hook.) Tuck.
C: 77-1048
Heath near stream.

Lecanora epibryon (Ach.) Ach.
C: 77-1052. B: 77-1144, 1172, 1184
Heath, bluff, and overbank deposits.

Lobaria linita (Ach.) Rabenh.
C: 77-1030, 1070, 1214
Heath.

Masonhalea richardsonii (Hook.) Kärnefelt (= *Cetraria richardsonii*)
C: 77-1084, 1214. B: 77-1151
Heath, rich grassy knoll, in sheltered site and on steep sandy bluff.

Nephroma arcticum (L.) Torss.
C: 77-1103
Margin of low-centered ice-wedge polygon.

Nephroma expallidum (Nyl.) Nyl.
C: 77-1082, 1206
Heath and sandy burrow area.

Ochrolechia frigida (Sw.) Lynge f. *thelephoroides* (Th. Fr.) Lynge
S: 77-859, 879. C: 1051
AWJ-3
Heath and under boards in area of microtine sign.

Ochrolechia upsaliensis (L.) Mass.
C: 77-1054
Heath.

Pannaria pezizoides (G. Web.) Trev.
S: 77-888. C: 77-1095, 1234
AWJ-4
Heath and stream bank.

Parmelia olivacea (L.) Ach.
S: 77-753B, det. T.L. Esslinger.
On exposed board.

Peltigera aphthosa (L.) Willd.
S: 77-788. C: 77-1032
Tussocks and heath.

Peltigera lepidophora (Nyl.) Vain.
S: 77-765
On airplane fabric.

Peltigera leucophlebia (Nyl.) Gyeln.
S: 77-917
AWJ-4
Heath.

Peltigera malacea (Ach.) Funck
S: 77-857, 917
AWJ-3, 4
Heath.

Peltigera cf. *spuria* (Ach.) DC.
B: 77-1149
Steep sandy bluff.

Pertusaria bryontha (Ach.) Nyl.
C: 77-1208
Heath.

Solorina bispora Nyl.
C: 77-1215. B: 1150
Heath and steep sandy bluff.

Solorina octospora Arn.
C: 77-1049
Heath, near stream.

Solorina spongiosa (Sm.) Anzi
C: 77-1056
Heath.

Sphaerophorus globosus (Huds.) Vain.
S: 77-862. C: 77-1026
AWJ-3
Heath.

Stereocaulon specimens have not been identified.

Thamnolia
S: 77-803, 889, 924, 981, 1000. C: 77-1028, 1217.
B: 77-1185
AWJ-4, 9, 12, 14
Berm of bladed trail (AWJ-1, 2), heath, and bluff; also on wood at Test Well site.
Specimens have not yet been tested with ultraviolet light to determine whether they are referrable to *T. vermicularis* or *T. subuliformis*.

APPENDIX E: VASCULAR PLANT COMPOSITION AND PERCENTAGE COVER IN RELEVÉS REPRESENTATIVE FOR THE FISH CREEK MAPPING UNITS (V. Komárková and P.J. Webber)

Mapping unit number	*1*		*2*	*5*		*6*		*7*		*8*		*10*		*Area too small for a mapping unit*	
Vegetation classification	*Evergreen dwarf scrub*		*Seasonal short grass*	*Evergreen dwarf scrub*	*Deciduous dwarf scrub*	*Deciduous shrub savanna*		*Deciduous shrub savanna*		*Seasonal short grass*		*Deciduous dwarf scrub*	*Seasonal short grass*	*Seasonal short grass*	*Seasonal open submerged meadow*
Landform	*Ridge*		*Upland*	*Snowpatch*		*Lowland*		*Stränge in Strangmoor*		*Marsh*		*Man-disturbed ground*		*Arctic ground squirrel mound*	*Stream*
Relevé	*6*	*9*	*1*	*2*	*5*	*4*	*13*	*10*	*3*	*11*	*12*	*14*	*15*	*8*	*7*
Alopecurus alpinus ssp. *alpinus*	•	•	•	•	•	•	•	•	•	•	•	+	•	•	•
Alsinanthe rossii (R.Br.) Löve & Löve (= *Minuartia rossii* (R.Br.) Graebn.	•	•	•	-	•	•	•	•	•	•	•	•	•	•	•
Androsace chamaejasme Host ssp. *lehmanniana* (Spreng.) Hultén	•	•	•	•	•	•	•	•	•	•	•	•	•	+	•
Androsace septentrionalis L.	•	•	•	•	•	•	•	•	•	•	•	•	•	-	•
Antennaria monocephala DC. ssp. *angustata* (Greene) (= *Antennaria angustata* Greene)	•	•	•	2	•	•	•	•	•	•	•	•	•	•	•
Arctagrostis arundinacea (Trin.) Beal	•	•	+	•	1	•	+	•	•	•	•	18	•	•	•
Arctagrostis latifolia (R.Br.) Griseb., s.str. [= *Arctagrostis latifolia* (R.Br.) Griseb. var. *latifolia*]	•	•	•	•	•	•	•	•	•	•	•	•	30	•	•
Arctophila fulva (Trin.) Anderss.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	+
Arctous alpina (L.) Niedenzu ssp. *rubra* (Rehd. & Wils.) Hultén [= *Arctostaphylos rubra* (Rehd. & Wils.) Fern.]	•	•	•	•	•	•	+	•	•	•	•	•	•	•	•
Artemisia arctica Less., s.str.	•	•	•	•	•	•	•	•	•	•	•	3	•	•	•
Astragalus alpinus L. var. *alpinus*	•	•	•	+	•	•	•	•	•	•	•	12	•	1	•
Astragalus umbellatus Bge.	+	10	•	•	•	•	•	•	•	•	•	4	•	•	•
Betula nana L. ssp. *exilis* (Sukacz.) Hultén	•	•	+	•	•	2	•	•	•	•	•	•	•	•	•
Bistorta plumosa (Small) Greene [= *Polygonum bistorta* L. ssp. *plumosum* (Small) Hultén]	•	-	2	4	2	1	•	•	•	•	•	•	2	•	•
Bistorta vivipara (L.) S.F. gray, s.str. (= *Polygonum viviparum* L.)	•	+	-	•	•	1	1	1	•	•	1	+	•	•	•
Caltha minor Mill. ssp. *arctica* (R.Br.) Löve & Löve (= *Caltha arctica* R.Br.)	•	•	•	•	•	•	•	•	2	•	•	•	•	•	2

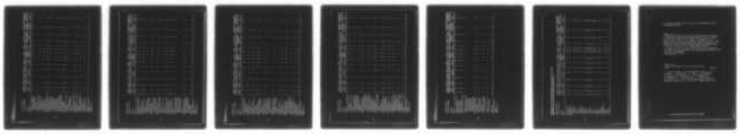
+ Present but less than 1%.
• Absent.
- Single plants only.

PRECEDING PAGE BLANK-NOT FILMED

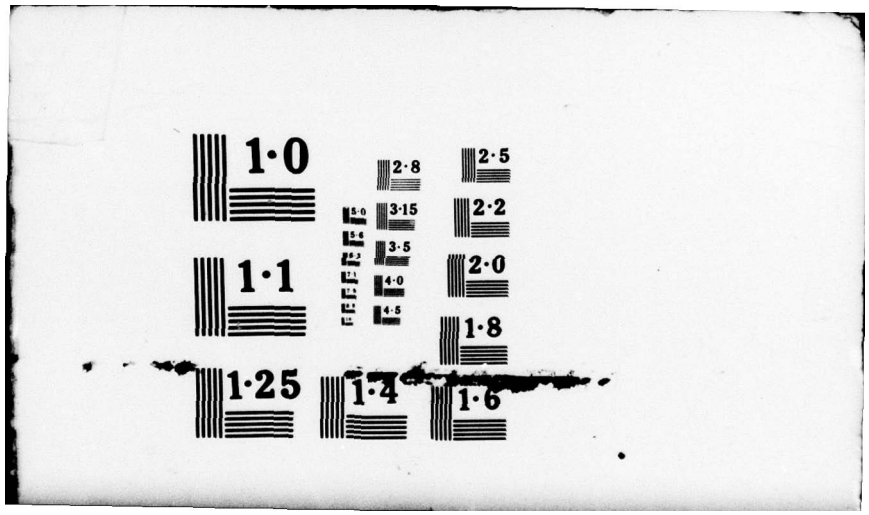
AD-A065 192 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 15/7
TUNDRA DISTURBANCES AND RECOVERY FOLLOWING THE 1949 EXPLORATORY--ETC(U)
DEC 78 D E LAWSON, J BROWN, K R EVERETT

UNCLASSIFIED CRREL-78-28 NL

2 OF 2
ADA
065192



END
DATE FILMED
4-79
DDC


1·0
1·1
1·25
1·4
1·6
1·8
2·0
2·2
2·5
2·8
3·15
3·5
4·0
4·5

Mapping unit number	1		2	5		6		7		8		10		Area too small for a mapping unit	
Vegetation classification	Evergreen dwarf scrub		Seasonal short grass	Evergreen dwarf scrub	Deciduous dwarf scrub	Deciduous shrub savanna		Deciduous shrub savanna		Seasonal short grass		Deciduous dwarf scrub	Seasonal short grass	Seasonal short grass	Seasonal open submerged meadow
Landform	Ridge		Upland	Snowpatch		Lowland		Sträuche in Strangmoor		Marsh		Man-disturbed ground		Arctic ground squirrel mound	Stream
Relevé	6	9	1	2	5	4	13	10	3	11	12	14	15	8	7
Cardamine nymanii Gandoger [= *Cardamine pratensis* L. ssp. *angustifolia* (Hook.) O.E. Schulz]	•	•	•	•	•	•	-	•	•	•	•	•	•	•	•
Cardamine richardsonii Hultén (= *Cardamine hyperborea* O.E. Schulz, p.p.)	•	•	+	•	+	+	+	-	•	•	•	•	•	•	•
Carex aquatilis Wg. ssp. *stans* (Drejer) Hultén	•	•	•	3	•	5	20	35	60	70	8	1	2	•	3
Carex atrofusca Schkuhr	•	•	•	•	•	•	1	•	•	•	•	•	•	•	•
Carex bigelowii Torr. ssp. *bigelowii*	•	•	2	•	+	15	35	6	•	•	•	•	5	•	•
Carex chordorrhiza Ehrh.	•	•	•	•	o	•	•	•	+	•	+	•	•	•	•
Carex fuliginosa Schkuhr ssp. *misandra* (R.Br.) W. Dietr. (= *Carex misandra* R.Br.)	•	•	•	•	•	•	+	+	•	•	•	-	•	•	•
Carex lachenalii Schkuhr (= *Carex tripartita* All.)	•	•	•	1	•	•	•	•	•	•	5	•	•	•	•
Carex membranacea Hook.	•	•	•	+	•	•	•	•	•	•	•	•	•	•	•
Carex nardina Fr. ssp. *hepburnii* (Boott) Löve, Löve & Kapoor	1	•	•	•	•	•	•	•	•	•	•	•	•	2	•
Carex rariflora (Wg.) Sm., s.str.	•	•	•	•	•	•	•	•	4	•	5	•	•	•	•
Carex rotundata Wg.	•	•	•	•	•	•	•	•	•	2	•	•	•	•	•
Carex rupestris All.	3	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Carex saxatilis L. ssp. *laxa* (Trautv.) Kalela, s.str.	•	•	•	•	•	•	•	•	•	-	-	•	•	•	•
Carex scirpoidea Michx. ssp. *stenochlaena* (Holm) Löve & Löve	•	1	•	•	+	•	•	•	•	•	-	+	•	•	•
Carex vaginata Tausch ssp. *vaginata*	•	•	•	•	•	•	•	-	•	•	•	•	•	•	•
Carex williamsii Britt.	•	•	•	•	•	•	•	+	•	•	+	•	•	•	•
Cassiope tetragona (L.) D. Don ssp. *tetragona*	1	25	3	•	75	1	4	6	•	•	•	-	•	•	•
Cerastium beeringianum Cham. & Schlecht. var. *grandiflorum* (Fenzl) Hultén	•	•	•	•	•	•	•	•	•	•	•	+	•	•	•
Comarum palustre L., s.str. [= *Potentilla palustris* (L.) Scop.]	•	•	•	•	•	•	•	•	3	•	•	•	•	•	•

+ Present but less than 1%.
• Absent.
- Single plants only.

Mapping unit number	1		2	5		6		7		8		10		Area too small for a mapping unit	
Vegetation classification	Evergreen dwarf scrub		Seasonal short grass	Evergreen dwarf scrub	Deciduous dwarf scrub	Deciduous shrub savanna		Deciduous shrub savanna		Seasonal short grass		Deciduous dwarf scrub	Seasonal short grass	Seasonal short grass	Seasonal open submerged meadow
Landform	Ridge		Upland	Snowpatch		Lowland		Strange in Strangmoor		Marsh		Man-disturbed ground		Arctic ground squirrel mound	Stream
Relevé	6	9	1	2	5	4	13	10	3	11	12	14	15	8	7
Deschampsia brevifolia R.Br., s.str.	•	•	•	•	•	•	•	•	•	•	•	+	•	•	•
Draba alpina L. s.str. (= *Draba pilosa* DC.)	•	•	•	•	+	•	•	•	•	•	•	•	+	•	•
Draba cinerea Adams, s.str.	•	•	•	•	•	•	•	•	•	•	•	•	•	2	•
Dryas integrifolia M. Vahl ssp. *integrifolia*	60	30	•	•	2	+	18	5	•	•	–	2	•	5	•
Dupontia psilosantha Rupr. [= *Dupontia fisheri* R.Br. ssp. *pilosantha* (Rupr.) Hultén]	•	•	•	•	•	•	–	•	8	2	•	•	•	•	•
Equisetum arvense L.	•	•	•	2	•	•	•	•	•	•	•	•	•	•	•
Erigeron eriocephalus J. Vahl [= *Erigeron uniflorus* L. ssp. *eriocephalus* (J. Vahl) Cronq.	•	•	•	•	•	•	•	•	•	•	•	+	•	2	•
Erigeron humilis Grah.	•	•	•	2	•	•	•	•	•	•	•	•	•	•	•
Eriophorun angustifolium Honck. ssp. *subarcticum* (V. Vassil.) Hultén	•	•	•	•	•	•	2	+	+	2	1	+	2	•	•
Eriophorum russeolum Fr. ssp. *russeolum*	•	•	•	•	•	•	•	•	•	3	+	•	•	•	•
Eriophorum scheuchzeri Hoppe	•	•	•	•	•	•	•	•	•	•	4	•	•	•	•
Eriophorum vaginatum L. ssp. *spissum* (Fern.) Hultén	•	•	60	•	•	30	2	4	•	•	–	•	•	•	•
Eutreme edwardsii R.Br.	•	–	+	•	–	•	–	•	•	•	•	•	•	•	•
Festuca brachyphylla Schult. & Schult.	•	+	•	•	•	•	•	•	•	•	•	1	•	+	•
Gastrolychnis apetala (L.) Tolm. & Kozh., s.str. ssp. *uralensis* (Rupr.) Löve & Löve [= *Melandrium apetalum* (L.) Fenzl ssp. *arcticum* (Fr.) Hultén, p.p.]	•	•	•	•	•	•	+	–	•	•	+	•	•	•	•
Hierochloë pauciflora R.Br.	•	•	•	•	•	•	•	•	•	•	–	•	•	•	•
Hippochaete variegata (Schleich.) Bruhin ssp. *variegata* (= *Equisetum variegatum* Schleich. ssp. *variegatum*)	•	•	•	•	•	•	•	•	•	•	+	3	•	•	•
Hippuris vulgaris L.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	10

+ Present but less than 1%.
• Absent.
– Single plants only.

Mapping unit number	1		2	5		6		7		8		10		Area too small for a mapping unit	
Vegetation classification	Evergreen dwarf scrub		Seasonal short grass	Evergreen dwarf scrub	Deciduous dwarf scrub	Deciduous shrub savanna		Deciduous shrub savanna		Seasonal short grass		Deciduous dwarf scrub	Seasonal short grass	Seasonal short grass	Seasonal open submerged meadow
Landform	Ridge		Upland	Snowpatch		Lowland		Stränge in Strangmoor		Marsh		Man-disturbed ground		Arctic ground squirrel mound	Stream
Relevé	6	9	1	2	5	4	13	10	3	11	12	14	15	8	7
Juncus albescens Fern. [= *Juncus triglumis* L. ssp. *albescens* (Lange) Hultén]	•	•	•	•	•	•	•	•	•	•	3	•	•	•	•
Juncus biglumis L.	•	•	•	•	•	•	•	•	•	+	5	•	•	•	•
Kobresia myosuroides (Vill.) Fiori & Paol.	4	•	•	•	•	•	•	•	•	•	•	•	•	2	•
Koeleria asiatica Domin	•	•	•	•	•	•	•	•	•	•	•	+	•	2	•
Ledum palustre L. ssp. *decumbens* (Ait.) Hultén	•	•	8	•	•	•	•	•	•	•	•	•	•	•	•
Luzula arctica Blytt	•	+	+	•	+	•	•	•	•	•	•	•	1	•	•
Luzula confusa Lindeb., s.str.	•	•	•	•	+	•	•	•	•	•	•	-	3	•	•
Luzula kjellmaniana Miyabe & Kudo, s.str. (= *Luzula tundricola* Gorodk.)	•	2	•	•	+	•	•	•	•	•	•	1	•	•	•
Nardosmia frigida (L.) Hook. [= *Petasites frigidus* (L.) Fr.]	•	•	•	4	•	•	•	•	•	•	•	•	•	•	•
Oxytropis gorodkovii Jurtsev [= *Oxytropis nigrescens* (Pall.) Fisch. ssp. *pygmaea* (Pall.) Hultén]	3	-	•	•	•	•	•	•	•	•	•	2	•	•	•
Papaver radicatum Rottb., s.str. ssp. *radicatum* (= *Papaver radicatum* Rottb. ssp. *occidentale* Lundstr.)	•	•	+	•	+	•	•	•	•	•	•	+	•	-	•
Parnassia kotzebuei Cham. & Schlecht., s.str.	•	•	•	•	•	•	•	•	•	•	•	1	•	•	•
Parrya nudicaulis (L.) Rgl. ssp. *septentrionalis*	•	•	•	+	•	•	•	•	•	•	•	+	•	•	•
Pedicularis capitata Adams	1	2	•	•	+	+	•	•	•	•	•	1	•	•	•
Pedicularis lanata Cham. & Schlecht. ssp. *lanata* (= *Pedicularis kanei* Durand ssp. *kanei*)	•	•	-	•	•	•	•	•	•	•	•	•	•	•	•
Pedicularis langsdorffii Fisch. ssp. *arctica* (R.Br.) Pennell	•	•	•	•	+	•	•	•	•	•	•	+	•	•	•
Pedicularis sudetica Willd. ssp. *albolabiata* Hultén	•	•	•	•	•	+	•	+	•	•	2	•	•	•	•
Poa arctica R.Br., s.str.	+	+	•	1	+	1	•	•	•	•	•	1	25	•	•
Poa glauca M. Vahl	•	•	•	•	•	•	•	•	•	•	•	2	•	15	•

+ Present but less than 1%.
• Absent.
- Single plants only.

Mapping unit number	1		2	5		6		7		8		10		Area too small for a mapping unit	
Vegetation classification	Evergreen dwarf scrub		Seasonal short grass	Evergreen dwarf scrub	Deciduous dwarf scrub	Deciduous shrub savanna		Deciduous shrub savanna		Seasonal short grass		Deciduous dwarf scrub	Seasonal short grass	Seasonal short grass	Seasonal open submerged meadow
Landform	Ridge		Upland	Snowpatch		Lowland		Strange in Strangmoor		Marsh		Man-disturbed ground		Arctic ground squirrel mound	Stream
Relevé	6	9	1	2	5	4	13	10	3	11	12	14	15	8	7
Poa rigens Hartm. [= *Poa alpigena* (Fr.) Lindm.]	•	•	•	•	•	•	•	•	•	•	•	•	15	•	•
Polemonium boreale Adams ssp. *boreale*	•	•	•	•	•	•	•	•	•	•	•	•	•	25	•
Potentilla robbinsiana Oakes ssp. *hyparctica* (Malte) D. Löve (= *Potentilla hyparctica* Malte)	•	•	•	1	•	•	•	•	•	•	•	•	•	•	•
Pyrola grandiflora Radius ssp. *grandiflora*	•	+	+	•	+	3	•	3	•	•	•	•	•	•	•
Ranunculus nivalis L., s.str.	•	•	•	1	•	•	•	•	•	•	•	•	•	•	•
Ranunculus affinis R.Br., s.str. [= *Ranunculus pedatifidus* Sm. var. *Leiocarpus* (Trautv.) Fern.]	•	•	•	•	•	•	•	•	•	•	•	•	•	1	•
Salix glauca L. ssp. *acutifolia* Hultén (= *Salix seemanii* Rydb.)	1	•	•	•	•	•	•	•	•	•	•	•	1	•	•
Salix lanata L. ssp. *richardsonii* (Hook.) Skvortsov	•	•	•	•	•	•	7	•	•	•	•	1	•	•	•
Salix phlebophylla Anderss.	•	15	4	•	•	•	•	•	•	•	•	•	1	•	•
Salix polaris Wg., s.str.	•	•	•	•	•	•	3	•	•	•	2	•	•	•	•
Salix pulchra Cham. [= *Salix planifolia* Pursh ssp. *pulchra* (Cham.) Argus]	•	•	6	•	•	55	•	25	•	•	•	+	•	•	•
Salix reticulata L.	•	-	•	+	•	3	8	6	•	•	-	6	5	•	•
Salix rotundifolia Trautv.	•	•	•	75	3	•	•	•	•	•	•	25	•	•	•
Saussurea angustifolia Willd., s.str.	•	+	•	•	+	•	•	•	•	•	•	+	•	•	•
Saussurea viscida Hultén var. *yukonensis* (Pors.) Hultén	•	•	+	•	•	•	•	•	•	•	•	•	•	•	•
Saxifraga cernua L.	•	•	•	•	•	•	•	•	•	•	•	•	2	•	•
Saxifraga foliolosa R.Br., s.str. var. *fallolosa*	•	•	•	•	•	•	•	•	•	+	•	•	•	•	•
Saxifraga hieraciifolia W. & K., s.str.	•	1	•	•	-	•	•	•	•	•	•	•	•	•	•
Saxifraga nelsoniana D. Don, s.str. [*Saxifraga punctata* L. ssp. *nelsoniana* (D.Don) Hultén)	•	+	+	2	3	•	•	•	•	•	•	+	1	•	•
Saxifraga propinqua R.Br. [= *Saxifraga hirculus* L. var. *propinqua* (R.Br.) Simm.]	•	•	•	•	•	•	+	1	•	•	+	•	•	•	•
Silene acaulis (L.) ssp. *arctica* Löve & Löve	1	+	•	•	•	•	•	•	•	•	•	+	•	•	•

+ Present but less than 1%.
• Absent.
- Single plants only.

Mapping unit number	1		2	5		6		7		8		10		Area too small for a mapping unit	
Vegetation classification	Evergreen dwarf scrub		Seasonal short grass	Evergreen dwarf scrub	Deciduous dwarf scrub	Deciduous shrub savanna		Deciduous shrub savanna		Seasonal short grass		Deciduous dwarf scrub	Seasonal short grass	Seasonal short grass	Seasonal open submerged meadow
Landform	Ridge		Upland	Snowpatch		Lowland		Strange in Strangmoor		Marsh		Man-disturbed ground		Arctic ground squirrel mound	Stream
Relevé	6	9	1	2	5	4	13	10	3	11	12	14	15	8	7
Sparganium hyperboreum Laest.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	25
Stellaria edwardsii R.Br.	•	•	+	•	•	•	•	•	•	•	–	•	8	•	•
Stellaria laeta Richards.	•	•	•	•	+	+	•	•	•	•	•	+	•	•	•
Stellaria monantha Hultén	•	•	•	•	•	•	•	•	•	•	•	•	•	+	•
Taraxacum ceratophorum (Ledeb.) Dt.	•	•	•	+	•	•	•	•	•	•	•	+	•	+	•
Tephroseris atropurpurea (Ledeb.) Löve & Löve ssp. *frigida* (Richards.) Löve & Löve [= *Senecio atropurpureus* (Ledeb.) B. Fedtsch. ssp. *frigidus* (Richards.) Hultén]	•	•	+	•	+	•	+	+	•	•	•	•	•	•	•
Tofieldia pusilla (Michx.) Pers.	•	•	•	•	•	•	•	+	•	•	•	•	•	•	•
Trisetum spicatum (L.) Richt. ssp. *spicatum*	•	•	•	2	•	•	•	•	•	•	•	5	1	1	•
Tryphane rubella (Wg.) Rchb., s.str. [= *Minuartia rubella* (Wg.) Hiern]	•	•	•	•	•	•	•	•	•	•	•	•	•	+	•
Vaccinium gaultherioides Bigel. (= *Vaccinium uliginosum* L., p.p.)	•	•	•	•	•	+	•	•	•	•	•	•	•	•	•
Vaccinium vitis-idaea L. ssp. *minus* (Lodd.) Hultén	•	•	4	•	+	•	•	+	•	•	•	•	•	•	•
Number of taxa	11	20	21	19	24	17	21	20	7	8	23	39	17	19	5

+ Present but less than 1%.
• Absent.
– Single plants only.

APPENDIX F: SELECTED ENVIRONMENTAL VARIABLES FOR RELEVÉS REPRESENTATIVE FOR THE FISH CREEK MAPPING UNITS

Mapping unit number	*1*		*2*	*5*		*6*		*7*	*8*			*10*		*Area too small for a mapping unit*	
Vegetation classification	*Evergreen dwarf scrub*		*Seasonal short grass*	*Evergreen dwarf scrub*	*Deciduous dwarf scrub*	*Deciduous shrub savanna*		*Deciduous shrub savanna*	*Seasonal short grass*			*Deciduous dwarf scrub*	*Seasonal short grass*	*Seasonal short grass*	*Seasonal open submerged meadow*
Landform	*Ridge*		*Upland*	*Snowpatch*		*Lowland*		*Stränge in Strangmoor*				*Man-disturbed ground*		*Arctic ground squirrel mound*	*Stream*
Relevé	*6*	*9*	*1*	*2*	*5*	*4*	*13*	*10*	*3*	*11*	*12*	*14*	*15*	*8*	*7*
Elevation (m.s.m.)	6	16	16	8	8	16	8	16	8	16	16	8	16	16	8
Slope aspect	N	–	–	NW	SE	–	–	–	–	–	–	S	–	–	–
Slope inclination (°)	2	0	0	15	15	0	0	0	0	0	0	2	0	0	0
Scale (0-10)															
Moisture site	3	4	5	6	6	6	6	7	8	8.5	8	4	5	3	10
Temperature	5	5	5	3	3	5	5	4	4	4	5	4	5	6	2
Snow	3	4	5	8	8	6	6	6	6	6	6	7	5	2	7
Wind	6	6	6	3	3	5	6	6	4	6	6	6	6	7	0
Surface age	6	7	7	4	4	4	4	3	3	3	4	1	1	2	1
Stability	5	6	8	4	6	7	5	6	3	3	5	3	4	1	2
Cryoturbation	5	8	7	3	4	6	4	8	2	2	4	1	1	0	0
Cover (%)															
Vegetation	75	80	92	90	98	95	90	95	80	75	85	75	90	60	40
Shrubs	1	0	6	0	0	55	7	25	0	0	0	1	1	0	0
Herbs	65	55	75	90	85	60	80	65	75	75	35	75	85	60	35
Cryptogams	25	35	30	10	45	18	40	40	5	8	65	3	8	5	10
Litter	6	15	18	10	10	18	15	25	35	25	15	15	35	10	8
Rock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bare soil	15	18	3	3	2	3	8	5	10	40	15	25	10	55	90
Water	0	0	0	0	0	0	0	0	4	50	10	0	0	0	100
Height (cm)															
Shrubs	8	0	15	0	0	20	25	20	0	0	0	7	10	0	0
Herbs	2	4	15	7	10	15	18	18	30	25	15	15	20	12	25
Cryptogams	1	2	4	1	2	3	2	3	1	1	1	1	1	1	4
Biomass scale (0-10)															
Overall	3	3	4	3	4	5	3	4	4	4	2	2.5	3	3	3
Shrubs	1	0	1	0	0	5	2	2	0	0	0	1	1	0	0
Herbs	4	4	7	4	5	5	4	4	7	6	2	2.5	3	4	3
Cryptogams	2	3	3	1	5	4	3	4	1	1	4	1	2	1	2

A facsimile catalog card in Library of Congress MARC format is reproduced below.

Lawson, D.E.
Tundra disturbances and recovery following the 1949 exploratory drilling, Fish Creek, northern Alaska / by D.E. Lawson, J. Brown, K.R. Everett, A.W. Johnson, V. Komárková, B.M. Murray, D.F. Murray and P.J. Webber. Hanover, N.H.: U.S. Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1978.
x, 112 p., illus.; 27 cm. (CRREL Report 78-28.)
Prepared for U.S. Geological Survey by Corps of Engineers, U.S. Army Cold Regions Research and Engineering Laboratory under DA Project 4A161102AT24.
Bibliography: p. 54.

Lawson, D.E.
Tundra disturbances and recovery following...
1978 (Card 2)

1. Arctic regions. 2. Environmental effects. 3. Oil pollution. 4. Permafrost. 5. Tundra. 6. Vegetation. I. Brown, J. II. Everett, K.R. III. Johnson, A.W. IV. Komárková, V. V. Murray, B.M. VI. Murray, D.F. VII. Webber, P.J. VIII. United States. Army. Corps of Engineers. Hanover, N.H. IX. Series: CRREL Report 78-28.

☆U.S. GOVERNMENT PRINTING OFFICE: 1978 – A-1093/284