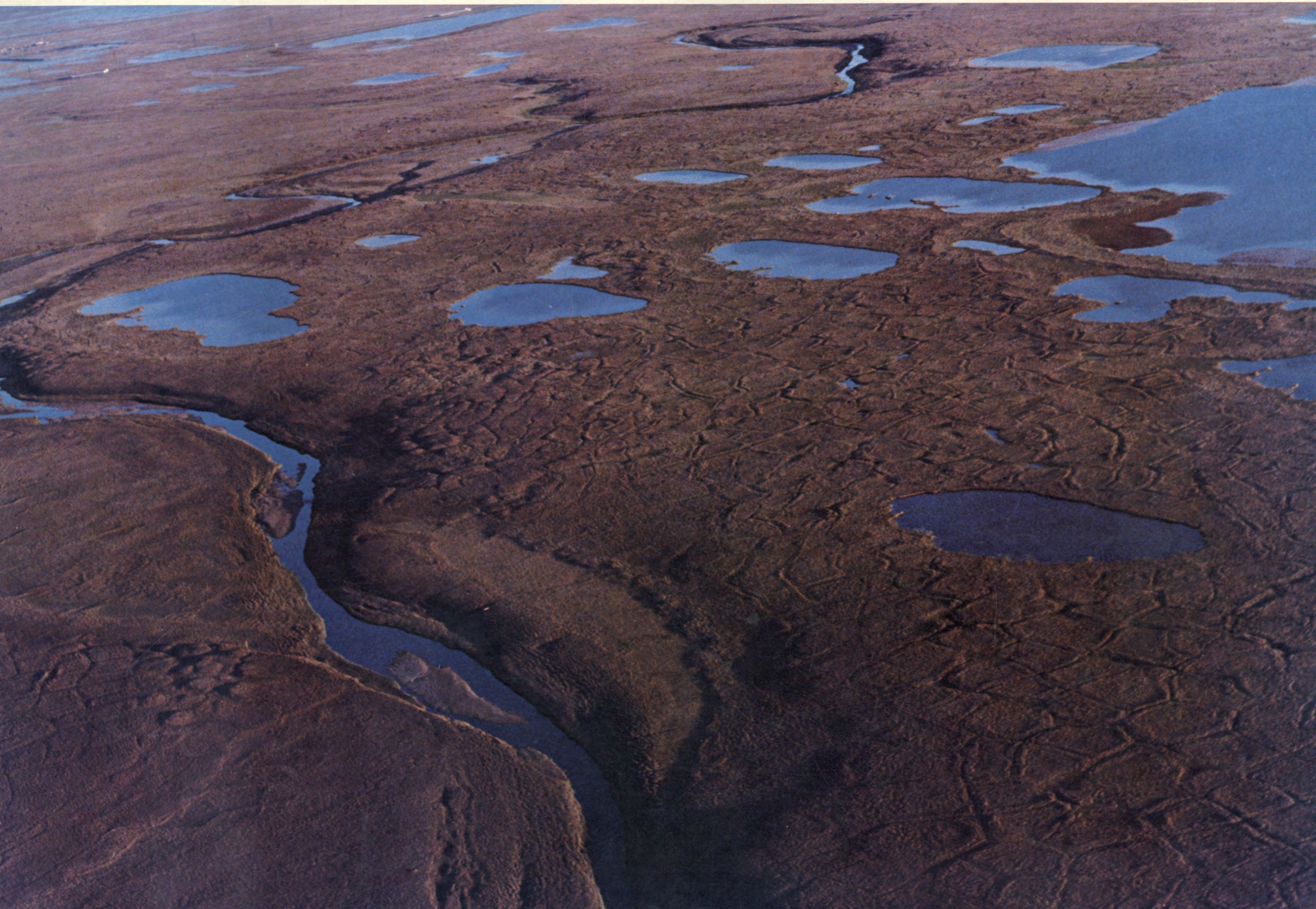


# **Geobotanical Atlas of the Prudhoe Bay Region, Alaska**





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D.A. Walker, K.R. Everett,  
P.J. Webber and J. Brown

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United States Army Corps of Engineers  
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International Biological Program  
U.S. Tundra Biome



U.S. Program on Man and the Biosphere  
UNESCO MAB Project 6



## Abstract

This atlas illustrates the interrelationships among the landforms, soils and vegetation of a portion of the Arctic Coastal Plain of Alaska. The Prudhoe Bay region is dominated by an alkaline peaty coastal tundra, a type that has not been intensively studied. Forty-two vegetation communities, thirteen major landforms, and eight soil types are described. Several of the plant communities and one soil, the Pergelic Cryoboroll, have not been described previously. The vegetation is discussed with respect to three important gradients: temperature, soil pH and soil moisture. Other aspects of the Prudhoe Bay environment, including geology, permafrost, and winter and summer climate, are discussed and illustrated. Also included are historical descriptions of the development of the oilfield and of selected scientific investigations in the Alaskan Arctic. Master maps present the landforms, soils and vegetation of a 145-km<sup>2</sup> portion of the oilfield road network at a scale of 1:12,000. Derived geobotanical special purpose maps, useful for land-use planning and management of the ecosystem, are explained and several examples are shown for a 3.6-km<sup>2</sup> portion of the oilfield.

## Preface

This atlas was prepared by Donald A. Walker, Plant Ecologist, Institute of Arctic and Alpine Research (INSTAAR), University of Colorado; Dr. Kaye R. Everett, Soil Scientist, Institute of Polar Studies, Ohio State University; Dr. Patrick J. Webber, Plant Ecologist, INSTAAR, University of Colorado; and Dr. Jerry Brown, Research Soil Scientist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. It is based on studies initiated in 1971 under the U.S. Tundra Biome portion of the International Biological Program (IBP) and as part of CRREL research activities conducted under DA Project 4A161102AT24, *Research in Snow, Ice and Frozen Ground*, Scientific Area 02, *Cold Regions Environmental Interactions*, Work Unit 002, *Cold Regions Environmental Factors*. Portions of the field and office studies by Ohio State University and the University of Colorado were undertaken with nonrestricted contributions to the University of Alaska's Tundra Biome Center from the Prudhoe Bay Environmental Subcommittee of the Alaska Oil and Gas Association. Personnel and other support were shared with Tundra Biome projects sponsored by the National Science Foundation which were based at Barrow, Alaska, and utilized the Naval Arctic Research Laboratory as a logistical base. The report is a contribution to the U.S. International Biological Program (IBP), the Man and the Biosphere Program (MAB), and the U.S.-U.S.S.R. bilateral Environmental Protection Agreement, Project V, Protection of Northern Ecosystems (Scriabine 1978).

The authors acknowledge the many individuals and companies at Prudhoe Bay that facilitated the field work, particularly Charles Wark, Richard V. Shafer, and D.S. Braden of Sohio Petroleum Co. (formerly BP Alaska Inc.) and C.P. Falls, Landon Kelley, and Angus Gavin of Atlantic Richfield Co. (Mr. Braden is currently with the U.S. Geological Survey.) The topographic maps from which the base maps were compiled were provided by these companies, which also gave permission to procure industry-owned aerial photographs of the region. The authors particularly wish to remember the late Scott Parrish, with whom they discussed many aspects of these early studies and who materially assisted them in the field. Robert Parkinson assisted with the soils investigations in 1974 and 1975. John Batty, John Davidson, Fred Rowley, Jane Westley, Eleanor Werbe and Ken Bowman assisted with the vegetation surveys. The base maps were drafted by Vicki Dow and Lynda Ladwig, University of Colorado. Ronald Coffman of Ohio State University and Eleanor Huke of CRREL assisted in preparing other illustrations. Stephen Bowen, CRREL Technical Editor, Donna Murphy and Jeanne Tucker provided editorial support and typesetting, and Elaine Babcock, Dartmouth Printing Company, designed the atlas layout.

Reviewers have made many helpful suggestions. Dr. Roger G. Barry, University of Colorado, reviewed the climate chapter, and Dr. Vera Komárková, University of Colorado, reviewed the vegetation chapter. The entire text was reviewed by Dr. John Andrews of the University of Colorado and Richard K. Haugen of CRREL.



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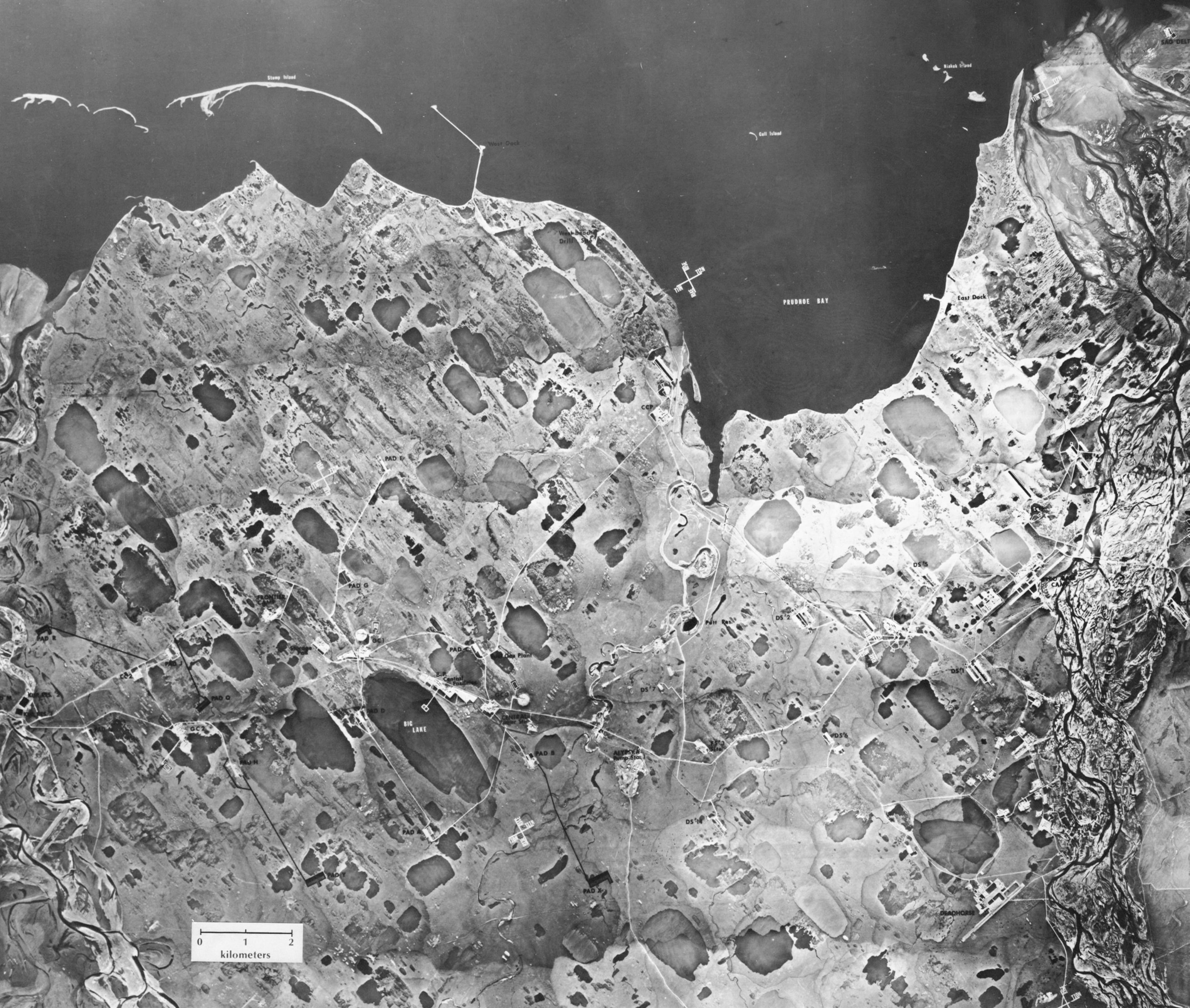
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**Frontispiece. The Prudhoe Bay region as of 1977.** The region discussed in this atlas lies between the Sagavanirktok River on the right and the Kuparuk River on the left. The smaller river near the center of the photograph flowing into Prudhoe Bay is the Putqigayuk River. Numerous oriented lakes are apparent. Also note the region of sand dunes near the mouth of the Sagavanirktok River and the East Dock. Drill sites, camp facilities and the road network are also visible. Mosaic prepared by Air Photo Tech, Anchorage.



# Introduction

## Overview

J. Brown

THE PRUDHOE BAY OILFIELD lies on the northern edge of the Arctic Coastal Plain of Alaska. It occupies a region of low relief covered by numerous shallow lakes and drained lake basins, and much of the terrain is saturated with water during the short summer. The main oil reservoir and the area of development are between the Sagavanirktok and Kuparuk Rivers. The region was initially accessible only by air. Later, ocean-going barges began making the journey via the West Coast and Mackenzie River. Since 1974 it has been linked to central Alaska by the haul road from the Yukon River.

To allow exploration and development of the oilfield, a network of over 200 km of gravel roads was constructed between the Sagavanirktok and Kuparuk Rivers. This provided, for the first time in the Alaskan Arctic, easy access by vehicle to a large area of tundra where a variety of scientific investigations could be performed. The initial results of these investigations were published in Brown (1975). Included in these research efforts were first approaches to the mapping of the soil, vegetation and landforms along portions of the road network (Webber and Walker 1975, Everett 1975). This mapping was subsequently expanded to include most of the oilfield then under development.

These early mapping activities led to the formulation of the following objectives of this atlas:

1. To document a brief history of industrial development and scientific research in and adjacent to the region.
2. To describe the main components of the environment, i.e. the climate, geology, landforms, soils and vegetation, with emphasis on mapping of the last three.
3. To describe the mapping techniques, and to show how the methods are particularly suited to the derivation of special purpose maps for land-use considerations.

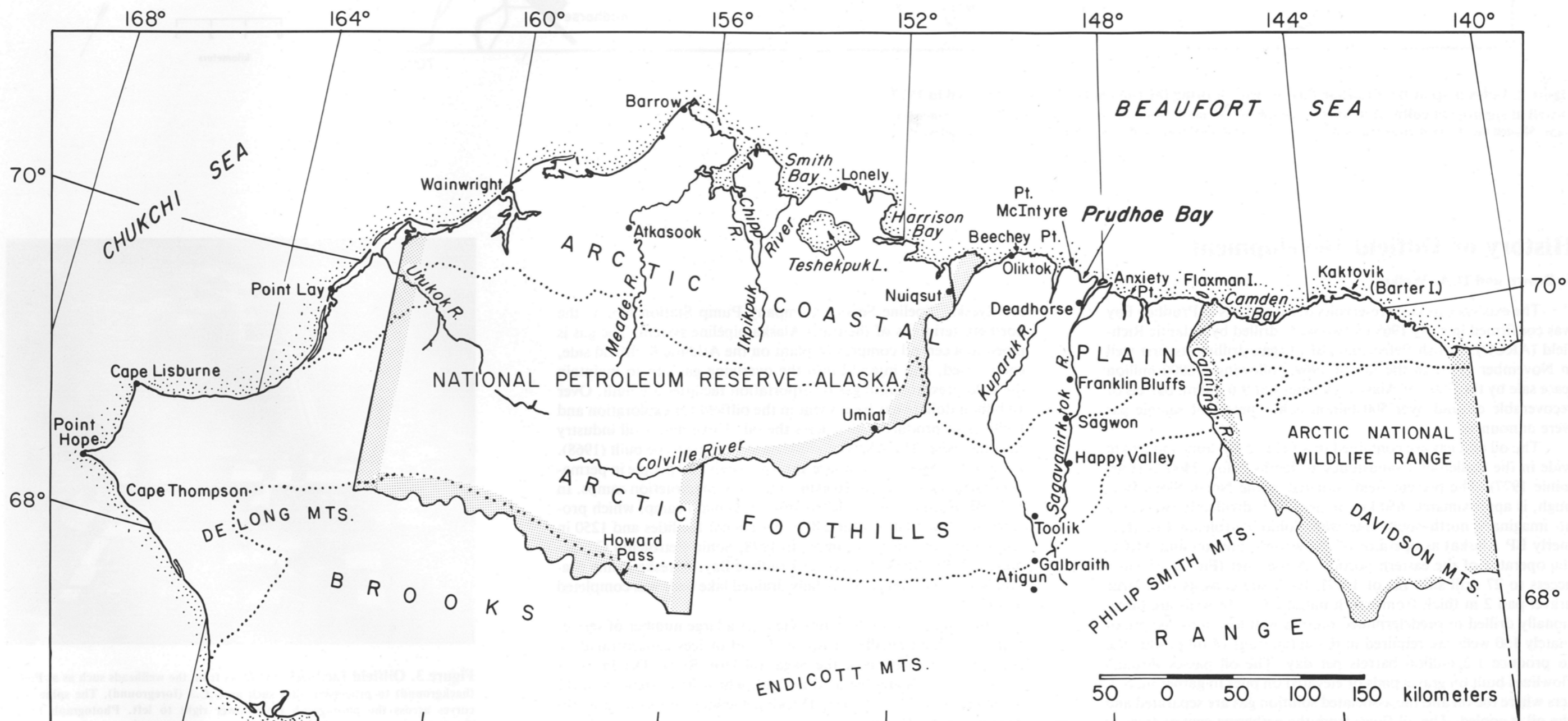
The mapping of the Prudhoe Bay region was based on aerial photographs taken in 1973 at a scale of 1:6000. This atlas is thus a static representation of a type of arctic tundra at a time when only relatively minor terrain disturbance had occurred. It can be used as a baseline against which further natural and human-induced changes to the landscape can be measured. It is anticipated that the methods and information developed will be useful for planning

and implementing future arctic developments in an environmentally sound manner. It is our contention that detailed vegetation, soils and landform maps at a scale of 1:12,000 are a prerequisite for site and route selection in order to minimize environmental impacts and protect terrestrial and aquatic habitats.

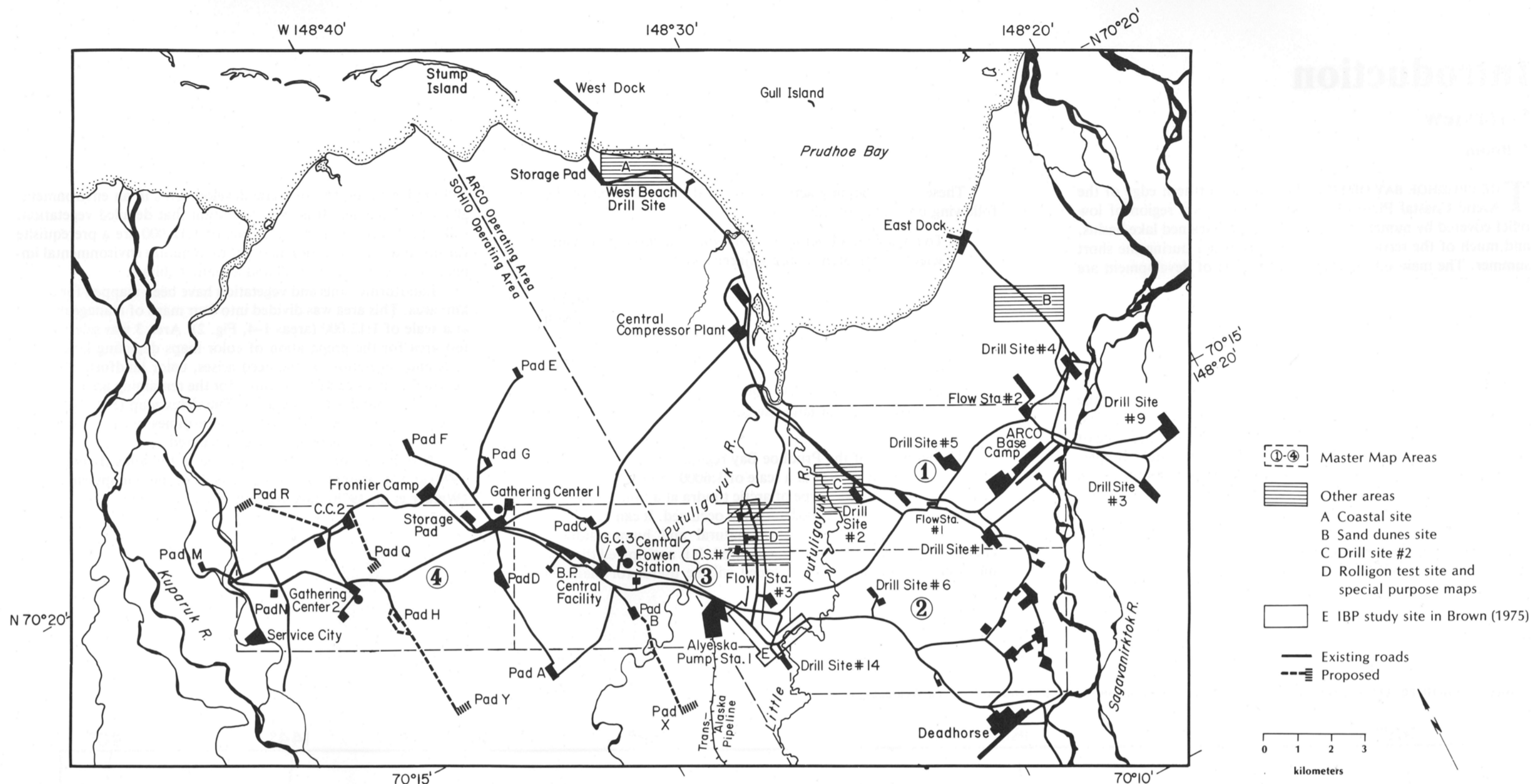
Landforms, soils and vegetation have been mapped for a 145-km<sup>2</sup> area. This area was divided into four maps of manageable size at a scale of 1:12,000 (areas 1-4, Fig. 2). Area 3 was selected as a test area for the preparation of color maps depicting landforms, soils and vegetation. If the need arises, color landform, soil and vegetation maps can be generated for the remaining areas from information contained in the atlas. The index map (Fig. 2) also delineates other areas, such as the sand dunes and the coast, for which vegetation maps have been prepared.

A summary of the approach used in the atlas (Everett et al. 1978) and an example of how the special purpose maps can be used (Walker et al. 1978) have recently been published.

Figure 1. Northern Alaska. Dotted lines indicate boundaries of physiographic subdivisions based on Wahrhaftig (1965).







**Figure 2.** Index map of the Prudhoe Bay oilfield showing the road network as it appeared in 1977 as well as significant cultural features. Large dashed rectangles delineate areas covered by the master landscape maps. Shaded and lettered areas represent locations of additional maps and study areas discussed in this atlas.

## History of Oilfield Development

J. Brown and D.A. Walker

The existence of large reservoirs of oil and gas at Prudhoe Bay was confirmed in early 1968 by two wells drilled by Atlantic Richfield (ARCO). British Petroleum (BP) began drilling its first well in November 1968. In the fall of 1969, following a \$900 million lease sale by the State of Alaska, estimates of 9.6 billion barrels of recoverable oil and over 500 billion cubic meters of salable gas were announced.

The oil and gas are contained in a field 72 km long and 29 km wide in the Sadlerochit sandstones at depths below 2400 m (Larminie 1977). The present field, situated in the North Slope Borough, is approximately 650 km<sup>2</sup> in area. It is divided in two along an imaginary north-south line with Sohio Petroleum Co. (formerly BP Alaska) as operator of the western portion and ARCO the operator of the eastern portion. A road net (Fig. 2) provides access to 27 drill sites (as of 1977). Each site consists of a large gravel pad 2 m thick from which initially 6 to 18 wells are directionally drilled to predetermined bottom well locations. Approximately 150 wells are required in the initial stage of oil production to produce 1.2 million barrels per day. The oil passes through flowlines built on gravel pads or elevated on piles to gathering centers where the oil and the associated solution gas are separated and the oil is cooled. The oil flows from the gathering centers (Fig. 3)

to Alyeska Pipeline Service Company Pump Station No. 1, the northern terminus of the trans-Alaska pipeline system. The gas is piped to a central compressor plant on the Atlantic Richfield side, compressed, and injected into the overlying gas cap to maintain the field pressure until gas transportation facilities are built. Over 10 billion dollars has been spent in the oilfield for exploration and facilities to produce and process the oil. Three major oil industry facilities exist. The ARCO complex was the first to be built (1968). It was later expanded to house approximately 500 people in permanent facilities and about 2600 in temporary construction camps. In 1972 BP Alaska began construction of its main camp, which provides accommodations for 250 in permanent facilities and 1250 in temporary construction camps. In 1978, Sohio Petroleum Co. acquired all BP Alaska's assets at Prudhoe Bay. Alyeska Pump Station No. 1, built on an artificially drained lake bed, was completed in 1977.

In addition to these major facilities a large number of service companies have smaller camps and field offices concentrated on State-operated land near the Sagavanirktok River. Deadhorse is the site of the State-operated airfield, which was extended in the summers of 1977 and 1978. Docking facilities are located at the East and West Docks.



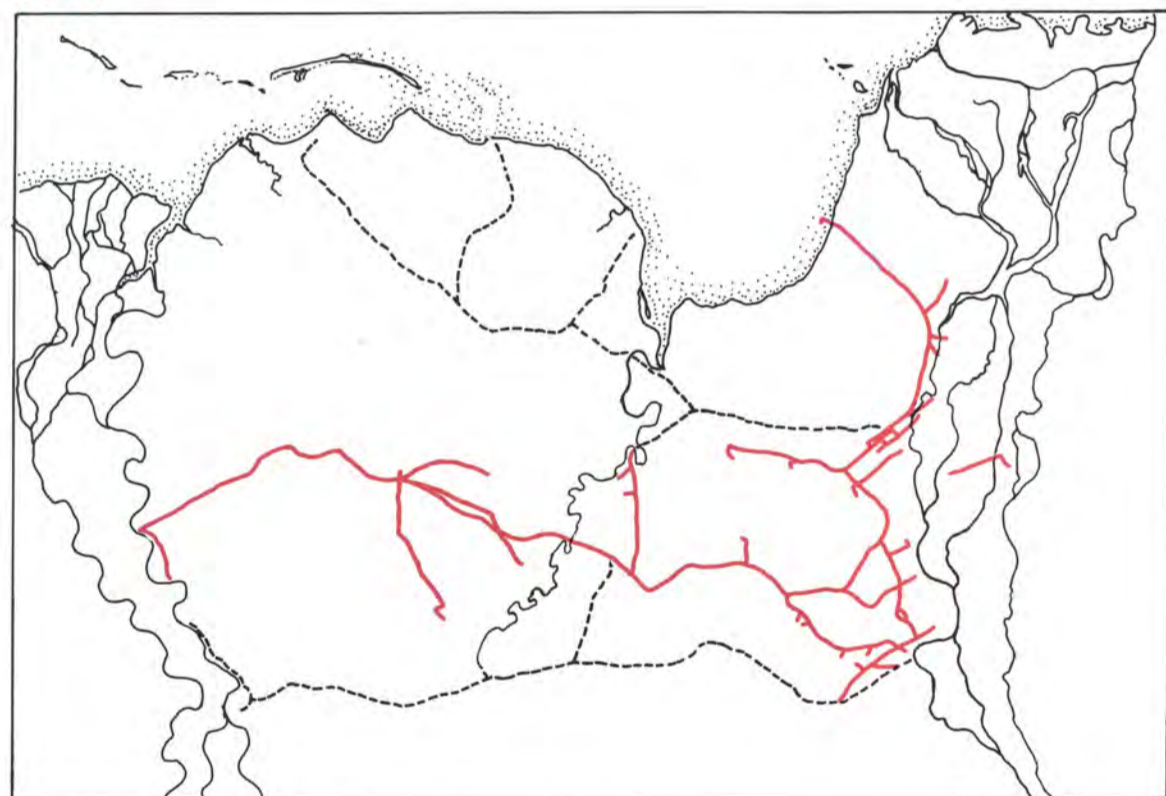
**Figure 3.** Oilfield facilities. Oil flows from the wellheads such as at Pad B (background) to processing sites such as G.C.3 (foreground). The spine road curves across the photograph from lower right to left. Photograph by K. Bowman.



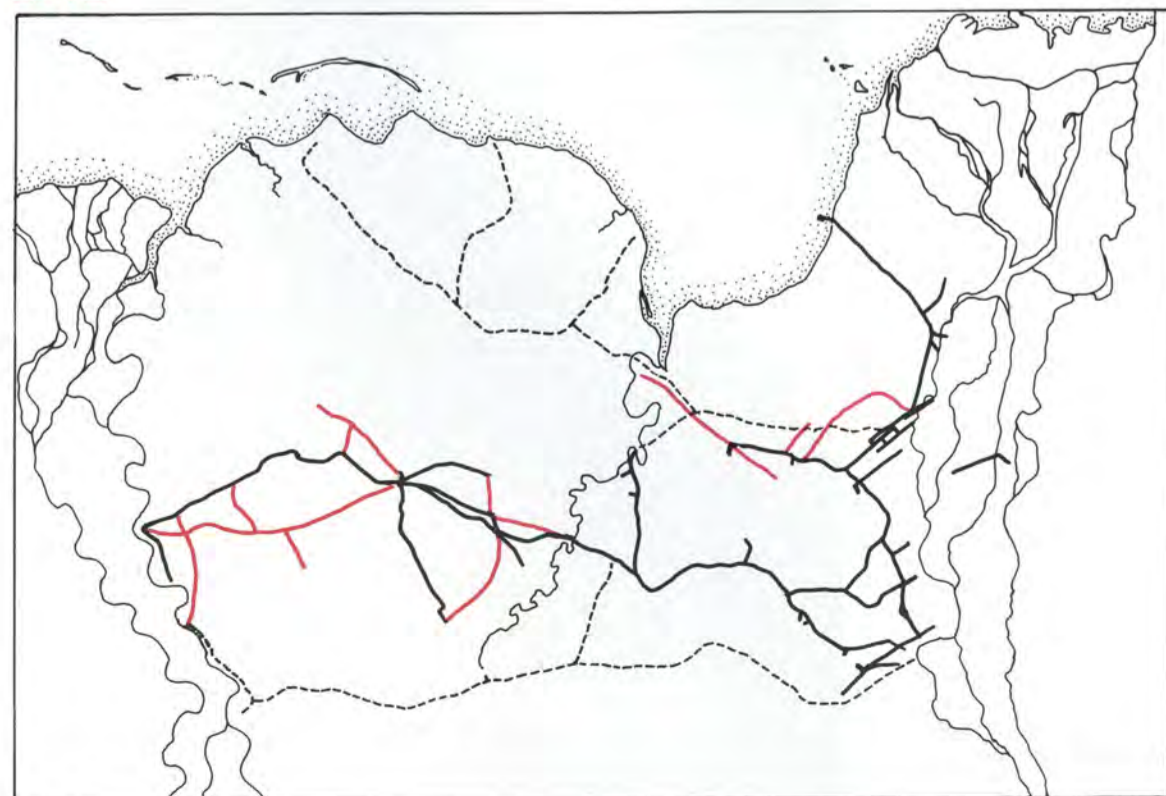
Those of us who began environmental research at Prudhoe Bay in the early 1970's had little conception of the massive build-up in roads, gathering lines, and facilities development that was to follow. Research sites that were selected for their remoteness were often subsequently surrounded or covered by access roads, power transmission lines or gravel pads. In order to illustrate and record for future use this successive change in surface development, we have compiled a series of road maps based on sequential aerial photography of the region (Fig. 4, Table 1). Included are the major off-road trails used in the late 1960's prior to construction of the road network.

**Figure 4. Development of the Prudhoe Bay road network, 1970-77.** Dashed lines = trails; heavy solid lines = gravel roads; red lines = new gravel roads built during the preceding time interval. The maps are based on the aerial photo coverage listed in Table 1.

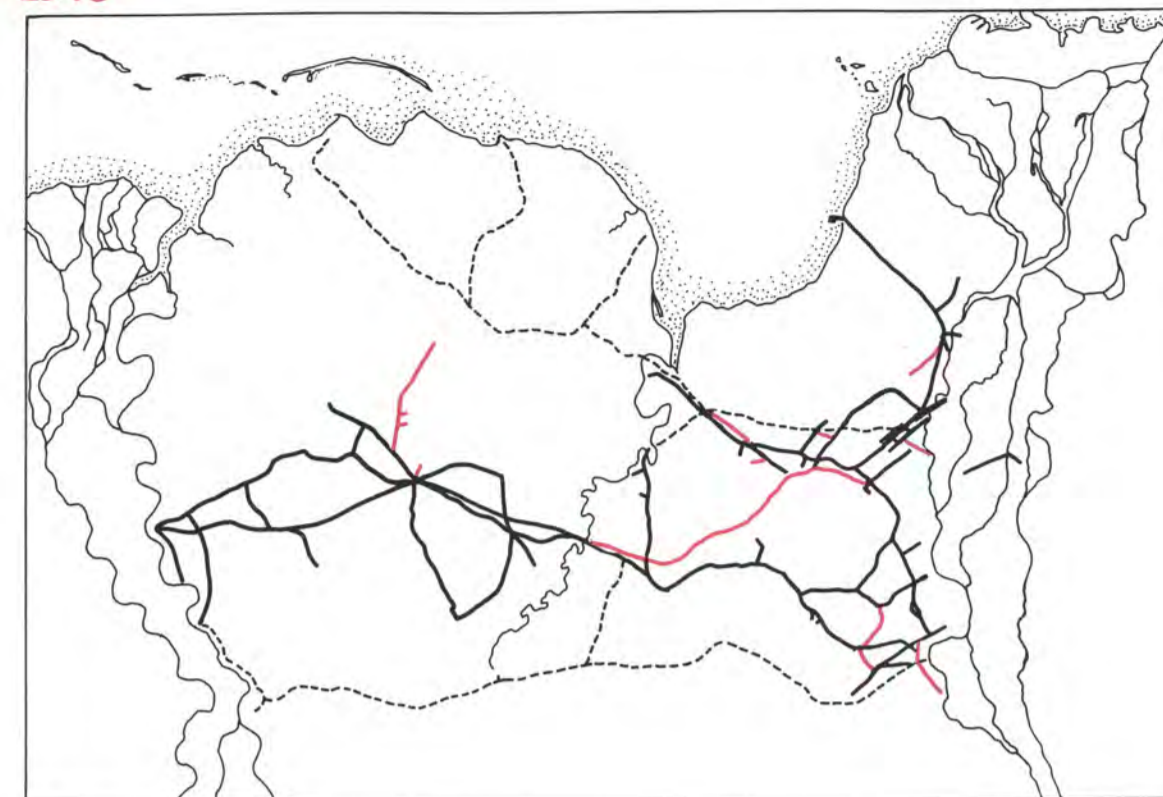
1970



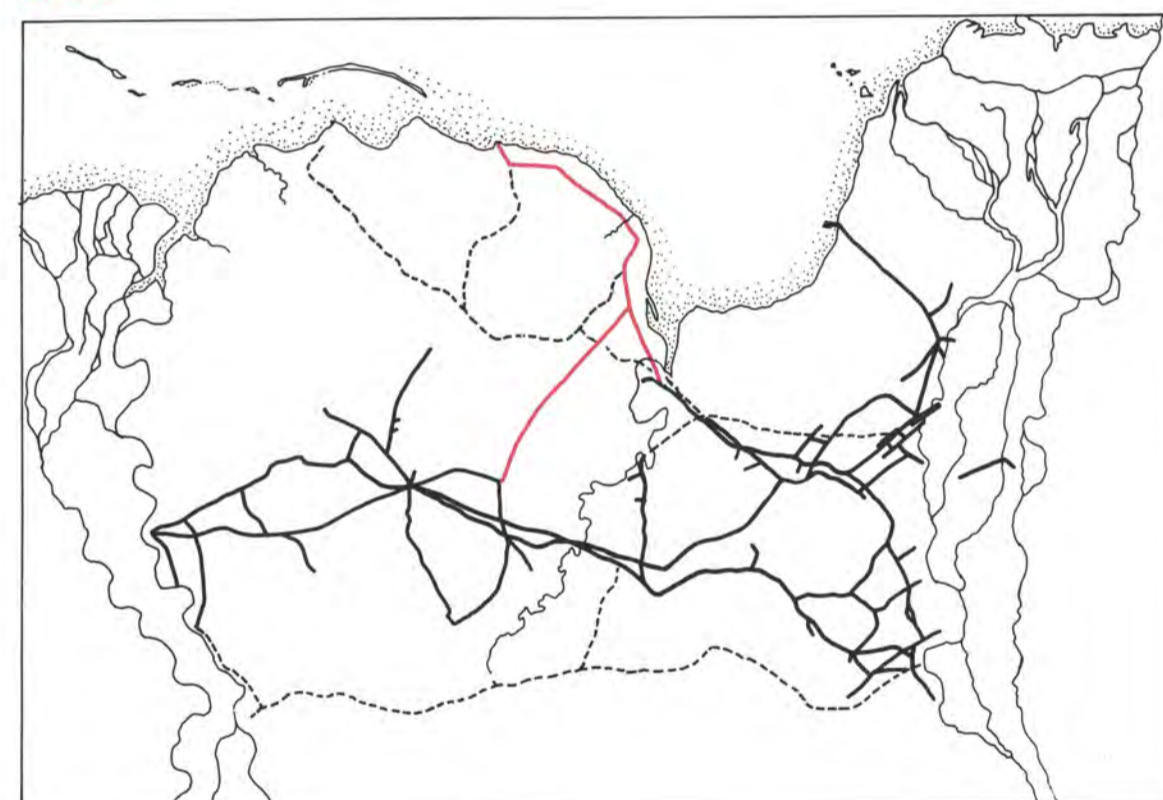
1972



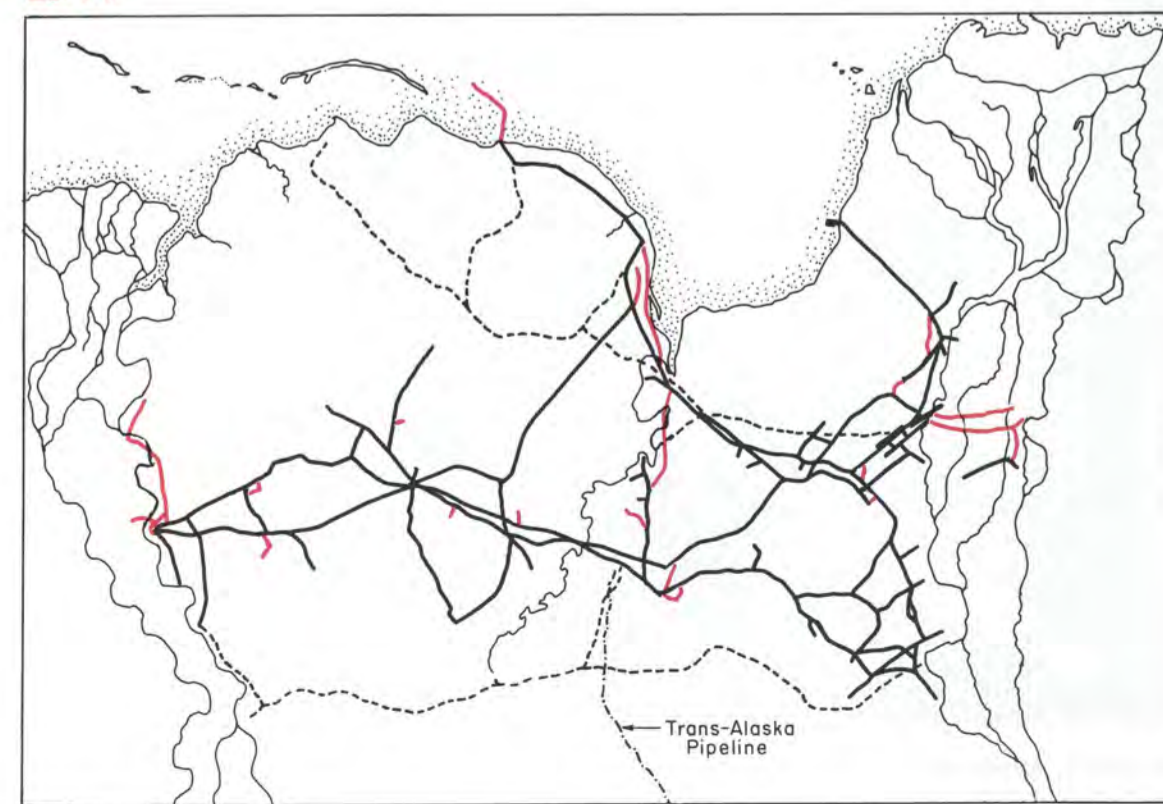
1973



1975



1977

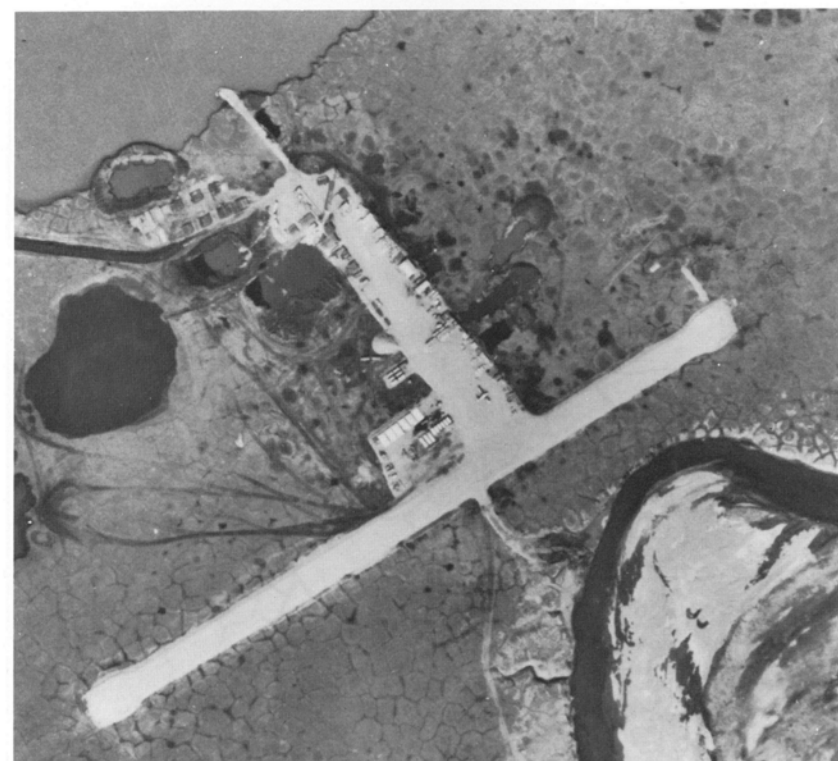




To further illustrate the successive stages of development of the oilfield a sequential series of aerial photographs of the three main facilities (BP/Sohio, ARCO and Alyeska Pump Station No. 1) are presented (Fig. 5 and 6). The initial photography was obtained in 1948 and 1949 when most of northern Alaska was photographed by the U.S. Navy (Table 1). The 1970 imagery was used for the United States Geological Survey orthographic mapping project which covers the Prudhoe Bay region at a scale of 1:24,000. Subsequent imagery was obtained by CRREL, industry and NASA overflights. The 1973 industry imagery was used to prepare 1.4-m (5-ft) contour maps that have been employed for oil spill contingency planning. This imagery was updated for the western part of the field as of July 1977 and for the entire unit in 1979.

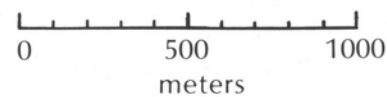
**Table 1. Major aerial photographic missions in the Prudhoe Bay region.**

Date	Mission	Sponsor and location of film	Scale
July 1948 and 1949	BAR	U.S. Navy (EROS, Sioux Falls, S.D.)	1:20,000
June-Sept 1955	AMS	Army Map Service (EROS, Sioux Falls, S.D.)	1:50,000
July 1968	ARCO (Color)	Atlantic Richfield Co. Anchorage, Alaska	1:12,000
June 1970	GS-VCIK	USGS (EROS, Sioux Falls, S.D.)	1:76,000
July 1972	Air Photo Tech Inc.	CRREL Hanover, N.H.	1:3000 1:24,000
July 1973	Air Photo Tech Inc.	BP Alaska Anchorage, Alaska (Air Photo Tech Inc.)	1:18,000 1:6000
June 1974	NASA (U-2)	NASA (EROS, Sioux Falls, S.D.)	1:30,000
June 1977	NASA (U-2)	NASA (EROS, Sioux Falls, S.D.)	1:30,000
July 1977	Air Photo Tech Inc.	Prudhoe Bay Environmental Unit (Air Photo Tech Inc.)	1:6000



**Figure 5. Aerial view of the ARCO camp as it appeared in 1968. This facility was the first permanent development at Prudhoe Bay.**

**Figure 6. Stages of development at the three major oilfield facilities. Sources and dates of photography are given in Table 1.**



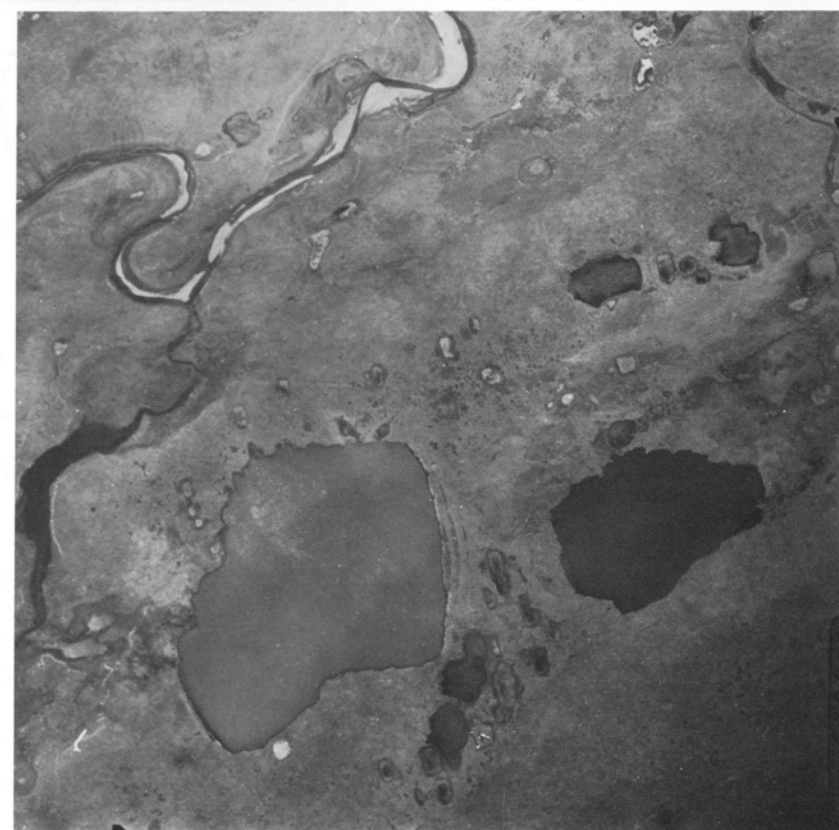
Scale for all photographs

**BP/Sohio Base Camp: 1948:** prior to construction; **1970:** a) spine road, b) pad for Gathering Center No. 1, c) ponding along road to Pad C, also note thin deposits of gravel along the edges of the roads (arrows), d) service road for gathering lines, e) road to Pad D, note large ponded area and compare with 1948 photograph taken at about the same time of year; **1972:** a) pad for BP/Sohio Base Camp (note ponding between two short access roads), b) service road to Pads E and F, c) service road to Gathering Center No. 2, arrows indicate examples of natural changes in lake shore boundary since 1948; **1977:** a) expansion of BP/Sohio Base Camp facilities (includes headquarters, oil storage facilities and construction camp), b) water supply facility in Big Lake, c) expansion of Gathering Center No. 1 and additional flaring facility, d) improved drainage in this area, probably as a result of the installation of new or larger culverts.

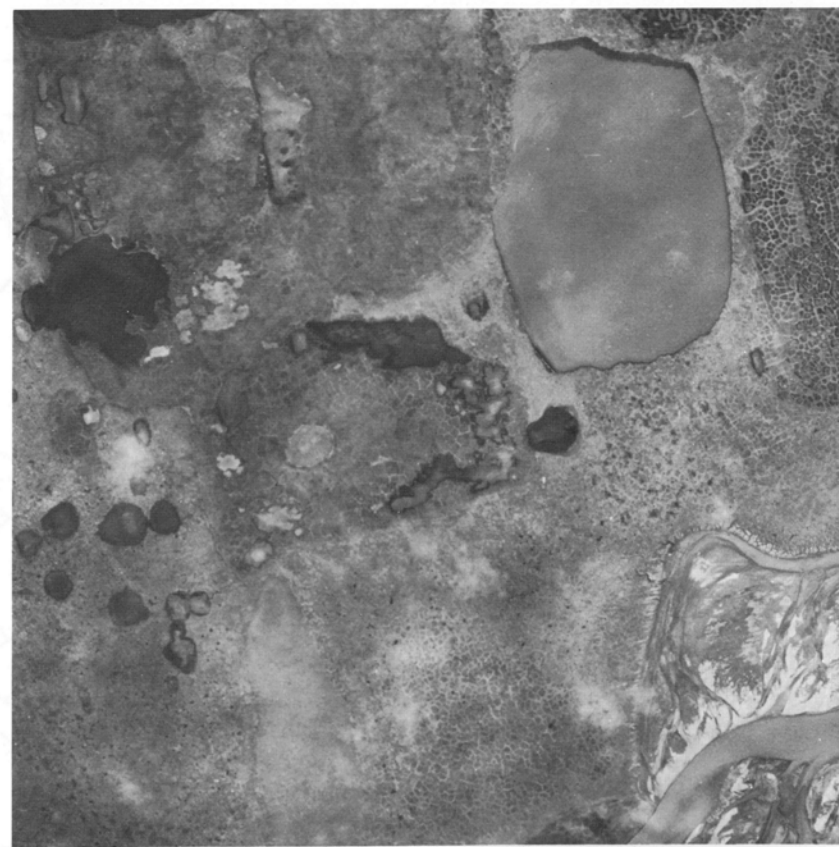
1948



**Alyeska Pump Station No. 1: 1948:** prior to construction (the largest lake was drained for a construction site for Pump Station No. 1); **1970:** a) spine road, b) gravel mining operation along the Putuligayuk River, c) vehicle trails on tundra; **1972:** a) road for water truck access (note ponding at junction was present in 1970 before access road was built but was not present in 1948), b) increased number of summer and winter vehicle tracks; **1977:** a) completion of gathering lines with expansion loops (arrow), b) ditch used for drainage of lake (fall of 1974), c) Pump Station No. 1, d) beginning of trans-Alaska pipeline and work pad.



**ARCO Base Camp: 1948:** prior to construction; **1970:** a) trails and expedient roads constructed with turned soil prior to 1968 (see Fig. 80), b) ARCO Base Camp and airfield, c) spine road to East Dock, d) oil gathering lines, e) sewage settling pond, f) gravel mining operations in Sagavanirktok River channel; **1972:** a) service road for gathering lines (note break in road caused by ponding), b) Flow Station No. 2; **1977:** a) expansion of Base Camp facilities, b) Parsons construction camp, c) expansion of Flow Station No. 2 with flaring facilities (out of photograph), d) new gathering lines and roads with increased ponding.



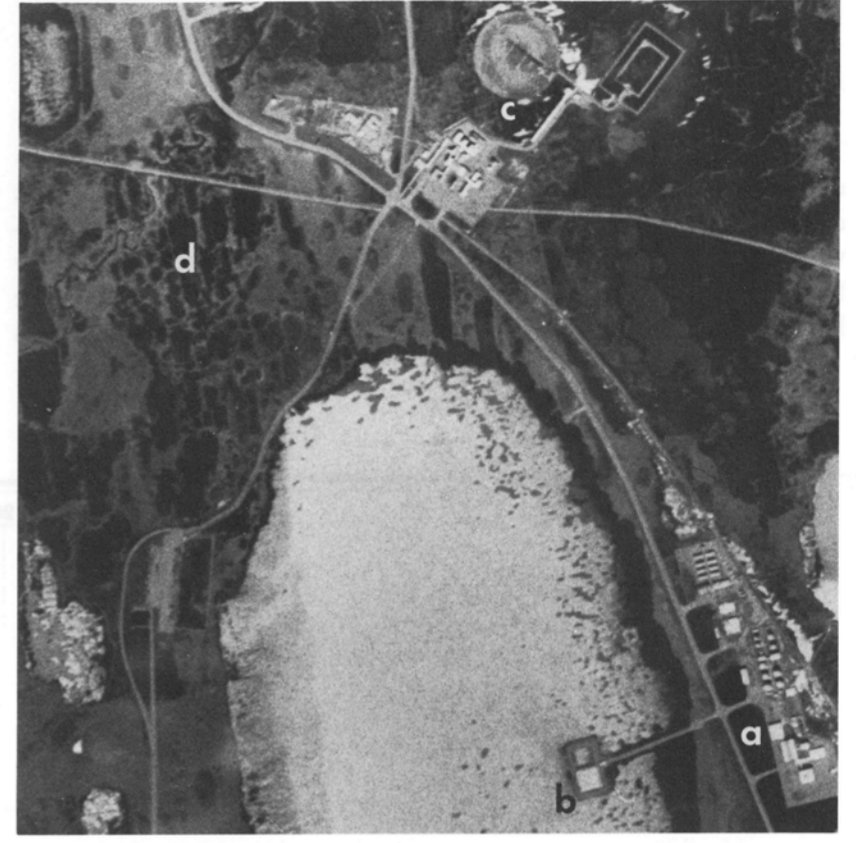


1970

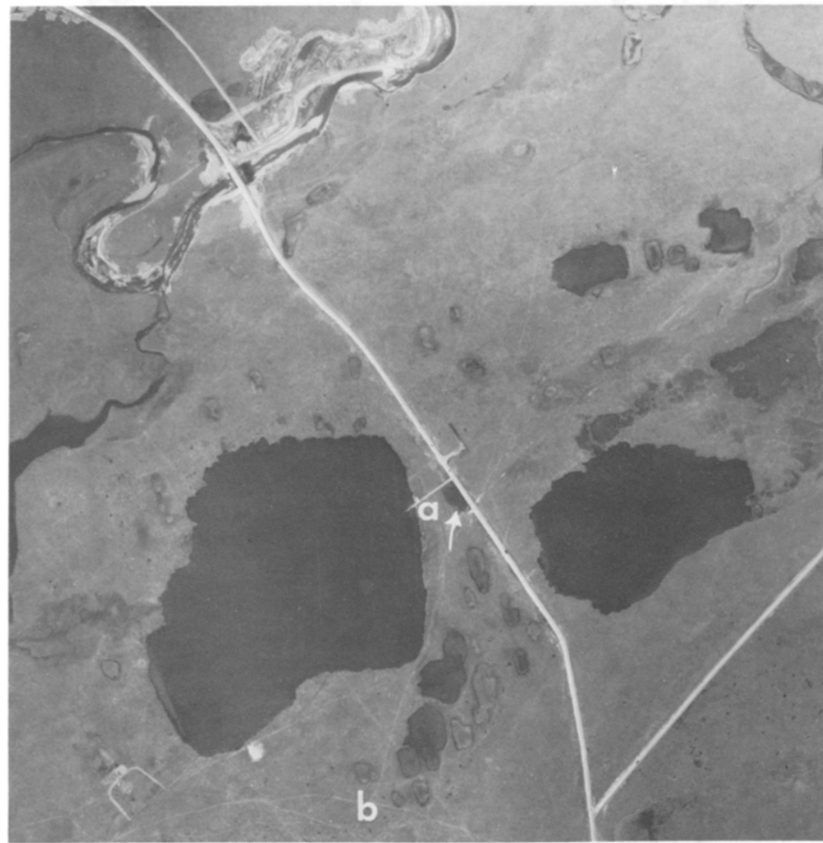
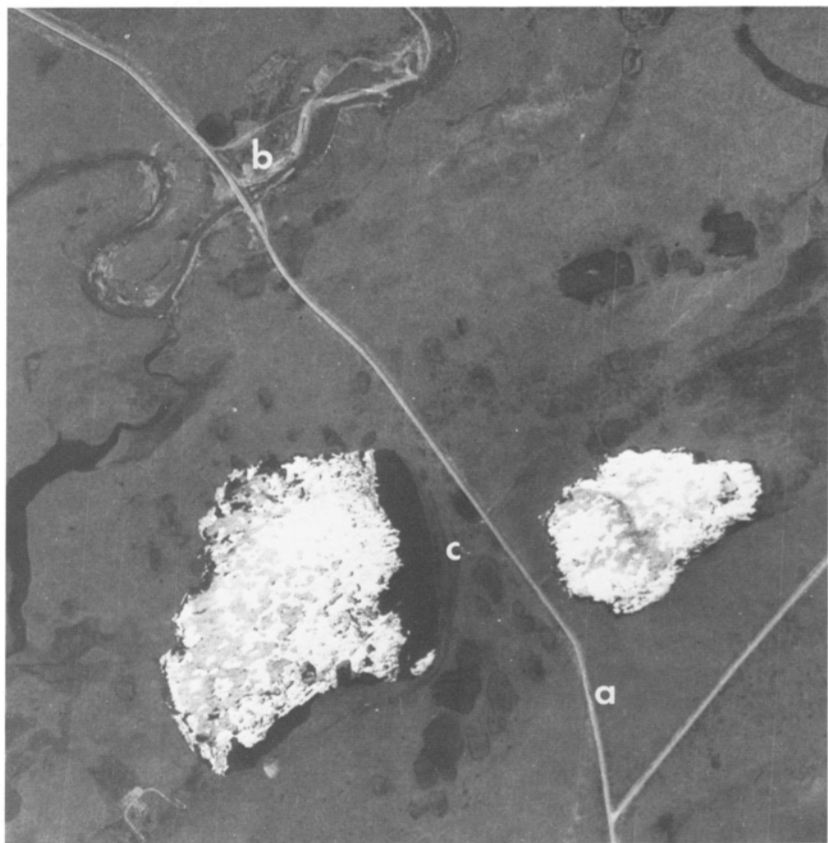
1972

1977

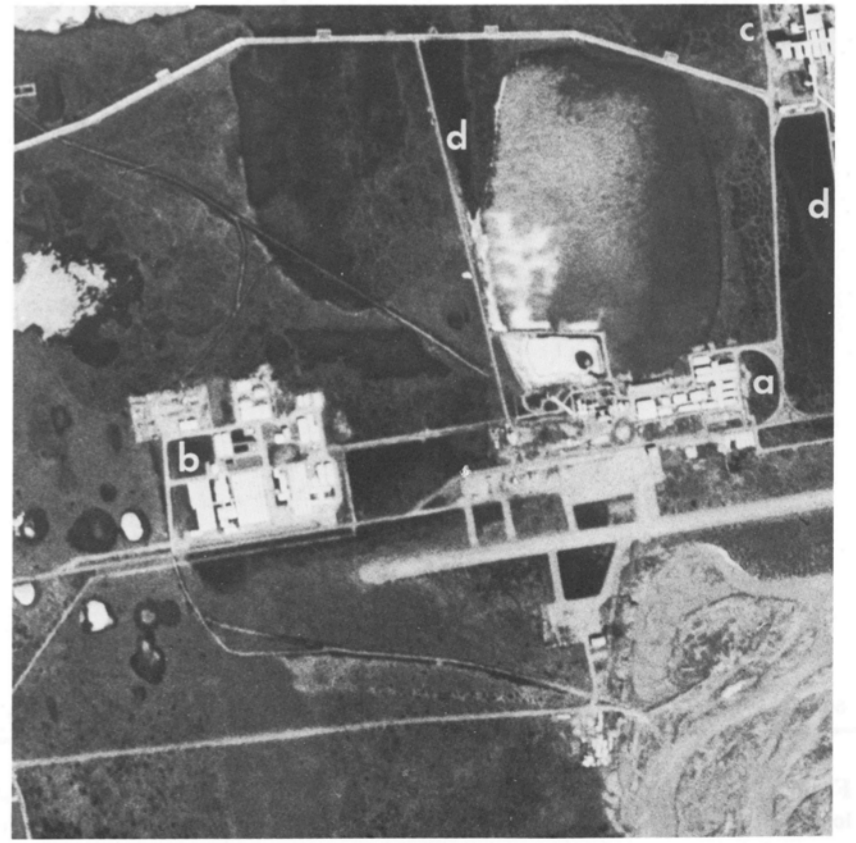
Figure 6 (cont'd.)



BP/Sohio Base Camp →



Alyeska Pump Station No. 1 →



ARCO Base Camp →



## Scientific History

K.R. Everett

The northern portion of the Arctic Coastal Plain of Alaska remained virtually unknown to all but the Inuit until the first years of the 19th century. The general outlines of the arctic coast eastward from Beechey Point west of Prudhoe Bay were defined by Franklin in 1826 on his second expedition (Franklin 1828). The Prudhoe Bay region was the westernmost point reached on his

journey and he named the bay on 16 August 1826. Eleven years later the Simpson-Dease expedition charted the coast from the Mackenzie River to Point Barrow. In the years following 1837, through the Franklin search and into the first decades of the 20th century, the coastal waters were navigated many times, but few and very limited excursions were made inland. Army Lt. P.H. Ray, having established an international polar station at Barrow in

1881, made several expeditions to the south and mapped part of the Meade River. In 1886 Navy Ensign W.L. Howard became the first westerner to cross the coastal plain from south to north. After crossing the Brooks Range he led his party from the Colville drainage northward along the Ikpikpuk River, then north and west along the present Chipp River, finally crossing overland to Barrow.

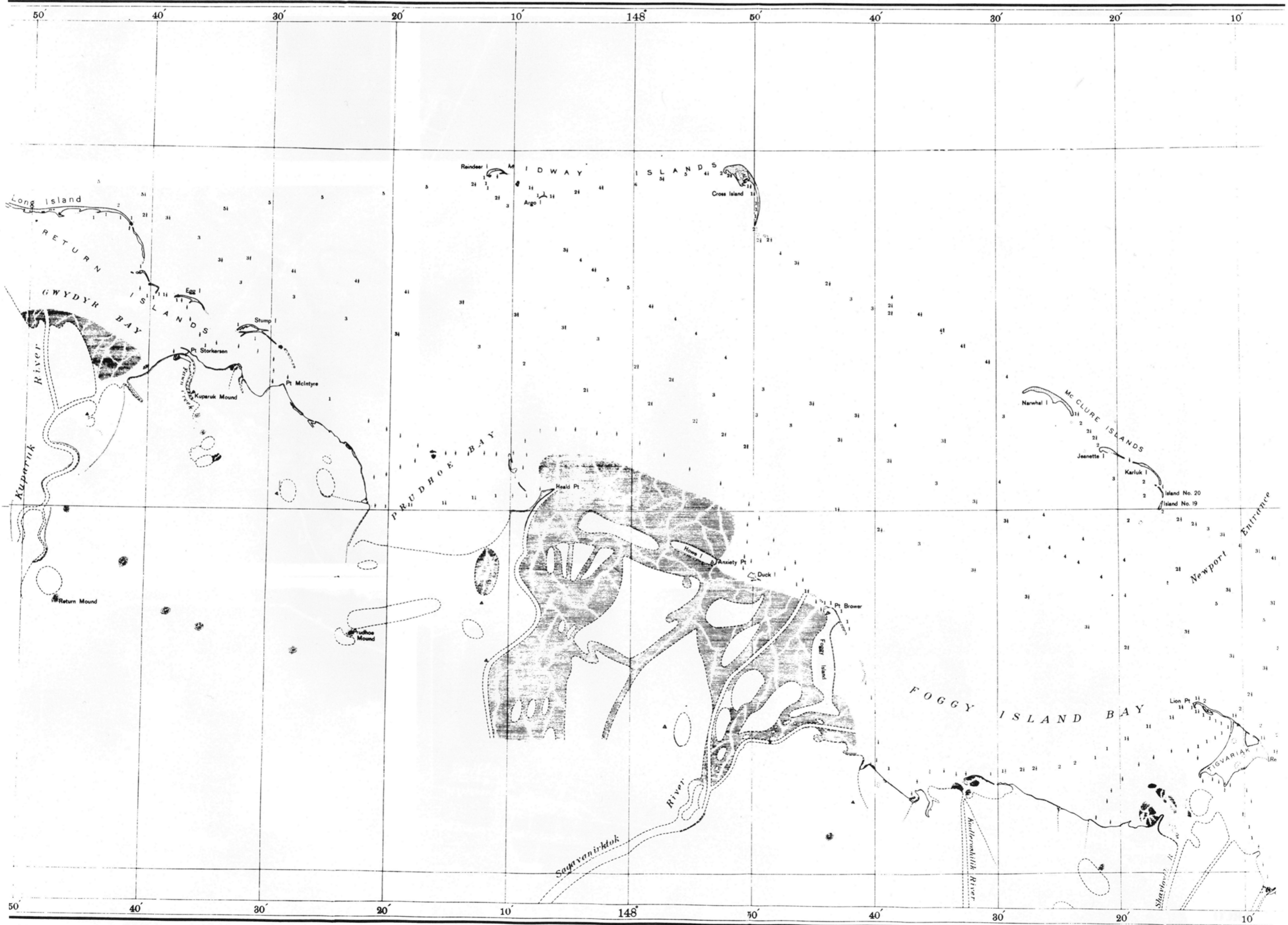


Figure 7. Early map of the Prudhoe Bay region. It was originally published as part of a U.S. Geological Survey Professional Paper (Leffingwell 1919) and represents what was known of the region in 1914.



The first scientific party to cross the Alaskan portion of the coastal plain was that of F.C. Schrader and W.J. Peters in 1901 under the auspices of the U.S. Geological Survey. Their report included a short list of plant species (Schrader and Peters 1904). These geologists first applied the term *Arctic Coastal Plain* to the flat, lake-dotted tundra north of the Endicott Mountains. At the same time, gold prospectors, notably S.J. Marsh and F.G. Carter, investigated the Camden Bay-Canning River region in 1901-03. And from 1901 to 1912 H.T. (Ned) Arey lived in the neighborhood of the Canning River delta and became familiar with the Prudhoe Bay area. He provided Marsh with maps based on Inuit descriptions showing, among other things, the location of the Sawanukto River—the Sagavanirktok River of today. It is certain that in those early years of the century, prospectors reached the arctic coast by way of the Sagavanirktok (Leffingwell 1919). Leffingwell, under the aegis of the U.S. Geological Survey, conducted reconnaissance geological surveys in the lower Canning River-Flaxman Island region and westward to Prudhoe Bay in 1901, from 1909 through 1912, and again in 1913-14. Part of his work included preparation of a map of the northern coast of Alaska (Fig. 7). The period of the early 1920's was one of considerable exploration by field parties of the U.S. Geological Survey north and west of the Colville River within what was then designated Naval Petroleum Reserve No. 4.

These early expeditions of discovery and geological reconnaissance produced some information on the flora of the region, but this was mostly from the immediate coastal area (see Hultén 1940). The coastal plain was visited with increasing frequency beginning about 1945, especially by U.S. Geological Survey parties again investigating Naval Petroleum Reserve No. 4 (Reed 1958). Associated with these investigations was Lloyd A. Spetzman, who conducted botanical studies and made numerous plant collections throughout the coastal plain region (Spetzman 1951, 1959).

With the end of World War II and the opening of the Naval Arctic Research Laboratory at Barrow in 1947 (Reed and Ronhovde 1971) an increasing number of scientists began investigations on the coastal plain, mainly in the vicinity of Barrow. The oriented thaw lakes that characterize so much of the region were described by Cabot (1947) and Black and Barksdale (1949). Frost (1950) illustrated and discussed many of the regionally significant landscape elements of the coastal plain in a two-volume evaluation of soils and permafrost in Alaska prepared for the Army Corps of Engineers. Beginning in the late 1940's the U.S. Geological Survey began a comprehensive investigation of permafrost and polygonal ground (MacCarthy 1952, Black 1954, Brewer 1958, Lachenbruch et al. 1962). And in 1951 Wiggins published on the vascular plants of the Barrow region and their relationship to patterned ground. In 1954, Koranda completed a phytosociological study at Barrow, and the following year Churchill (1955) published on the phytosociological and environmental characteristics of some plant communities at Umiat.

In 1955 Tedrow and Hill published the first soil studies of the coastal plain at Barrow, although tundra soils in northern Alaska had already been portrayed generally by Kellogg and Nygard (1951). These investigations of a well-drained soil with affinities to the Podzols of more southern regions began a period of extensive soils investigations in the Barrow area that defined their morphological, physical and chemical characteristics and their relationship to topography (Drew 1957, Drew and Tedrow 1957, Tedrow et al. 1958, Tedrow and Cantlon 1958). In 1957 Britton published the single most important paper on the vegetation of the arctic tundra. In it he discussed vegetation, landforms and permafrost-related processes, including the thaw-lake cycle. Clebsch (1957, Clebsch and Shanks 1968) investigated the vegetation-climatic gradient between Barrow and Atkasook (Meade River).

Beginning in 1959 and extending through 1963 a large multidisciplinary program was conducted at Cape Thompson. These studies produced the first detailed maps of soils, landforms and vegetation of a single northern Alaska landscape (Holowaychuk et al. 1966, Johnson et al. 1966).

Douglas and Tedrow (1960) considered the tundra soils of arctic Alaska and many of their frost-induced morphological features, and Douglas (1961) and Hill and Tedrow (1961) published soil investigations from other areas. The problem of origin and development of the oriented thaw lakes received further consideration by Livingstone (1954) and Rex (1961), and in the late 1950's and early 1960's by Carson and Hussey (1959, 1962). Black reviewed the thaw lake literature in 1969. Tedrow (1969) discussed coastal plain soils in relation to the oriented thaw lakes and thaw sinks.

Throughout the 1960's soil, landform and vegetation investigations were extended to an ever-widening area of the coastal plain and adjoining foothills to the south. Koranda (1960) studied the vegetation of the Franklin Bluffs area just south of the Prudhoe Bay region. Tedrow and Brown (1962) described the soils of the foothills of the Brooks Range, and Brown (1962, 1966) completed a study of the soils of the Okpilak River region east of Prudhoe Bay. In 1965 MacNamara completed a study of the soils in the Howard Pass region, and in the same year Brown and Johnson (1965) published in detail on the relationships among soils, vegetation and microenvironments at Barrow. Brown later described the relationship between soil properties and microrelief patterns for this same site (Brown 1969) and Brown et al. (1968) reported on the hydrology of a small basin adjacent to it.

The pace of research on the tundra of the Arctic Coastal Plain began to accelerate in 1969 when a multinational interdisciplinary research effort was initiated on the dynamics of the tundra ecosystem as part of the International Biological Program Tundra Biome (Brown et al. 1969, Bunnell et al. 1975). Soil, vegetation and landform studies were undertaken as part of that program (Tieszen 1978, Brown et al., in press, b).

In 1973 the soils and vegetation studies were extended under the Tundra Biome research to the Prudhoe Bay region. Here, previous investigations, together with those of Neiland and Hok (1975), showed soils and vegetation to be strongly influenced by microtopographic position. An experimental program was developed to determine if soils and vegetation could be characterized and portrayed on a single landform base map similar to that developed by Carey (1972) for the Barrow area (Webber and Walker 1975, Everett 1975, Walker 1977). An analysis of the soils and their relation to the evolution of the Prudhoe Bay landscape was published by Everett and Parkinson (1977) and Parkinson (1978).

A generalized soils map for arctic Alaska, including the coastal plain, was published at a scale of 1:1,000,000 as part of the Alaska Regional Profiles series (Alaska, University 1975). It was based on exploratory soil surveys undertaken by the U.S. Department of Agriculture, Soil Conservation Service and since published (Rieger et al. 1979). In addition to the work of Carey (1972) already mentioned there was the more general work of Lewellen (1972), H.J. Walker (1973), and Sellmann et al. (1975) on coastal plain morphology, and of Wiseman et al. (1973) and Harper (1978) on coastal processes. The study by Sellmann et al. (1975) summarized the major sea level transgressions in northern Alaska. In 1971 Young proposed a vegetation zonation for the Arctic and considered broad changes in the vegetation of the region as a function of climate. Additional studies of shoreline erosion and subsea topography have been made by Hopkins and Hartz (1978) and Barnes and Reimnitz (1974). These investigations continue in part under the auspices of the Outer Continental Shelf Environmental Assessment Program (Weller and Norton 1977). A summary of literature

on winter water supplies in arctic Alaska published in 1977 (Wilson et al.) presents information on types of water sources and their geologic settings and uses. Kovacs and Morey (1979) located a freshwater pool in the Sagavanirktok River delta using impulse radar techniques. In 1977 a proposed wetland classification system for the Prudhoe Bay region was published which is particularly useful for purposes of waterfowl management (Bergman et al. 1977). Finally Updike and Howland (1979) have recently published a series of geologic maps of the Prudhoe Bay oilfield and discussions of hydrologic processes.

This historical outline has of necessity focused on the broader or more general aspects of natural history and vegetation and soils research on the Arctic Coastal Plain and areas immediately to the south. Ideally, it serves as a background for the state-of-the-knowledge of vegetation, soils and landform analyses presented in this atlas. It should be pointed out that several summary papers and bibliographies exist of the hundreds of investigations on climate, landforms, soils, fauna and vegetation (Gunn 1973, Britton 1973). A significant number of those publications are the direct result of programs federally funded with partial oil industry support, such as:

- the NSF-sponsored U.S. Tundra Biome (Tieszen 1978, Brown et al., in press, b, Hobbie, in press)
- the more recent NSF-sponsored RATE (Research on Arctic Tundra Environment) program at Atkasook (Meade River) (Batzli and Brown 1976)
- ONR-funded research, logistically supported by the Naval Arctic Research Laboratory (Reed and Ronhovde 1971).



# Geology and Permafrost

K.R. Everett

## Pre-Quaternary Geology

PRUDHOE BAY IS UNDERLAIN by a major structural feature, the Barrow arch, which consists of uplifted lower Paleozoic rocks. Above the arch is approximately 3750 m of post-Devonian sediments. The thickness of these rocks increases southward toward the Colville trough (Fig. 8). The pre-Cretaceous sediments beneath Prudhoe Bay are mostly terrestrial, having been derived from sources to the north. Repeated uplift of the Barrow arch, especially during Triassic and Jurassic time, resulted in a number of erosional unconformities. One of the most important of these occurred near the end of the Jurassic, affecting not only Jurassic rocks but older rocks as well. By Early Cretaceous the Barrow arch and the northern sediment sources had begun to subside and the source of sediments shifted to the south in response to the rising Brooks Range. An Early Cretaceous marine shale deposited over the Late Jurassic unconformity provided an impermeable seal beneath which hydrocarbons were trapped. The hydrocarbons are believed to be derived from the capping shale as nearly 2500 m of marine and non-marine sediments accumulated above it through the Mesozoic and into the Tertiary (Morgridge and Smith 1972).

## Quaternary Geology

The Prudhoe Bay region is situated on a thick section of unconsolidated Quaternary sediments which lie unconformably on northward-dipping, weakly cemented sands, gravels, clays and silts of the Tertiary Sagavanirktok Formation. The majority of the Quaternary deposits are unconsolidated sands and gravels composed of reworked Tertiary materials and materials derived from

the Brooks Range to the south. They are similar to terrace and bed deposits of the present Sagavanirktok and Kuparuk Rivers. Overlying these deposits are between 1.5 and 2.5 m of ice-rich silts with variable amounts of organic matter. The silts are probably equivalent to the Barrow member of the Gubik Formation (Black 1964). Juxtaposed with, or immediately overlying, the silts are deposits of loess 1 m or less thick that have been derived from the braided channels and deltas of the Sagavanirktok and Kuparuk Rivers. Surface organic deposits overlie the loess and, in many cases, are co-extensive with the underlying organic-rich sediments. Locally, sand dunes derived from the Sagavanirktok River overlie the silts.

In the Prudhoe Bay region thaw lakes have modified the landscape over the last 10,000 years through the combined processes of thermokarst and thermal erosion (Everett and Parkinson 1977). The initiation, expansion and eventual drainage of these lakes constitute the principal elements of the thaw lake cycle as originally defined by Hopkins (1949) and Britton (1957) (see Fig. 28). In a manner similar to that described by Brown et al. (in press, a) at Barrow, the growth of the larger and deeper lakes has melted the ground ice contained in the permafrost and lowered the land surface in some areas perhaps as much as several meters. Fluvial, aeolian and frost activity have been locally important in reworking these Holocene deposits.

Remnants of the pre-thaw lake cycle surfaces, or primary land surfaces, occur as isolated ridges and shorelines. Reestablishment of permafrost in drained lake basins has resulted in a variety of polygonized forms, string bogs and, sporadically, pingos, the unique landform of the region (Fig. 9).



Figure 9. Drained thaw lake near Prudhoe Bay. It drained through the channel on the right. High-centered polygons are evident around the margins of the lake. The pingo in the basin is a result of permafrost becoming reestablished in the lake bed (see Fig. 42).

## Permafrost

Permafrost is a condition of the Earth's surface in which a temperature below 0°C has existed for two or more years (Lachenbruch et al. 1962). It is not implicit in this definition that ice be present although it commonly is. The amount of ice depends on topographic position, material type, its porosity and permeability, and the past geomorphic history. At Prudhoe Bay permafrost extends to a depth of about 660 m (Gold and Lachenbruch 1973, Howitt 1971, Fig. 10). This is the greatest known depth in Alaska.

In portions of northern Alaska not covered by Quaternary glaciers, permafrost formed and was modified perhaps several times during the glacial and interglacial ages of the Pleistocene. Increasing glacier ice during the last major glaciation (the Wisconsinan) caused a lowering of sea level and its retreat many kilometers north of the present coastline. The sediments exposed by the regression of the sea then froze to form permafrost on what is now the continental shelf. Relying upon evidence from Barrow, Brown (1965) determined that ice wedges were forming in a tundra somewhat colder and drier than at present. It is reasonable to assume then that thaw lakes were also present and that surface modifications as a result of these lakes (the thaw lake cycle) were taking place. Thus far, the oldest radiocarbon date from a lake basin on the Barrow tundra is 12,600 years old (Lewellen 1972). A date obtained from the basin of the lake drained for Pump Station No. 1 (Everett 1975) indicates that thaw lakes could have been actively reworking the surface in the Prudhoe Bay region at least 9330 years before present (Fig. 11). Several younger dates and associated pollen profiles from peat sections in river cuts and coastal bluffs have been obtained from the Prudhoe Bay region (Andrews et al., in prep.).

Permafrost that formed on the exposed continental shelf is today still found in the subsea environment where it has persisted since marine inundation began at the close of the last glaciation (Lachenbruch and Marshall 1977, Sellmann and Chamberlain 1979). At present the coastline in the Prudhoe Bay region is retreating at an average rate of 1.5 m/yr, largely as a result of thermal erosion (Hopkins and Hartz 1978). As the newly eroded land-based permafrost is inundated it becomes part of the subsea permafrost.

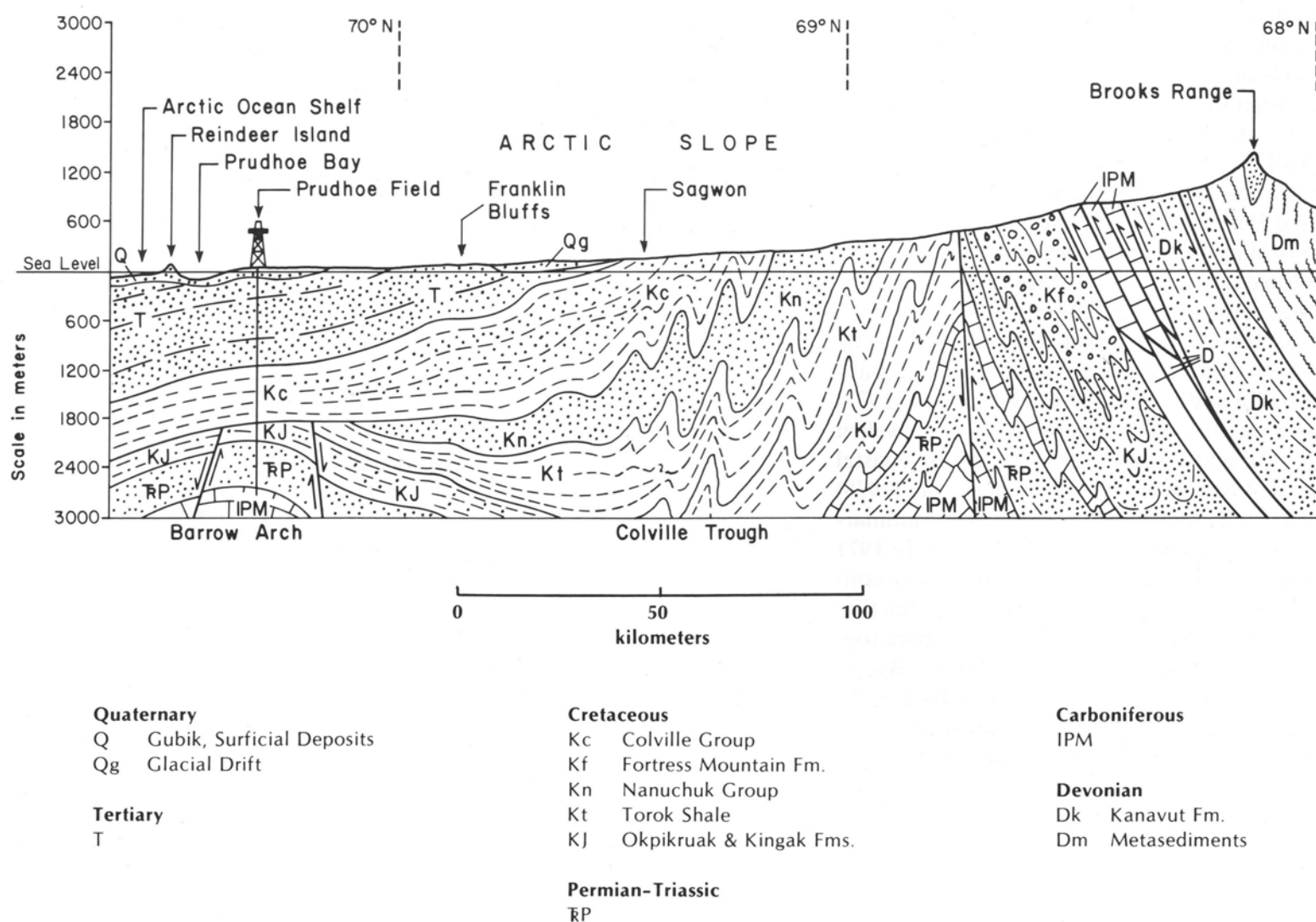


Figure 8. Geologic stratigraphic transect between the Prudhoe Bay region and the Brooks Range. Modified from Bennison (1974).



The perennially frozen sediments of the coastal tundra have relatively large volumes of ice, mostly in the upper 5 to 10 m (Brown and Sellmann 1973). The ice occurs as segregations (Fig. 12) and wedge-shaped bodies (Fig. 13) related to the contraction crack polygons so characteristic of the entire coastal plain.

The initial polygonal outline develops in response to rapid, intense winter cooling and subsequent contraction of the fine-grained coastal plain sediments (Fig. 14, Lachenbruch 1962). The narrow thermal contraction cracks thus formed are subsequently filled by ice in the form of winter hoarfrost or water produced from melting of the snow cover. The process of cracking and filling, repeated over many centuries, results in the growth of vertical wedge-shaped masses of ice that penetrate many meters and may attain widths up to several tens of meters. The increase in volume caused by the expanding ice wedges commonly produces a buckling or heaving of the tundra on either side and parallel with them. The ridges or rims so produced, together with melting of the wedge tops, cause linear depressions or troughs to form immediately above the ice wedges that commonly define the polygonal surface pattern (Fig. 15 and 16).

In the seasonally thawed soil or active layer of the tundra horizontal ice segregations (ice lenses) like those shown in Figure 12 develop each fall as water moves by capillary action along a moisture tension gradient to the freezing plane. The amount of soil moisture below the freezing front and the rate at which freezing occurs govern the thickness of the individual segregations. A freezing front may also move up from the top of the permafrost table as the soil cools, especially in coarser-textured materials. The position of the segregated ice is determined to a considerable extent by the structure of the mineral soil, e.g. the platy structure inherent in silty soils provides physical boundaries toward which water moves. Segregated ice below the active layer dates to an earlier time when the saturated sediments were thawed. Segregations of nearly pure ice up to 5 m thick have been recorded in the Prudhoe Bay region but such thicknesses are rare and lenses a few millimeters to a few centimeters thick are more common. Below a depth of about 10 m ice lenses are uncommon, and the ice that does occur is mostly intergranular, cementing sand and gravel fragments.

Maximum depth of seasonal soil thaw is approximately 1 m on the well-drained sandy and gravelly sites, and up to 50 cm in the areas of wet tundra. It is within the seasonally thawed soil or active layer that the processes of soil formation, frost churning or cryoturbation and plant-soil interaction (i.e. nutrient cycling) take place. Summer temperatures in the active layer are generally low, although at the air/soil or air/vegetation interfaces they may reach 30°C or higher on clear, sunny days. Even these high temperatures are quickly attenuated by the poor conductivity of the vegetation and the near-surface organic soil horizons. In the low-centered polygon areas typical of the Prudhoe Bay region, mean summer temperatures (21 June–15 August) at 8 cm depth range between 3.6 and 3.9°C. This depth generally marks the lower boundary of maximum biological activity.

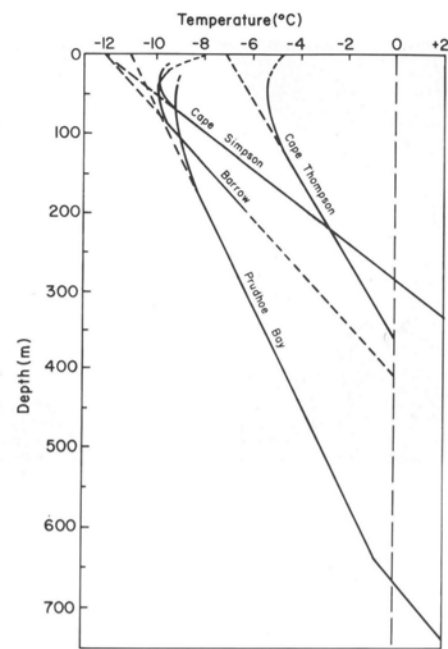


Figure 10. Generalized geothermal profiles showing measured permafrost temperatures on land along the Alaskan arctic coast. The dashed lines represent extrapolations. From Gold and Lachenbruch (1973).

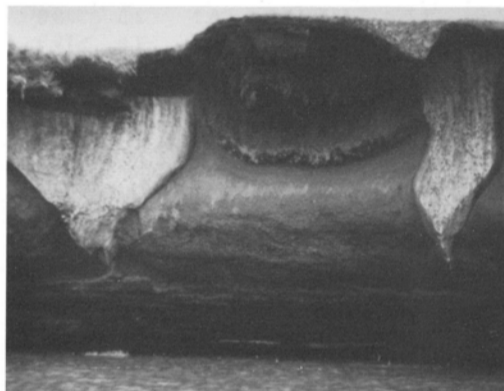


Figure 13. Large ice wedges in tundra exposed near Drew Point, Alaska. At Prudhoe Bay similar ice wedges occur beneath polygon troughs (Fig. 15 and 16). From Black (1976).

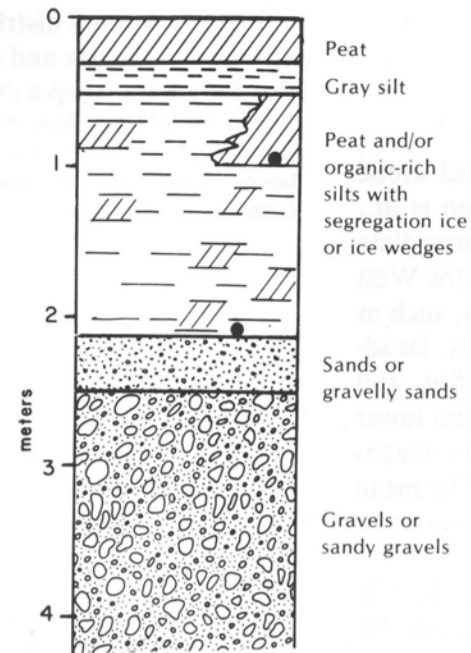


Figure 11. Generalized stratigraphic section of the near-surface deposits in the Prudhoe Bay region. Radiocarbon dates are indicated by dots. The upper date (4700 years BP) was obtained from the basin of a low-centered polygon. The lower date (9330 years BP) came from the drained lake site of Pump Station No. 1.

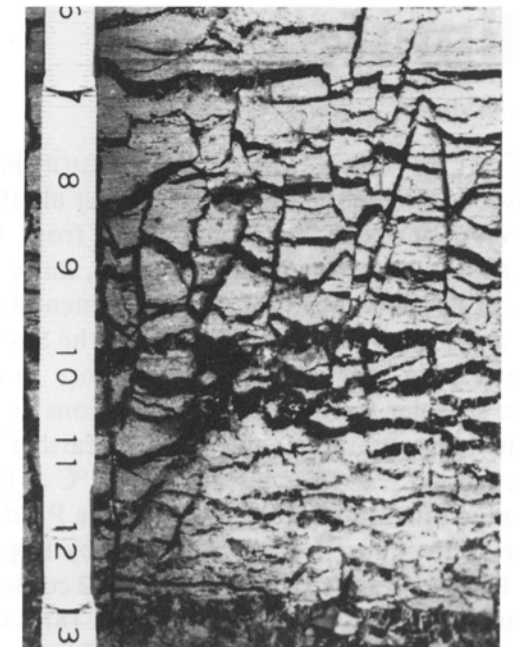


Figure 12. Segregation ice in silts 15 to 30 cm below the surface at Prudhoe Bay. Such ice is typical of frozen soils and sediments and its volume can reach 70%. The scale is in inches.

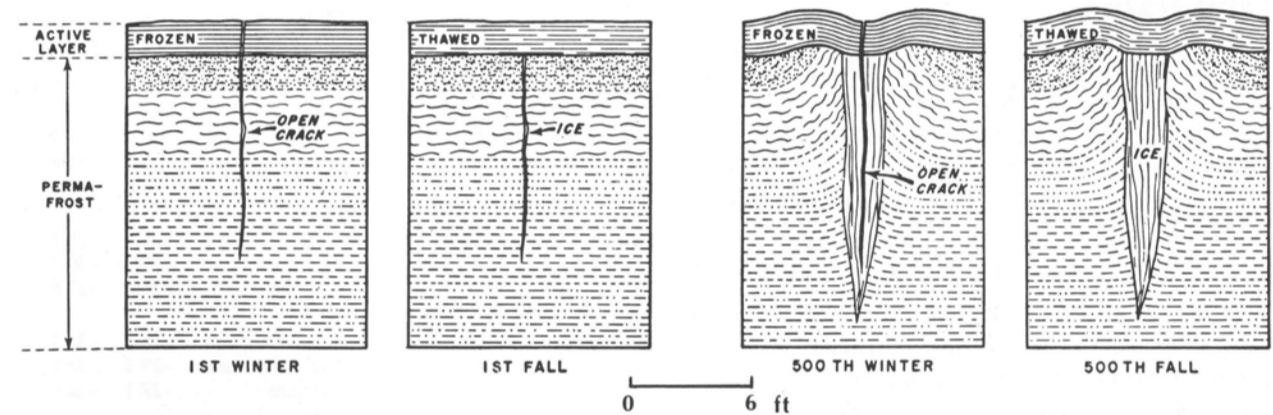


Figure 14. The evolution of an ice wedge according to the contraction crack theory. Fine-grained mineral soils contract and crack in response to very low air temperature. The cracks are expressed at the surface commonly in polygonal forms. Winter hoarfrost and snow meltwater fill the crack, resulting in expansion of the ice mass. Surface expression of the crack may disappear during the summer. These processes, repeated over long periods of time, produce ice wedges (Fig. 13) and much of the surface pattern, as seen in Figure 15. From Lachenbruch (1962).

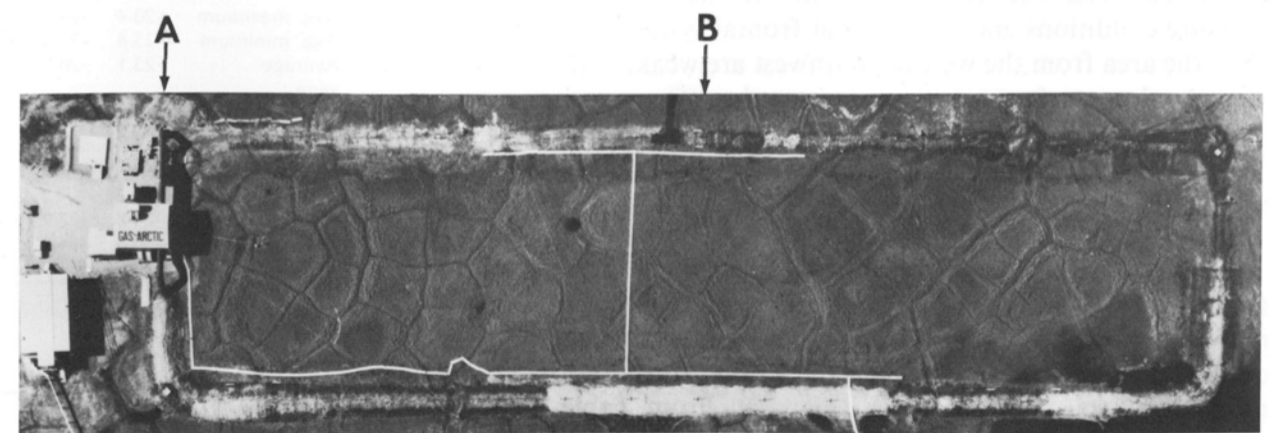


Figure 15. Detail of polygonal tundra surface at an experimental gas pipeline test site (Arctic Gas test facility) at Prudhoe Bay. At this site construction techniques for burial of 122-cm (48-in.) pipeline were tested and their effects on the surface and permafrost environments were evaluated. Letters (A and B) denote the portion of the trench detailed in Figure 16.

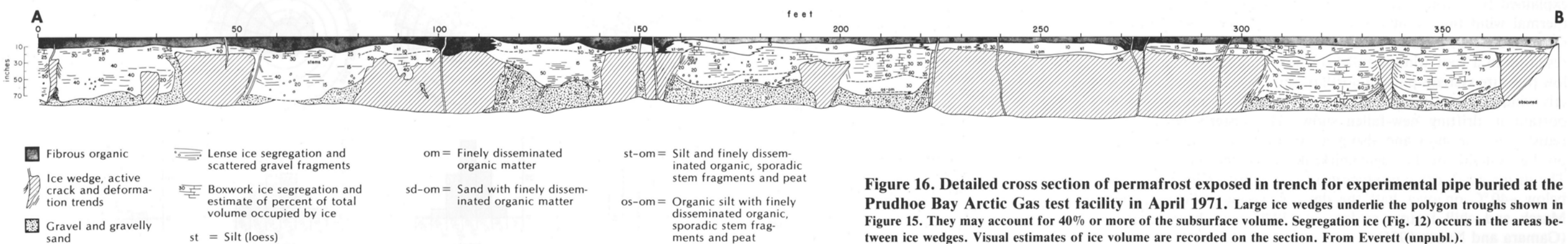


Figure 16. Detailed cross section of permafrost exposed in trench for experimental pipe buried at the Prudhoe Bay Arctic Gas test facility in April 1971. Large ice wedges underlie the polygon troughs shown in Figure 15. They may account for 40% or more of the subsurface volume. Segregation ice (Fig. 12) occurs in the areas between ice wedges. Visual estimates of ice volume are recorded on the section. From Everett (unpubl.).



# Climate

D.A. Walker

MOST OF THE PRUDHOE BAY REGION has a modified arctic coastal climatic regime (Brown et al. 1975, Dingman et al., in press), and can be distinguished from both the immediate coastal area, as exemplified by Barrow, Barter Island and the West Dock at Prudhoe Bay, and more continental inland areas, such as Atkasook, Umiat, Happy Valley and the Sagwon Uplands. Deadhorse (12 km from the coast) has more sunshine, less fog, and higher summer temperatures than stations on the coast, and lower summer temperatures than stations farther inland. July means range from 4°C at the coast to about 7°C at Deadhorse. The mean annual temperature of -13°C places the Prudhoe Bay region within the arctic climatic zone as defined by Köppen (1936).

The sun is above the horizon for 72 consecutive days (Fig. 17). Net annual radiation at the coast (Fig. 18) is probably comparable to that at Barrow, with 420 to 450 MJ/m<sup>2</sup> yr, nearly all of which occurs from June to mid-September (Dingman et al., in press). For comparison, the value at treeline in northern Alaska is about 670 MJ/m<sup>2</sup> yr (Hare and Ritchie 1972).

## Winter Climate (October to May)

### Temperature

The sun is below the horizon for 49 consecutive days during midwinter (Fig. 17). The absence of incoming solar energy during this period leads to extremely low temperatures. Sea ice covers the coastal waters after mid-October, so that winter temperatures in the Prudhoe Bay region are not moderated by the ocean. Mean monthly temperatures are below 0°C from September through May (Table 2, Fig. 19). During this period the region is typically covered by a deep polar air mass associated with a high pressure ridge over the ocean. A temperature inversion 1000 to 1500 m deep covers northern Alaska during most of the winter and keeps surface temperatures consistently low. Mean temperatures at Prudhoe Bay for the months of January, February and March are around -30°C (Table 2), somewhat lower than at either Barrow or Kaktovik (Barter Island). The lowest temperature recorded was -49°C in February 1971 and January 1976. Skies are clear to partly cloudy more than 60% of the time during winter (Brower et al. 1977). The clear weather is due mainly to the dominance of high pressure conditions and the fact that frontal systems that do penetrate the area from the west or southwest are weak, and rarely disrupt the deep surface temperature inversion (Conover 1960).

### Winds

Prudhoe Bay lies between two dominant pressure systems. One is an area of semi-permanent high pressure to the north that is responsible for anticyclonic airflow and easterly winds, and the other is a deep low over the Gulf of Alaska. In winter, winds are most commonly from the west (Fig. 20). From Table 3, which compares the available wind data from the coastal areas, we see that Oliktok (about 50 km northwest of Prudhoe Bay) and Barter Island also have frequent wintertime westerly winds, while stations farther west (Lonely and Barrow) have winds mainly from the east-northeast. The strength and dominance of the westerly winds decrease as the Brooks Range is approached. Schwerdtfeger (1973) explained the strong wintertime westerlies as being caused by a thermal wind that results when cold, stable air flows from the north and stacks against the barrier formed by the Brooks Range, resulting in a west wind parallel to the mountains. Occasionally, low pressure systems passing north of the coast also produce westerly winds. The westerly winds occur with snowstorms and are important in drifting new-fallen snow. The easterly winds often redistribute the snow and also generate dust from the sand dunes on the west side of the Sagavanirktok River (Benson et al. 1975). The strong winds often produce ground blizzards. Chill factors are below -40°C on over half the days in January, February and March and chill factors as low as -79°C have been recorded (Gamara and Nunes 1976).

Figure 17. Annual distribution of times of sunrise and sunset, Prudhoe Bay, Alaska (70°20' N, 148°45' W). Dashed lines, when projected to hour scale, give possible hours of sunshine. Modified from Gamara and Nunes (1976).

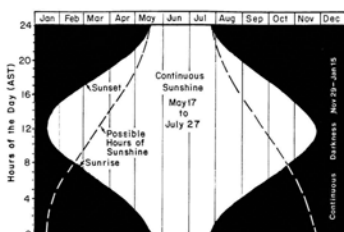


Table 2. Nine-year temperature record (°C), Prudhoe Bay (ARCO Airfield), Alaska.

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
<b>1970</b>													
Avg. maximum	-24.7	-24.7	-25.5	-15.2	-3.2	5.2	8.4	7.8	-0.1	-14.7	-15.2	-22.7	-10.4
Avg. minimum	-30.5	-31.9	-32.4	-21.9	-9.6	-0.4	2.0	2.3	-4.9	-20.2	-23.7	-30.5	-16.8
Average	-27.6	-28.3	-29.0	-18.6	-6.4	2.3	5.2	5.1	-2.5	-17.4	-19.4	-26.6	-13.6
<b>1971</b>													
Avg. maximum	-27.4	-33.5	-24.9	-17.3	-3.7	7.4	11.5	6.1	2.3	-8.0	-16.7	-25.7	-10.8
Avg. minimum	-36.8	-40.1	-32.6	-26.8	-9.6	1.4	3.9	0.6	-1.6	-15.9	-23.2	-29.4	-17.5
Average	-32.1	-36.8	-28.7	-21.7	-6.7	4.4	7.7	3.3	0.5	-11.9	-19.9	-27.6	-14.2
<b>1972</b>													
Avg. maximum	-26.4	-29.1	-28.2	-15.7	-2.9	4.6	10.1	9.4	0.9	-4.8	-15.7	-19.8	-9.8
Avg. minimum	-31.2	-34.8	-34.1	-24.3	-8.6	0.9	4.0	3.6	-1.2	-9.8	-19.3	-24.6	-15.1
Average	-28.8	-31.9	-31.1	-20.1	-5.8	2.7	7.1	6.5	-0.7	-7.3	-17.6	-22.0	-12.4
<b>1973</b>													
Avg. maximum	-24.4	-25.3	-29.5	-13.8	-2.2	4.3	11.2	9.7	4.8	-7.1	-15.3	-19.9	-8.9
Avg. minimum	-29.1	-30.3	-35.9	-22.3	-7.1	0.9	4.8	4.6	0.4	-11.1	-18.8	-23.8	-14.0
Average	-26.7	-27.8	-32.7	-18.0	-4.7	2.6	8.0	7.2	2.6	-9.1	-17.1	-21.9	-11.4
<b>1974</b>													
Avg. maximum	-24.8	-34.1	-26.6	-17.0	-3.5	3.6	10.0	10.8	2.2	-12.8	-22.7	-32.9	-12.3
Avg. minimum	-29.3	-38.0	-33.9	-26.2	-9.4	-1.1	2.9	2.3	-1.4	-17.7	-27.7	-39.3	-18.2
Average	-27.1	-36.1	-30.2	-21.6	-6.4	1.2	6.5	6.6	0.4	-15.2	-25.2	-36.1	-15.3
<b>1975</b>													
Avg. maximum	-31.9	ND	-19.5	-14.3	-4.2	5.9	9.8	7.0	-0.5	-12.0	-24.7	-29.8	-10.4
Avg. minimum	-37.4	ND	-28.0	-24.7	-8.6	1.1	3.9	1.8	-4.6	-15.4	-27.9	-33.7	-15.8
Average	-34.7	ND	-23.7	-19.5	-6.4	3.5	6.8	4.4	-2.5	-13.7	-26.3	-31.7	-13.1
<b>1976</b>													
Avg. maximum	-27.5	-27.7	-24.8	-10.9	-2.9	6.9	10.4	10.4	4.3	-6.7	-12.9	-27.1	-9.0
Avg. minimum	-34.1	-36.1	-33.2	-22.0	-8.9	-0.6	3.1	2.8	-1.0	-13.2	-20.2	-33.5	-16.4
Average	-30.8	-31.9	-29.0	-16.5	-5.9	3.2	6.8	6.6	1.6	-11.4	-16.6	-30.3	-12.7
<b>1977</b>													
Avg. maximum	-20.4	-24.4	-26.7	-13.9	-2.6	6.6	9.2	12.5	5.8	-2.6	-17.9	-19.0	-7.8
Avg. minimum	-25.8	-31.5	-36.8	-24.5	-8.4	0.9	1.7	3.8	-0.8	-6.8	-25.0	-27.8	-15.1
Average	-23.1	-28.0	-31.8	-19.2	-5.5	3.7	5.4	8.2	2.5	-4.7	-21.4	-23.4	-11.4
<b>1978</b>													
Avg. maximum	-17.1	-23.0	-20.4	-10.7	-4.2	5.8	12.7	9.8	5.6	-10.9	-10.6	-20.3	-7.0
Avg. minimum	-23.2	-29.0	-29.8	-22.2	-11.1	-0.2	4.0	0.6	-0.3	-14.9	-18.9	-26.3	-14.3
Average	-20.1	-26.0	-25.1	-16.5	-7.6	2.8	8.4	5.2	2.6	-12.9	-14.8	-23.3	-10.6
<b>9-yr mean (1970-78)</b>													
Mean maximum	-24.8	-27.7	-25.2	-14.3	-3.3	5.6	10.4	9.3	2.8	-8.9	-16.7	-24.1	-9.7
Mean minimum	-30.8	-34.0	-33.0	-23.9	-9.0	0.3	3.4	2.5	-1.8	-13.9	-22.7	-29.9	-16.1
Mean	-27.9	-30.9	-29.0	-19.1	-6.2	2.9	6.9	5.9	0.6	-11.4	-19.8	-27.0	-12.9

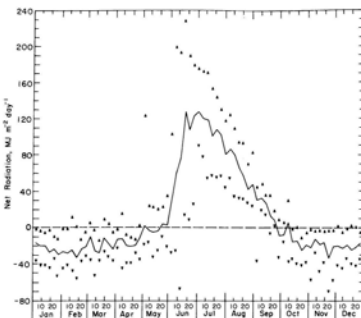


Figure 18. Net radiation for five-day intervals over the coastal tundra at Barrow, Alaska. Variation of mean values shown by solid line; ▲ = maximum; ▼ = minimum. Data based on the years 1962 and 1964-66. From LeDrew and Weller (1978); based on Maykut and Church (1973).

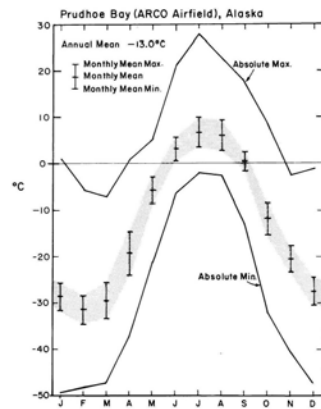


Figure 19. Yearly range in mean and extreme air temperature for the Prudhoe Bay region based on an eight-year record, 1970-77.

Figure 20. Wind direction and velocity for the Prudhoe Bay region, June 1974 through June 1975. During late spring and summer the wind is predominantly from the east and northeast. However, southerly components are common during summer when the Arctic Front moves northward from the coast. During fall and throughout the winter a strong west and west-southwest component develops. Mean annual wind velocity is about 22 km/hr. Highest means are during the spring, early summer and fall. Lowest mean velocities occur in late winter. Calm conditions develop especially in late winter and are associated with deep, stable inversions and extremely low temperatures. From Gamara and Nunes (1976).

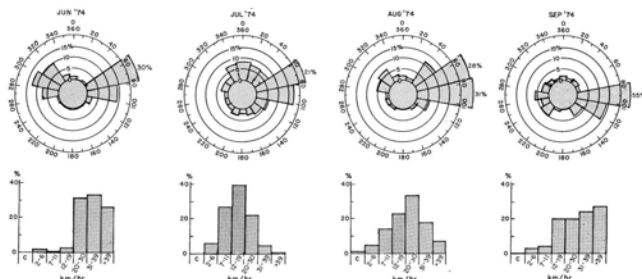




Table 3. Mean wind speeds (km/hr) and predominant directions at four Alaskan arctic coastal stations.

Station	J	F	M	A	M	J	J	A	S	O	N	D	Yr	Period of record
Barrow	19.1	17.0	18.3	18.5	18.7	18.7	18.5	19.6	20.6	20.8	21.9	17.6	19.1	1948-1974
	ENE	ENE	ENE	ENE	ENE	E	E	E	E	E	ENE	ENE	ENE	
Lonely	16.9	14.4	15.0	14.6	14.8	15.2	14.4	15.6	17.4	17.8	19.8	15.4	15.9	1957-1975
	ENE	ENE	ENE	ENE	ENE	ENE	ENE	E	E	ENE	ENE	ENE	ENE	
Oliktok	21.1	18.3	18.9	17.4	17.0	17.2	16.7	17.6	20.2	19.5	21.7	19.3	18.7	1957-1975
	ENE&SW	ENE&SW	ENE&SW	ENE	ENE	ENE	ENE	ENE	E	ENE	ENE	ENE&SW	ENE	
Barter Island	24.1	22.4	21.9	19.1	19.6	18.1	17.0	18.5	21.1	23.0	24.5	22.8	20.9	1949-1974
	W&E	W&E	W&E	E&W	E	E	ENE	E	E	E&W	E&W	W&E	E&W	

Source: Brower et al. (1977).

Table 4. Temperatures for Prudhoe Bay region, Barrow, Barter Island and the northern section of the haul road.

Station	Year	Temperature (°C)												Thaw degree days	Distance to coast (km)	
		J	F	M	A	M	J	J	A	S	O	N	D			Yr
<b>TAPS haul road localities</b>																
Prudhoe Bay, W. Dock	1976						1.7	4.1	4.2	0.3					287	0.7
	1977						-1.5	2.6	4.2	1.6	-3.1				318	
Prudhoe Bay, Pad F	1976							5.4	4.1	1.1						7.1
	1977						4.0	4.2	6.2	1.7	-4.0				491	
Prudhoe Bay, Drill Site II	1977						0.1	4.2	7.1	2.2	-3.2					4.6
Prudhoe Bay, ARCO	1976	-30.8	-31.9	-29.0	-16.5	-5.9	3.2	6.8	6.6	1.6	-11.4	-16.6	-30.3	-12.7	571	6.0
	1977	-23.1	-28.0	-31.8	-19.2	-5.5	3.7	5.4	8.2	2.5	-4.7	-21.4	-23.4	-11.4	643	
Deadhorse	1976					-1.9	4.3	7.3	5.8	1.4					556	11.8
	1977					-1.2	5.7	7.6	9.8	5.8	-6.0				879	
Franklin Bluffs	1976				-18.4	-7.2	3.2	9.8	9.4	2.7	-12.6	-19.2	-35.1	-7.5	793	71.0
	1977	-25.1	-29.6	-33.7	-20.0	-3.4	5.7	7.5	12.1	3.2					884	
Sagwon Upland	1976					-2.2	5.0	10.8	10.5	2.7					913	102.0
	1977					-3.5	6.5	10.0	12.9	3.3	-9.2				1040	
Happy Valley	1976	-28.4	-29.3	-23.7	-13.9	-5.2	7.4	11.8	11.6	4.0	-13.0	-19.5	-35.6	-11.1	1093	122.0
	1977	-24.5	-31.2	-32.5	-18.0	-4.5	8.0	2.1	12.4	2.5	-9.8	-24.9	-21.6	-11.0	1125	
<b>Barrow</b>	1976	-28.3	-30.5	-26.3	-18.9	-8.2	0.8	3.6	3.0	0.1	-10.2	-16.4	-26.9	-13.2	277	0.6
	1977	-22.2	-26.9	-30.1	-21.3	-7.2	1.2	3.8	6.9	2.1	-6.6	-20.5	-22.0	-11.9	441	
	30-yr means (48-77)	-25.9	-28.1	-26.1	-18.3	-7.3	0.6	3.7	3.2	0.9	-9.3	-18.1	-24.6	-12.6	228	
<b>Barter Island</b>	1976	-29.2	-30.7	-27.9	-19.3	-6.7	1.1	3.5	4.3	0.9	-11.0	-15.0	-30.2	-13.1	326	0.1
	1977	-23.4	-27.3	-32.3	-20.1	-5.9	1.4	3.1	5.2	2.1	-4.9	-19.8	-21.7	-12.0	375	
	29-yr means (49-77)	-26.2	-28.6	-25.9	-17.7	-5.4	1.2	1.8	3.8	0.2	-8.7	-17.7	-24.7	-12.2	—	

Data: R.K. Haugen, CRREL (in press), U.S. Department of Commerce (1976-77).

Precipitation

Prior to 1977, records of Prudhoe Bay winter precipitation were unreliable because of the difficulty of measuring small amounts of snow under very windy conditions. Total 1971-72 winter accumulation through May 1972, measured on the ground, was 100 mm water equivalent (Benson et al. 1975). During the winter of 1976-77 a Wyoming snow gauge (Fig. 21) recorded an accumulation of 137 mm water equivalent from September through 15 April (U.S. Department of Agriculture 1977). A snow survey for the same period showed 130 mm water equivalent.

The average April wind-packed snow depth is between 30 and 40 cm (Benson et al. 1975, Everett and Parkinson 1977). The snowpack has anywhere from a few centimeters to as much as 20 cm of recrystallized low density (generally less than 250 kg/m<sup>3</sup>) snow, or depth hoar, at the base, with upper layers of higher density (to 480 kg/m<sup>3</sup>) wind-packed snow (Everett, unpubl. data). The snow surface is rough and covered by snow dunes and sastrugi (Fig. 22). Most of the snow falls during September and October when there is still open water on the Beaufort Sea to provide a source of moisture.

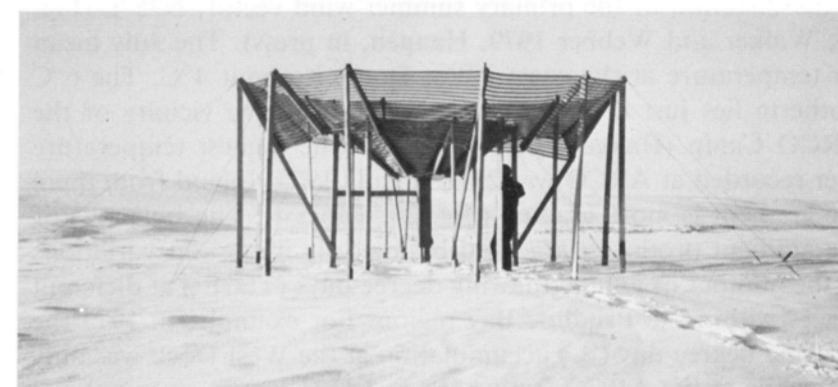


Figure 21. A Wyoming-type snow gauge. It is designed as an efficient collector of snow. The series of slotted blinds exclude blowing snow and produce a relatively still atmosphere through which snow can fall into the collector. The collector's height above the ground prevents drifting snow from entering it. Photograph by R.K. Haugen.



Figure 22. Winter scene east of Prudhoe Bay. The snow surface has considerable microrelief in the form of low dunes, scour pits and, in the foreground, sastrugi sculptured by snow drifting under strong winds. Several pingos may be seen in the background.

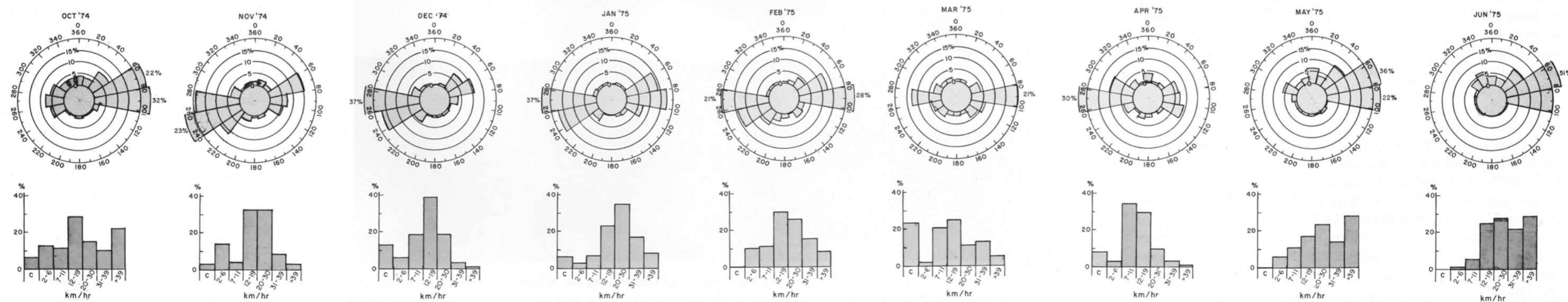


Figure 20 (continued).



## Summer and Fall Climate (June to September)

### Temperature and Winds

Summer temperatures at the coast remain consistently within a few degrees of freezing because of the combined influences of the ice-covered Beaufort Sea to the north which depresses temperatures near the coast, and the Brooks Range to the south, which limits the flow of warm continental air from the interior. Cold air dominates longer into summer in northern Alaska than in the interior. After snowmelt in early June the region remains under the influence of the mass of cold air associated with the Arctic Ocean. Conover (1960) has described the seasonal action of this air mass. During mid- and late summer the southern edge of the cold air (i.e. the Arctic Front) oscillates back and forth across the coastal plain, occasionally retreating to the coast. By late September cold Arctic Polar air regains complete dominance and covers all of northern Alaska.

Near the coast the summertime temperature gradient is steep. Temperatures at different points within the oilfield are most closely correlated with the distance to the Beaufort Sea measured in the direction of the primary summer wind vector, N75°E (Fig. 23; Walker and Webber 1979, Haugen, in press). The July mean air temperature at the coast (West Dock) is about 4°C. The 6°C isotherm lies just a few kilometers inland, in the vicinity of the ARCO Camp (Haugen, pers. comm.). The highest temperature ever recorded at ARCO was 28°C in July 1975. Inland from there the gradient is more gradual (Fig. 24, Table 4). The steepness of the gradient produces large and biologically important variations in the number of annual thawing degree-days (TDD's) at different places within the Prudhoe Bay region. For example, in 1977 the thawing degree-day (°C) accumulation at the West Dock was only 318 while at the ARCO station it was 643 (Haugen, in press).

The cold air at the surface and the overriding warm air produce a strong summertime temperature inversion. This is often apparent when smoke plumes produced by burn-offs at the drill sites do not mix into the warmer upper layer of air but form a flat surface at the boundary between the cold and warm air masses (Fig. 25). During midsummer, when winds occasionally blow from the west and south, the inversion temporarily dissipates, allowing warm air to cover all areas except that immediately adjacent to the coast. This coastal area is usually influenced by cool sea breezes on days when it is warm inland (Moritz 1977). Everett (in press) measured wind direction and velocity at the Arctic Gas test facility and found a high percentage of winds from the south and west in the summer of 1977, which was an abnormally warm summer (see data for ARCO station in Table 2). It is under these conditions of higher inland temperatures that the greatest contrast in temperature exists between the coast and inland areas.

The date of breakup of the sea ice is a matter of special concern to the oilfield operators since most drilling supplies and building components arrive on ocean-going barges. Rogers (1978) has shown that the severity of sea ice conditions is closely correlated with sea level pressures over the Arctic Ocean. Summers with less severe ice conditions are associated with higher than normal sea level barometric pressure northeast of Alaska and lower than normal pressure over the East Siberian Sea. This pressure gradient produces more southerly surface winds which tend to push the ice away from shore. Summers with severe ice conditions are associated with the opposite pressure gradient and more northerly winds. Rogers' data suggest that climatic conditions favoring heavy-ice summers have become more common since 1953 than in the 30 years preceding 1953.

The light-ice summers create mild falls and extended thaw seasons since the open water causes relatively higher temperatures near the coast, whereas interior areas of the coastal plain rapidly cool during the fall due to decreased net radiation. This was evident in 1977, which was a light-ice year. October temperatures at the coast were over 6°C higher than at Happy Valley, 122 km inland (compare ARCO and Happy Valley, Table 4). In August of the same year the opposite situation existed, with Happy Valley 8°C warmer than the coast, and by December both areas had comparable temperatures. Compared to inland areas, the coast is cooler during the spring and summer, warmer during the short fall season, and about as cold during the winter.

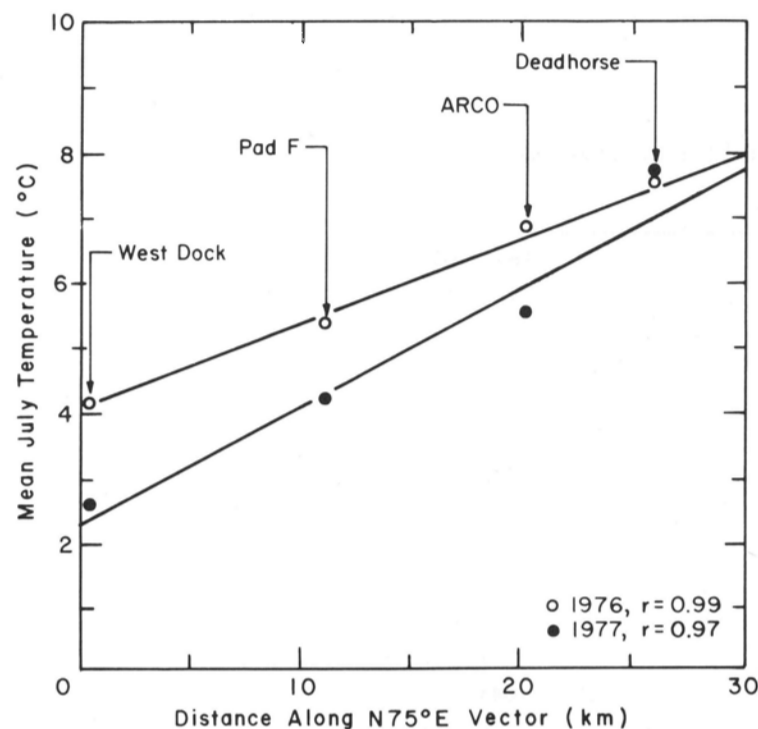


Figure 23. Mean July air temperatures along a transect inland from the coast within the Prudhoe Bay region for 1976 and 1977. Temperatures are closely correlated with the distance to the coast as measured in the direction of the primary summertime winds (N75°E).

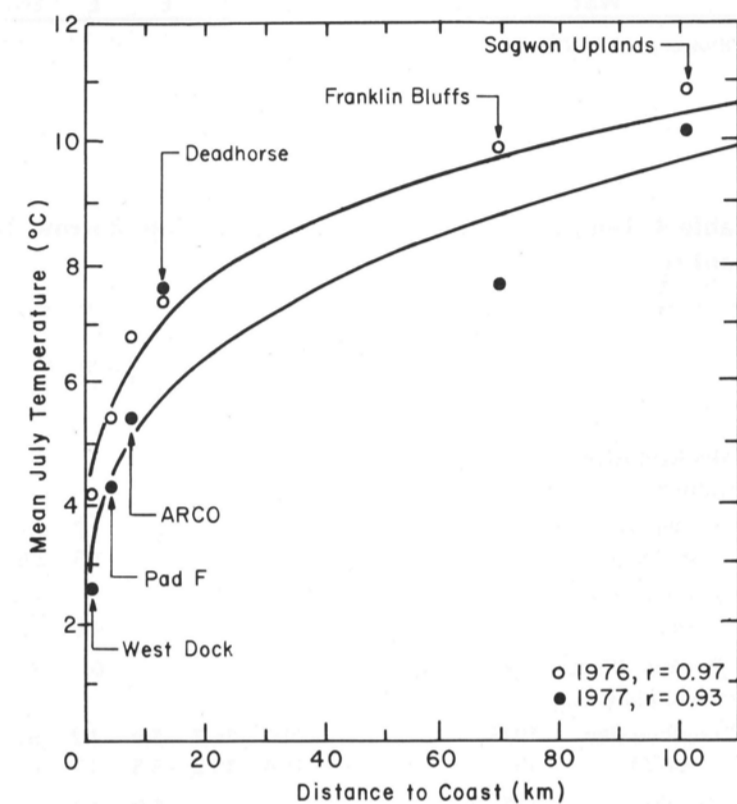


Figure 24. The mean July coastal-inland temperature gradient for 1976 and 1977 from Prudhoe Bay to Sagwon Uplands. Note the steepness of the gradient within the Prudhoe Bay region.



Figure 25. Smoke plume produced by the burn-off of oil illustrating the height of a summertime temperature inversion in the Prudhoe Bay region. The flat upper surface of the plume marks the boundary at about 300 m between warm air above and cold surface air below.



## Precipitation

Records of annual precipitation at Prudhoe Bay have been kept only since October 1976, using a Wyoming-type snow gauge (Fig. 21). This gauge, designed for windy conditions, has recorded precipitation totals considerably higher than previously recorded on the coastal plain. The 1977 and 1978 totals for Prudhoe Bay (Table 5) are 2 to 2.7 times those recorded for the same period at Barrow and Barter Island by conventional U.S. Weather Service instruments. Both years were exceptionally dry. The 30-year means at Barrow and Barter Island are 170 mm and 179 mm respectively. The available data indicate that about 35% of the total annual precipitation falls in the summer as rain. Storms frequently track north of the coast and derive moisture from the Arctic Ocean. However, drizzle and light rain are the most common forms so amounts are not large. Fog associated with the Arctic Front is common in the mornings and it often lingers later at the coast after it has dissipated at Deadhorse and inland areas.

## Microclimate

The surface and subsurface temperatures are of primary importance to soil development and the vegetation. The temperature at the surface on sunny days is commonly as much as 10°C higher than the ambient air temperature 1 m above the surface (Conover 1960, Kelley and Weaver 1969, Weller and Holmgren 1974). Beneath the surface the temperature is more sharply attenuated because of the presence of permafrost. Plants take advantage of the warmer surface environment by producing short and prostrate growth forms and by confining the majority of their roots and subsurface nutrient storage organs to the top 10 cm of soil. Microorganisms and soil invertebrates, important for soil formation, also confine their activities to this near-surface environment. Microtopography also plays an important role. For example in low-centered polygon terrain, temperatures near the surface range considerably within the confines of individual polygons (Fig. 26).

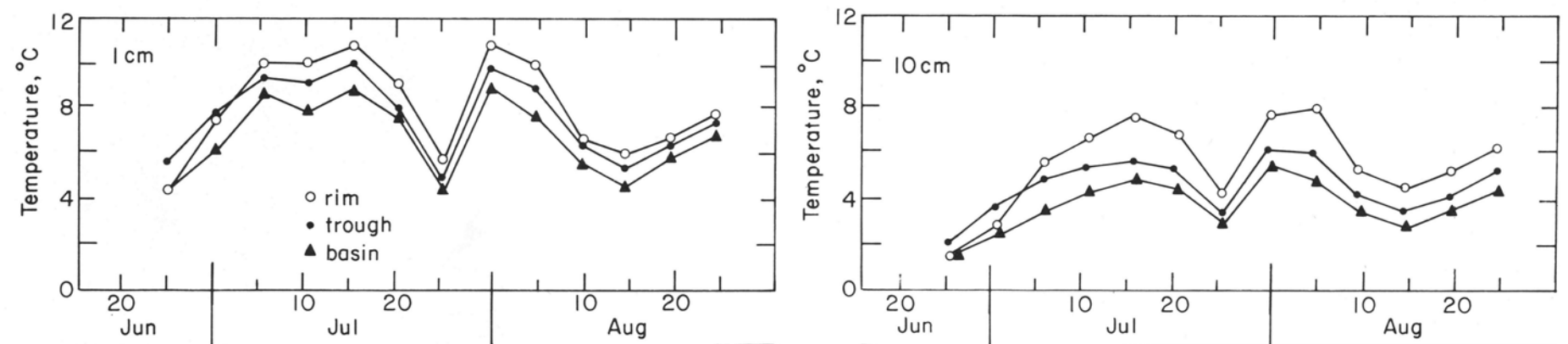
In midwinter the soil surface is considerably warmer than the upper snow surface (Fig. 27). This has important implications for the plants, which confine the majority of their overwintering buds to the ground surface. At the base of the snowpack low-density depth hoar forms. This is a layer of recrystallized snow caused by the flow of heat and moisture upward from the soil through the snowpack. The higher temperatures, the ease of burrowing, and the protection afforded by the wind slabs allow the small animals to reproduce while remaining almost immune to predation and the effects of the extreme environment above the snow surface. This snow microenvironment is discussed in more detail by Benson et al. (1975).

The microclimate of the arctic coastal tundra, particularly the annual changes in the radiation budget, is discussed by Dingman et al. (in press). The regional climate and microclimate are treated more thoroughly in Mather and Thornthwaite (1956, 1958), Conover (1960), McKay et al. (1969), and Searby and Hunter (1971). Moritz (1979) describes in detail the synoptic climatology of the region.

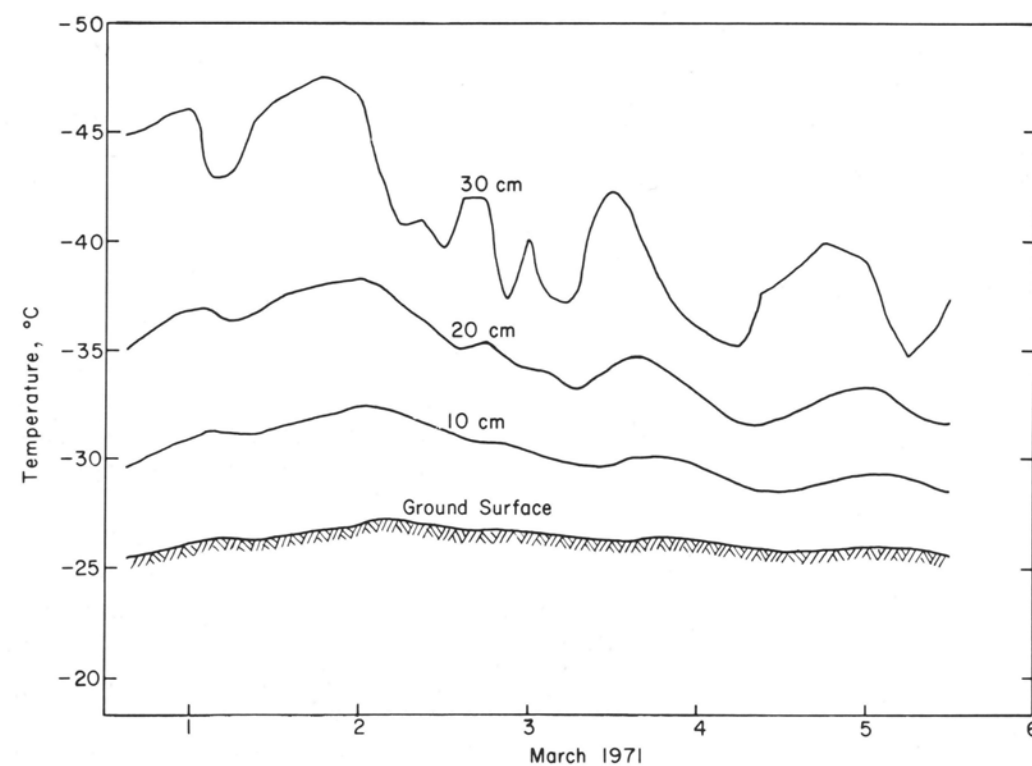
**Table 5. Precipitation (mm) for 1977 and 1978 at three arctic coastal stations. From Haugen (in press).** All Prudhoe Bay values are approximate due to length of intervals between instrument readings (13 readings between Dec 1976 and Jan 1979).

Year	Prudhoe Bay*			Barrow†	Barter Island†
	Rain	Snow (water equivalent)	Total		
1977	81	142	223	83	85
1978	58	125	183	98	91

\* Modified Wyoming snow gauge.  
† Standard NWS instruments.



**Figure 26. Temperatures at two depths on a polygon rim, trough, and basin during the course of summer 1972.** From Bunnell et al. (1975).



**Figure 27. Temperatures in the snow at Barrow, Alaska, during the period 1 through 6 March, the coldest period in 1971.** Numbers on the temperature curves are distances above the ground surface. The relatively moderate temperatures within the depth hoar layer (commonly the lower 10 to 15 cm) are apparent. From Dingman et al. (in press).



# Landforms

K.R. Everett

## Introduction

THE PRUDHOE BAY REGION is essentially flat, with elevations rising gradually from between about 3 m at the top of the sea bluffs to between 15 and 23 m some 20 km inland. The mean surface elevation is approximately 10 m. Over large areas absolute relief differences are small, about 2 m. However, differences of 6 to 12 m are encountered in association with the larger streams and with some of the larger pingos. The dominant geomorphic elements of the landscape, especially when it is viewed from the air or from maps, are the numerous elliptical lakes. It is estimated that in the Prudhoe Bay area lakes occupy 25 to 30% of the landscape (C.J. Merry, pers. comm.). Most of the larger lakes of the coastal plain and many of the smaller ones have a long axis orientation of N15°W (Black and Barksdale 1949). The vast majority of the lakes are shallow, 0.6 to 2 m deep, and are geomorphologically short-lived features.

The landscape between the lakes is characterized by a variety of patterned ground forms. The most common of these is the low-centered polygon, which, together with much less extensive areas of high-centered polygons, and transitional forms, constitute the principal microrelief. Where best expressed the microrelief contrast between polygon centers and troughs is 0.5 to 1 m, but extensive areas of polygonal ground patterns with microrelief contrast less than 0.5 m are common. Frost boils are also common. Other features include non-patterned tundra; small (0.5 m diameter) polygons and hummocks along river banks; large diameter, low relief (~10 cm) high-centered polygons on narrow interfluvies and adjacent to most streams; pingos; and sand dunes near the mouth of the Sagavanirktok River. These then are the landforms with which the area's soils and vegetation assemblages are so closely associated.

## Evolution of the Landscape

Before describing the landform units in more detail, we should first consider the development of the regional landscape, and central to this is the thaw lake cycle (Fig. 28).

The development of an oriented thaw lake begins with climatic change or disruption of the vegetation and organic cover of the polygonized tundra (A). Thaw of the ice-rich near-surface materials and melting of ice wedges can result in a pool of standing water and the development of a shallow pond that eventually becomes a thaw lake (B). If the pond is large enough, permafrost thaws beneath it and along its sides, resulting in expansion of the water body (C). Bank thaw proceeds most rapidly at and below the water level, eroding the surrounding tundra and rapidly melting and truncating ice wedges to produce an irregular shoreline (D). Eventually thawed and frozen blocks of tundra collapse into the growing lake. Their organic and mineral components are subsequently broken up and redistributed by wave and current action. Underwater shelves form where the tundra is eroded, usually along shorelines perpendicular to the wind direction. Sediments and detritus are moved into the enlarging lake basin. Plants such as *Arctophila fulva*, *Carex aquatilis*, *Eriophorum angustifolium* and mosses may occupy these shelves for several tens of meters from the shore (Hopkins 1949, Britton 1957, Webber 1978). The lake grows most rapidly along the axis perpendicular to the wind, partially because of the increased velocity and the seasonally higher temperatures of the water at the ends of the lake (Carson and Hussey 1962). The result is an oriented thaw lake.

Stream capture or the breaching of low divides may interrupt the lake phase by draining an expanding or stabilized lake. This produces relatively broad, drained or partly drained basins (E). Even completely drained basins commonly remain very wet or have shallow standing water for protracted periods during the summer. Upon drainage *Arctophila fulva* and/or *Carex aquatilis* often colonize the newly exposed lake sediments. Mosses such as *Scorpidium scorpioides* and *Drepanocladus* spp. may also occur

with the *Carex*. Organic matter production is high in this vegetation assemblage and conditions are ideal for its accumulation and preservation. Airborne particulates that are occasionally transported from the nearby river floodplains are a major source of mineral materials.

With time, permafrost and ice wedges become reestablished in the drained basins. If the ice wedges were not completely removed in the lake portion of the cycle, they are reaccentuated. The result is the development of a surface polygonal pattern (F). In some cases large orthogonal polygons are established, sometimes in rows parallel to the margins of the lake basins (Lachenbruch 1962). In the Prudhoe Bay region, networks of non-orthogonal polygons are more common. In the early stages of polygon expression, microrelief contrasts are minor. As the pattern becomes more accentuated with the expansion and/or melting of the ice wedges and the associated displacement of soil, significant microrelief contrasts may

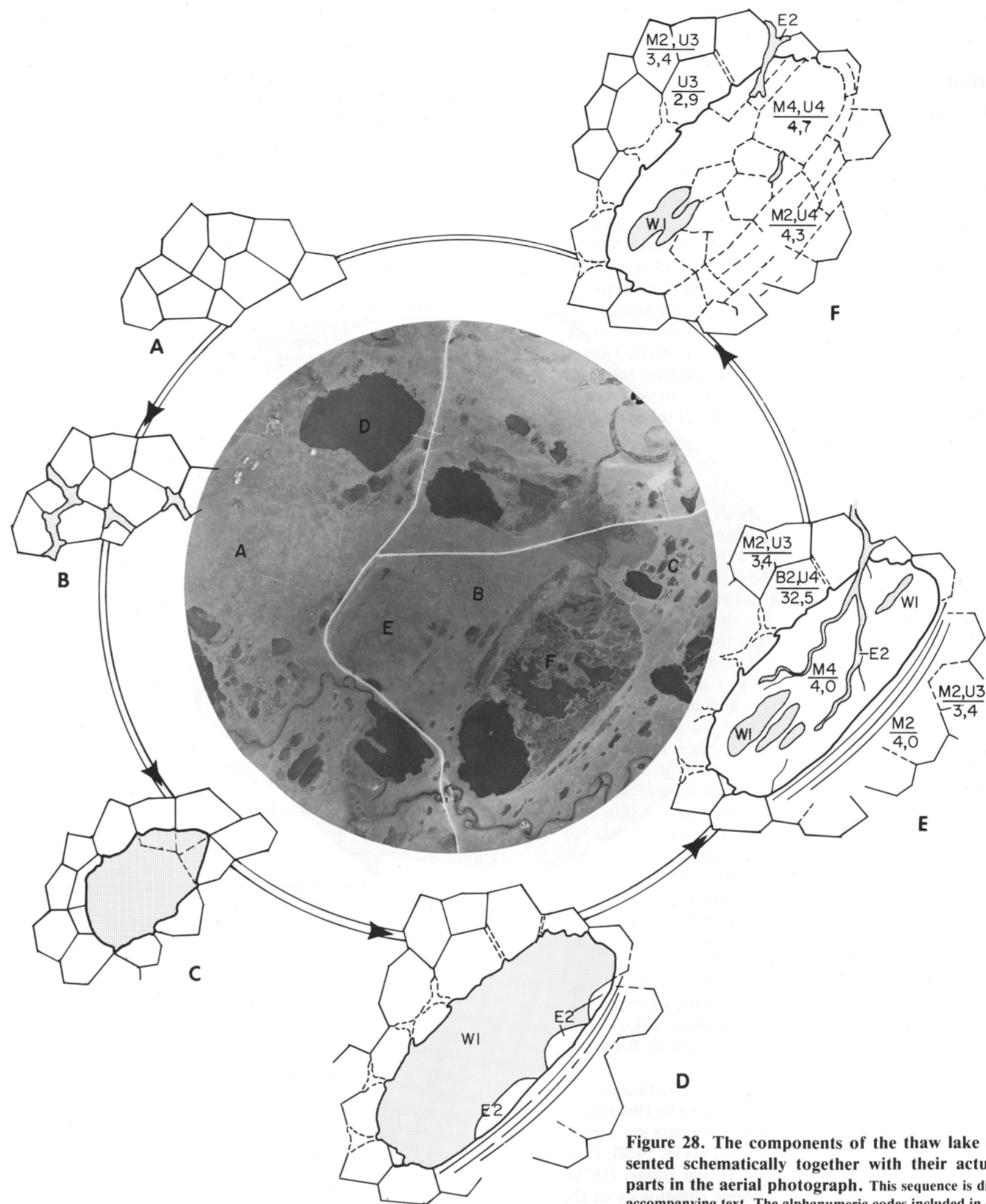


Figure 28. The components of the thaw lake cycle represented schematically together with their actual counterparts in the aerial photograph. This sequence is discussed in the accompanying text. The alphanumeric codes included in drawings D, E and F are used on the master landscape maps. The numerator combinations refer to vegetation. The denominator symbols identify soils and landform units. The reader is referred to pages 36 and 51 for a complete explanation of the code terms.

develop between the polygon centers, rims and troughs. Pingo formation may take place in some lake basins.

The drainage of thaw lakes and the headward erosion of streams sometimes change poorly drained terrain, such as lake basins and polygonal areas, into relatively well-drained areas. Thawing and erosion of polygon troughs caused by meltwater flowing through these low channels may convert low-centered polygons to high-centered polygons. The reduction in organic thickness due to oxidation, together with the better drainage, contribute to increased frost churning in the underlying mineral soil. Eventually this instability may be expressed in the form of frost boils.

In the processes outlined above, the landscape elements and their associated soils are continuously created, evolve, and are destroyed, with their organic and mineral constituents being incorporated within subsequent lake and polygon cycles.



## Landform Units

Landform units described here are for the most part patterned ground forms (Washburn 1980) that occur within drained lake basins and floodplains, and on interfluvial areas. Within the Prudhoe Bay region, at a scale of 1:6000, areas could be delineated that were composed essentially of a single landform that might itself be made up of one or more elements repeating over and over within the unit. In all, 13 landform units were recognized. More units might have been identified, but with the consequence that map unit boundaries and unit definitions would have become increasingly complex. The tendency in such cases would have been to decrease the regional applicability of the map and to exclude all but specialists from its use. The landform units recognized are described here in numerical order as they appear in the legends of the master maps (Appendix A). The vertical aerial photographs in the accompanying figures are at a scale of 1:3000, and were acquired for CRREL in 1972 (Table 1).

### Unit 1: High-Centered Polygons, Center-Trough Relief > 0.5 m (Fig. 29)

High-centered polygons in the Prudhoe Bay region occur most commonly in a narrow band extending only a few tens of meters inland along streams and the shorelines of former thaw lakes. They are the product of thermokarst and/or thermal erosion in the troughs of former low-centered polygons. These processes become active when drainage of the thaw lakes or change in stream gradient permits better surface and subsurface drainage, resulting in melting of the ice and subsequent deepening of the troughs. The over-deepened (greater than 0.5 m deep and commonly 1.0 m or more) troughs permit slumping of the rim elements and a gradual topographic reversal of the polygon center. This is accompanied by a reduction in surface area of the center. Unit 1 commonly has no other units included with it, although in some circumstances Unit 5 (mixed high- and low-centered polygons) may be associated.

### Unit 2: High-Centered Polygons, Center-Trough Relief ≤ 0.5 m (Fig. 30)

Certain upland areas, or broadly convex interfluvial areas, have large-diameter (5 to 10 m) polygons whose centers are slightly convex or raised with respect to the adjoining contraction crack or trough. Although the difference in height between the center and the trough may reach 0.5 m it is commonly on the order of 10 to 20 cm and sometimes much less. The central portions of these polygons may be patterned with small (25-50 cm) polygons suggestive of desiccation. The unit may include Unit 9 (reticulate-patterned ground) in areas where the desiccation cracks (polygons) are the dominant landform.

### Unit 3: Low-Centered Polygons, Rim-Center Relief > 0.5 m (Fig. 31)

Low-centered polygons predominate in this unit. In plan the landform consists of polygonal cells with diameters ranging between 5 and 12 m. Each polygon is composed of three elements. The central portion, circular or weakly polygonal in shape and commonly 8 to 10 m in diameter, is surrounded by a rim 0.5 m or slightly more high and up to 1.0 m wide. Centers may contain up to 10 cm of standing water early in the summer but commonly become only moist as the thaw season progresses. The rim of one polygon is separated from that of the adjacent one by a trough whose depth ranges to 50 cm below the rim crest. The troughs mark the position of contraction cracks and ice wedges that extend to depths of 3 to 5 m. Associated landform units that in aggregate compose less than 20% of Unit 3 include Unit 4, Unit 5 and Unit 6.

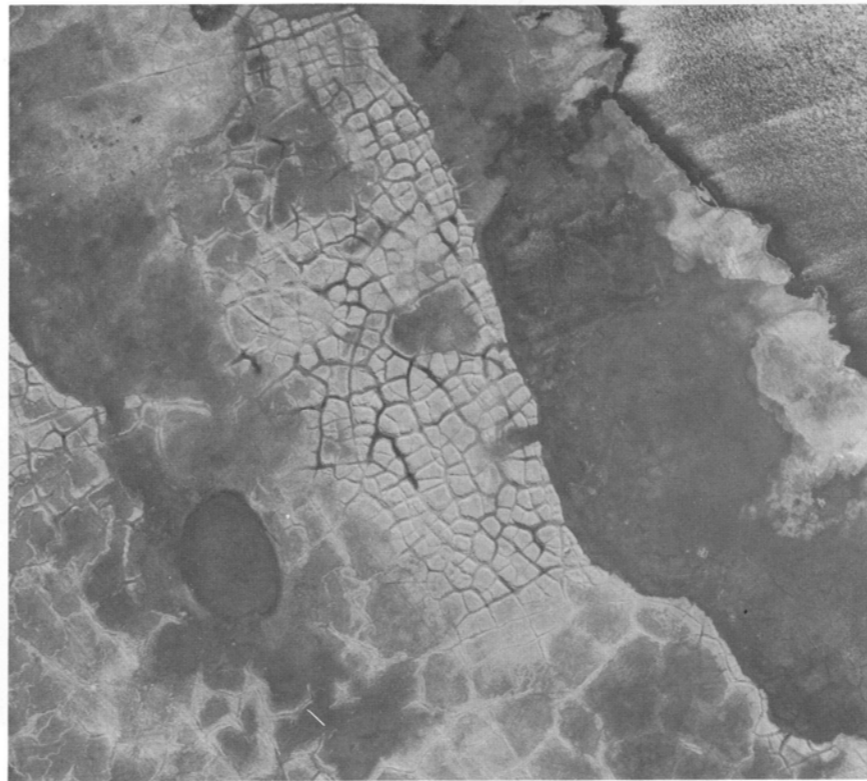


Figure 29. Unit 1. Left: Polygons near Frontier Camp. Right: Ground view of high-centered polygons near the Little Putuligayuk River.



Figure 30. Unit 2. Left: High-centered polygons near the sand dunes, a) <0.5 m, b) >0.5 m. Right: High-centered polygons near the coast, with water-filled thermokarst pits in the polygon troughs.

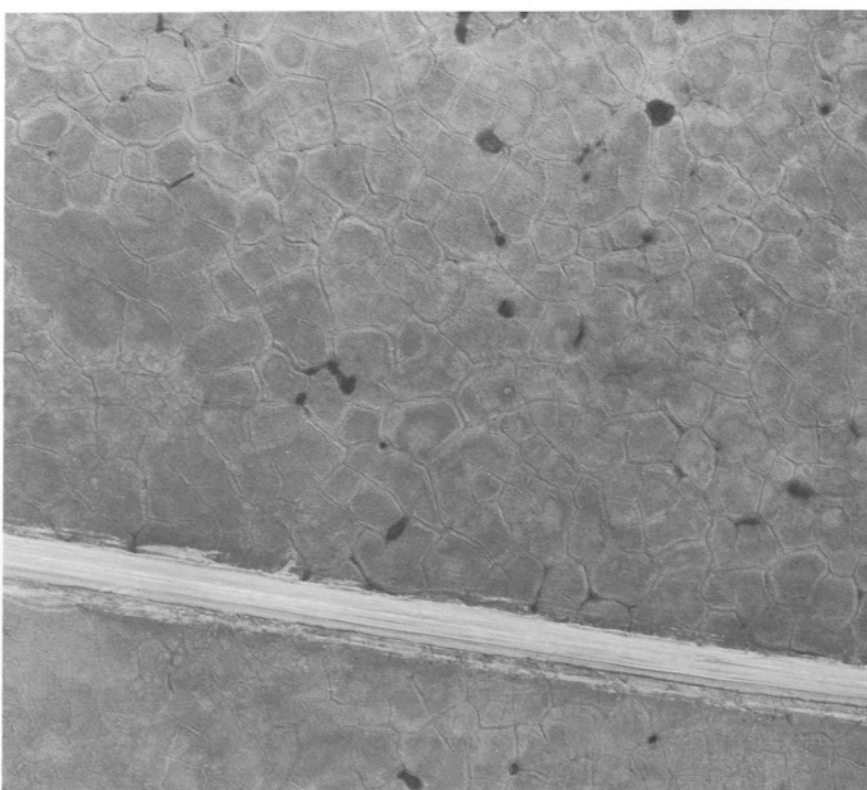
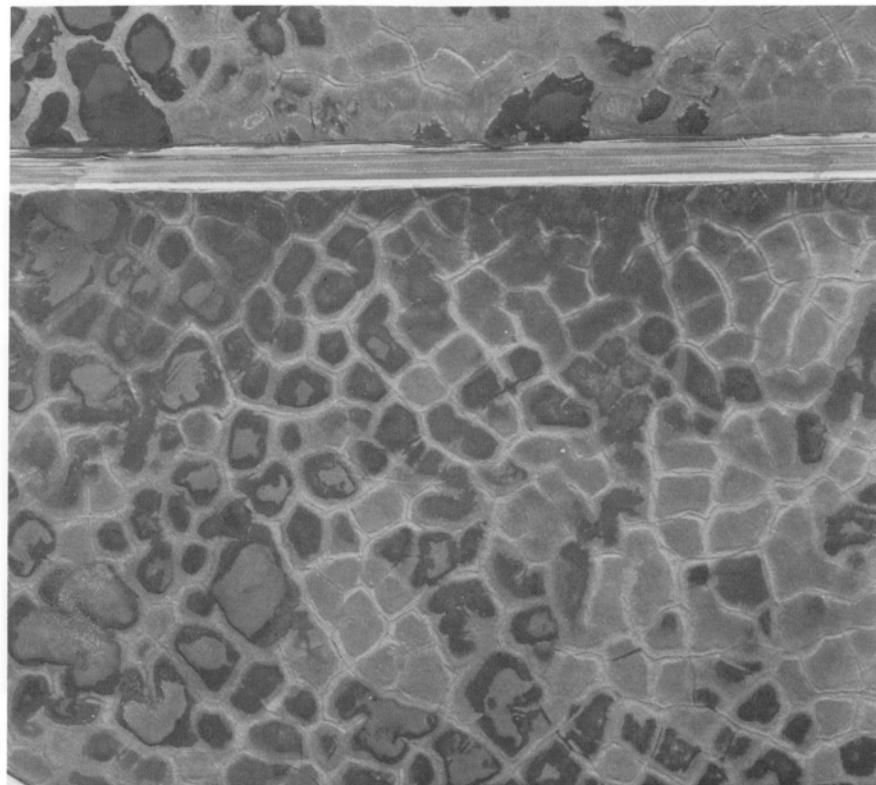


Figure 31. Unit 3. Left: Low-centered polygons with thermokarst pits at the junction of polygon troughs. Right: Similar polygons near Drill Site 2.

0 50 100  
meters





**Figure 32. Unit 4.** Left: Polygons in the sand dune area. Right: The same polygons showing the perennially wet centers.



#### **Unit 4: Low-Centered Polygons, Rim-Center Relief $\leq 0.5$ m (Fig. 32)**

In this extensive unit the polygons tend to be more orthogonal than those of Unit 3 and relief contrast is commonly less than 0.5 m. Basin areas of these polygons are quite wet, with water at or near the surface throughout the thaw period. Landform elements commonly associated with Unit 4 are Units 7, 3 and 0.



**Figure 33. Unit 5.** Left: Mixed polygon types near Gathering Center 1. Right: Terrain with Unit 7 in foreground and mixed polygon types in the middle ground between the lakes. This area is east of the Sagavanirktok River, near the coast.



#### **Unit 5: Mixed High- and Low-Centered Polygons (Fig. 33)**

This landform unit contains high-centered polygons similar to those of Unit 1 and low-centered polygons undergoing topographic reversal and conversion to high-centered polygons. The unit is restricted areally and represents incomplete topographic adjustment to recently decreased base level, for example the drainage of a thaw lake or the relatively recent headward extension of a tributary drainage.



**Figure 34. Unit 6.** Left: Frost-boil terrain in the IBP study area. Right: Poorly defined perimeters of the frost boils are evident; see Figure 71 for frost boil with well-defined perimeter.



#### **Unit 6: Frost-Boil Tundra (Fig. 34)**

Frost-boil tundra reaches its maximum development in the Prudhoe Bay region along the Putuligayuk River. The landform consists of two elements, the frost boils proper and the vegetated areas between them. The boils consist of active, frost-susceptible mineral materials exposed at the surface or apparently inactive beneath a thin organic mat. The center spacing of individual boils is on the order of 2.5 m; however, areas with much closer spacings are common. Ordinarily other landform units do not occur within Unit 6, although Unit 9 may border it adjacent to the Putuligayuk River.



### Unit 7: Strangmoor and/or Disjunct Polygon Rims (Fig. 35)

This very wet landscape unit consists of string bogs (strangmoor) in which the hummock ridges (strangs) are less than 0.5 m high and are commonly discontinuous. In extreme cases they are merely an aligned series of hummocks. In some instances the strangs appear oriented normal to the hydrologic gradient and thus serve as a clue to the direction of surface and subsurface water movement. Commonly, however, they grade to low, discontinuous rims of poorly defined, large diameter polygonal cells. The landscape unit is a young terrain feature. The principal associated landscape units are Unit 0 and Unit 4.

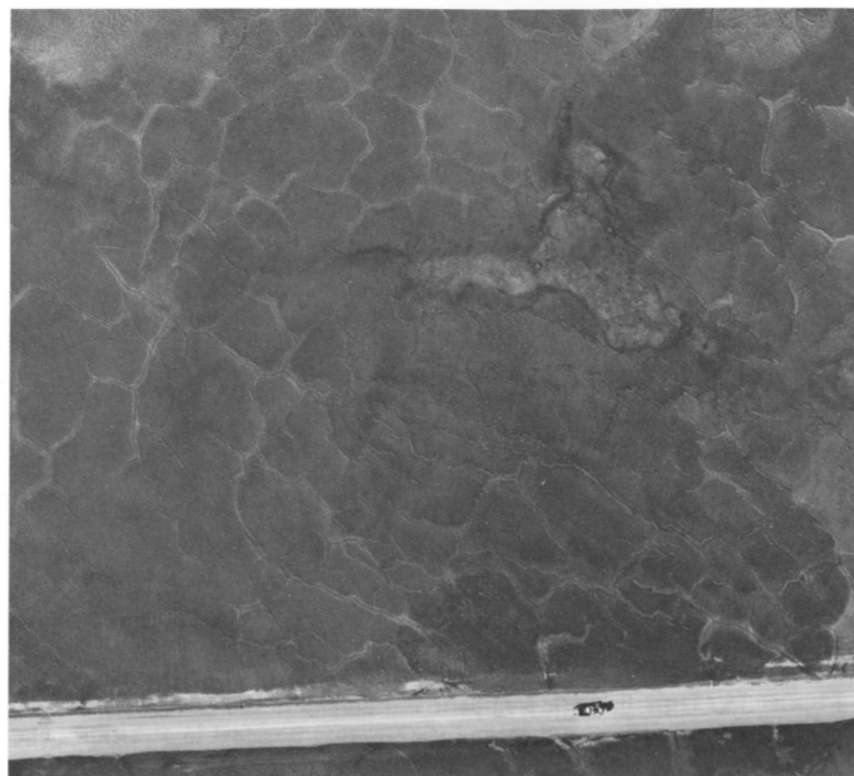


Figure 35. Unit 7. Left: Area with disjunct polygon rims. Right: Small aligned hummocks near Pad F.

### Unit 8: Hummocky Terrain (Fig. 36)

This unit is common on slopes greater than 6% on the sides of pingos and along stream bluffs. It consists of hummocks whose surface areas range between 25 and 50 cm and which extend to 20 cm or more above the adjacent interhummock areas. The unit commonly grades into Unit 9 as slope angle decreases at the top of the bluff or slope. Thus the hummocks may represent the Unit 9 landform rounded and accentuated by erosion, partly thermal and partly related to runoff from the snowbanks which form in these areas.



Figure 36. Unit 8. Left (arrows): Hummocky terrain along steep slope bordering an oxbow lake in the vicinity of the Kuparuk River. Right: Similar terrain on a pingo near Frontier Camp.

### Unit 9: Reticulate-Patterned Ground (Fig. 37)

The reticulate landform occurs on the uplands immediately adjacent to active drainageways and on low linear interfluvies or hydrostatic forms underlain by sandy-textured mineral materials. The pattern is an intricate arrangement of slightly convex, small diameter polygons (less than 1.0 m), commonly with a hummocky microrelief (less than 15 cm). As topographic slope steepens toward an adjacent drainage the reticulate landform becomes gradational to the large hummocks of Unit 8. Away from the drainage and marginal to the wetter tundra elements, especially along the Putuligayuk River, Unit 9 may include small amounts of Unit 6 and Unit 2.



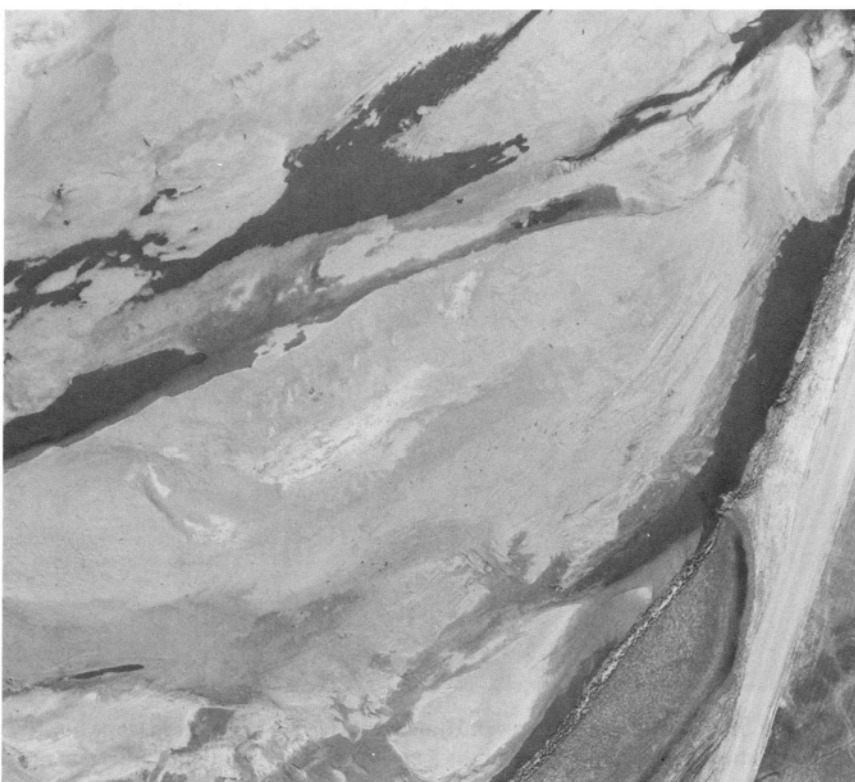
Figure 37. Unit 9. Left (arrows): Reticulate patterned ground along the Little Putuligayuk River near the IBP study area. Right: Finely patterned reticulate ground along the Little Putuligayuk River near Drill Site 2. From Everett and Parkinson (1977).

0 50 100  
meters

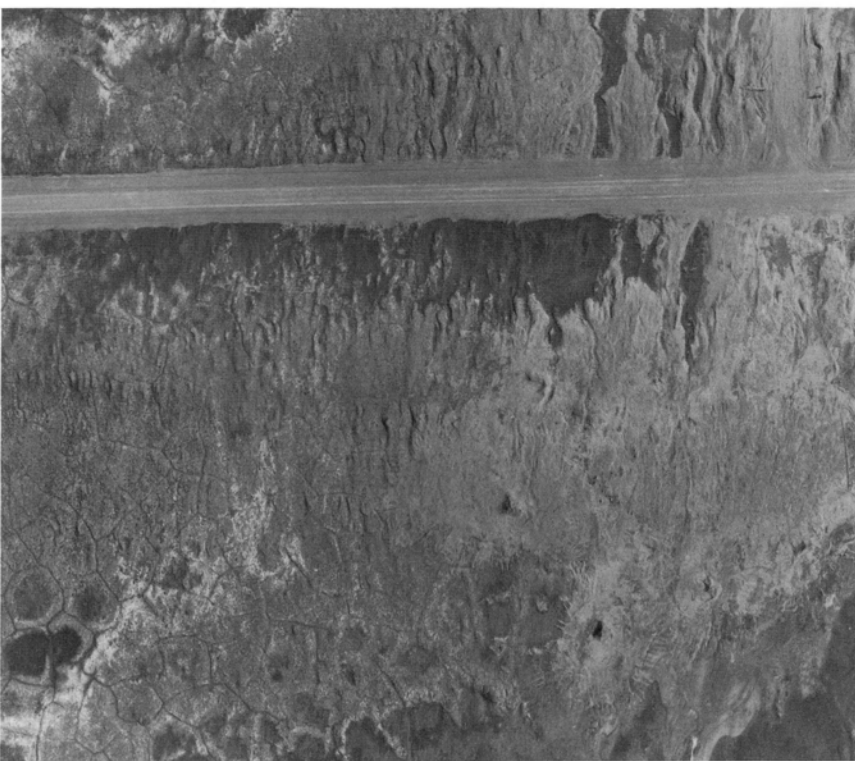




**Figure 38. Unit 0.** Left: Non-patterned ground in the vicinity of the sand dunes. Right: Non-patterned ground (foreground) marginal to a shallow pond with emergent vegetation.



**Figure 39. Unit A.** Left: Braided channel of the Kuparuk River. Right: An oblique view of same area.



**Figure 40. Sand dunes.** Left: Sand dunes near the delta of the Sagavanirktok River. Prevailing winds are from the east-northeast (top of photo). Right: The same dunes; active part of dune is in foreground and partially stabilized coppice dunes are in background. From Everett and Parkinson (1977).

0 50 100  
meters

### Unit 0: Non-Patterned Ground (Fig. 38)

Areas designated as non-patterned ground occur within the basins of recently drained thaw lakes and surrounding shallow, active thaw lakes. Such areas are wet, commonly with standing water throughout the thaw period. They are considered to represent some of the youngest areas in the landscape. Randomly distributed hummocks or short non-aligned hummock ridges, a few tens of centimeters in height, may characterize the surface in some localities. Low relief, low-centered polygons of Unit 4 may compose up to 20% of this unit.

### Unit A: Alluvial Floodplain (Fig. 39)

This unit contains the river floodplains. Microtopographic expression is commonly lacking or consists of undulating scour pits and abandoned stream channels and bars or the beds of intermittently flowing streams.

### Sand Dunes (Fig. 40)

Although they do not appear on the main mapped areas in this atlas, sand dunes form a unique landform element in the area just west of the delta of the Sagavanirktok River. Dunes consist of sand ridges 1 to 2 m high extending leeward from stabilized or partly stabilized coppice-like dunes or dune remnants. Sandy areas between the ridges are mostly devoid of vegetation and commonly moist. In some areas polygon terrain similar to Unit 4 can be seen underlying areas recently or thinly covered by the sands.

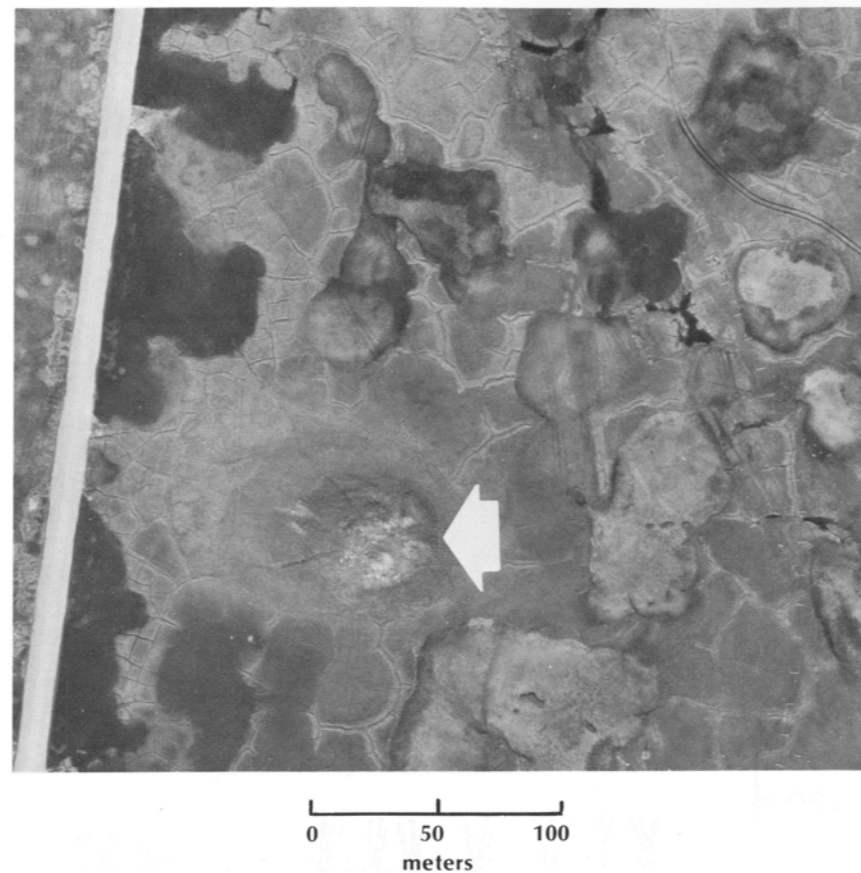


**Unit P: Pingo (Fig. 41 and 42)**

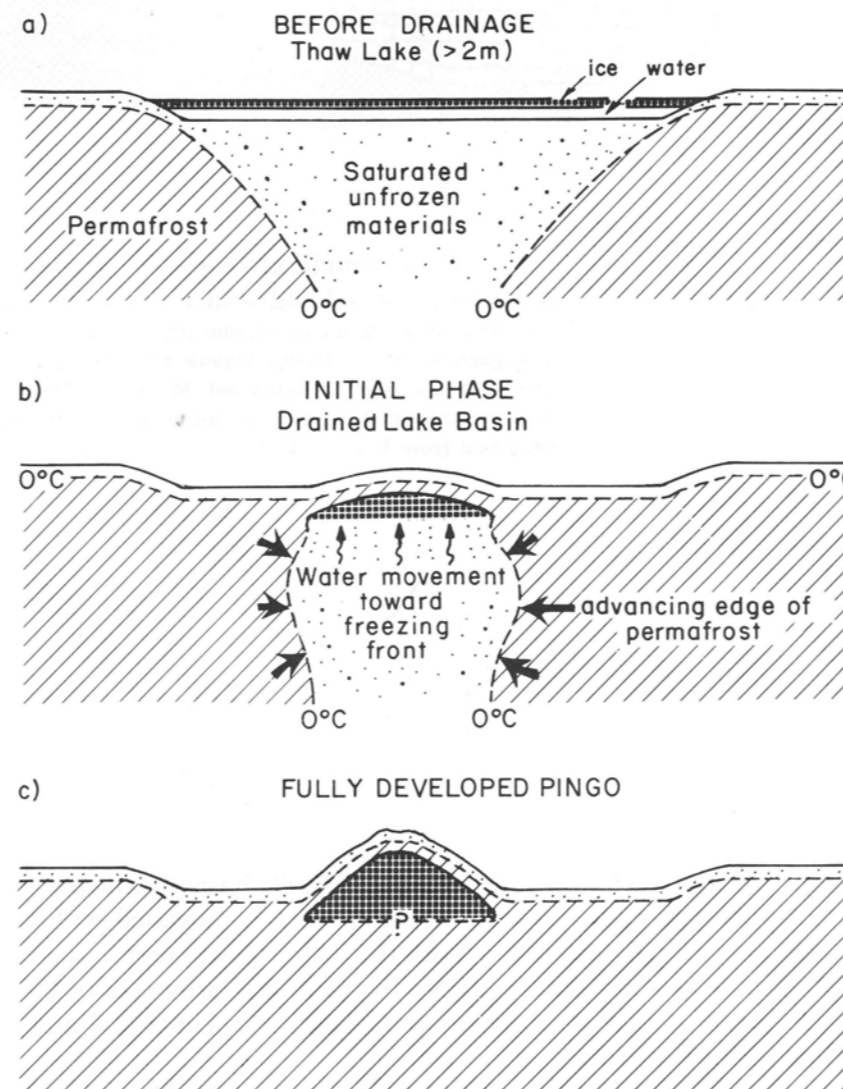
Pingos are probably the most distinctive and least extensive of the landform units recognized at Prudhoe Bay. The term *pingo*, which was introduced into the geomorphologic vocabulary by the botanist A.E. Porsild (1938), derives from the Inuit word *Pi-nok-tja-lu-it* meaning conical hills (Mackay 1979). In the area covered by this atlas the features are conical to slightly elliptical in form, with basal diameters of several tens to several hundreds of meters. They extend up to 15 m above the surrounding tundra. Their summits may be cracked or may have a central depression due to collapse as the ice core melts. Although the upper portions of the steep side slopes may be severely wind-eroded, the lower portions display the hummock forms of Unit 8.

Pingos are common features in drained lake basins, particularly those where the former water depth was sufficient to develop a deep bulb-shaped thaw zone in the permafrost (Fig. 42) (Mackay 1979). When this thaw bulb is again exposed to the arctic climate following lake drainage, permafrost re-forms. Hydrostatic forces develop as the thaw bulb is frozen from all sides. Water is expelled from the freezing soil and an ice core develops. The pressure is commonly released by the upward movement of the former lake bottom and the formation of the pingo. The resultant conically shaped pingo is among the best-drained and highest sites in the Prudhoe Bay region.

Other landform units in the Prudhoe Bay region include coastal bluffs and marine beaches. However, because they fall outside the four main map areas they are not included on the map legends and are therefore not described. The interested reader is referred to Lewellen (1972) and Everett and Parkinson (1977) for additional descriptive material.



**Figure 41. Unit P.** Left: Prudhoe Mound, a pingo near Drill Site 2. Right: A similar-sized pingo in the IBP study area.



**Figure 42. Schematic representation of pingo development.** a: In lakes where water depth exceeds 2 m, winter ice does not extend to the lake bottom and the underlying sediments. In the case of large lakes the unfrozen zone may be very deep or permafrost may be absent altogether. b: Drainage of such lakes in the course of the thaw lake cycle permits refreezing of the surface and progressive extension of frost into the subsurface. It is likely that refreezing from the sides of the thawed zone occurs as well. A year-round supply of water is available to move toward the freezing front where it freezes and becomes part of a growing ice mass which expands upward, forcing the surface to mound. c: Growth of the pingo may continue for many centuries as is the case for some of the very large pingos (60 m high) in the Mackenzie River delta to the east of Prudhoe Bay. In the case of the Prudhoe Bay pingos the active growth phase may have lasted only decades. Growth ceases when the groundwater source is cut off by the lateral extension of permafrost or it is depleted. The ice core may be maintained for long periods if the insulating organic materials and sediments remain undisturbed on its top and sides and regional climate does not warm appreciably. Diagram modified from French (1976) and Mackay (1979).



# Soils

K.R. Everett

## Introduction

SOILS ARE THREE-DIMENSIONAL ENTITIES whose morphological, physical and chemical characteristics are governed by the composition of the materials in which they form, the elements of climate and microclimate, site stability, their topographic and hydrologic setting, the local flora and fauna, and the length of time during which these and other controls have been operative. Generally the greater the topographic diversity of a region, the greater the diversity of the soils. Conceptually soils can be arranged on a drainage gradient, commonly corresponding to a topographic gradient where the drier well-drained soils occur on higher microsites, and wet (bog) soils occur at the lowest sites (Tedrow 1977).

Casual observation of the Prudhoe Bay landscape would suggest that the soils should all be wet and rather homogeneous in their characteristics. Although gross topographic contrast is slight and vast areas appear flat and waterlogged, close examination shows that topographic contrast is present nearly everywhere in the form of patterned microrelief. Thus even in this wet environment it is useful to retain the concept of a drainage gradient, if only on a microscale.

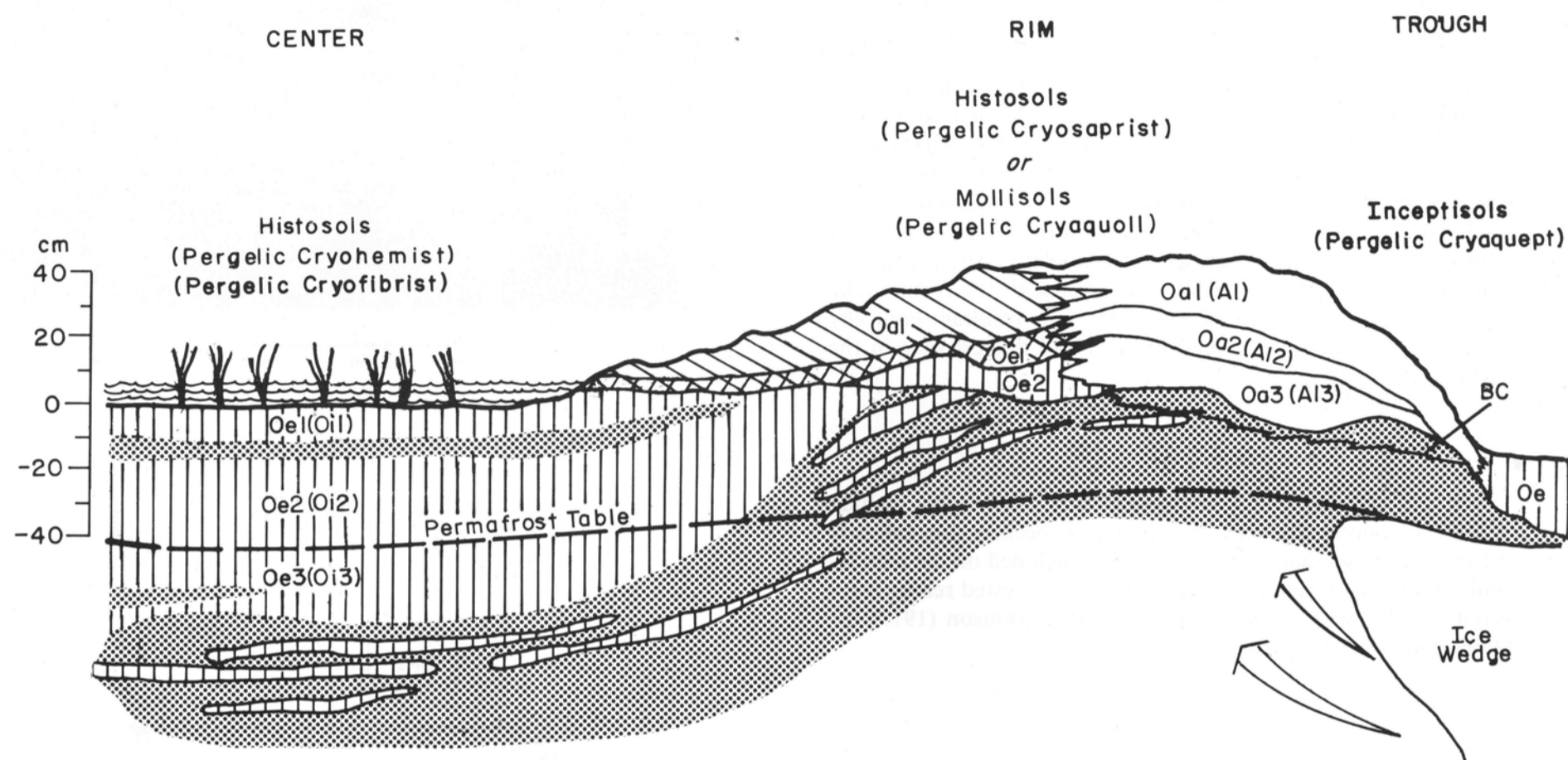
Because the landscape is to a very large extent patterned, distinct soils and vegetation are found on landform elements that repeat many times, often at regular intervals within a landform unit. At a very large scale (e.g. 1:500) it would be possible to show landform elements and their corresponding soil and vegetation associations. This is seldom practical, however. It is necessary in such cases to employ the concept of the soil pedon, which recognizes a *soil individual* whose area may range between 1 and 10 m<sup>2</sup>. In the case of many of the landform units as defined for the Prudhoe Bay region a pedon may consist of several characteristic soil morphologies (soils). In the low-centered polygon unit, for example, the corresponding soil pedon may consist of three morphologic sections—center, rim, and trough (Fig. 43)—with each section corresponding to a landform element. Other landform units such as Unit 0 (featureless terrain) and Unit 7 (strangmoor) may consist of a pedon with only one soil. Eight soils have been recognized as distinct morphologic entities for the Prudhoe Bay region. They have been classified according to criteria set forth in the soil taxonomy adopted by the U.S. Department of Agriculture (Soil Survey Staff 1975). Therefore, before the soils themselves are described it is necessary to briefly review some of the elements of this classification (Everett and Parkinson 1977, Parkinson 1978).

## Elements of Soil Classification

Of the ten soil orders recognized in the United States (Soil Survey Staff 1975), four are represented within the Prudhoe Bay region: the Entisols, Inceptisols, Mollisols and Histosols. Soil orders are differentiated from one another by the presence or absence of diagnostic horizons or features that record differences in the degree and kind of the dominant sets of soil-forming processes.

The Entisols include soils that show little or no evidence of the influence of the factors that affect soil development. They occupy very recent and often unstable landform units such as river floodplains and partially stabilized sand dunes.

Inceptisols are mineral soils that show some effect (the inception) of the soil-forming processes in the development of horizons with distinctive chemical and physical characteristics. In the Prudhoe Bay region they commonly have a thick organic or organic-rich horizon. Soils in this order may be found in virtually all landform units in the area. They are least extensive in Landform Units 8 and 9, and in the pingo and floodplain units.



**Figure 43. Schematic cross section of the soils of a portion of a low-centered polygon similar to those that characterize Landform Units 3 and 4.** Stippled areas represent mineral soil materials (C horizon). Other patterns represent organic or organic-mineral materials. Soil horizon designations Oe, Oi and Oa indicate decomposition stage of organic materials. Highly organic mineral horizons are designated as A horizons. Horizons in parentheses are alternatives and refer to the second listed soil. Many A or Oa horizons are the result of oxidation of organic materials in better-drained sites (rims) created by uplift of soil by the expanding ice wedge. The arrows suggest forces associated with wedge expansion. Modified from Everett (1979).

The order Mollisols includes dark, highly base-saturated soils. Soils belonging to this order are not usually associated with the tundra landscape, but rather with the mid-latitude steppes such as the southern and central portions of the prairie provinces of Canada. Mollisols are most extensive in Landform Units 6, 8 and 9, and in the pingo units.

In the Prudhoe Bay region, soils whose upper 40 cm is composed of organic materials are included within the order Histosols. Such soils are widely distributed in the area but are most commonly encountered in Landform Units 3, 4, 7 and 0.

Each of the soil orders is represented in the mapped areas by one or more suborders. The suborder represents an expression of one of the soil-forming factors that, in combination with the other factors, have served to define the order. For example, an Inceptisol whose properties result from protracted periods of high water due to poor drainage is termed an Aquept, *Aqu* referring to wetness and *ept* reflecting the order Inceptisols. The next lower level

of soil classification, the great group, involves the entire soil profile and combines soils with similar horizon arrangements, degrees of horizon expression, soil moisture, soil temperature, and base status. For example, a cold (mean annual soil temperature above 0°C but less than 8°C) Aquept has the prefix *Cry* (cryic reflecting the cold temperature) and is a Cryaquept.

The soil subgroup, the next lower level of classification, emphasizes subordinate processes (subordinate in a particular order but not in all orders) that modify the characteristics of the dominant process, for example the presence of permafrost. A defining term, for instance Pergelic, connoting permanent frost, precedes the great group name, e.g. Pergelic Cryaquept or a cold, wet Inceptisol underlain by permafrost. The Prudhoe Bay soils have been classified to the subgroup level in the soils map legend. Profile descriptions (Appendix B) representative of each of the soils in the Prudhoe Bay region carry their classification to a still lower level, the family, which defines texture and/or mineralogy.



## Soil Types

### Soil Unit 1, Pergelic Cryoboroll (Fig. 44)

Order	Mollisols
Suborder	Borolls
Great Group	Cryoborolls
Subgroup	Pergelic Cryoborolls

These soils occupy the best-drained landscape elements in the Prudhoe Bay region, i.e. pingos and some well-developed high-centered polygons associated with old thaw lake shorelines, or drainageways. Such sites, especially the pingos, are underlain by mineral materials ranging in texture from very fine sandy loam to very gravelly sand. The exposed positions of these sites permit the accumulation of only a thin, discontinuous snow cover. The combination of site factors leads to rapid and relatively deep seasonal thaw, usually a meter or slightly more.

Nodular carbonate deposits are common on the underside of gravels and cobbles on the surface as well as within the soil profile. Silt coatings are common on the upper surfaces of many coarse fragments, especially between the 30 and 80 cm depths. These features are not restricted to the Prudhoe Bay region and occur in many relatively well-drained arctic soils with coarse, calcareous parent materials. Their presence reflects the seasonal downward transfer of fines in meltwater together with the solubilization of carbonates and their subsequent precipitation in the profile during dry periods.

The soils of the relatively well-drained sites, particularly the pingos, are unique to the Prudhoe Bay region in that they have a thick and well-developed mollic epipedon in which free carbonates have precipitated. The carbonate precipitate ranges between 5% and 15% by volume in the A horizon (Appendix B, site 2). Thus, these soils have a calcic horizon.



Cryoborolls have been described by Retzer (1974) from Rocky Mountain alpine environments where they are extensively developed on well-drained base-rich materials. In Alaska, Rieger (1966) has described similar soils from near Tununak on Nelson Island, and Ugolini and Tedrow (1963) discuss a Rendzina soil (Cryoboroll) from the Anaktuvuk Pass area in the Brooks Range. However, these soils all apparently lack a calcic horizon, although some display carbonate deposition on the underside of gravel fragments.

The Pergelic Cryoborolls of the Prudhoe Bay region represent the fullest expression of the regional climate on well-drained base-rich sites. They thus represent the zonal soil and are the eastward representative of the Pergelic Cryumbrepts/Pergelic Cryochrepts (Arctic Brown soils) of the well-drained, base-poor environments found on the western coastal plain, for example the gravel beach ridges at Barrow (Drew and Tedrow 1957).

←

**Figure 44. Unit 1.** Calcium carbonate precipitates appear as white granules and in small lenses at center of photograph. These organic-rich mineral soils occupy well-drained sites on pingos (Landform Unit P) and some high-centered polygons (Landform Unit 1). Section is approximately 20 cm long.

### Soil Units 2, Pergelic Cryaquoll, and 6, Pergelic Ruptic Aqueptic Cryaquoll (Fig. 45 and 46).

Order	Mollisols
Suborder	Aquolls
Great Group	Cryaquolls
Subgroup	Pergelic Cryaquolls

As the classification implies, these Mollisols occupy less well-drained environments than the Borolls, and mottles are common in the lower part of the mollic epipedon. Pergelic Cryaquolls may be the only soils present marginal to stream banks or on some slightly convex interfluvies where microrelief is often less than 10 cm, and in the form of large diameter high-centered polygons. Most such polygon patterns have superimposed on their surfaces eruptions of mineral materials, i.e. frost boils, or a network of smaller, polygonal markings, about 30 cm in diameter (see Fig. 34). Thus the mollic epipedon is commonly interrupted and the term *Ruptic* may be applied to the subgroup name. These interruptions are seldom simple. There is usually a considerable amount of involution and contortion due to frost action, collectively referred to as cryoturbation. The disruptions increase in intensity as slope angles exceed 2%.

In the course of mapping, the soil-landform association just described has been separated from rather extensive areas, primarily interfluvies and broad slopes adjacent to the Putuligayuk River, on which the Mollisols are interrupted by widely spaced mineral frost boils. The center spacing of the frost boils is on the order of 2.5 m and the term *Ruptic* is applied at the subgroup level of classification, viz. Pergelic-Ruptic-Cryaqueptic Cryaquolls. As yet, however, there is no established taxon. The mineral soils are tentatively assigned to the Cryaqueptic subgroup of the Inceptisols.

The extent of the mineral soil interruptions, and as a consequence the extent of the Mollisols within the pedon, can seldom be appreciated by surface observation. The Pergelic Cryaquolls constitute about 20% of the undisturbed pedon, whereas the Pergelic Cryaquepts compose nearly 80% and are thus the dominant element. In such cases a soil association is recognized consisting of Pergelic Cryaquepts, Pergelic Cryaquolls, and occasionally Histic Pergelic Cryaquepts (Appendix B, site 4).



**Figure 45. Unit 2.** These moderately well-drained organic-rich mineral soils are common on high-centered polygons (Landform Units 1 and 2) and on the well-developed rims of low-centered polygons (Landform Units 3 and 4). They are also associated with frost boils (Landform Unit 6) and constitute the principal soil of areas with reticulate microrelief (Landform Unit 9). In all of the above sites the Pergelic Cryaquolls may be associated with Pergelic Cryosaprists.



**Figure 46. Unit 6.** Section of an active frost boil. Mineral material appears to have been injected beneath the organic soil horizon. Buried organic material is in the shadow. A: Pergelic Cryaquoll (or in some cases Histic Pergelic Cryaquept). B: Pergelic Cryaqueptic. These soils form the components of Soil Unit 6. The term *ruptic* reflects the frost boil interruption of the A and B horizons of the Cryaquoll soil.



**Soil Units 3(1) and 4(1), Histic Pergelic Cryaquept (Fig. 47)**

Order	Inceptisols
Suborder	Aquepts
Great Group	Cryaquepts
Subgroup	Histic Pergelic Cryaquepts

Histic Pergelic Cryaquepts occupy the wetter landscapes where they may be intimately associated with Histosols, Pergelic Cryohemists and/or Pergelic Cryofibrists. Simple examination of that part of the site exhibited in the active layer is usually not sufficient to determine which of the three soils is present at a given point. The decision rests upon examination of materials below the active layer, i.e. within the permafrost. A soil profile such as No. 3(1) in Appendix B, site 1, may be characterized by between 18 and 25 cm of very dark brown to very dark grayish brown, moderately decomposed but fibrous organic material. This constitutes a histic epipedon if the horizon terminates on silt or silt loam mineral soil that extends to a depth of 40 cm or more. Commonly, however, the surface organic horizon terminates on a relatively thin horizon of mineral material that is in turn underlain by more organic materials, or in some instances organic-rich silts that extend to a depth of 40 cm or more. In such cases the soil may meet the criteria for an organic soil and, depending upon the predominant state of organic matter decomposition, it will be classified as a Cryohemist or Cryofibrist.

Histic Pergelic Cryaquepts are widely distributed in the Prudhoe Bay region, especially in areas of low-centered polygons (Fig. 31 and 32) where they are most commonly associated with Pergelic Cryohemists or Pergelic Cryofibrists. They also occur in the very wet areas that lack surface patterns or have strangmoor patterns.

Where the soil occurs in rim elements of low-centered polygons, the upper horizons commonly are highly decomposed and assume many of the morphologic characteristics of a mollic epipedon. In such relatively well-drained sites the soils show a definite nodular carbonate-oxidized iron banding. The carbonates appear

light-colored and usually in a position above the rust-colored ferric materials. The iron occurs as soft segregations or as stains, probably on the carbonates. The depth of the banding within the A horizon appears related to drainage, being deeper in the better-drained sites. The iron band probably marks the seasonal mean limit of oxidizing conditions in the soil. Depending upon the morphology of the portion of the profile below the active layer, some polygon rim soils may be regarded as Pergelic Cryaquolls.

In contrast to the Histic Pergelic Cryaquepts of the wetter landscapes, those associated with the low centers of polygons that become dry during the summer may show a zone of carbonate segregation within a few centimeters of the surface. However, iron accumulation is generally lacking. In addition, the organic matter is more highly decomposed.

In wetter terrain the histic epipedon of the Histic Pergelic Cryaquepts is both thicker, 23 to 40 cm, and more fibrous than in low-centered polygon areas. Thus the associated organic soils are Cryofibrists (see description, Appendix B, site 24).

Mineral input from airborne sources is responsible for the generally low organic carbon values of the histic materials. In some cases it is sufficient to change the classification of the soils from Histic Pergelic Cryaquepts to Pergelic Cryaquepts.

Pergelic Cryaquepts may occur on any landform unit in the Prudhoe Bay region. Some, which occur in drained lake basins or on floodplains, are morphologically similar to Histic Pergelic Cryaquepts but have a surface horizon that fails to meet the criteria for a histic epipedon. Others are closely related to the sandy Entisols. They have not been included separately in the map legend because they seldom occupy as much as 20% of a map unit.



**Figure 47. Units 3(1) and 4(1).** These soils with thick organic surface horizons are widely distributed in the Prudhoe Bay area. They occur in the centers of low-centered polygons (Landform Units 3 and 4) and are common in Landform Units 7 and 0. Figure 43 depicts schematically the relation of this soil and that in Unit 3(2) to the Pergelic Cryosaprists (Fig. 49).

**Soil Units 3(2), Pergelic Cryohemist (Fig. 48); 3(3), Pergelic Cryosaprist (Fig. 49); and 4(2), Pergelic Cryofibrist**

Order	Histosols
Suborders	Fibrists, Hemists and Saprist
Great Groups	Cryofibrists, Cryohemists and Cryosaprists
Subgroups	Pergelic Cryofibrists, Pergelic Cryohemists and Pergelic Cryosaprists

At the suborder level organic soils (Histosols) are differentiated on the basis of the state of decomposition of their organic materials. The least decomposed Histosols are called Fibrists, the most decomposed are Saprist, and those with intermediate decomposition belong to the suborder Hemists. All three suborders occur in the Prudhoe Bay region.

The Pergelic Cryofibrists (Appendix B, site 24) are composed of coarsely fibrous sedge peat to depths of 40 to 45 cm. A high proportion of silt and very fine sand is commonly intermixed. These soils occur sporadically in Landform Units 7 (strangmoor) and 0 (featureless), and may compose a part of the soil pedon in Unit 4 (low-centered polygons), where they occur in the polygon centers.

The organic material of Cryohemists (Fig. 48 and Appendix B, site 22) is usually dark gray-brown, and the organic fragments are only partially identifiable as to botanical origin. The organic matter of these soils is commonly interrupted at the base of the active layer by 2 to 10 cm of silty mineral material. Below the mineral material, which may represent old lake deposits, organic matter is again encountered. The soils are common in Unit 3 where they make up the polygon center of the pedon. In one such polygon the organic materials occurred to a depth of 75 cm (32 cm below the base of the August active layer). A radiocarbon date of these materials at one site showed them to be  $4860 \pm 130$  years old (DIC 698).

The most highly decomposed of the Histosols, the Pergelic Cryosaprists, are black to very dark reddish brown (Fig. 49 and Appendix B, site 7). No plant fragments are recognizable. They form the rim element of the pedon in the drier low-centered polygon areas (Landform Unit 3) and compose the soils of some high-centered polygons (Landform Unit 1).



**Figure 48. Unit 3(2).** Such fibrous organic soils occupy very poorly drained areas or areas with shallow standing water such as the centers of low-centered polygons (Landform Unit 3). These soils occur sporadically in Landform Units 4, 7 and 0.



**Figure 49. Unit 3(3).** These soils consist of highly decomposed organic matter and are common to well-developed rims of low-centered polygons (Landform Units 3 and 4) and high-centered polygons (Landform Unit 1). They are considered to have developed from Pergelic Cryohemists or Pergelic Cryofibrists that have undergone decomposition in response to better drainage. See Figure 43.



### Soil Unit 5, Pergelic Cryorthent

Order	Entisols
Suborder	Orthents
Great Group	Cryorthents
Subgroup	Pergelic Cryorthents

Soils designated Pergelic Cryorthents are restricted to low, relatively recent river terraces and terrace remnants between distributary channels within the Sagavanirktok, Kuparuk and Putuligayuk Rivers. Portions of these more elevated areas are subject to aperiodic deposition and scour during the brief spring breakup. They are often sites of dwarf willow (*Salix lanata*) thickets and river bar barrens. Seasonal thaw penetrates to 50 cm or more. The only indications of the short-term seasonal saturation are the few high chroma mottles in the upper portion of the profile (see Appendix B, site 29).

Numerous and abrupt textural changes are a characteristic of these soils. Commonly the upper portion of the profile consists of silt loam with thin lenses of fine and medium sand, and sporadic lenses of clay and/or recently deposited organic residues, including reworked coal. The lower portion of the profile is composed mostly of gravelly sands. Because of their gravel component these soils have been extensively excavated for construction materials.

### Pergelic Cryopsamments (Dune Soil, Not Found Within the Mapped Areas)

Order	Entisols
Suborder	Psamments
Great Group	Cryopsamments
Subgroup	Pergelic Cryopsamments

These are soils of the active sand dune area that extends 1 to 3 km inland from the west bank of the Sagavanirktok River as it approaches its delta. Although this area is not included on the soil maps presented in the atlas the Pergelic Cryopsamment soil description is included here for completeness. The soil is restricted to the active or quasi-stable dunes where the loose, single-grain structure of the soil promotes thaw deeper than 75 cm by August. The sands are only temporarily held in sporadically distributed root mats. The site instability prevents the soil forming processes from producing a well-differentiated profile morphology, i.e. distinct horizons (see Appendix B, site 28). This characteristic places these soils in the order Entisols.

Soils in the interdune areas and those sandy soils in the weakly polygonized region that extends up to 1.5 km leeward of the active dune area have a temperature and moisture regime that excludes them from the Entisols. They are currently classified within the Inceptisols, as relatively coarse-textured Pergelic Cryaquepts, or rarely as Histic Pergelic Cryaquepts (Everett and Parkinson 1977). During protracted dry periods surface salt efflorescence is a common occurrence.

## Soils in Relation to the Evolution of Landscape and Landform Units

In order to fully develop the relationships among the various landform units and their soils, reference will once again be made to the thaw lake cycle (Fig. 28). The basins of partially or completely drained thaw lakes commonly remain very wet for protracted periods. They provide sites for the development of dense, often monospecific stands of sedge or grass rooted in lacustrine sediments and/or in organic deposits reworked during the lake phase. Thick moss mats are a common adjunct. Organic matter production is high and conditions are ideal for its accumulation and preservation. The occurrence of these conditions in a given basin is highly variable. Featureless landforms (Landform Unit 0), interrupted polygon rims, and/or strangmoor (Landform Unit 7) and Pergelic Cryaquepts (Soil Unit 4) are commonly associated with this stage.

Continued organic accumulation in the situation just described will result in the development of a histic epipedon (Histic Pergelic Cryaquept, Soil Units 3(1) or 4(1)). The accumulation of the organic material over old and reworked organic deposits results in Pergelic Cryofibrists (Soil Unit 4(2)) or Pergelic Cryohemists (Soil Unit 3(2)) in conjunction with polygonal (Landform Units 3 or 4), strangmoor (Landform Unit 7), or featureless (Landform Unit 0) landforms.

With the passage of time, and as permafrost and ice wedges become established or reestablished, a non-orthogonal polygonal network commonly develops. In the early stages of polygon development microrelief contrasts are minor and the soils are little, if any, different from those of non-patterned basins. In time, however, significant microrelief may develop between the polygon rims and centers. In the centers, organic materials may continue to accumulate (Histic Pergelic Cryaquepts, Soil Units 3(1) or 4(1), or Pergelic Cryofibrists, Soil Unit 4(2)). On the elevated rims, with their better drainage, organic matter accumulation decreases and the processes of decomposition convert the soils to Pergelic Cryohemists (Soil Unit 3(2)) or, less commonly, Pergelic Cryosaprist (Soil Unit 3(3)).

As the polygon rims become more accentuated and the polygon itself better drained, organic matter is more completely decomposed. Where inorganic lake sediments lie close to the organic surface horizon the soil is gradually transformed from a Histic Pergelic Cryaquept to a Pergelic Cryaquoll (Soil Unit 2). In cases

where the total organic thickness is great enough to define a Histosol, e.g. Pergelic Cryohemist, the conversion is to a Pergelic Cryosaprist (Soil Unit 3(3)). These soils commonly occur in areas with mixed polygons (Landform Unit 5) or low-centered polygons (Landform Unit 3).

The drainage of thaw lakes and/or the headward erosion of streams commonly converts formerly poorly drained environments such as lake basins and low-centered polygon terrain into relatively well-drained areas. Thermokarst and thermal erosion processes quickly convert the low-centered polygons to high-centered forms in which the Pergelic Cryofibrist or Cryohemist soils are subjected to improved drainage and are converted to Pergelic Cryohemists (Soil Unit 3(2)) or Pergelic Cryosaprist (Soil Unit 3(3)). Less commonly, if the substrate is mostly mineral, Histic Pergelic Cryaquepts are converted to Pergelic Cryaquolls (Soil Unit 2) or Pergelic Cryoborolls (Soil Unit 1). The most commonly associated landform units are high-centered polygons (Landform Units 1 and 2) and mixed polygons (Landform Unit 5).

Adjacent to drainageways, especially in the vicinity of the Putuligayuk River, reduction of the organic thickness by oxidation in response to better drainage contributes to an increase in frost heaving and consequently the formation of frost boils. The frost-boil soils, Pergelic Cryaquepts, form a finely textured repeating association with Pergelic Cryaquoll or Histic Pergelic Cryaquept soils that characterize frost-boil tundra (Landform Unit 6) and to a lesser extent occur on reticulate-patterned ground (Landform Unit 9).

On pingos, the organic lake sediments have been uplifted and are among the best drained in the region. The resulting soils are, for the most part, the calcium-rich Pergelic Cryoborolls (Soil Unit 1). The same soils also occur in conjunction with occasional former lake or beach ridges with hummocky microrelief (Landform Unit 8). The basal organic materials of a Pergelic Cryoboroll on Angel Pingo (Appendix B, site 2) were found to be 4710 ± 70 years old (DIC 1318). This date provides a minimum age for the pingo itself and the drainage of the lake in which it formed.

Alluvial soils, Cryorthents (Soil Unit A), are most common on the bars and low terraces associated with the Sagavanirktok and Kuparuk Rivers.



# Vegetation

D.A. Walker and P.J. Webber

## Introduction

THE PRUDHOE BAY REGION is located on the northern edge of the "wet tundra" that dominates the Arctic Coastal Plain on most vegetation maps of Alaska (Fig. 50, Spetzman 1963, Kuchler 1966, Viereck 1971, Joint Federal-State Land Use Planning Commission for Alaska 1973). While wet sites are certainly the most common, the tundra is actually composed of a wide variety of habitats, many of which are not wet. In low, marshy areas, such as the basins of low-centered polygons and recently drained thaw lakes, sedge and moss communities are dominant. Slightly elevated sites such as polygon rims, high-centered polygons and sloping stream margins have more of an upland character, with sedges and mosses mixed with lichens, and prostrate woody shrubs. Very dry alpine-like habitats are found on pingos and along some river bluffs. The pingos and rivers are, in fact, responsible for much of the botanical variety within the region. The larger rivers have numerous braided channels with extensive gravel and sand bars. Smaller streams, such as the Putuligayuk and Little Putuligayuk Rivers, have willow- and sedge-covered banks. Bluffs, terraces, and steep pingo sides provide sufficient terrain relief for snow patches and their associated plant communities. The sand dunes in the delta of the Sagavanirktok River offer a desert-like contrast to the surrounding wet tundra. The seacoast also has diverse plant habitats, such as coastal bluffs, driftwood-littered strand lines, sand beaches, salt water lagoons, and estuaries. Within this variety of habitats many of the differences between regional plant communities can be attributed to three important environmental gradients: temperature, soil pH, and soil moisture.

## Soil Moisture Gradient

Moisture profoundly affects the vegetation in the Prudhoe Bay region. Water is at or near the surface and, as elsewhere in the Arctic, microrelief differences of a few centimeters can radically change the soil moisture characteristics. For example, in a wet meadow environment small moss or sedge hummocks, or even a local accumulation of plant litter, are relatively elevated sites and offer habitats for plants normally associated with mesic conditions. Conversely, in a dry environment, such as high-centered polygons, moister conditions may be found in the polygon troughs or in the transitional area between the trough and the raised center. The same plants found on the higher places in the wet meadow will be found in the lower places in high-centered polygon complexes. The range in elevation associated with ice-wedge polygon systems of 20 to 50 cm is sufficient to create complex mosaics, with wetland plant communities occurring in the polygon centers and troughs, and upland communities on the polygon rims (Neiland and Hok 1975, Webber and Walker 1975).

In some areas mesoscale relief, such as that associated with pingos and river drainages, is sufficient to create relatively large areas of tundra with upland character. Mesoscale relief features are often responsible for variations in other environmental parameters such as slope, aspect and winter snow depth. Snow accumulates around the basal areas of pingos, especially on the west or leeward sides. Distinctive snow patch communities are found in these sites, often within a few meters of barren tundra communities on the windblown sides of pingos. Snow patch communities are also found along drainage systems, particularly in areas with steep but stable river bluffs. Aspect is also important. River banks and pingo slopes with a southern exposure have more diverse and productive communities than similar cooler north-facing slopes. This is due partly to higher temperatures and partly to the increased nutrients contributed by animals, which also prefer the southern exposures.

The predictable effect of microrelief on soil characteristics and vegetation composition is the underlying principle of the master landscape map concept. This is discussed more fully in a following section (see *Mapping*).

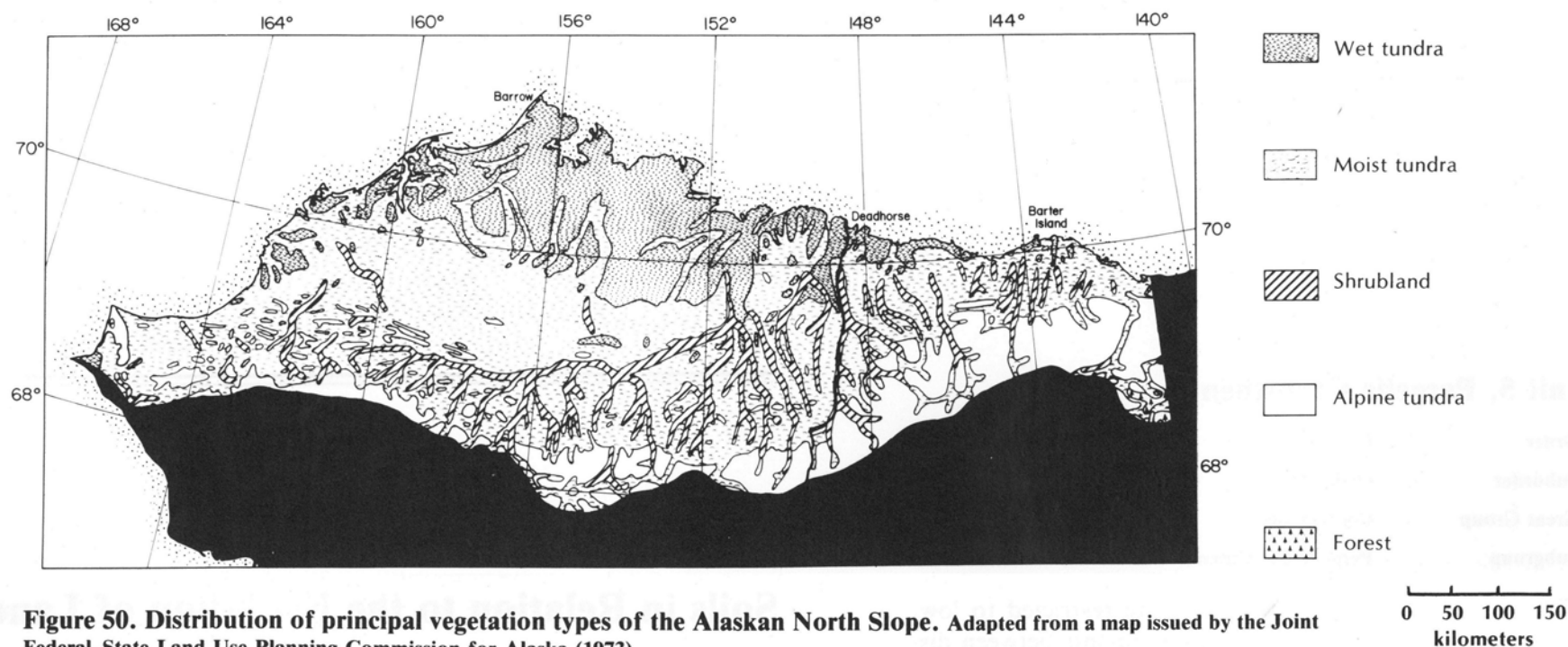


Figure 50. Distribution of principal vegetation types of the Alaskan North Slope. Adapted from a map issued by the Joint Federal-State Land Use Planning Commission for Alaska (1973).

## Coastal Air Temperature Gradient

The ice-covered Beaufort Sea causes a steep summer temperature gradient inland from the coast that is reflected in the vegetation (see *Climate*). Since the mean summer temperatures at the coast are not much above freezing, slight differences in summer warmth have important effects on the vegetation (Clebsch 1957, Cantlon 1961, Clebsch and Shanks 1968). Three vegetation areas are recognized in relation to summer air temperature: a cold coastal strip, an intermediate area containing most of the Prudhoe Bay region, and a warmer inland tundra located somewhat south of Deadhorse.

The coastal area has considerably lower summer temperatures than Deadhorse or the ARCO airfield (Table 2, Fig. 23 and 24). The July mean temperature at the West Dock is about 4°C (1976 and 1977), and commonly there are less than 300 total seasonal thawing degree-days. The low summer temperatures and more frequent foggy days result in delayed snowmelt, a short growing season, and reduced plant growth at the coast. The summer temperatures are similar to those at Barrow, Lonely, Oliktok and Barter Island. Likewise, the physiognomy of the vegetation at all these sites is similar. Compared to inland areas, the coast has no erect shrubs, no sedge-tussock development, and poorly developed moss and lichen communities. The coastal area is also floristically poor. Several taxa, such as *Eriophorum vaginatum*, *Salix lanata* ssp. *richardsonii*, *Carex scirpoidea*, and *C. saxatilis* ssp. *laxa*, that are common inland within the Prudhoe Bay region are rare or absent at the coast. The absence of these and other taxa from the coastal area is the result of cool summers (Young 1971).

Inland areas have all of the previously mentioned taxa. Dwarf shrubs (*Salix lanata*) up to 15 cm in height occur along some stream margins near the spine road, and small cottongrass tussocks are common on well-drained sites. The only heath communities within the region are *Cassiope tetragona* snow patch communities. *Arctostaphylos rubra* and *Vaccinium vitis-idaea* have been collected but are rare east of the Kuparuk River. At the ARCO airfield, 6 km inland, the average mean July temperature is 6.9°C (1970-77) and there are over 500 annual thawing degree-days, nearly double the value at the coast.

South of the oilfield the vegetation continues to change as a result of increased summer warmth. Shrubs show a particularly dramatic response to the higher temperatures inland. *Salix lanata* is abundant along the Sagavanirktok River, and as the distance from the coast increases, the height of the shrub also increases (Fig. 51). The increased height, particularly in streamside environments, is strongly correlated with the annual thaw degree-day accumulation (Fig. 52). In the Prudhoe Bay region *Salix lanata* is the only commonly occurring erect willow, but to the south several other species appear. At Franklin Bluffs, which is 70 km from the coast, the streamside willow communities include *Salix lanata*, *S. alaxensis*, *S. niphoclada* and *S. glauca*. *S. lanata* reaches heights of

up to 150 cm in some protected microsites. The flora at Franklin Bluffs is also richer and includes many additional woody plants such as *Arctostaphylos rubra*, *Rhododendron lapponicum*, *Ledum palustre* ssp. *decumbens*, *Dryas octopetala*, and *Betula nana* (Koranda 1960). *Eriophorum vaginatum* tussocks grow to 45 cm tall on the bluffs (Koranda 1960), whereas in the Prudhoe Bay region they rarely exceed 20 cm. The July mean temperature at Franklin Bluffs is about 8.5°C (1975-77) and there are over 800 thawing degree-days (Haugen, in press).

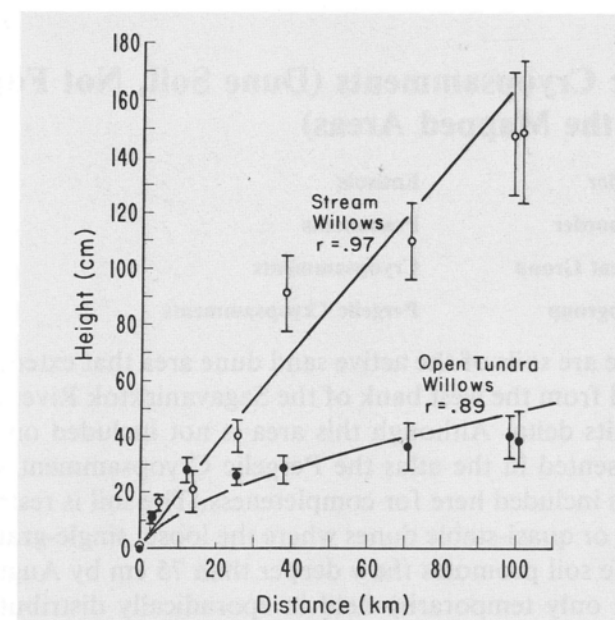


Figure 51. Height of *Salix lanata* ssp. *richardsonii* vs shortest distance to the coast.

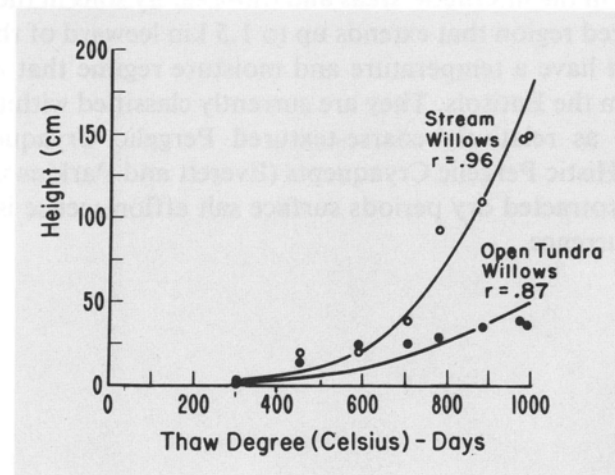


Figure 52. Height of *Salix lanata* ssp. *richardsonii* vs thawing degree-days in 1977.



## Soil pH Gradient

Wet tundra in most arctic regions is characteristically acidic. The Prudhoe Bay soils, however, are mostly alkaline. High base concentrations are maintained by the deposition of carbonate-rich loess from the Sagavanirktok River. The source of much of the river deposits is the carbonate bedrock in the Brooks Range. Prevailing winds from the east-northeast during the summer months blow the fine river alluvium across most of the Prudhoe Bay region (Fig. 53, Parkinson 1978, Walker and Webber 1979). East of the Putu'ligayuk River, soil pH values at 10 cm depth range between 7.2 and 8.4. There is a general drop in pH with increasing distance downwind from the sand dunes and the Sagavanirktok River. A large land area on the western side of Prudhoe Bay is not downwind from the source of loess and has acidic soils in the range pH 5.4 to 6.9. Soils are acidic in wet sites north of a line drawn along the wind vector westward from the mouth of the Sagavanirktok.

The calcareous nature of much of the Prudhoe Bay landscape has important effects on the vegetation. Wet alkaline sites commonly have a surface deposit of carbonates (marl) several millimeters thick. In small ponds and water-filled thermokarst pits, such deposits often hamper or prevent the growth of sedges and mosses. The abundance of calciphilic plants has been noted by Steere (1976) and Murray (1978). *Dryas integrifolia*, a mat-forming dicotyledon that occurs on dry calcium-rich substrates throughout its range (Sørensen 1941, Bamberg and Major 1968), is abundant on all moist and dry sites in the Prudhoe Bay region and is even found in many fairly wet sites. *Saxifraga oppositifolia*, another calciphile, which normally grows in dry microsites (Porsild 1957, Bamberg and Major 1968), is also abundant. Several mosses typical of calcium-rich areas, such as *Scorpidium scorpioides*, *Drepanocladus brevifolius*, and *Catascopium nigratum*, are common in wet microsites. Steere (1976) has commented on the absence of *Sphagnum* and the relative scarcity of other acidiphilic mosses such as species of *Dicranum* and the Polytrichaceae.

Several plants occur locally only in the acidic tundra area north and west of the BP/Sohio Base Camp, including *Vaccinium vitis-idaea*, *Salix planifolia* ssp. *pulchra*, *Saxifraga foliolosa*, and several cryptogams.

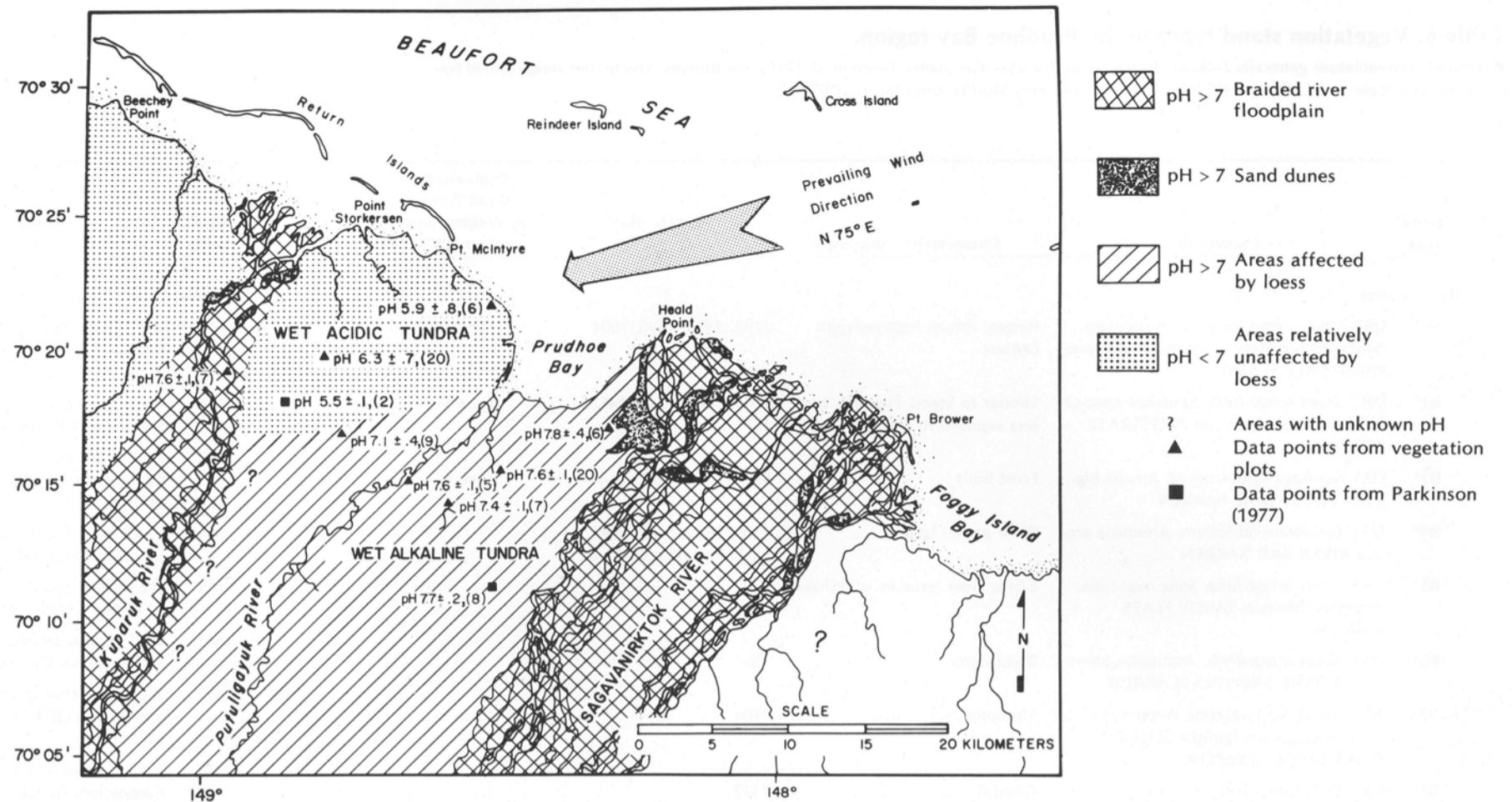
## Vegetation Descriptions

For purposes of vegetation mapping, the region was divided into four broad groups based on site moisture regime. The rationale was that these groups could usually be distinguished on aerial photographs at a scale of 1:6000. Because the actual floristic composition of the vegetation communities is difficult to interpret on aerial photographs the broad categories represent the level of description which can be interpreted directly from black and white aerial photographs. These categories are applicable for the Prudhoe Bay region and could be extended over a large portion of the coastal plain. The following alphabetic prefixes are used to designate the moisture regime categories and appear as the first part of the vegetation codes on the master maps:

- B** Vegetation growing on dry, barren or exposed sites
- U** Vegetation growing on moist, well-drained upland sites or well-drained microsites
- M** Vegetation growing on wet or lowland sites
- E** Vegetation growing on sites where water is present during the entire growing season, i.e. aquatic vegetation

A few specific vegetation stand types are associated with unique sites which have characteristic signatures on aerial photographs. These include communities on gravel bars, sand dunes and snow patches. These are not extensive, and are included within the broader moisture regime categories listed above.

Following the alphabetic code is a number that represents a specific plant community type. A total of 42 such plant communities have been defined (Table 6); 24 of these occur within areas shown on the four large master maps (Fig. 2). Most of the remainder occur along the seacoast and in the sand dunes. Of the communities within the mapped area only 11 can be considered common. These are described below under the headings *Alkaline tundra stand types* and *Acidic tundra stand types*. Following these are descriptions of 11 communities occurring in special habitats (e.g. snow patches, river banks, animal denning sites) and 8 disturbance types (e.g. dust-covered areas, vehicle tracks).



**Figure 53. Relationship between prevailing summer winds (arrow) and soil pH in the Prudhoe Bay region. The wet alkaline tundra receives wind-borne calcium-rich silt from the Sagavanirktok River delta, whereas the wet acidic area receives little or no loess. Soil pH values are shown as pH  $\pm$  standard deviation (number of samples). After Walker and Webber (1979).**

Plant communities are named according to a system developed by the authors for several map sites along the Yukon River to Prudhoe Bay haul road. Each community name contains three parts: 1) a site moisture category (**DRY, MOIST, WET** or **VERY WET**); 2) several taxa that are typical of the community, sufficient to adequately define it; and 3) a physiognomic descriptor, which may include a landform modifier. Although the plant communities are defined according to species composition, the map units on the colored vegetation maps (Appendix A, Fig. A5) are necessarily simplified and based on either vegetation physiognomy or specific landform units (see legend, Fig. A5).

### Alkaline Tundra Stand Types

Wet alkaline tundra covers most of the mapped region. The name "wet alkaline tundra" does not mean, however, that all the tundra in this region is necessarily wet. As discussed earlier, lakes, partially drained lakes, and large expanses of low-centered polygons dominate the landscape to be sure, but there are many drier microsites.

The most common alkaline stand types are described below and ordered according to their position on the moisture gradient starting with the driest habitats. The representative taxa for each type are listed in order of relative abundance, based on preliminary tabulation of quadrat data.

#### Dry Alkaline Tundra

**Stand Type B1, DRY *Dryas integrifolia*, *Oxytropis nigrescens*, *Lecanora epibryon* PROSTRATE SCRUB** (Fig. 54).

##### Common Taxa

**Vascular Plants:** *Dryas integrifolia*, *Oxytropis nigrescens*, *Carex rupestris*, *Saxifraga oppositifolia*.

**Mosses:** *Distichium capillaceum*, *Ditrichum flexicaule*, *Bryum* spp.

**Lichens:** *Lecanora epibryon*, *Pertusaria* spp., *Thamnolia vermicularis*.

Type B1 occurs on the driest, most exposed microsites, such as the sides of pingos, the tops of some river bluffs, and a few small, elevated ridge-like features that are blown free of snow in the winter. These sites generally have a barren appearance with abundant crustose lichens covering most of the soil surface. *Dryas*

*integrifolia* forms a discontinuous prostrate mat with *Carex rupestris* and *Oxytropis nigrescens*. Frost activity is common, and the soil surface is broken into a fine pattern of hummocks about 5 to 10 cm high and 15 to 20 cm in diameter. The cracks or depressions between the hummocks often support a richer cryptogam flora than that found on the tops of the hummocks. Species in these depressed microsites include the lichens *Thamnolia vermicularis*, *Alectoria nigricans*, *Cornicularia divergens*, *Cetraria cucullata*, *C. islandica*, *Dactylina arctica*, and the mosses *Hypnum procerimum*, *Drepanocladus uncinatus*, *Tomenthypnum nitens*, *Encalypta alpinum* and *Timmia* spp.

This type is most often associated with Landform Units P (pingo), 1 (high-centered polygons, greater than 0.5 m relief contrast), and 8 (hummocky terrain), and with Soil Unit 1 (Pergelic Cryoboroll).

**Stand Type B2, DRY *Dryas integrifolia*, *Saxifraga oppositifolia*, *Lecanora epibryon* PROSTRATE SCRUB** (Fig. 55).

##### Common Taxa

**Vascular plants:** *Dryas integrifolia*, *Saxifraga oppositifolia*, *Pedicularis lanata* ssp. *kanei*, *P. capitata*, *Eriophorum angustifolium*, *Salix reticulata*, *S. arctica*, *Polygonum viviparum*, *Papaver macounii*.

**Mosses:** *Ditrichum flexicaule*, *Distichium capillaceum*, *Bryum* spp.

**Lichens:** *Lecanora epibryon*, *Thamnolia vermicularis*, *Cetraria islandica*, *C. cucullata*, *Dactylina arctica*.

Type B2 occurs on sites such as high-centered polygons, and the margins of many drained lake basins and creek bluffs that are somewhat less exposed than the Type B1 microsites. Type B2 is transitional between the distinctive Type B1 barren vegetation and Type U3 (upland tundra). Cryoturbation is usually pronounced, and crustose lichens cover much of the exposed soil. *Saxifraga oppositifolia*, *Salix reticulata* and *S. arctica* are usually more abundant in this type than in Type B1, and *Carex rupestris* and *Oxytropis nigrescens* are commonly absent or much less common than in Type B1.

This type is associated with Landform Units 1 (high-centered polygons, greater than 0.5 m relief contrast), and 2 (high-centered polygons, less than 0.5 m relief contrast) and with Soil Units 1 (Pergelic Cryoboroll) and 2 (Pergelic Cryaquoll).



Table 6. Vegetation stand types in the Prudhoe Bay region.

Botanical nomenclature generally follows Hultén (1968) for vascular plants, Crum et al. (1973) for mosses, Steere and Inoue (1978) for hepatics, and Hale and Culbertson (1970) for lichens. See also Murray and Murray (1975, 1978).

Stand type	Community	Characteristic microsite	Sample plot** (App. A)	Equivalent stand types in Webber and Walker (1975)
<b>B—Dry sites</b>				
B1*	DRY <i>Dryas integrifolia</i> , <i>Carex rupestris</i> , <i>Oxytropis nigrescens</i> , <i>Lecanora epibryon</i> PROSTRATE SCRUB	Pingos, ridges, high polygon centers	010B, 1411, 1520, 1001	Type 10
B2*	DRY <i>Dryas integrifolia</i> , <i>Saxifraga oppositifolia</i> , <i>Lecanora epibryon</i> PROSTRATE SCRUB	Similar to Stand Type B1, but less exposed to wind	010A, 1401, 1505, 1412, 1513	Type 1
B3*	DRY <i>Saxifraga oppositifolia</i> , <i>Juncus biglumis</i> FROST BOIL BARREN	Frost boils	0801, 1419, 1506	Type 8
B4*	DRY <i>Epilobium latifolium</i> , <i>Artemisia arctica</i> RIVER BAR BARREN	River gravel bars	1105, Species list from Little Putuligayuk River	
B5*	DRY <i>Dryas integrifolia</i> , <i>Salix ovalifolia</i> , <i>Artemisia borealis</i> SANDY FLATS BARREN	Sandy river terraces, stabilized	1207	
B6*	DRY <i>Dryas integrifolia</i> , <i>Astragalus alpinus</i> RIVER BANK PROSTRATE SCRUB	River banks	1507	
B7* <sup>1</sup>	DRY <i>Braya purpurascens</i> , <i>Anemone parviflora</i> , <i>Arctagrostis latifolia</i> SLUMPING RIVER BLUFF COMPLEX	Slumping river bluffs	1104	Type 11
B8	DRY <i>Cochlearia officinalis</i> , <i>Puccinellia phryganodes</i> COASTAL BEACH BARREN	Coastal beaches	1312	
B9	DRY <i>Elymus arenarius</i> , <i>Dupontia fisheri</i> SAND DUNE BARREN	Active sand dunes, sandy creek banks	1201	
B10	DRY <i>Braya purpurascens</i> , <i>Puccinellia andersonii</i> COASTAL BLUFF BARREN	Coastal bluffs with salt-killed vegetation	1301	
B11	DRY <i>Dryas integrifolia</i> , <i>Sedum rosea</i> COASTAL BLUFF BARREN	Dry coastal bluffs and ridges	Species list from vicinity of mouth of Putuligayuk R.	
B12	DRY <i>Salix rotundifolia</i> , <i>Salix planifolia</i> , <i>Ochrolechia frigida</i> COASTAL PROSTRATE SCRUB	Coastal high polygon centers	1305	
B13	DRY <i>Salix ovalifolia</i> , <i>Artemisia borealis</i> SANDY FLATS BARREN	Stabilized sand dunes	1208, 1202, 1106	
B14*	DRY <i>Dryas integrifolia</i> , <i>Salix reticulata</i> , <i>Cetraria richardsonii</i> SNOW PATCH PROSTRATE SCRUB	Dry, early-thawing snowbanks with hummocky terrain	Species list from pingo near Pad F	
B15	MOIST <i>Carex aquatilis</i> , <i>Dicranum elongatum</i> , <i>Ochrolechia frigida</i> COASTAL GRAMINOID MEADOW	Coastal polygon rims and high polygon centers	1313	
<b>U—Moist sites</b>				
U1*	MOIST <i>Carex aquatilis</i> , <i>Ochrolechia frigida</i> GRAMINOID MEADOW	Polygon rims and aligned hummocks in acidic tundra region	1405, 1406, 1410, 1415	Type 2
U2*	MOIST <i>Eriophorum vaginatum</i> , <i>Dryas integrifolia</i> , <i>Tomenthypnum nitens</i> , <i>Thamnolia vermicularis</i> TUSSOCK GRAMINOID MEADOW	Well-drained upland sites	0203	Type 2
U3*	MOIST <i>Eriophorum angustifolium</i> , <i>Dryas integrifolia</i> , <i>Tomenthypnum nitens</i> , <i>Thamnolia vermicularis</i> GRAMINOID MEADOW	Well-drained upland sites, polygon rims, aligned hummocks	020B, 1403, 1406, 1409, 1504, 1510, 1515	
U4*	MOIST <i>Carex aquatilis</i> , <i>Dryas integrifolia</i> , <i>Tomenthypnum nitens</i> , <i>Salix arctica</i> GRAMINOID MEADOW	Moister upland sites, centers of drier low polygon centers, polygon rims, aligned hummocks	030B, 0303, 030A, 1512, 1514, 1519	Type 3
U6*	DRY <i>Dryas integrifolia</i> , <i>Cassiope tetragona</i> SNOW PATCH DWARF SCRUB	Well-drained snowbanks	0901, 1416, 1509	Type 9
U7*	MOIST <i>Salix rotundifolia</i> SNOW PATCH PROSTRATE SCRUB	Late-thawing snowbanks	0902, 1417	Type 9
U8*	MOIST <i>Salix lanata</i> , <i>Carex aquatilis</i> STREAM BANK DWARF SCRUB	Stream banks, lake margins	1103	Type 13
U9	MOIST <i>Dryas integrifolia</i> , <i>Eriophorum angustifolium</i> , <i>Tomenthypnum nitens</i> , <i>Didymodon asperifolius</i> STREAM BANK GRAMINOID MEADOW	Upland stream banks which are swept by the spring flood	1102	
U10*	MOIST <i>Festuca baffinensis</i> , <i>Papaver macounii</i> GRAMINOID MEADOW	Pingo tops, bird mounds and animal dens	1002, 1418, 1502	
U12	MOIST <i>Carex aquatilis</i> , <i>Salix planifolia</i> ssp. <i>pulchra</i> COASTAL GRAMINOID MEADOW	Mesic coastal meadows	1303, 1311	
U13	MOIST <i>Dupontia fisheri</i> , <i>Cochlearia officinalis</i> COASTAL SALINE GRAMINOID MEADOW	Coastal meadows below highest strand line	1309	
U14	MOIST <i>Carex aquatilis</i> , <i>Dryas integrifolia</i> GRAMINOID MEADOW	Polygon rims in sand dune region	1210	

Stand type	Community	Characteristic microsite	Sample plot** (App. A)	Equivalent stand types in Webber and Walker (1975)
<b>M—Wet sites</b>				
M1*	WET <i>Carex aquatilis</i> , <i>Carex rariflora</i> , <i>Saxifraga foliolosa</i> GRAMINOID MEADOW	Wet microsites in acidic tundra areas primarily associated with aligned hummocks	1420, 1414, 1404, 1407	
M2*	WET <i>Carex aquatilis</i> , <i>Drepanocladus brevifolius</i> GRAMINOID MEADOW	Wet polygon centers and troughs, lake margins	040B, 1503, 1511, 1516, 1501, 040A	Type 4
M3* <sup>2</sup>	WET <i>Carex aquatilis</i> , <i>Dupontia fisheri</i> , <i>Calliergon richardsonii</i> GRAMINOID MEADOW	Wet polygon centers and meadows in sand dune region and along Kuparuk River	1203, 1205	
M4*	VERY WET <i>Carex aquatilis</i> , <i>Scorpidium scorpioides</i> GRAMINOID MEADOW	Low, wet sites, polygon centers, drained lakes, lake margins	050A, 050B	Type 5
M5*	WET <i>Carex aquatilis</i> , <i>Salix rotundifolia</i> STREAM BANK GRAMINOID MEADOW	Moist stream banks	1101, 1508	Type 12
M6	WET <i>Juncus arcticus</i> , <i>Salix ovalifolia</i> RIVER BANK GRAMINOID MEADOW	Wet sandy river bars	Species list from Sagavanirktok R. delta	
M7	WET <i>Equisetum arvense</i> , <i>Alopecurus alpinus</i> RIVER BANK GRAMINOID MEADOW	Wet, sandy sites along rivers	1107	
M8	WET <i>Dupontia fisheri</i> , <i>Carex aquatilis</i> , <i>Campylium stellatum</i> COASTAL LAND GRAMINOID MEADOW	Wet polygon troughs in coastal vicinity	1306	
M9	WET <i>Carex subspathacea</i> , <i>Puccinellia phryganodes</i> COASTAL SALINE GRAMINOID MEADOW	Coastal estuaries and lagoons	1302, 1318	
M10	WET <i>Carex aquatilis</i> , <i>Dupontia fisheri</i> , <i>Eriophorum angustifolium</i> COASTAL LAND GRAMINOID MEADOW	Coastal wet polygon centers and meadows	1310	
M11	WET <i>Carex aquatilis</i> , <i>Dupontia fisheri</i> , <i>Salix ovalifolia</i> GRAMINOID MEADOW	Wet areas in sand dune region	1209	
<b>E—Emergent sites</b>				
E1*	VERY WET <i>Carex aquatilis</i> GRAMINOID MEADOW	Water to about 30 cm	1402, 1408, 1413, 1518	Type 6
E2*	VERY WET <i>Arctophila fulva</i> GRAMINOID MEADOW	Water to about 100 cm	060B, 060A, 1307	Type 6
E3*	VERY WET <i>Scorpidium scorpioides</i> AQUATIC MOSS MEADOW	Water to about 100 cm in sand dunes region	1206	
E4	VERY WET <i>Dupontia fisheri</i> , <i>Carex aquatilis</i> GRAMINOID MEADOW	Shallow water in sand dunes		
<b>W—Open water</b>				
W1*	None	Lakes and ponds		Type 7
W2*	None	Streams and rivers		Type 7
W3*	Varies	Flooded areas caused by roads or pads		
<b>Type of disturbance</b>				
<b>D—Disturbed sites</b>				
D1* <sup>1</sup>	Bare earth with pioneering species, e.g. <i>Braya purpurascens</i> , <i>Leptobryum pyriforme</i> , <i>Marchantia polymorpha</i>			
D2*	Foreign gravel or construction debris			
D3*	Dust-covered areas adjacent to roads			
D4*	Vehicle tracks—deeply rutted			
D5*	Vehicle tracks—not deeply rutted			
D6*	Winter road			
D7*	Excavated areas primarily in river gravels			
W3*	Flooded areas caused by roads or pads			

\*Occurs on at least one of the four master maps (App. A).

\*\*Italicized plot numbers are 1-x-10-m ordination plots; remainder are 1-x-1-m plots.

<sup>1</sup>Complex consisting of several communities.

<sup>2</sup>M3 has been grouped with M2 on the master maps.





Figure 54. Stand Type B1 located on the side of Prudhoe Mound, a pingo near the ARCO Base Camp.



Figure 55. Stand Type B2 on small high-centered polygon.



Figure 56. Stand Type U2. Diameters of the tussocks range from 10 to 25 cm.

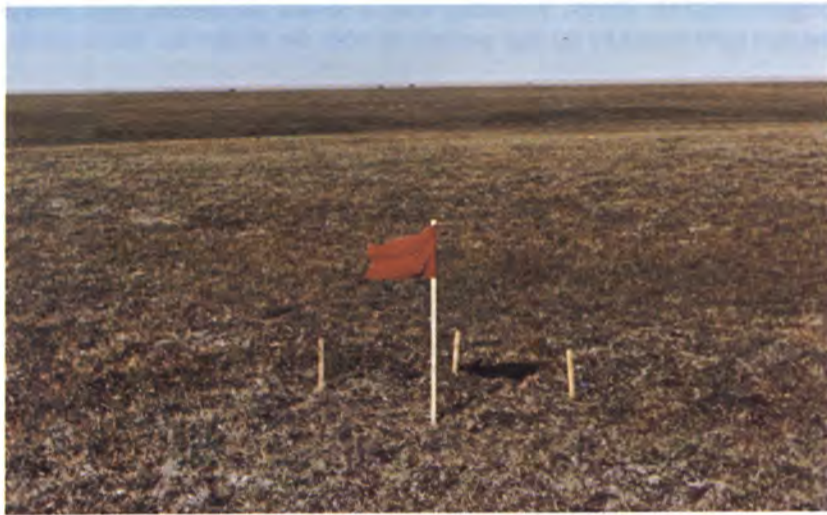


Figure 57. Stand Type U3 on an upland meadow near the Putuligayuk River.



Figure 58. Close-up of Stand Type U3, showing fruticose lichens, including *Thamnolia vermicularis*, *Cetraria cucullata*, *C. islandica*, and *Dactylina arctica*.



Figure 59. Stand Type M2 in the basin of a low-centered polygon.

### Moist Alkaline Tundra

**Stand Type U2, MOIST** *Eriophorum vaginatum*, *Dryas integrifolia*, *Tomenthypnum nitens*, *Thamnolia vermicularis* TUSsock GRAMINOID MEADOW (Fig. 56).

**Stand Type U3, MOIST** *Eriophorum angustifolium*, *Dryas integrifolia*, *Tomenthypnum nitens*, *Thamnolia vermicularis* GRAMINOID MEADOW (Fig. 57 and 58).

#### Common Taxa

**Vascular plants (Type U3):** *Eriophorum angustifolium*, *Carex bigelowii*, *C. membranacea*, *C. aquatilis*, *Dryas integrifolia*, *Salix reticulata*, *S. arctica*, *Senecio atropurpureus*, *Papaver macounii*, *Chrysanthemum integrifolium*, *Pedicularis lanata* ssp. *kanei*, *Polygonum viviparum*.

**Mosses:** *Tomenthypnum nitens*, *Ditrichum flexicaule*, *Hypnum bambergeri*, *Distichium capillaceum*, *Orthothecium chryseum*, *Drepanocladus brevifolius*.

**Lichens:** *Thamnolia vermicularis*, *Cetraria islandica*, *C. cucullata*, *Dactylina arctica*.

(Type U2 contains basically the same species except that *Eriophorum vaginatum* is the dominant sedge.)

Types U2 and U3 are the two primary types occurring on well-drained upland areas adjacent to rivers and streams or on the lower slopes of many pingos. They are also found on extensive areas of well-drained polygons with slightly raised centers. Type U3 is often the principal type on the rims of low-centered polygons. These types are easily distinguished from Types B1 and B2 by their dense-sedge cover and the abundance of the moss *Tomenthypnum nitens*. They are distinguished from moister types, such as U4 and M2, by the abundance of fruticose lichens. Type U2 has *Eriophorum vaginatum* tussocks. The tussocks are small (less than 20 cm high) and nearly impossible to see on aerial photographs at a scale of 1:6000, so undoubtedly many Type U2 areas have been mapped as Type U3.

Type U2 occurs mainly with Landform Units 9 (reticulate patterned ground) and 2 (high-centered polygons, less than 0.5 m relief contrast). Type U3 occurs with Landform Units 9 and 2, the rim elements of Units 3, 4 and 5 (low-centered and mixed polygons), and the trough element of Units 1 and 2. The associated soil on the best drained sites is mainly Soil Unit 2 (Pergelic Cryaquoll). On low-centered polygon rims, Soil Units 3(1) (Histic Pergelic Cryaquept), 3(2) (Pergelic Cryohemist), and 3(3) (Pergelic Cryosaprist) are common.

**Stand Type U4, MOIST** *Carex aquatilis*, *Dryas integrifolia*, *Salix arctica*, *Tomenthypnum nitens* GRAMINOID MEADOW.

#### Common Taxa

**Vascular Plants:** *Carex aquatilis*, *Eriophorum angustifolium*, *Dryas integrifolia*, *Salix arctica*, *S. lanata*, *S. reticulata*.

**Mosses:** *Tomenthypnum nitens*, *Drepanocladus brevifolius*, *Distichium capillaceum*, *Campyllum stellatum*, *Ditrichum flexicaule*, *Catascopium nigratum*, *Hypnum bambergeri*.

Type U4 is transitional between the more distinctive upland tundra types (Types U2 and U3) and wet tundra (Type M2). It occurs in the basins of drier low-centered polygons and also on polygon rims and hummocks in wet areas. This type commonly has a denser prostrate willow cover than Types U2 and U3, and less cover of *Dryas integrifolia*. Lichens are uncommon. In many polygon centers where there are abundant small moss hummocks (commonly less than 10 cm high), the tops of the hummocks support Type U4 vegetation while the areas between hummocks are moister and support Type M2.

Type U4 is commonly associated with the center element of Landform Unit 4 (low-centered polygons) and the hummock element of Unit 7 (strangmoor or disjunct polygon rims). The associated Soil Units are most often 3(1) (Histic Pergelic Cryaquept) or 3(2) (Pergelic Cryohemist).

### Wet Alkaline Tundra

**Stand Type M2, WET** *Carex aquatilis*, *Drepanocladus brevifolius* GRAMINOID MEADOW (Fig. 59).

#### Common Taxa

**Vascular Plants:** *Carex aquatilis*, *Eriophorum angustifolium*, *E. russeolum*, *Carex rotundata*, *Pedicularis sudetica*, *Salix arctica*.

**Mosses:** *Drepanocladus brevifolius*, *Cinclidium latifolium*, *C. arcticum*, *Meesia triquetra*, *Calliergon richardsonii*, *Catascopium nigratum*, *Campyllum stellatum*, *Distichium capillaceum*.

**Algae:** *Nostoc* sp.

Type M2 is dominant over much of the landscape. It occurs in most low-centered polygons and in other wet sites such as those adjacent to lakes and in wet meadows. Early in the summer, there is standing water on most Type M2 sites, but the excess water is usually gone by midsummer. The mosses, which are dominated by *Drepanocladus brevifolius*, are usually covered by light gray calcium carbonate deposits. *Carex aquatilis* is by far the most common sedge in this type, but it often accompanies several others such as *Eriophorum angustifolium*, *E. russeolum*, *Carex marina*, *C. atrofusca*, *C. saxatilis* and others.

This type occurs in low microsites, i.e. low polygon centers, troughs, and inter-hummock areas in Landform Units 3 (low-centered polygons, greater than 0.5 m relief contrast), 4 (low-centered polygons, less than 0.5 m relief contrast), 7 (strangmoor or disjunct polygon rims), and 0 (featureless). The associated Soil Units are commonly 3(1) or 4(1) (Histic Pergelic Cryaquept), or 4(2) (Pergelic Cryofibrust).



**Stand Type M4, VERY WET *Carex aquatilis*, *Scorpidium scorpioides* GRAMINOID MEADOW.**

**Common Taxa**

**Vascular Plants:** *Carex aquatilis*, *C. saxatilis* ssp. *laxa*, *Eriophorum angustifolium*, *Pedicularis sudetica*.

**Mosses:** *Scorpidium scorpioides*, *Drepanocladus brevifolius*.

**Algae:** *Nostoc* sp.

Type M4 commonly occurs in sites where there is shallow water up to 10 cm deep throughout the summer. In dry years these sites may be drained of all excess water, but the soil remains completely saturated. The robust moss *Scorpidium scorpioides* is often the only component in the cryptogam layer and is usually encrusted with calcium carbonate.

Very wet low-centered polygons, partially drained lake basins, and the wet lake margins often have Type M4 vegetation. Type M4 is usually associated with wet microsites in Landform Units 4 (low-centered polygons, less than 0.5 m relief contrast), 7 (strangmoor, or disjunct polygon rims), and 0 (featureless). Associated Soil Units are 4(1) (Histic Pergelic Cryaquept) and 4(2) (Pergelic Cryofibrist).

**Emergent Tundra**

**Stand Type E1, VERY WET *Carex aquatilis* GRAMINOID MEADOW (Fig. 60).**

**Common Taxa**

**Vascular Plants:** *Carex aquatilis*, *Caltha palustris*, *Eriophorum angustifolium*

Type E1 occurs on sites with water up to 25 cm deep throughout the summer. *Carex aquatilis* is often the only vascular plant, but sometimes there are other species such as *Eriophorum angustifolium*, *E. scheuchzeri*, *Ranunculus pallasii*, *Utricularia vulgaris* and *Caltha palustris*. Type E1 is most commonly found in partially drained lake basins, marginal to areas of deeper water.

**Stand Type E2, VERY WET *Arctophila fulva* GRAMINOID MEADOW (Fig. 61).**

**Common Taxa**

**Vascular Plants:** *Arctophila fulva*, *Hippuris vulgaris*, *Caltha palustris*.

Type E2 occurs in water up to 1 m deep. It is commonly found along lake margins, particularly on the sublittoral shelves of oriented lakes, and in ponds of partially drained lake basins. Other species sometimes found with *Arctophila* include *Hippuris vulgaris* and *Caltha palustris*. In late summer the grass *Arctophila fulva* turns bright red, making this type easily distinguishable in color photography.



Figure 60. Stand Type E1 bordering a lake near Frontier Camp.



Figure 61. Stand Type E2 in a lake near the BP/Sohio Base Camp.

**The Sagavanirktok River Sand Dunes.** The sand dunes at the mouth of the Sagavanirktok River are ecologically interesting. They are, however, outside the limits of the four main master maps, so they are only briefly described here. The dunes region can be divided into two smaller areas: 1) an area of barren sandy sites of the dunes proper, and 2) a more continuously vegetated peripheral area.

An aerial view of the region (Fig. 62) shows extensive barren dune fields oriented in the direction of the prevailing wind. The steep-sided dunes have sparse vegetation, consisting mainly of the grass *Elymus arenarius* var. *mollis* with scattered individuals of *Dupontia fisheri*, *Polemonium boreale* and *Artemisia borealis* (Stand Type B9, Fig. 63). Inter-dune areas are often completely barren or have vegetation composed mainly of *Salix ovalifolia*. The sand at the western margin of the dunes area is more stable, and has extensive mats of vegetation. In partially stable areas *S. ovalifolia* and *Artemisia borealis* are dominant, with *Parrya nudicaulis*, *Armeria maritima* and *Androsace chamaejasme* (Stand Type B13). *Dryas integrifolia*, *Kobresia myosuroides* and *Oxytropis nigrescens* (Stand Type B5) dominate the most stable areas.

Ice wedge polygons immediately to the west (Fig. 64) receive abundant aeolian material from the sand dunes. Vegetation on these polygon rims has a negligible moss component compared to most areas at Prudhoe Bay. Important species on the rims include *Carex aquatilis*, *Dryas integrifolia*, *Salix ovalifolia* and *Polygonum viviparum* (Stand Type U14). The centers of the polygons, in contrast, have very thick moss carpets composed of *Drepanocladus brevifolius*, *Cinclidium latifolium* and *Meesia triquetra* (Stand Type M3). The difference in the cover of moss on the rims and in the centers causes very different thaw depths within the confines of single polygons. Maximum thaw on the rims has been measured at 80 cm, while thaw in the polygon centers rarely exceeds 45 cm. Some areas of low-centered polygons have ponds up to 1 m deep, with dense submerged carpets of the moss *Scorpidium scorpioides* (Stand Type E3). A representative map of the sand dunes region is presented in Figure 65.

The primary soils of the sand dunes region are Pergelic Cryaquepts, Histic Pergelic Cryaquepts, and Pergelic Cryohemists in wet areas, and Pergelic Cryopsamments in the dunes proper. It should be noted that there is also a small area of dunes that was not investigated at the mouth of the Kuparuk River.



Figure 62. Aerial oblique view of sand dunes near the mouth of the Sagavanirktok River. Prevailing wind is toward the camera. Note several perched lakes caused by the high permafrost table. See Walker and Harris (1976).



Figure 63. Active dunes with Stand Type B9, DRY *Elymus arenarius*, *Dupontia fisheri* SAND DUNE BARREN.



Figure 64. An area of low-centered polygons on the west periphery of the dunes. In the foreground polygonal patterns are apparent beneath recently deposited aeolian materials.



Pattern and floristic code



**Prostrate Scrub Type**

i DRY *Dryas integrifolia*, *Artemisia borealis*, *Kobresia myosuroides* PROSTRATE SCRUB



**Moist Graminoid Meadow Types**

aq MOIST *Carex aquatilis*, *Dryas integrifolia* GRAMINOID MEADOW (Stand Type U14)

xx<sub>a</sub> LOW-CENTERED POLYGON VEGETATION COMPLEX  
 a) Polygon basins: MOIST *Carex aquatilis*, *Dryas integrifolia* GRAMINOID MEADOW (Stand Type U14)  
 b) Polygon rims: DRY *Salix ovalifolia*, *Artemisia borealis* SANDY FLATS BARREN (Stand Type B13)



**Wet Graminoid Meadow Types**

aq WET *Carex aquatilis*, *Dupontia fisheri*, *Drepanocladus brevifolius*, *Calliergon richardsonii* GRAMINOID MEADOW (Stand Type M3)

bg WET *Dupontia fisheri*, *Carex aquatilis*, *Salix ovalifolia* GRAMINOID MEADOW (Stand Type M11)

xx<sub>a</sub> LOW-CENTERED POLYGON VEGETATION COMPLEX  
 a) Polygon basins and lower microsites: WET *Carex aquatilis*, *Dupontia fisheri*, *Drepanocladus brevifolius*, *Calliergon richardsonii* GRAMINOID MEADOW (Stand Type M3)  
 b) Polygon rims: MOIST *Carex aquatilis*, *Dryas integrifolia* GRAMINOID MEADOW (Stand Type U14)

xx<sub>d</sub> DISCONTINUOUS LOW-CENTERED POLYGON VEGETATION COMPLEX  
 Same communities as for xx<sub>a</sub>



**Very Wet Graminoid Meadow Type**

bg VERY WET *Dupontia fisheri*, *Carex aquatilis* GRAMINOID MEADOW (Stand Type E4)



**Aquatic Graminoid Meadow Type**

ab VERY WET *Arctophila fulva* GRAMINOID MEADOW (Stand Type E2)



**Barren Types**

s DRY *Salix ovalifolia*, *Artemisia borealis* SANDY FLATS BARREN (Stand Type B13)



bh No vegetation



bg Dead vegetation caused by flooding with salt water



**SAND DUNE VEGETATION COMPLEX**

a) Dunes: DRY *Elymus arenarius*, *Dupontia fisheri* SAND DUNE BARREN (Stand Type B9)  
 b) Inter-dune areas: No vegetation  
 Isolated sand dune



**Water Types**

w1 Fresh water  
 w4 Brackish water



**Disturbed Sites**



Road

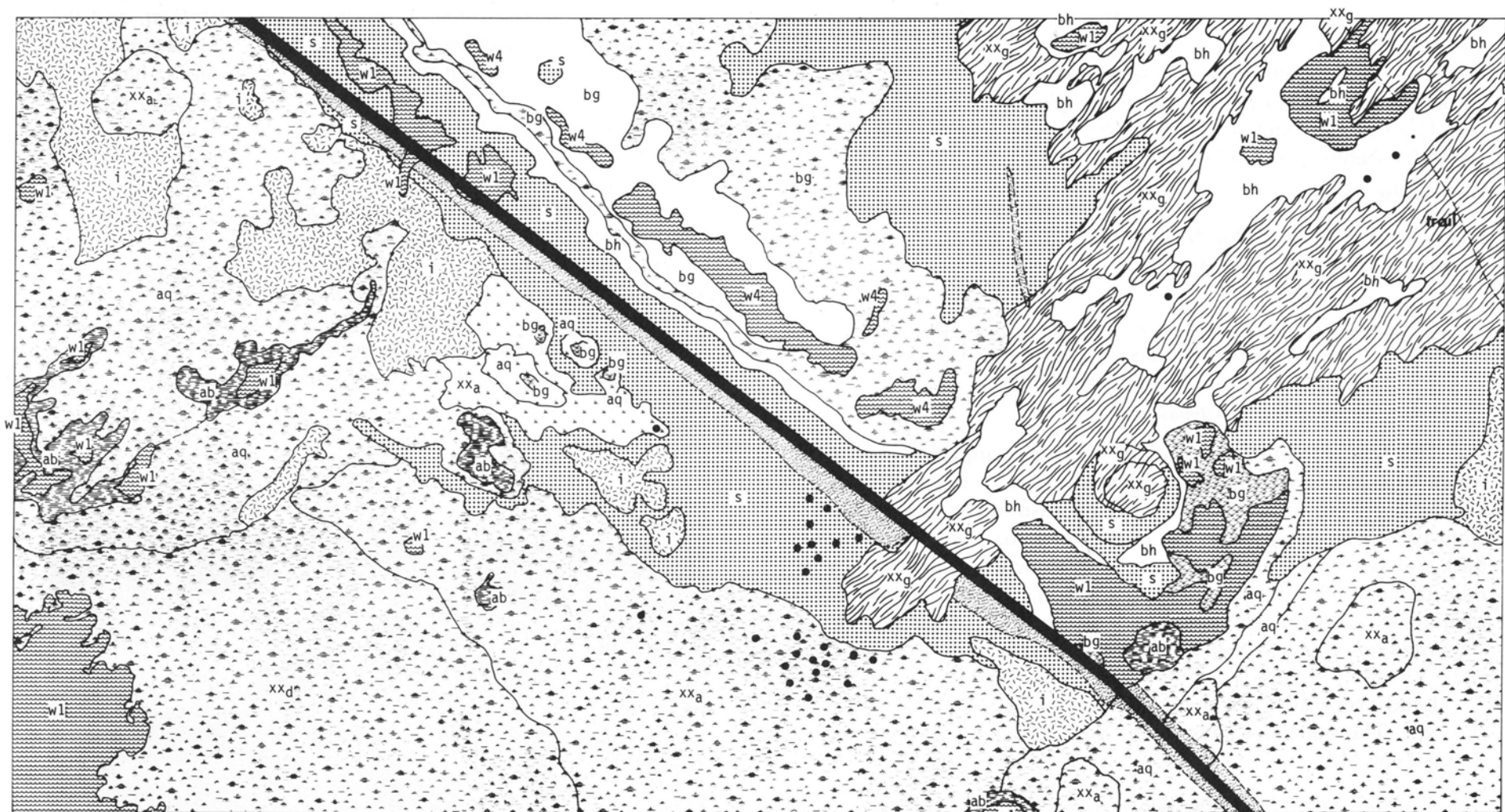
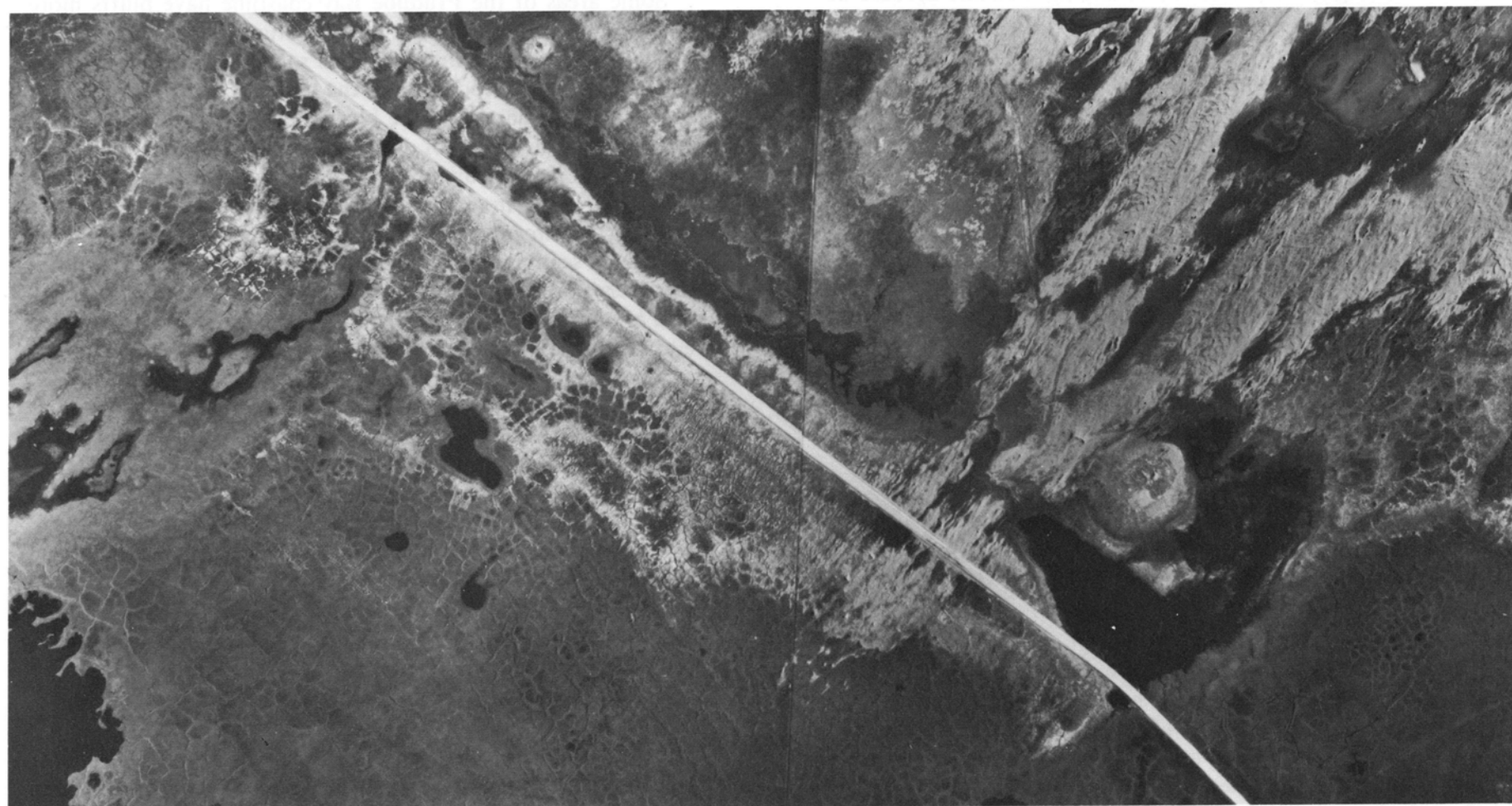


Figure 65. Aerial photograph and vegetation map of the Prudhoe Bay sand dunes. The map patterns denote dominant physiognomic plant growth-forms; the letter codes within the patterns denote dominant plant species.



## Acidic Tundra Stand Types

The vegetation north of the BP/Sohio Base Camp has a noticeably different character that is presumably related to the lower soil pH and lower summer temperatures (Fig. 53). Although this northern region has been characterized as “wet acidic tundra,” the infrequent dry sites are commonly alkaline because of the base-rich parent material and the lack of accumulation of organic matter. Dry sites, therefore, often have the same vegetation (Types B1 and B2) as similar sites in areas to the south and east. In very wet sites, Types E1 and E2 occur. The acidic region is partially represented on the master map of area 4 (Appendix A, Fig. A8). Included here are descriptions of two stand types common in the acidic region that are noticeably different from types on similar microsites in the wet alkaline area.

### Moist Acidic Tundra

**Stand Type U1, MOIST *Carex aquatilis*, *Ochrolechia frigida* GRAMINOID MEADOW.**

#### Common Taxa

**Vascular Plants:** *Carex aquatilis*, *Dryas integrifolia*, *C. misandra*, *C. bigelowii*, *Eriophorum angustifolium*, *Salix arctica*, *S. reticulata*, *S. rotundifolia*, *Saxifraga hirculus*.

**Mosses:** *Tomenthypnum nitens*, *Distichium capillaceum*, *Dicranum elongatum*, *Pogonatum alpinum*, *Oncophorus wahlenbergii*, *Orthothecium chryseum*.

**Lichens:** *Ochrolechia frigida* f. *theleporoides*, *Thamnolia vermicularis*, *Cetraria cucullata*, *C. nivalis*, *Cladonia pocillum*, *C. gracilis*, *Alectoria nigricans*, *Dactylina arctica*.

Type U1 is best developed on hummocks and aligned strangmoor features, especially in areas where Type M1 is dominant. Here Type U1 replaces Type U3 which grows on similar microsites in wet calcareous areas. The most noticeable difference between Types U1 and U3 is the abundance of the lichen *Ochrolechia frigida* f. *theleporoides* in Type U1. *Cladonia* lichens are also more common in Type U1. Several mosses, including *Pogonatum alpinum*, *Oncophorus wahlenbergii* and *Dicranum elongatum*, and liverworts, including *Ptilidium ciliare*, *Scapania simmonsii* and *Radula prolifera*, are more common in Type U1 than in Type U3. *Carex misandra* is a vascular plant that is noticeably more abundant in Type U1.

The most commonly associated Landform Unit is No. 7 (strangmoor or disjunct polygon rims). The primary associated Soil Units are 4(1) and 3(1) (Histic Pergelic Cryaquept), 3(2) (Pergelic Cryohemist), and 3(3) (Pergelic Cryosaprist).

### Wet Acidic Tundra

**Stand Type M1, WET *Carex aquatilis*, *C. rariflora*, *Saxifraga foliolosa* GRAMINOID MEADOW.**

#### Common Taxa

**Vascular Plants:** *Carex aquatilis*, *C. rariflora*, *C. subspathacea*, *Eriophorum angustifolium*, *C. misandra*, *Saxifraga foliolosa*, *S. hirculus*, *C. rotundata*, *Melandrium apetalum*, *Pedicularis sudetica*.

**Mosses:** *Drepanocladus brevifolius*.

This type is found in many moist microsites similar to sites on which Type M2 occurs in the wet calcareous area. It has a different appearance from Type M2, primarily because of the lack of calcium carbonate deposits on the mosses and the presence of the dark gray covering formed by a species of algae which dries out by midsummer and forms a crust on the soil. The abundance of plants such as *Carex misandra*, *C. rariflora*, *C. subspathacea*, *Saxifraga foliolosa* and *S. hirculus* clearly separates this from Type M2.

Landform Units 7 (strangmoor) and 0 (featureless) occur with this type. The associated soils are the same as those accompanying Stand Type M2.

**The Coastal Area.** Like the sand dunes, the coastal area is a distinctive and interesting part of the Prudhoe Bay region that was not covered in the main mapping program. This discussion briefly describes the vegetation within a small coastal area near the West Dock (Fig. 66).

The coastal beaches (Fig. 67) are commonly sandy and strewn with peat blocks that have been eroded from coastal bluffs. The lower parts of the beaches are completely barren of vegetation as a

result of wave action and the scouring effects of sea ice. The higher parts of the beaches sometimes have scattered plants such as *Cochlearia officinalis*, *Stellaria humifusa* and *Puccinellia andersonii* (Stand Type B8, Fig. 68). More stable areas between the active beach and the upper strand line are usually dominated by *Dupontia fisheri* (Stand Type U13).

Some areas of the Prudhoe Bay coastline have bluffs more than 3 m high, with essentially no vegetation between the water's edge and the top of the bluff except for some that is attached to the peat blocks that are eroding from the bluffs. There are many sites along the coast, mainly on the bluff tops and on tundra upland sites, with extensive areas of dead vegetation. The dead vegetation is the result of inundation by the sea during storm surges (Reimnitz and Maurer 1979). In many of these areas, the main ground cover is dead *Dryas integrifolia*. Currently the only live plants on these sites include scattered individuals of *Braya purpurascens*, *Puccinellia andersonii* and the lichens *Thamnolia vermicularis* and *Fulgensia bracteata* (Stand Type B10). Lowland areas that are flooded are apparently less affected by the sea water since many of these sites now support continuous cover of coastal vegetation. However, in some lowland areas sea water flooding has caused complete vegetation kills. One such site is located in the vicinity of the sand dunes at the mouth of the Sagavanirktok River behind a coastal beach that was breached during one storm (see sand dunes map, Fig. 65). The sea water flooded a *Carex aquatilis* meadow to a depth of over 30 cm, forming a shallow brackish lake that killed the meadow.

In estuaries and lagoons, there is a distinctive saltwater community dominated by *Puccinellia phryganodes*, *Carex subspathacea*, *C. ursina* and *Stellaria humifusa* (Stand Type M9). This is a favorite feeding ground for migrating Black Brant geese (Bergman et al. 1977).

The vegetation above the highest strand line is controlled mainly by variations in microrelief caused by ice-wedge polygons. Low, wet sites, as in low-centered polygons and wet meadows, are dominated by *Carex aquatilis*, *Eriophorum angustifolium*, *Dupontia fisheri* and the mosses *Drepanocladus brevifolius* and *Campyllum stellatum* (Type M10). Mesic sites such as well-drained meadows, and some high-centered polygons, have *Carex aquatilis*, *Salix pulchra*, *S. ovalifolia*, *Eriophorum angustifolium*, and the mosses *Distichium capillaceum* and *Campyllum stellatum* (Stand Type U12). Many polygon rims and aligned hummocks have soils with clods of peat and moss which have been dislodged by frost heaving. The dominant taxa in these sites are *Carex aquatilis*, *Salix pulchra*, *S. reticulata*, the mosses *Dicranum* spp. and *Pogonatum alpinum*, and several soil lichens such as *Ochrolechia frigida*, *Lecanora epibryon*, *Sphaerophorus globosus* and *Cladonia pyxidata*. Dry microsites are dominated by crustose lichens such as *Ochrolechia frigida*, *Lecanora epibryon* and *Physcia muscigena*, with vascular plants such as *Salix rotundifolia*, *S. pulchra*, *Luzula arctica*, *Stellaria laeta*, *Dryas integrifolia*, *Artemisia arctica*, *Silene acaulis*, *Carex misandra* and *Salix reticulata* (Stand Type B12, Fig. 69). A vegetation map of the area discussed above is presented in Figure 70.



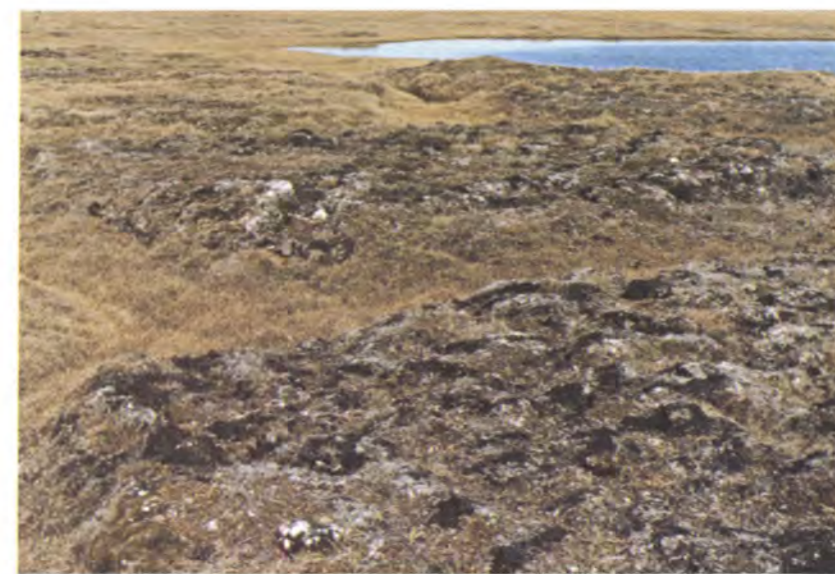
**Figure 66. Aerial oblique view of the coastal study site. The West Dock is in the background.**



**Figure 67. Coastal beach with slumping peat mat. Vegetation on the peat has been killed by salt. Height of the bluff is about 1 m.**










**Figure 68. Stand Type B8, DRY *Cochlearia officinalis*, *Puccinellia phryganodes* COASTAL BEACH BARREN. Note the peat blocks in the background that have been washed onto the beach.**







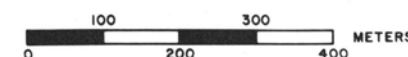
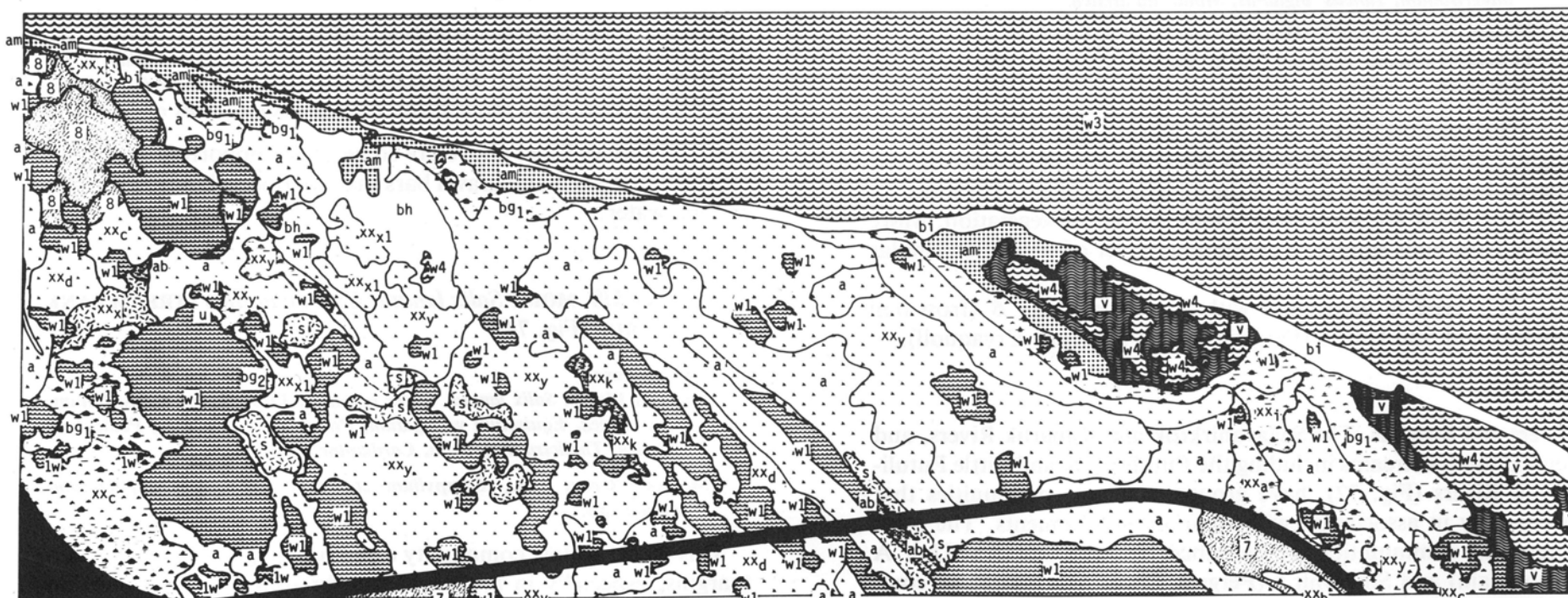
**Figure 69. Coastal high-centered polygons with Stand Type B12, DRY *Salix rotundifolia*, *Salix planifolia*, *Ochrolechia frigida* COASTAL PROSTRATE SCRUB.**






- Pattern and floristic code**
-  **Prostrate Scrub Type**  
s DRY *Salix rotundifolia*, *S. planifolia*, *Ochrolechia frigida* PROSTRATE SCRUB (Stand Type B12)
  -  **Moist Graminoid Meadow Types**  
u MOIST *Carex aquatilis*, *Dicranum elongatum*, *Ochrolechia frigida* COASTAL GRAMINOID MEADOW (Stand Type B15)  
a MOIST *Carex aquatilis*, *Salix planifolia*, COASTAL GRAMINOID MEADOW (Stand Type U12)
  -  **Wet Graminoid Meadow Types**  
aq WET *Carex aquatilis*, *Dupontia fisheri*, *Eriophorum angustifolium*, *Drepanocladus* sp. COASTAL GRAMINOID MEADOW (Stand Type M10)  
bg<sub>1</sub> WET *Dupontia fisheri*, *Cochlearia officinalis* COASTAL GRAMINOID MEADOW (Stand Type M12)  
bg<sub>2</sub> WET *Dupontia fisheri*, *Carex aquatilis*, *Campylyium stellatum*, *Calliergon* sp. COASTAL GRAMINOID MEADOW (Stand Type M8)  
v WET *Carex subspathacea*, *Puccinellia phryganodes* COASTAL SALINE GRAMINOID MEADOW (Stand Type M9)
  -  **Very Wet Graminoid Meadow Type**  
ab VERY WET *Arctophila fulva* GRAMINOID MEADOW (Stand Type E2)
  -  **Barren Types**  
am DRY *Cochlearia officinalis*, *Puccinellia phryganodes* BEACH BARREN (Stand Type B8)
  -  bi Beach sand, and peat blocks
  -  bh Bare mud

**Vegetation Complexes**

-  **Prostrate Scrub Dominated**  
xx<sub>x</sub> MIXED HIGH- AND LOW-CENTERED POLYGON VEGETATION COMPLEX  
a) Higher microsites: floristic code s, Stand Type B12  
b) Lower microsites: floristic code a, Stand Type U12
-  **Moist Graminoid Meadow Dominated**  
xx<sub>x1</sub> MIXED HIGH- AND LOW-CENTERED POLYGON VEGETATION COMPLEX:  
a) Higher microsites: floristic code u, Stand Type B15  
b) Lower microsites: floristic code a, Stand Type U12  
xx<sub>x2</sub> a) Higher microsites: floristic code a, Stand Type U12  
b) Lower microsites: floristic code aq, Stand Type M10  
NON-ALIGNED HUMMOCK VEGETATION COMPLEX:  
xx<sub>d</sub> a) Higher microsites: floristic code a, Stand Type U12  
b) Lower microsites: fresh water  
xx<sub>c</sub> ALIGNED HUMMOCK VEGETATION COMPLEX  
a) Higher microsites: floristic code a, Stand Type U12  
b) Lower microsites: floristic code aq, Stand Type M10  
MEADOW VEGETATION COMPLEX:  
xx<sub>y</sub> Same communities as for xx<sub>c</sub>  
xx<sub>b</sub> HIGH-CENTERED POLYGON VEGETATION COMPLEX:  
a) High polygon centers: floristic code a, Stand Type U12  
b) Polygon troughs: floristic code bg<sub>2</sub>, Stand Type M8
-  **Wet Graminoid Meadow Dominated**  
xx<sub>c</sub> ALIGNED HUMMOCK VEGETATION COMPLEX  
a) Lower microsites: floristic code bg<sub>1</sub>, Stand Type M12  
b) Higher microsites: floristic code u, Stand Type B15  
xx<sub>i</sub> FROST-BOIL VEGETATION COMPLEX  
a) Inter-frost-boil areas: floristic codes bg<sub>1</sub> and a, Stand Types M12 and U12  
b) Frost-boils: no vegetation  
xx<sub>c</sub> ALIGNED HUMMOCK VEGETATION COMPLEX  
a) Lower microsites: floristic code aq, Stand Type M10  
b) Higher microsites: floristic code u, Stand Type B15  
xx<sub>y</sub> MIXED HIGH- AND LOW-CENTERED POLYGON VEGETATION COMPLEX  
Same communities as for xx<sub>c</sub>  
xx<sub>a</sub> LOW-CENTERED POLYGON VEGETATION COMPLEX:  
Same communities as for xx<sub>c</sub>
-  **Very Wet Graminoid Meadow Dominated**  
xx<sub>k</sub> MARSH VEGETATION COMPLEX:  
a) Shallow water: floristic code ab, Stand Type E2  
b) Deeper water: no vegetation



-  **Disturbed Types**  
7 Flooded area  
8 Gravel and debris
-  **Water Types**  
w3 Ocean  
w4 Brackish water  
w1 Fresh water
-  Road or pad

**Figure 70. Aerial photograph and vegetation map of the Prudhoe Bay coastal site. The map is coded according to the scheme used in Figure 65.**





Figure 71. Stand Type B3 on an active frost boil.



Figure 73. *Epilobium latifolium*, the River Beauty, a common plant on gravel bars with Stand Type B4.



Figure 75. Stand Type M5 along the margins of a creek near the Kuparuk River. Summer temperatures are lower here than at the site shown in Figure 74 and are probably too low for the growth of *Salix lanata*.

## Stand Types Occurring in Special Habitats

### Frost Boils

**Stand Type B3, DRY** *Saxifraga oppositifolia*, *Juncus biglumis* FROST-BOIL BARREN (Fig. 71).

#### Common Taxa

**Vascular plants:** *Saxifraga oppositifolia*, *Dryas integrifolia*, *Chrysanthemum integrifolium*, *Juncus biglumis*, *Minuartia arctica*.

**Mosses:** *Bryum wrightii*, *Distichium capillaceum*, *Encalypta alpina*.

**Lichens:** *Lecanora epibryon*, sterile black crust lichen, *Thamnolia vermicularis*.

This type occurs on frost boils. Normally such microsites are slightly elevated with respect to their surroundings and support species found at the dry end of the moisture gradient. The most active frost boils are sometimes totally devoid of vegetation. More stable frost boils support a continuous cover of vegetation similar to Type B2 or Type U3.

This type is associated with Landform Unit 6 (frost-boil tundra) and Soil Unit 6 (Pergelic Ruptic Aqueptic Cryaquoll).

**Rivers and Streams.** The Sagavanirktok and Kuparuk Rivers, and several tundra streams including the Putuligayuk and Little Putuligayuk Rivers (Fig. 72), have groups of plant communities that occur only in association with riparian environments. The most important communities are described below. Landform Unit A (floodplain) and Soil Unit 5 (Pergelic Cryorthent) are most commonly associated with these stand types. The rivers and streams of the region are floristically rich. The rarest plant in the region,

*Thlaspi arcticum*, is found on sandy terraces of the Kuparuk River (Murray and Murray 1975). Other plants that are primarily associated with stream banks include *Chrysanthemum bipinnatum*, *Wilhelmsia physodes* and *Gentianella propinqua* ssp. *propinqua*.

**Stand Type B4, DRY** *Epilobium latifolium*, *Artemisia arctica* RIVER BAR BARREN (Fig. 73).

**Common Taxa:** *Epilobium latifolium*, *Artemisia arctica*, *A. borealis*, *A. glomerata*, *Papaver lapponicum*, *Trisetum spicatum*, *Polemonium boreale*, *Elymus arenarius*, *Astragalus alpinus*, *Wilhelmsia physodes*, *Equisetum arvense*, *Braya purpurascens*, *Parrya nudicaulis*, *Salix ovalifolia*.

The species listed above are some of the opportunistic plants that occur on sand and gravel bars that are flooded during periods of high water.

**Stand Type U8, MOIST** *Salix lanata*, *Carex aquatilis* STREAM BANK DWARF SCRUB (Fig. 74).

#### Common Taxa

**Vascular Plants:** *Salix lanata*, *Carex aquatilis*, *Eriophorum angustifolium*, *Salix arctica*, *Equisetum variegatum*, *Polygonum viviparum*, *Pedicularis sudetica*, *Thalictrum alpinum*, *Cardamine hyperborea*.

**Mosses:** *Bryum* spp., *Campylium stellatum*, *Distichium capillaceum*, *Mnium* spp.

This dwarf willow community often occurs inland along stream margins, especially in areas which offer some winter protection due to snowbanks. It also occurs around the margins of some lakes. *Salix lanata* rarely grows over 15 cm tall within the region.

**Stand Type M5, WET** *Carex aquatilis*, *Salix rotundifolia* STREAM BANK GRAMINOID MEADOW (Fig. 75).

#### Common Taxa

**Vascular Plants:** *Carex aquatilis*, *Salix arctica*, *Eriophorum angustifolium*, *Pedicularis sudetica*, *Saxifraga hirculus*, *Eriophorum russeolum*, *Salix rotundifolia*, *Dupontia fisheri*, *Polygonum viviparum*.

**Mosses:** *Catascopium nigrum*, *Campylium stellatum*, *Cinclidium arcticum*, *Distichium capillaceum*, *Calliergon* spp., *Bryum* spp.

Most stream banks, such as those along the Little Putuligayuk River and other small creeks, support lush sedge vegetation. In many instances, these areas have late-lying snow, and Type M5 will intergrade with Type U7, the *Salix rotundifolia* snowbank community.

**Stand Type B6, DRY** *Dryas integrifolia*, *Astragalus alpinus* RIVER BAR PROSTRATE SCRUB (Fig. 76).

#### Common Taxa

**Vascular Plants:** *Dryas integrifolia*, *Astragalus alpinus*, *A. umbellatus*, *Carex scirpoidea*, *Kobresia myosuroides*, *Silene acaulis*, *Papaver macounii*, *Parrya nudicaulis*, *Androsace chamaejasme*, *Polygonum viviparum*, *Anemone richardsonii*, *Salix rotundifolia*, *S. reticulata*, *Oxytropis borealis*.

**Mosses:** *Distichium capillaceum*, *Ditrichum flexicaule*.

Type B6 occurs on dry, sandy river banks, particularly along the Little Putuligayuk River. There is usually good coverage of the prostrate vegetation. There is a noticeable lack of fruticose lichens and prostrate dead vegetation because they are washed away annually in the spring flood.



Figure 72. Little Putuligayuk River near Drill Site 2. Many of the barren-appearing gravel bars support sparse Stand Type B4 vegetation.



Figure 74. Stand Type U8 along the Putuligayuk River. Height of the willows is about 15 cm.



Figure 76. Tundra stream near Prudhoe Bay showing high water boundary. Vegetation below the boundary is mainly Stand Types M5 (light areas adjacent to stream), B6 (darker areas) and U9 (lighter areas along the upper margin).



**Stand Type B7, DRY *Braya purpurascens*, *Anemone parviflora*, *Arctagrostis latifolia* SLUMPING RIVER BLUFF COMPLEX.**

**Common Taxa**

**Vascular Plants:** *Braya purpurascens*, *Anemone parviflora*, *Dryas integrifolia*, *Senecio resedifolius*, *Oxyria digyna*, *Parnassia kotzebuei*, *Erigeron humilis*, *Arctagrostis latifolia*, *Festuca rubra*, *F. baffinensis*, *Astragalus alpinus*, *Chrysanthemum integrifolium*, *Artemisia arctica*, *Salix reticulata*, *Androsace chamaejasme*, *Carex scirpoidea*, *Kobresia myosuroides*, *Lloydia serotina*, *Armeria maritima*, *Aster sibiricus*, *Epilobium latifolium*.

Stand Type B7 represents several distinct but usually small communities found along steep river bluffs. Some areas are unstable and totally barren. Other areas are well-stabilized and contain a large number of species. The greatest number of species occur on south-facing slopes with abundant ground squirrel holes. River bluffs have not been adequately sampled to define separate community types.

**Stand Type U9, DRY *Dryas integrifolia*, *Eriophorum angustifolium*, *Tomenthypnum nitens*, *Didymodon asperifolius* STREAM BANK GRAMINOID MEADOW (Fig. 76).**

**Common Taxa**

**Vascular Plants:** *Dryas integrifolia*, *Carex membranacea*, *Eriophorum angustifolium* s.l., *Salix rotundifolia*, *S. reticulata*, *Astragalus umbellatus*, *Saxifraga oppositifolia*, *Senecio atropurpureus*, *Papaver macounii*, *Chrysanthemum integrifolium*, *Parrya nudicaulis*.

**Mosses:** *Tomenthypnum nitens*, *Ditrichum flexicaule*, *Tortula ruralis*, *Tortella arctica*, *Didymodon asperifolius*, *Distichium capillaceum*, *Drepanocladus uncinatus*, *Hypnum* spp.

Type U9 occurs on sloping upland sites along the margins of rivers where it often grades into Type U3 vegetation. It is distinguished from Type U3 by the general lack of fruticose lichens and prostrate dead vegetation, which, as in Type B6, are washed away annually by floodwaters. Also there are several species normally not found in Type U3 such as *Didymodon asperifolius*, *Tortella arctica*, *Tortula ruralis*, *Senecio resedifolius* and *Parrya nudicaulis*. *Tomenthypnum nitens* and *Dryas integrifolia* are often the most conspicuous components of Type U9.

**Snow Patches.** Because of the subdued relief, late-lying snow patches are not common in the Prudhoe Bay region. However, snow patch communities do occur around the bases of pingos and along some creeks and rivers. In some snow patch areas the vegetation occurs in three distinctive bands. Stand Type B14 occurs near the upper edge of the area, Type U6 in the middle zone, and Type U7 at the base of the snowbank in the zone of deepest snow.

Snow patches are normally associated with steep slopes, i.e. creek bluffs with Landform Unit 8 (hummocky terrain) and pingos. Soils belong to Units 1 (Pergelic Cryoboroll) or 2 (Pergelic Cryaquept). In creekside areas Landform Unit A (alluvium) and Soil Unit 5 (Pergelic Cryopsamment) occur.

**Stand Type B14, DRY *Dryas integrifolia*, *Salix reticulata*, *Cetraria richardsonii* SNOW PATCH PROSTRATE SCRUB.**

**Common Taxa**

**Vascular Plants:** *Dryas integrifolia*, *Salix reticulata*, *Astragalus umbellatus*, *Pedicularis capitata*, *Papaver macounii*, *Carex rupestris*.

**Mosses:** *Tomenthypnum nitens*, *Rhytidium rugosum*, *Ditrichum flexicaule*, *Thuidium abietinum*, *Drepanocladus uncinatus*.

**Lichens:** *Thamnia vermicularis*, *Cetraria nivalis*, *Lecanora epibryon*, *Alectoria nigricans*, *Dactylina arctica*, *Cetraria cucullata*, *C. islandica*, *C. richardsonii*, *Cladonia* spp., *Alectoria ochroleuca*, *Cornicularis divergens*.

This is the least distinctive of the three types. It occurs near the top of many snowbanks, often on very hummocky microrelief, and grades into Type B1 near the upper margin.

**Stand Type U6, DRY *Dryas integrifolia*, *Cassiope tetragona* SNOW PATCH DWARF SCRUB (Fig. 77).**

**Common Taxa**

**Vascular Plants:** *Cassiope tetragona*, *Dryas integrifolia*, *Salix rotundifolia*, *Salix reticulata*, *Pedicularis capitata*, *Carex scirpoidea*, *Polygonum viviparum*, *Chrysanthemum integrifolium*, *Lloydia serotina*, *Papaver macounii*, *Silene acaulis*.

**Mosses:** *Ditrichum flexicaule*, *Drepanocladus uncinatus*, *Thuidium abietinum*, *Tomenthypnum nitens*.

**Lichens:** *Cetraria cucullata*, *C. richardsonii*, *C. islandica*, *C. nivalis*, *Peltigera canina*.

This is usually a distinctive vegetation band that occurs on steep, well-drained portions of snow patch areas. The abundance of *Cassiope tetragona* makes it an easily recognized community.



**Figure 77. Stand Type U6 in a snow patch area on Angel Pingo. *Cassiope tetragona* is the only common ericaceous shrub in the region.**

**Stand Type U7, MOIST *Salix rotundifolia* SNOW PATCH PROSTRATE SCRUB.**

**Common Taxa**

**Vascular Plants:** *Salix rotundifolia*, *Carex aquatilis*, *Senecio atropurpureus*, *Equisetum variegatum*, *Eriophorum angustifolium*.

**Mosses:** *Distichium capillaceum*, *Ditrichum flexicaule*.

Type U7 usually occurs in areas at the base of slopes in the transition to flat terrain where deep snow is present in winter. In very deep snowbanks this community can also cover the steep lower portions of embankments.

**Pingo Tops, Bird Mounds, Animal Dens**

**Stand Type U10, MOIST *Festuca baffinensis*, *Papaver macounii* GRAMINOID MEADOW (Fig. 78 and 79).**

**Common Taxa**

**Vascular Plants:** *Dryas integrifolia*, *Ranunculus pedatifidus*, *Festuca baffinensis*, *F. brachyphylla*, *F. rubra*, *Poa alpigena*, *Arctagrostis latifolia*, *Trisetum spicatum*, *Alopecurus alpinus*, *Saxifraga caespitosa*, *S. oppositifolia*, *Potentilla uniflora*, *Oxytropis maydelliana*, *Astragalus umbellatus*, *Androsace septentrionalis*, *Taraxacum ceratophorum*, *T. phymatocarpum*, *Polemonium boreale*.

**Mosses:** *Bryum* spp., *Tortula ruralis*, *Thuidium abietinum*, *Drepanocladus uncinatus*, *Encalypta* spp., *Hypnum* spp., *Rhytidium rugosum*, *Leptobryum pyriforme*, *Funaria arctica*, *Pohlia cruda*.

**Lichens:** *Dactylina arctica*, *Cetraria cucullata*, *C. islandica*, *C. tilesii*, *C. nivalis*, *C. richardsonii*, *Thamnia vermicularis*, *Peltigera canina*.

Type U10 is found in areas frequented by mammals and/or birds. The animals contribute to the nutrient pool with their feces, cough pellets, and debris from kills, which results in lush growths of grasses and dicotyledons. A common feature on the Prudhoe Bay landscape is the "bird mound," which is often located at an intersection of a polygon rim or another site where there is a slightly higher vantage point from which a bird can observe the surrounding terrain. The mounds usually have different plant communities than the surrounding terrain, and are dominated by grasses such as *Festuca baffinensis*, *Arctagrostis latifolia* and *Alopecurus alpinus*, with *Dryas integrifolia*, *Papaver macounii*, *Salix reticulata* and several species of mosses. The mounds apparently develop as plant production increases due to the addition of nutrients contributed by the birds. These features are too small to map at a scale of 1:6000, and no corresponding landform and soil codes have been designated.



**Figure 78. Bird mound with Stand Type U10 near Drill Site 2.**



**Figure 79. A display of wildflowers in a rich Type U10 community on a pingo near Frontier Camp.**

Some of the most interesting vegetation types at Prudhoe Bay are associated with pingos and river systems. Botanically, pingos are the richest sites in the Prudhoe Bay region. They contain outliers of alpine plants that have probably come from the Brooks Range such as *Oxytropis nigrescens* and *O. maydelliana*. Rich lichen communities, which are uncommon in this wet region, are found in the snowbed areas of pingos. Several species of birds, such as the buff-breasted sandpiper, snowy owl, jaeger and glaucous gull, use the pingos as breeding grounds or as observation points for viewing the surrounding terrain. The arctic fox, arctic ground squirrel and collared lemming have their homes in pingos and along streams. Unfortunately, pingos and streams also attract the activities of man. On nearly all the larger mounds in the Prudhoe Bay region there are vehicle tracks and debris left by surveyors; a few have deep bulldozer trenches formed in the search for gravel.



### Disturbed Sites

Several categories of disturbance are extensive enough in the Prudhoe Bay region to map. The following disturbance types are recognized.

**D1, Bare Earth with Pioneering Species.** Some areas adjacent to construction sites and several old drill sites have been stripped of vegetation. Revegetation is slow. Pioneering plants are most common, especially several species of mosses and liverworts. *Marchantia polymorpha*, *Bryum* spp., *Leptobryum pyriforme*, and *Funaria hygrometrica* are usually present. The primary vascular taxa include *Braya purpurascens* and *Eriophorum angustifolium*. An example of the slow recovery of these sites is evident from the 1968 trail leading to the ARCO base camp (Fig. 80) which was utilized before construction of the gravel road network. This surface still has only a sparse cover of vascular plants. Experiments with fertilizing these areas have shown increased moss cover but poor recovery of vascular plants.

**D2, Foreign Gravel or Construction Debris.** This type of disturbance is most prevalent in the vicinity of the older roads and pads, where gravel was deposited on the snow-covered tundra during construction and winter maintenance. Current construction methods have eliminated much of this type of disturbance. Vegetation varies depending on moisture and degree of disturbance.

**D3, Dust-Covered Areas Adjacent to Roads** (Fig. 81). This is one of the most common disturbances along the roads. The fine material in the gravels used for the roads is displaced by the heavy truck traffic and carried up to 1 km downwind from the roads (Benson et al. 1975, Everett, in press). Near the road only a few taxa such as *Eriophorum angustifolium*, *Braya purpurascens*, and a few species of *Salix* can tolerate the heavy dustfall. Nearly all the lichens and mosses are smothered and subsequently killed by the dust.

**D4, Vehicle Tracks—Deeply Rutted** (Fig. 80). These are remnants of the past when vehicles traveled indiscriminantly on the tundra during the summers. Many of these tracks have deepened due to thermokarst and thermal erosion. Current state and federal regulations prohibit travel by most vehicles on the tundra during the time when the active layer is thawed, immediately prior to spring snowmelt, and in the fall before there is an adequate snow cover. Vegetation in these sites is commonly composed of emergent communities of *Carex aquatilis* or *Eriophorum* spp.

**D5, Vehicle Tracks—Not Deeply Rutted.** These tracks can be caused by tracked vehicles during the winter months in areas with thin snow cover or by Rolligons or unauthorized vehicles during the summer. The vegetation is commonly unchanged from its original composition.

**D6, Winter Roads.** These roads are constructed during the winter on an ice-hardened snow surface. The locations of the roads are occasionally apparent during the summer because of gravel, debris, scraped areas and flattened microrelief. Flattening the microrelief commonly changes the composition of the plant communities because of a wetter microenvironment.

**D7, Excavated Areas, Primarily in River Gravels.** Many river sites have been mined for gravel. In some cases the disturbed areas extend into adjacent non-gravel areas, such as river banks and vegetated floodplains. Usually there is little or no vegetation on these sites. A few other areas, primarily on pingos and small ridges, were also excavated in search of gravel early in the development of the oilfield. Several pioneering plants such as *Epilobium latifolium*, *Braya purpurascens* and *Saxifraga oppositifolia* occur in these areas today.

**W3, Flooded Areas Caused by Roads or Pads** (Fig. 82; also see Fig. 6 for several examples). In many areas the roads and pads act as dikes, preventing the natural drainage of the landscape. Extensive shallow impoundments form, particularly in low areas such as drained lake basins. The effect on the vegetation is usually the elimination of all but very water-tolerant taxa such as *Eriophorum angustifolium* and *Carex aquatilis*.



Figure 80. Deeply rutted vehicle tracks and an early attempt at road construction prior to development of the main gravel road network. Trenches on either side of the road were source of material which was bladed onto the road. Note the thermokarst across the road and in the trenches.



Figure 81. Trucks causing heavy dust along the haul road south of Prudhoe Bay.



Figure 82. Ponding caused by damming effect of the road.



# Mapping

## Master and Geobotanical Maps

THE MASTER LANDSCAPE MAP contains landform, soil and vegetation information (Everett et al. 1978). This information is recorded in fraction form, similar to the codes on composite maps which have been developed independently by others. The most noteworthy examples in the United States are soil-vegetation maps constructed by the California State Cooperative Soil-Vegetation Survey (Wieslander 1935, Colwell 1977). The California maps, however, show no reference to the landforms within each map unit. In Canada a method of geocological mapping for areas in the discontinuous permafrost zone has been discussed by Crampton and Rutter (1973) and Rutter (1977). Similar methods have also been employed in Australia by the Commonwealth Scientific and Industrial Research Organization, CSIRO (Christian 1958, Christian and Stewart 1964).

Master maps are most easily developed in areas where soils and vegetation are highly correlated with the landforms. The Prudhoe Bay region is particularly well-suited for the construction of such maps. Soil and vegetation investigations in this region (Everett 1975, Webber and Walker 1975, Everett et al. 1978) and in other parts of the Alaskan (Wiggins 1951, Sigafos 1952, Tedrow and Cantlon 1958, Cantlon 1961) and Canadian Arctic (Lavkulich 1972, 1973, Zoltai and Pettapiece 1973) have shown that most soil and vegetation patterns are intimately related to microrelief patterns.

At Prudhoe Bay much of the regional variation in soils and vegetation can be found within the limits of a single polygon, i.e. between the center, rim, and trough and repeated over and over in polygon complexes that cover large areas. The problem, then, is to represent this variation on maps of a scale adequate for detailed land-use purposes (1:1000 through 1:12,000). Generally, it is impossible to show the detail of the individual plant communities

unless very large scale maps are drawn, e.g. 1:500. Such maps have been produced for the Soviet tundra (Matveyeva et al. 1974), at Barrow (Brown et al., in press, a, Everett 1973, Walker 1977), and at Prudhoe Bay. Maps of this type, however, require a great expenditure of time because each plant community must be visited and its underlying soil examined. Such a procedure is of little use in characterizing the tundra soils or vegetation at anything approaching a regional scale, for example 1:6000 or greater. At scales smaller than about 1:1000 it is necessary to resort to some type of generalized coding system that indicates the nature of the landforms as well as the vegetation or soil.

Separate vegetation and soils maps were prepared and published for the IBP U.S. Tundra Biome site at Prudhoe Bay (Everett 1975, Webber and Walker 1975, see Fig. 2). Each author found it necessary to include a description of the terrain to adequately map the soil or vegetation, which is testimony to the control exerted by the landforms. Comparison of these 1975 maps revealed strong similarities in map unit patterns. This is to be expected since the boundaries on vegetation and soils maps for the coastal plain usually follow changes in ground pattern. After examination of a large number of aerial photographs on which soils and vegetation were mapped separately, it was apparent that this information could be combined on a single map using the landform types as the unifying element.

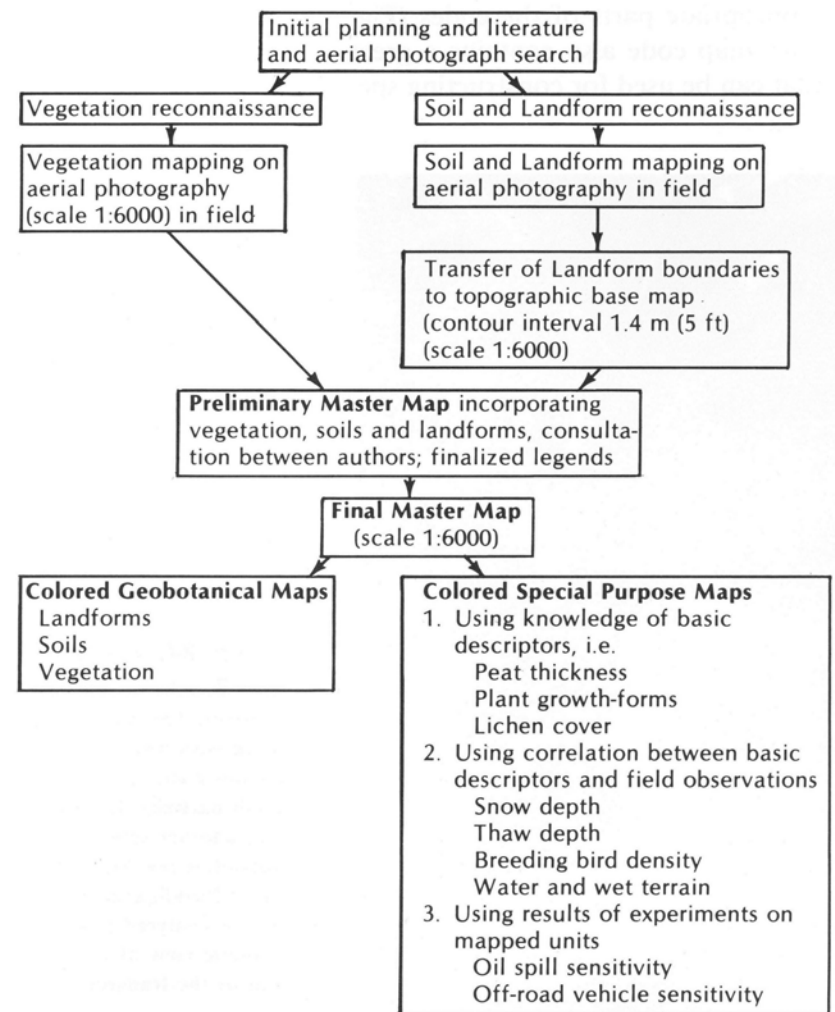


Figure 83. Flow diagram indicating procedures used in preparation of master, geobotanical, and special purpose maps.

With the recognition that the landforms are the controlling element for the vegetation and soils of the coastal plain tundra, a program was developed to map a 145-km<sup>2</sup> portion of the Prudhoe Bay region encompassing most of the main oilfield. The description and mapping of the soils and vegetation proceeded independently but the data were plotted on a single base map, which is termed the *master landscape map*. Such an approach has several advantages over producing separate landform, soils and vegetation maps. For one, it permits integration of a large body of diverse data onto a single map sheet. It also reduces greatly the time spent in developing separate legends.

The procedures followed in preparation of the master map are outlined in Figure 83. Landform boundaries are drawn on the aerial photographs prior to undertaking field transects. Soils and vegetation mapping then proceeds independently following the basic mapping principles outlined by Kùchler (1967). Soils and vegetation are mapped on separate field sheets and combined with the landform codes in the laboratory to form the master map. With a few exceptions a landform unit will include a single (dominant) soil or soil association, and a combination of vegetation stand types. Additional boundaries can be drawn at this stage to incorporate knowledge gained in the field. Small units (less than 2.5 hectares) or units with vegetation or soil similar to larger adjacent areas are often eliminated or combined.

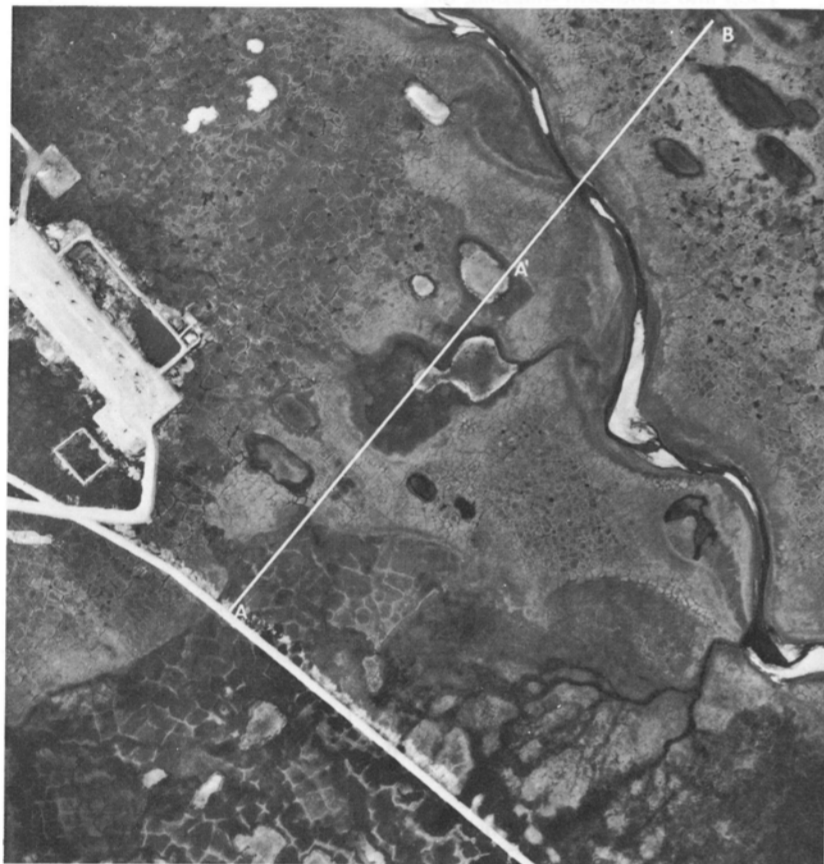


The terrain transect in Figures 84 and 85 illustrates the scale of elevation variations common in the Prudhoe Bay region and how they affect map unit boundaries. The final master map (Fig. 86 and Fig. A2 and A6-A8 in Appendix A) is coded with fractions representing vegetation, soils and landforms according to the format:

**Numerator:** Dominant vegetation type followed by subdominant vegetation types, each of which compose at least 20% of the unit

**Denominator:** Dominant soil, landform and slope class (the last is not included if slope is less than 2%)

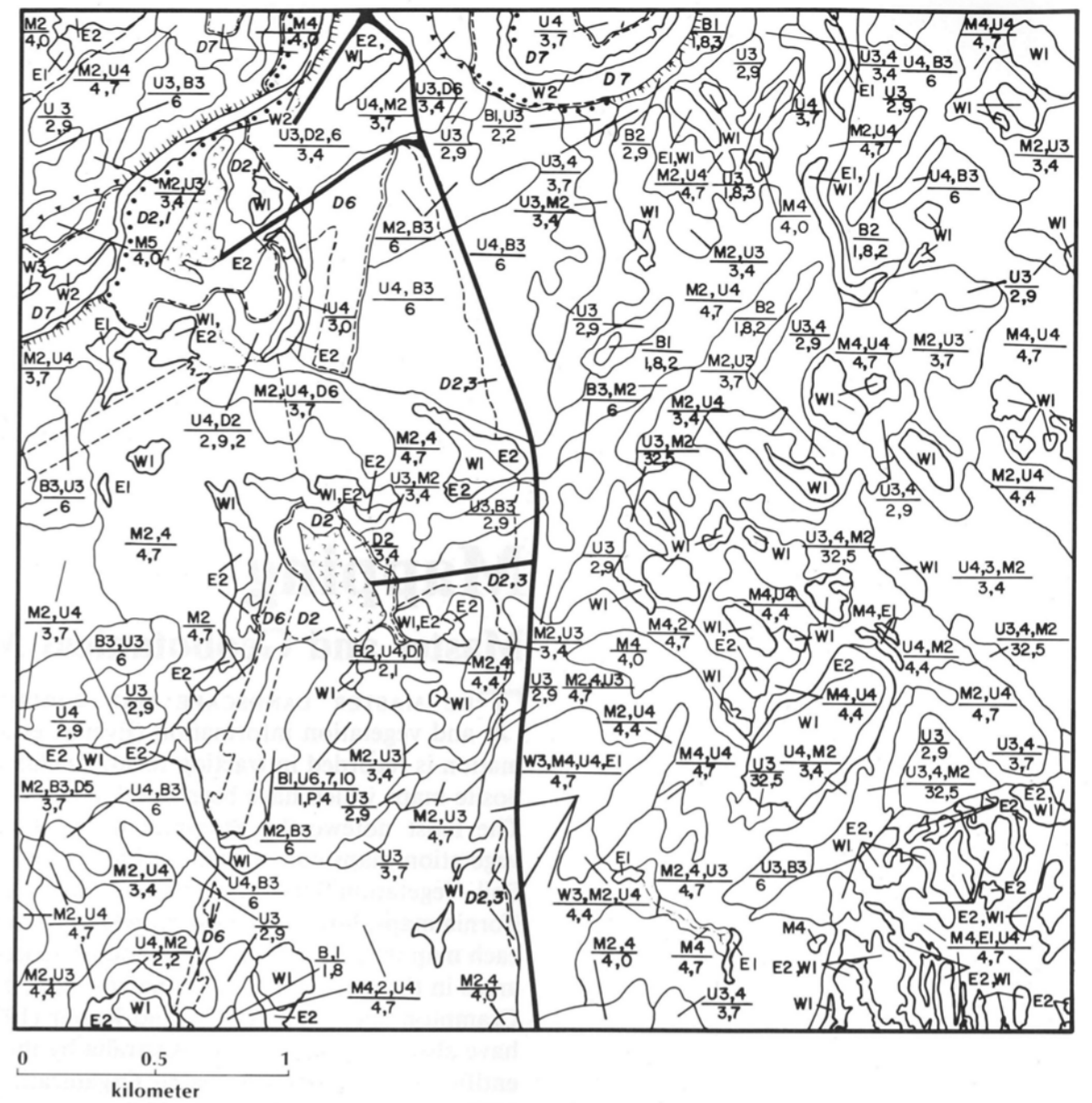
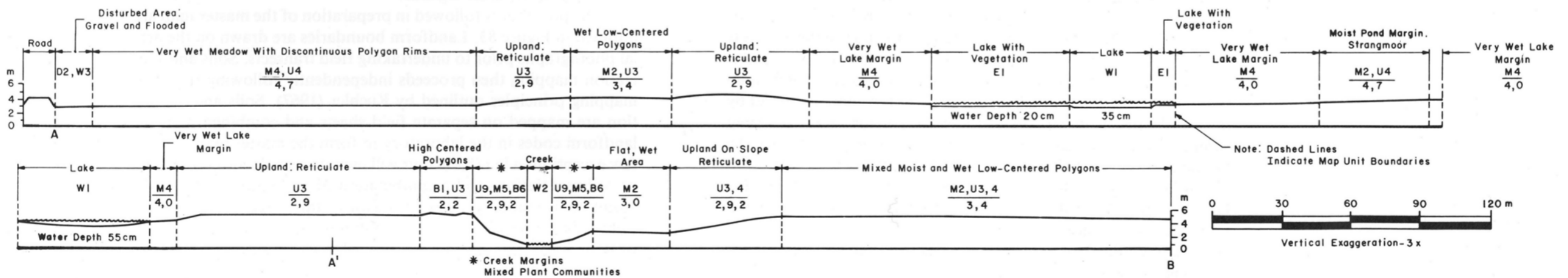
From the master map (Fig. 86) separate vegetation, soils or landform maps (*geobotanical maps*) may be produced by selectively coloring according to appropriate parts of the codes (Fig. 87-89). Each part of the master map code also contains a great deal of specific information that can be used for constructing special purpose maps.



**Figure 84. Terrain transect near Drill Site 2.** Above: Vertical aerial view of entire transect. The transect starts in a drained lake basin with discontinuous polygon rims (A), crosses a slightly elevated interlake area, a small partially drained lake, a low lake margin, another small lake, a reticulate-patterned upland, a few high-centered polygons, the Little Putuligayuk River, and ends in a group of low-centered polygons (B). Below: Oblique view of the upper right (southern) end of the transect (A'-B).



**Figure 85. Cross section of the terrain transect shown in Figure 84.** Appropriate vegetation, soil, and landform codes are below abbreviated landform descriptions. Refer to Figure A2 for explanation of the alphanumeric codes.



**Figure 86. Master map of approximately 3.6 km<sup>2</sup>** (see Fig. 2, Area D). It was developed according to the procedure outlined in the preceding text and serves as the base for the geobotanical maps on the facing page and the special purpose maps which follow. Refer to Figure A2 for explanation of the alphanumeric codes.



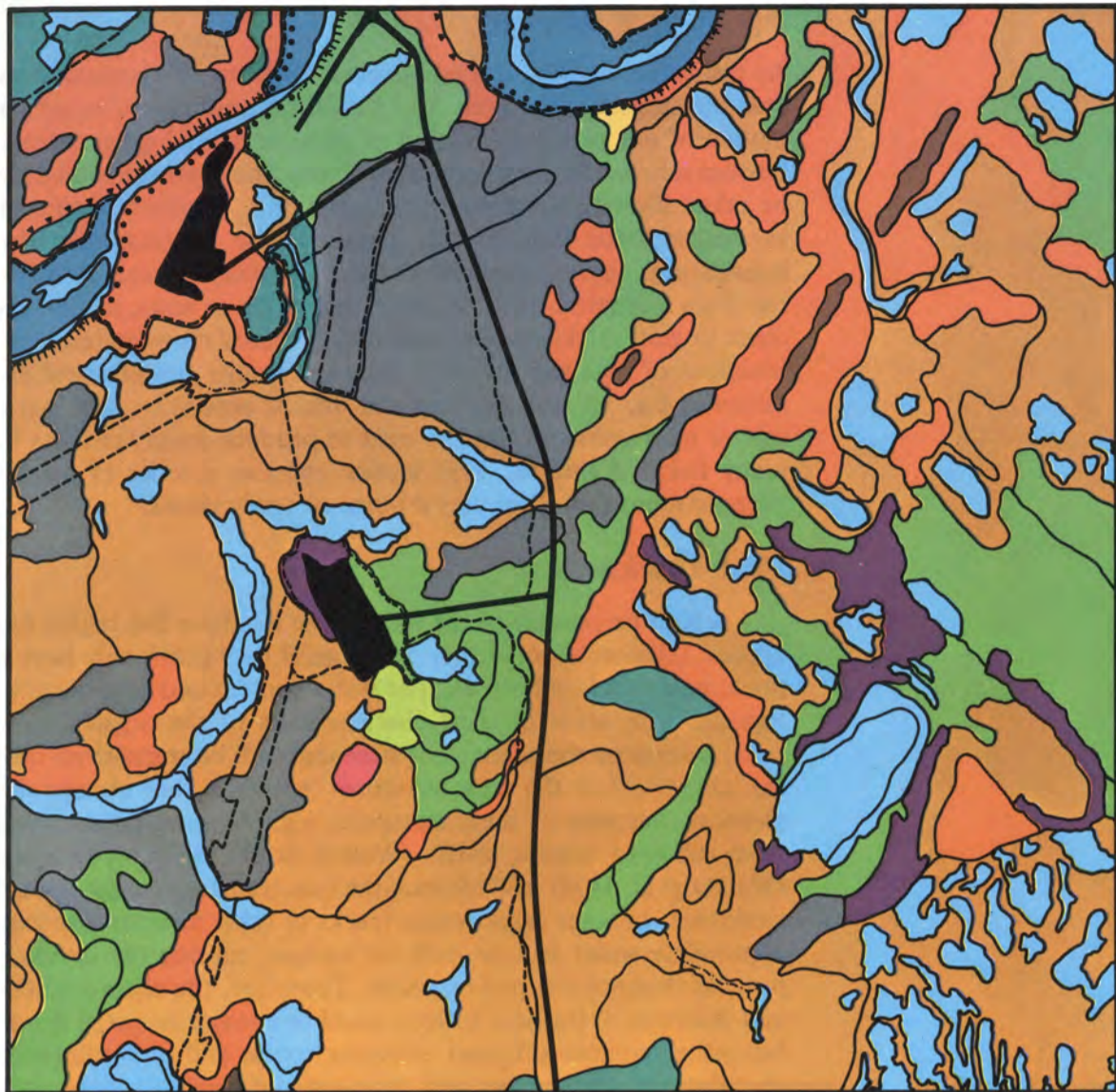


Figure 87. Landform map of area shown in Figure 86, derived from the second digit in the denominator of the master map code.

- High-centered polygons, > 0.5 m relief contrast
- High-centered polygons, ≤ 0.5 m relief contrast
- Low-centered polygons, ≤ 0.5 m relief contrast
- Mixed high- and low-centered polygons
- Frost-boil terrain
- Strangmoor and/or discontinuous polygon rims
- Hummocky terrain
- Reticulate-patterned ground
- Non-patterned ground
- Pingo
- Alluvium
- Water

- Dry tundra
- Pingo vegetation complex
- Frost boil vegetation complex
- Moist tundra
- Moist tundra vegetation complex
- Wet tundra
- Very wet tundra
- Emergent communities (shallow water)
- Emergent communities (deep water)
- Open water
- Ponded areas caused by roads or pads
- Stream bank vegetation complex
- Disturbed areas

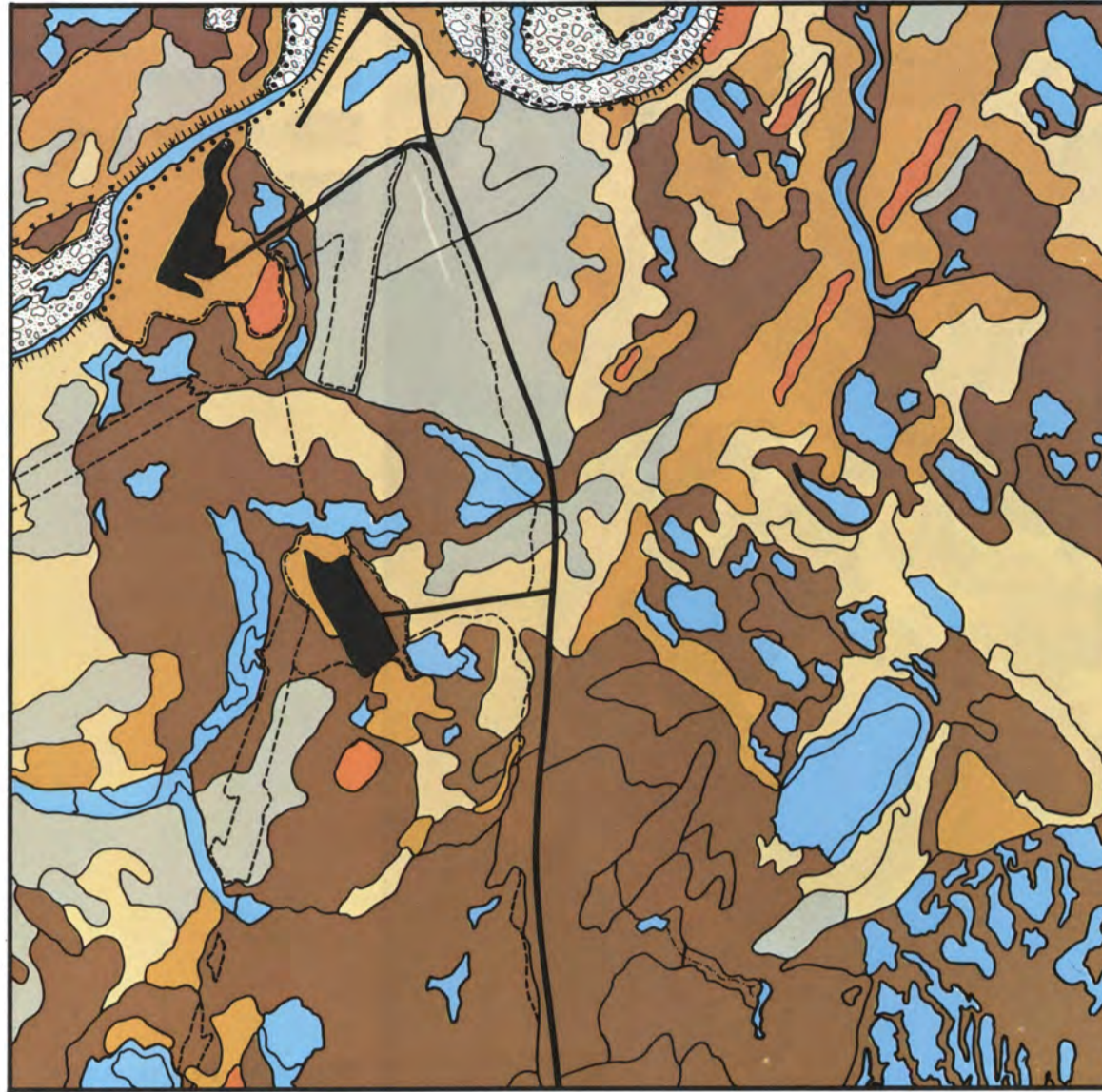


Figure 88. Soils map of area shown in Figure 86, derived from the first digit in the denominator of the master map code.

- Pergelic Cryoboroll
- Pergelic Cryaquoll
- Pergelic Ruptic-Aqueptic Cryaquoll
- Histic Pergelic Cryaquept-Pergelic Cryohemist Complex
- Histic Pergelic Cryaquept-Pergelic Cryofibril Complex
- Pergelic Cryorthent
- Water



Figure 89. Vegetation map of area shown in Figure 86, derived from the numerator of the master map code. See Appendix Figure A5 for expanded legend.



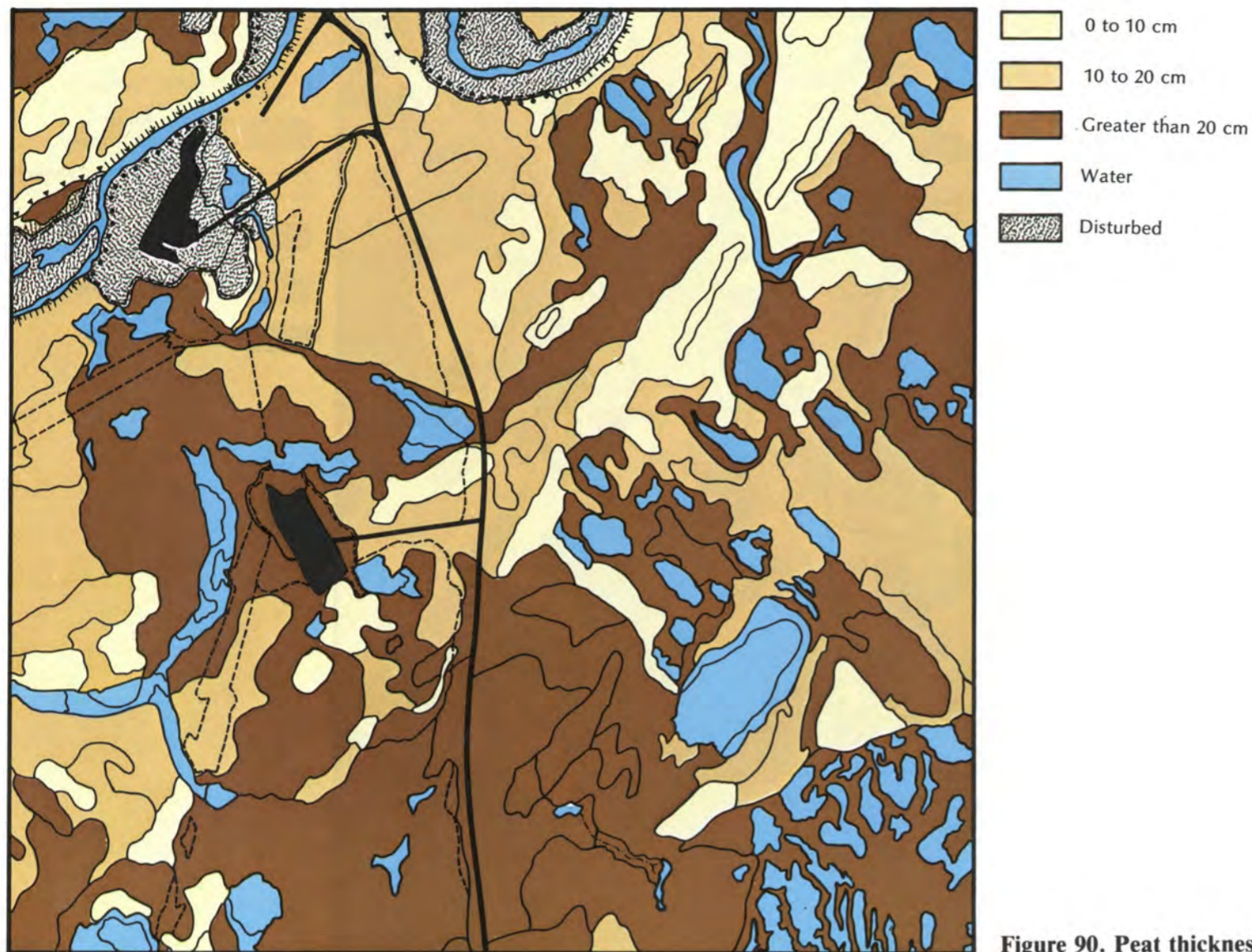


Figure 90. Peat thickness.

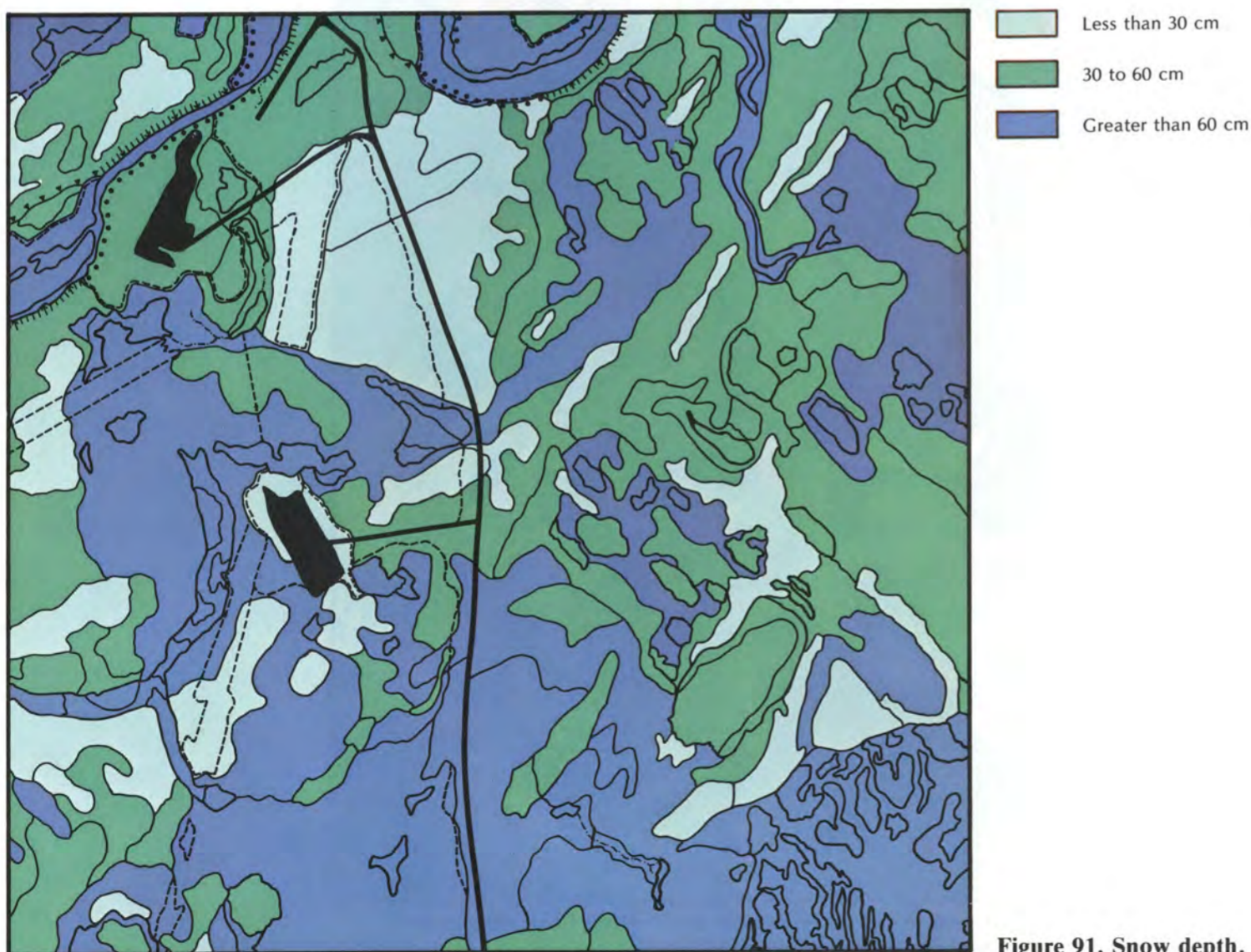


Figure 91. Snow depth.

## Special Purpose Maps

As the name implies, special purpose maps can be generated to deal with specific questions. The special purpose map is based on the use of one or a combination of physical or biological characteristics inherent in the master map codes. The characteristics may be taken directly from the map legend, e.g. landform, soil and vegetation maps (Fig. 87-89). They may be inferred from the legends, e.g. physiognomic life-forms. They may be taken or inferred from analytical data for either vegetation or soils, e.g. lichen cover or peat thickness. Or maps may be based on weighted combinations of data together with field test results and personal experience, e.g. oil spill sensitivity or vehicle sensitivity. The basic master map units can thus be used to produce maps for users in many fields of interest. This section contains a series of special purpose maps that illustrates a range of applications.

### Peat Thickness

A high percentage of the soils of the Prudhoe Bay region are organic (Histosols), or if they are mineral they commonly have a thick, peaty surface horizon. The water content and bulk density, together with other physical characteristics of the organic horizons, determine the amount of heat that will be transferred into the soil to affect the seasonal thaw. Activities that change the physical character of these materials, e.g. compression resulting from off-road vehicle traffic (Walker et al. 1977) or oil spills (Walker et al. 1978), will increase the heat transfer through the organic mat. In some cases vehicle tracks or other disturbances may accumulate water and/or melt ice wedges, causing the development of thermokarst pits or ponds. Therefore, the characteristics and thickness of the peat horizon could be a major factor in the selection of summer off-road vehicular routes and in contingency planning for containment and clean-up of oil spills.

Three peat thickness categories were used, based on a large number of soil profiles examined throughout the map area. Each of the six soils mapped in the area could be fitted into one or another class. This provides the basic information needed to develop the peat thickness map (Fig. 90).

### Snow Depth

Snow depth maps (Fig. 91) have a number of potential uses. For example, they may be used to assist in predicting snowmelt runoff values in either large or small watersheds, or they may be used as an aid in selecting winter routes for wheeled or off-road vehicles. Such routes should be selected to cross a minimum of area on which a thin snow cover will permit abrasion of the vegetated surface. Snow depth maps can be of value in designating areas within predetermined corridors where thin snow needs to be supplemented, for instance by the placement of snow fences, prior to the construction of snow or ice roads. Another potential use is prediction of the distribution of subnivean animal populations which rely on deep winter snow cover for protection from the extreme cold.

Snow depth maps can be generated rapidly from the master landform maps using landform as the predictive key. For example, in polygonal landform units where low-centered polygons are well developed and the microrelief contrast between rim and center is 0.5 m or more (unit 3 on the master map) the polygon centers quickly fill with snow to the level of the rims. The rims themselves may retain only a thin snow cover, or sporadically none at all. In other areas, where landform units of low microrelief contrast occur and are not elevated with respect to the general level of the region (for example, units 0 and 7 on the master map), snow depths tend to be uniform and are generally thick, approximating the regional April mean snow depth (regarded as the yearly maximum snow depth). However, similar units slightly elevated with respect to the surrounding terrain have thin snow covers, considerably less than the April mean depth.

The snow depth map was developed initially using only the microrelief contrast inherent in the landform units and a general knowledge of the regional April mean snow depth and snowpack characteristics (Benson et al. 1975, Everett, pers. comm.). Detailed snow thickness measurements made in April 1977 verified the correctness of the map.



### Active Layer Thickness

The active layer thickness or thaw depth map (Fig. 92) employs a single characteristic of the region's soils and hence involves only the soil portion of the master map code. A considerable amount of information on the thickness of the active layer was developed in the course of soils and vegetation mapping in the region. Depth of thaw observations from Barrow and Prudhoe Bay indicate that by late June about 50% of the potential seasonal thaw has taken place (Brown 1969, Kelley and Weaver 1969, Bilgin 1975, Walker, in prep.). By the first week in August, 90 to 95% of the potential thaw has occurred. Repeated late summer measurements over the period 1971-78 in the low-centered polygon tundra at the Arctic Gas test site have shown maximum thaw depth variation between any two years to be about 10% (Everett, pers. comm.). Similar results were obtained from Barrow between 1970 and 1974 (25 to 27 cm) (Brown et al., in press a). Thus there is considerable information on which to base the maximum seasonal (August) active layer thickness map. Extensive field checking of a portion of the map substantiates the thaw depth categories as shown.

Similar maps can be made depicting June or July thaw depth based on knowledge of the rates of thaw progression. Extrapolation beyond the Prudhoe Bay region would require additional thaw measurements in order to account for the regional climatic gradient.

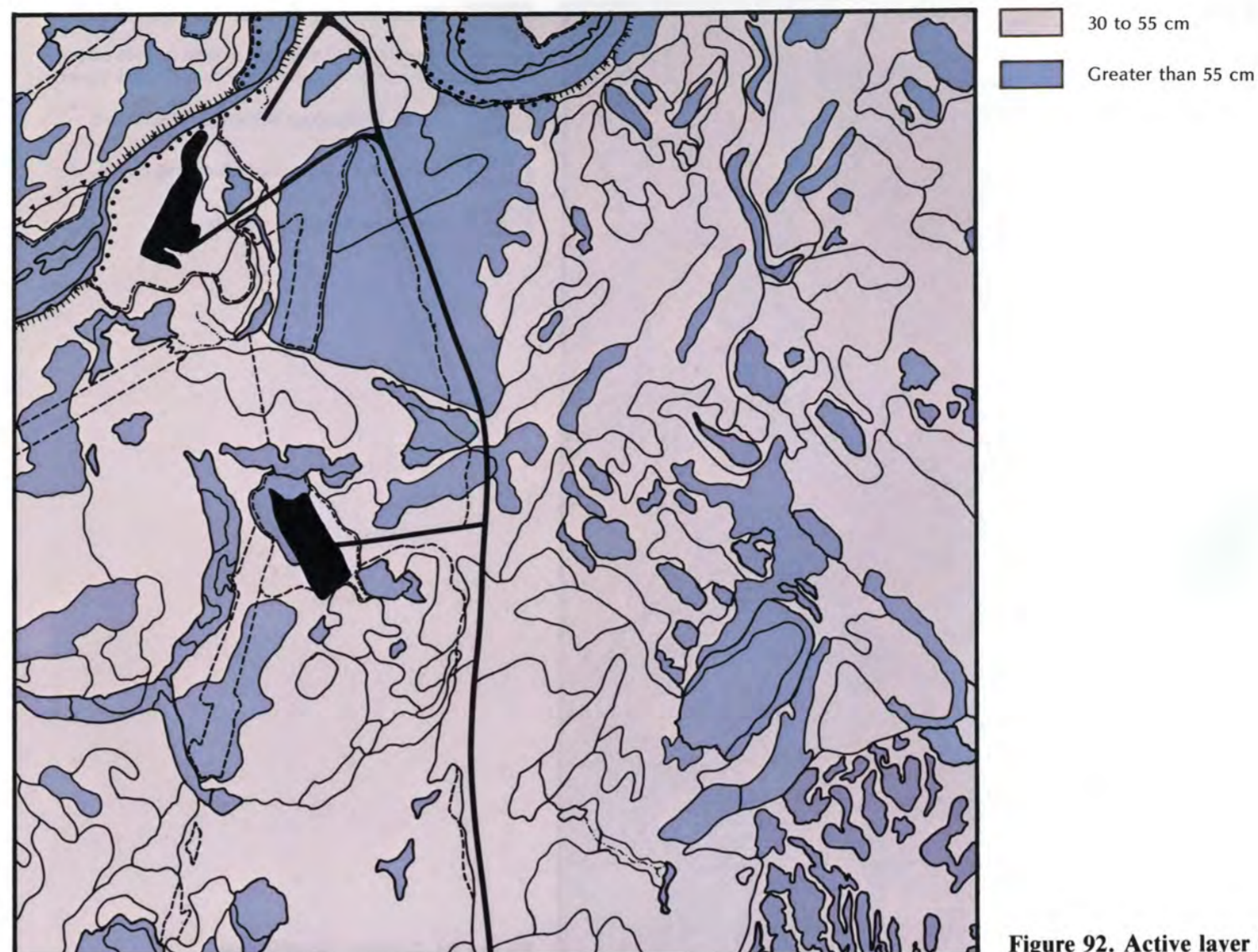


Figure 92. Active layer thickness.

### Plant Growth-Forms

In some instances a vegetation map containing detailed species information may be unnecessary, and a simplified version could be more satisfactory. In this atlas the principal unit of vegetation mapping, the stand type, is based primarily on species composition. But the actual map units are necessarily simplified and based on either vegetation physiognomy (e.g. upland tundra and barren tundra) or specific landform units (e.g. frost boil complex, pingo complex and stream complex). Another approach is to define units purely on the basis of dominant plant growth-forms (Fig. 93). The use of growth-forms in vegetation description and mapping is traditional (Raunkiaer 1934, DuRietz 1931, Ellenberg and Müller-Dombois 1966, Küchler 1949, 1967). The categories employed for this map have been used extensively at other Alaskan arctic study sites (Webber 1978). Such a map is valuable for habitat studies and can be an aid in contingency planning when it is known that certain growth-form types are more susceptible than others to oil pollution (see *Oil Spill Sensitivity*) or air pollution (next example).

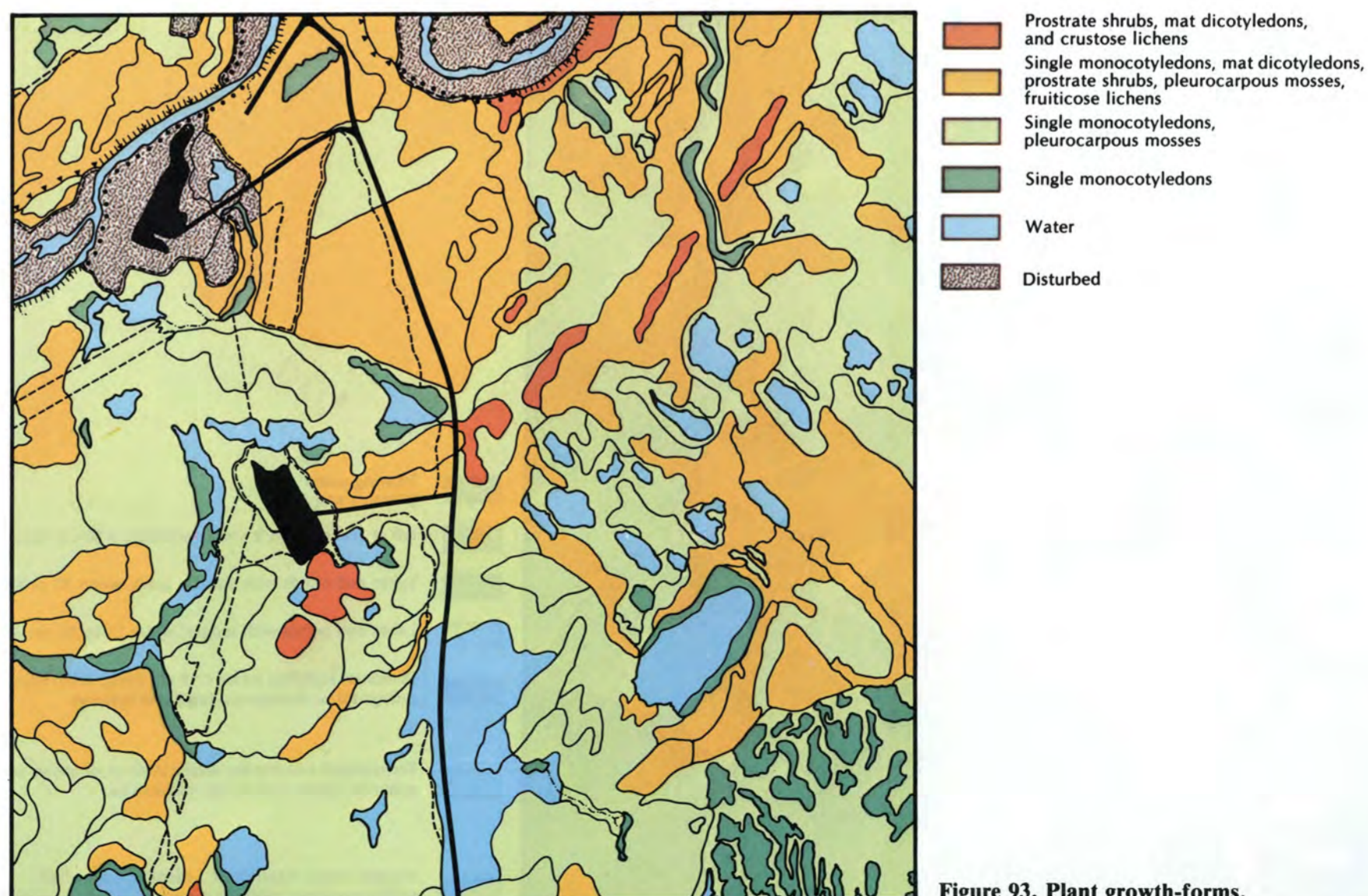


Figure 93. Plant growth-forms.



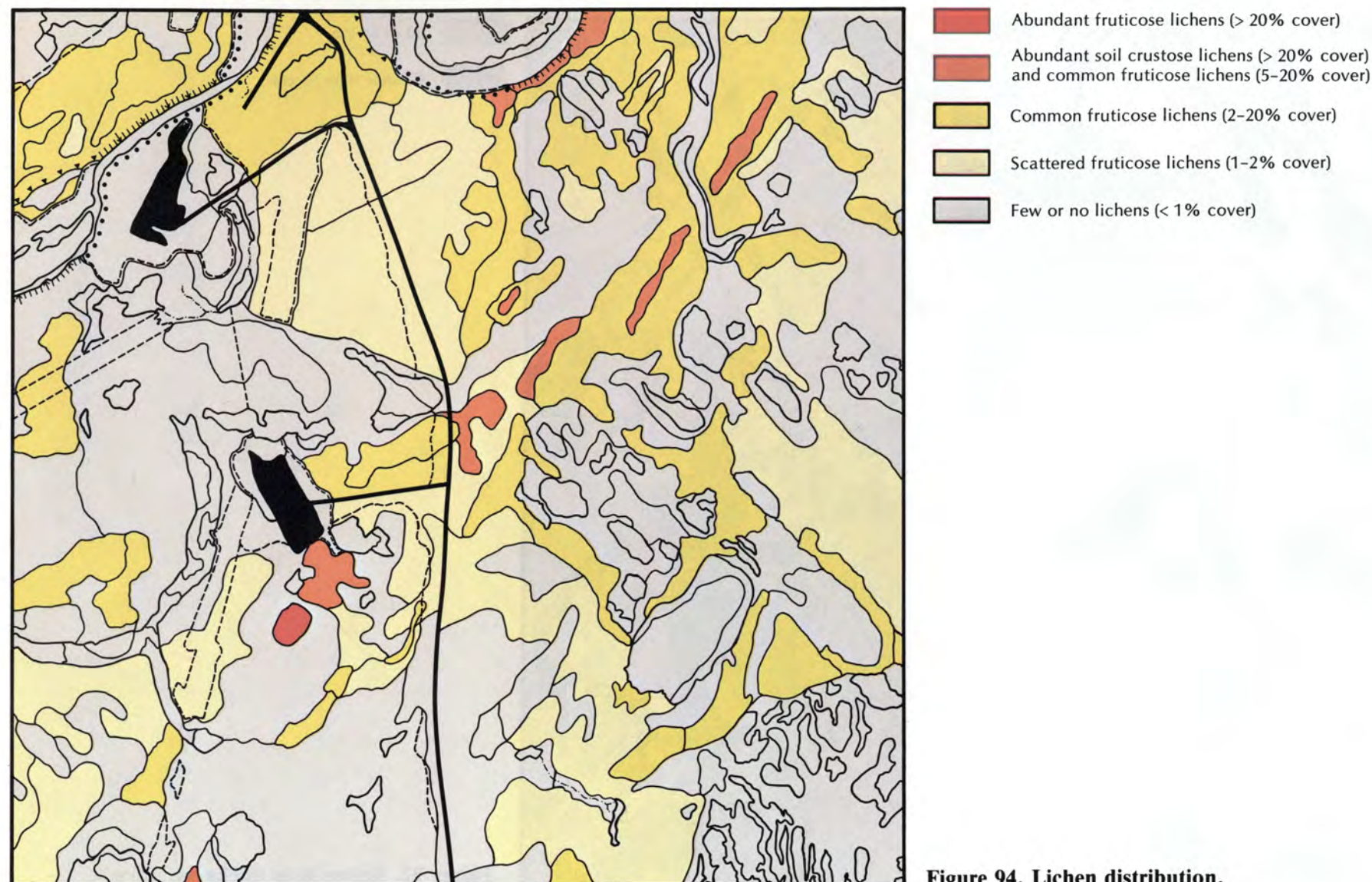


Figure 94. Lichen distribution.

### Lichen Distribution

Maps of the distribution of lichens (Fig. 94) or any other plant can be generated based on field observations and extensive species composition data from the various vegetation stand types (Walker, in prep.).

Lichens have been shown to be particularly sensitive indicators of industrial pollutants (Gilbert 1973, Ferry et al. 1973). Maps of the current distribution and composition of lichen-rich communities in the region may prove to be a valuable reference in future years as industrialization on the coastal plain increases. Pollutants from such sources as flaring natural gas and road dust have significant effects on growth and metabolism in lichens and could lead to their reduction or elimination in some areas. Many pollutants, such as sulfur, tend to accumulate in lichen tissues, and the periodic monitoring of lichen communities can be one approach to measuring the severity of the local air pollution (Stefan and Rudolph 1979). Maps like these can be used to locate lichen-rich areas in which to study the effects of such environmental variables as wind patterns and temperature and to establish air monitoring stations. Conversely they can be used to help position flaring operations away from lichen-rich areas.



Figure 95. Water and wet terrain.

### Water and Wet Terrain

Maps of different types of surface water conditions and wet terrain may be developed using characteristics of soils, vegetation or landforms, singly or in combination. In Figure 95 the August water table position within groups of map units was used to define wet terrain categories. This particular combination of soil-vegetation-landform units is especially applicable in the identification of wildlife habitat. Other wetland classifications, e.g. Bergman et al. (1977), could also be used as a basis for deriving such a map from the master map.

<span style="color: darkblue;">■</span> Flowing water (streams and rivers)	Map code W2
<span style="color: blue;">■</span> Lakes and ponds with no vegetation; > 50 cm deep	Map code W1
<span style="color: teal;">■</span> Lakes and ponds with aquatic grass; water 30 to 100 cm deep	Vegetation: E2
<span style="color: lightblue;">■</span> Lakes and ponds with sedges; water 15 to 30 cm deep	Vegetation: E1
<span style="color: green;">■</span> Perennial standing water < 15 cm deep; often with polygonal or strangmoor landform features	Vegetation: M4 Soil: 4 Landforms: 0, 4, 7
<span style="color: lightgreen;">■</span> Transitional wet terrain; water table at or above surface early in summer, below surface by mid-summer	Vegetation: B1, B2, U2 U3, U4 and others Soils: 1, 2, 6 Landforms: 2, 5, 6, 8, 9, F
<span style="color: tan;">■</span> Upland areas; water table absent or coincident with permafrost table all summer	Vegetation: M2 Soil: 3 Landforms: 3, 4, 6, 7



## Breeding Bird Density

This example uses the vegetation codes in reference to utilization by birds. During early summer large numbers of breeding birds (Fig. 96) occupy the Prudhoe Bay region. They are an important consideration, especially for activities such as travel by off-road vehicles. Myers and Pitelka (pers. comm.) have studied densities of breeding birds along many transects near Prudhoe Bay.

The birds with the highest population densities are the semipalmated sandpiper (*Calidris pusilla*), red phalarope (*Phalaropus fulicarius*), Lapland longspur (*Calcarius lapponicus*), and dunlin (*Calidris alpina*) (Norton et al. 1975). Waterfowl, i.e. ducks, geese, gulls, terns and loons, are not included in the density figures, but these larger birds are generally so sparsely distributed that they are not likely to affect the figures. Table 7 and Figure 97 show average densities on the various vegetation types during the third week in June. This example illustrates an application of the master map that relates the user's data to the basic master map units. Other maps of this type that could easily be constructed include habitat utilization by caribou, ground squirrels, foxes and lemmings.

Table 7. Density of breeding birds on the Prudhoe Bay tundra during the third week in June.

Habitat	Number of birds/ha	Density class
Frost boil vegetation complex	0.9	0-2
Moist tundra	1.2	
Moist tundra complex	1.7	
Moist tundra pond or lake margin	1.8	
Wet tundra	2.9	2-4
Pingo vegetation complex	3.9	
Stream vegetation complex	3.9	
Very wet tundra	4.2	4-6
Mixed ponds and polygons	5.7	



Figure 96. Nesting female pectoral sandpiper (*Calidris melanotos*) with brooding chicks. Photograph by P. Myers.

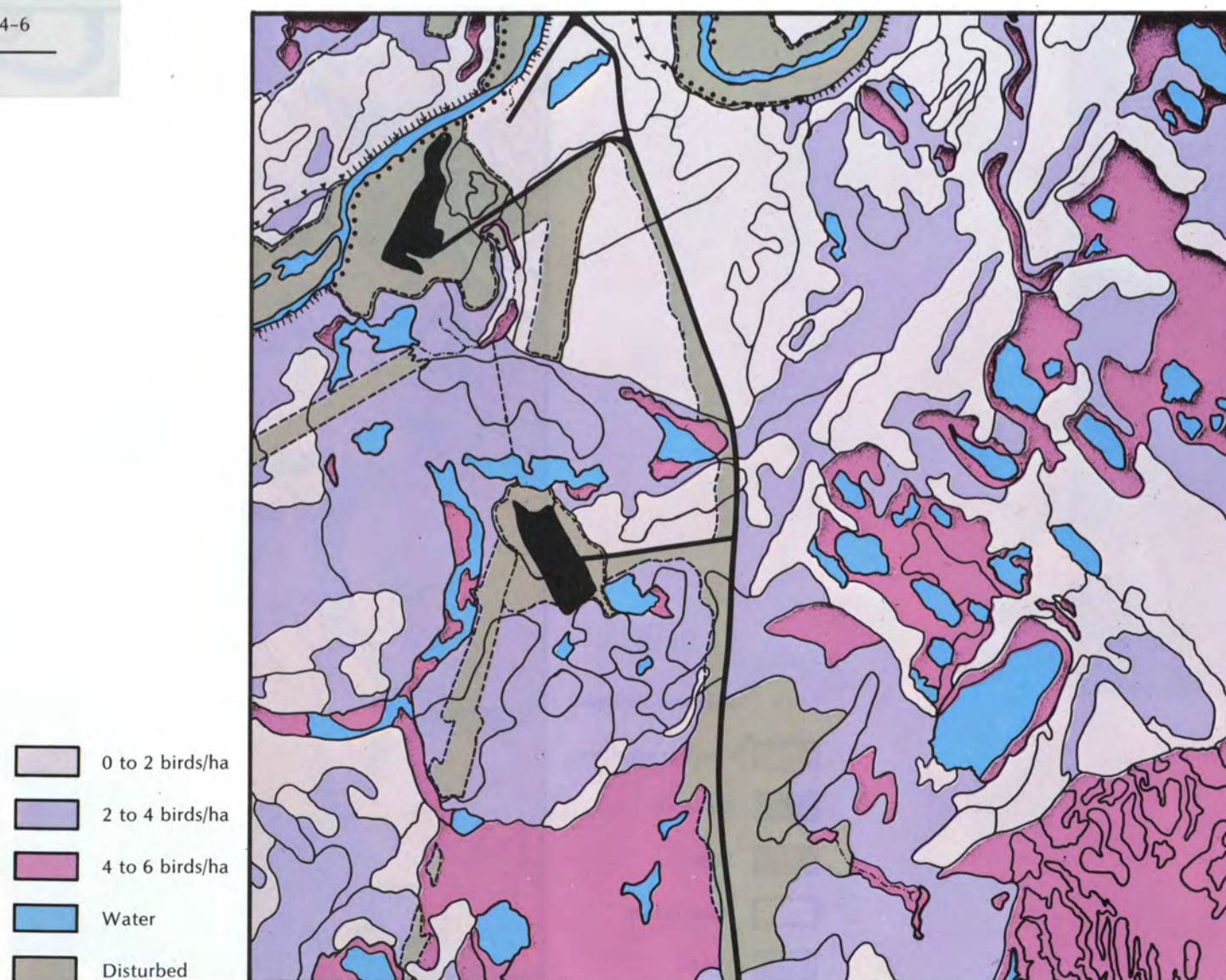


Figure 97. Breeding bird density.



## Oil Spill Sensitivity

Detailed landscape sensitivity maps based on experiments are needed to assess potential impacts in tundra areas. In Canada small scale sensitivity maps have been made for the Queen Elizabeth Islands (Babb and Bliss 1974) and the Mackenzie corridor (Van Eyk and Zoltai 1975). An assessment of sensitivity to a particular impact such as oil spills sometimes can be based on rather simple experiments involving the use of the master map.

The sensitivity of a landscape to crude oil spills depends on many factors such as time of year, type of spill (e.g. point spill or spray spill), volume, water content of the soil and the species composition of the affected area. One approach in preparing a sensitivity map is to first determine the plant species that have the ability to recover from crude oil spills, i.e. resilient species, and then rate the plant community sensitivity according to the relative cover of resilient species. In the Prudhoe Bay region, experiments (Fig. 98) have shown that two groups of plants, the sedges and the willows, show substantial recovery following spills of moderate intensity (Walker et al. 1978). Fortunately, these are major components of moist and wet vegetation communities. They are, however, relatively unimportant on dry sites. *Dryas integrifolia*, the principal component of dry communities, is particularly susceptible to oil toxicity. The relative cover of resilient plant species in the various communities is the basis for the sensitivity indices (Table 8). From these values a sensitivity map (Fig. 99) can be made. Similar experiments with other pollutants, such as road dust or toxic chemicals, would be of value for locating roads and industrial complexes, and as aids in contingency planning.

**Table 8. Indices of sensitivity to oil spills of 13 major Prudhoe Bay stand types.**  $C_t$  = total percentage cover of key plants;  $C_R$  = cover of plant taxa that exhibit good recovery; SI (sensitivity index) =  $C_R/C_t$ .

Master map code	$C_t$	$C_R$	SI	Recovery potential
E2	24	24	1.00	Excellent
E1	23	22	0.96	Excellent
M4	43	41	0.95	Excellent*
M5	57	40	0.70	Very good
U7	111	41	0.37	Moderate
M1	47	16	0.34	Moderate
M2	72	17	0.24	Moderate
U4	84	20	0.24	Moderate
U3	97	20	0.21	Moderate
U6	67	10	0.15	Poor
B3	38	4	0.11	Poor
B2	64	6	0.09	Poor
B1	43	4	0.09	Poor

\*If there is enough water to cover moss carpet.



**Figure 98. Experimental plot to determine terrain sensitivity to oil spills.** Several similar plots were placed in the common map units.



**Figure 99. Oil spill recovery potential.**



### Off-Road Vehicle Sensitivity

This map relies on information from several parts of the master map code. Rolligons (Fig. 100) are currently the only wheeled vehicles permitted on the tundra during the summer months. The impact of these vehicles varies considerably, depending on a number of factors including time of year, vegetation type, soil moisture, and surface roughness. In 1976 a test was conducted in the vicinity of the Putuligayuk River (Walker et al. 1977, Everett et al. 1978). The test was conducted in early summer across several examples of all the common Prudhoe Bay vegetation, soils and landform units. Each vegetation-microsite combination was rated for impact sensitivity according to the rating scheme in Table 9. The various vegetation-microsite combinations were then ranked according to the total scores they received, and divided into three categories of relative sensitivity (Table 10). The map (Fig. 101) was constructed based on the amount of each sensitivity category in the various map units. Recovery from impact was recorded at the test site for two years following the initial test to help verify the map and the sensitivity rating system.



**Figure 100. Off-road vehicle experiment.** Left: Rolligon test vehicle weighing 11,340 kg (25,000 lb) with 0.21 to 0.35 kg/cm<sup>2</sup> (3 to 5 psi) ground pressure. Center: impact to an upland area, code U3/2,9. Right: impact to a lowland area, code M4,U3/4,7.

**Table 9. Rating scheme for evaluating Rolligon impact.** Each impact category is rated according to observed impact (numerator) and predicted impact observable in one year (denominator).

**Table 10. Relative sensitivity of various vegetation-microsite categories to a single Rolligon pass, Prudhoe Bay, Alaska.**

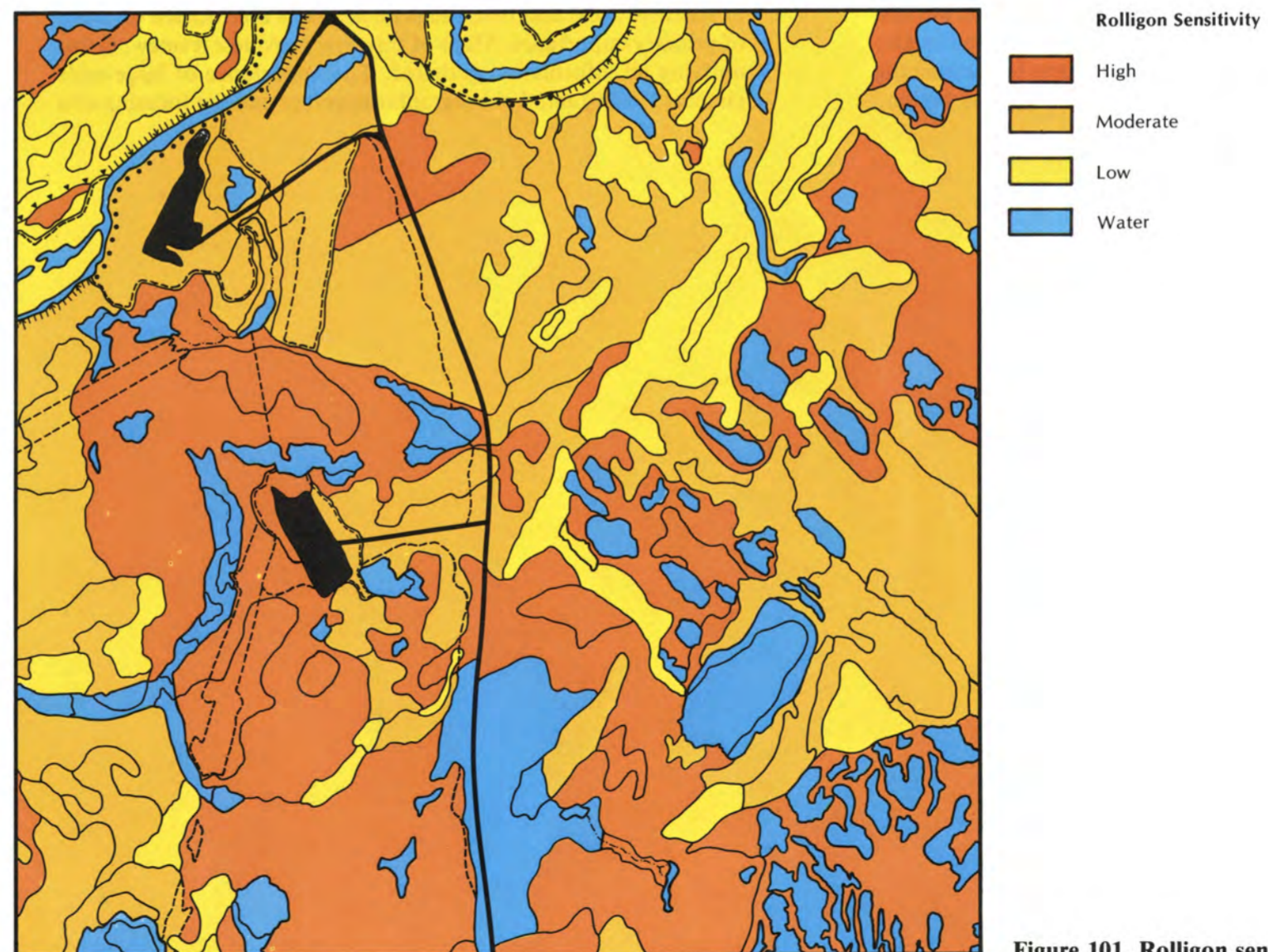
**Impact Categories**

1. *Compression to tundra surface*—refers to the permanent bending and compressing of live and standing dead vegetation to the tundra surface so that it becomes flattened and oriented to the direction of travel.
  - 0—no observable compression of vegetation to tundra surface.
  - 1—slight compression of vegetation (1 to 10% of plants affected).
  - 2—moderate compression of vegetation (11 to 50% of plants affected).
  - 3—severe compression of vegetation (more than 50% of plants affected).
2. *Compression below water surface*—refers to the compression of sedges and moss hummocks below a water surface.
  - 0—no water or no observable compression of vegetation below water surface.
  - 1—slight compression of vegetation below water surface (1 to 10% of plants affected).
  - 2—moderate compression of vegetation below water surface (11 to 50% of plants affected).
  - 3—severe compression of vegetation below water surface (more than 50% of plants affected).
3. *Displacement*—refers to several categories of disturbance, a) tussocks of moss or *Eriophorum vaginatum* moved or overturned, b) displacement of wet mosses such as *Scorpidium scorpioides* and *Drepanocladus brevifolius* by splashing action, c) exposure of bare soil by removal of vegetation mat.
  - 0—no displacement of vegetation.
  - 1—some displacement of vegetation (1 to 10% of plants affected).
  - 2—moderate displacement of vegetation (11 to 50% of plants affected).
  - 3—severe displacement of vegetation (more than 50% of plants affected).
4. *Breakage*—refers to breakage of plant stems or flowering stalks.
  - 0—no breakage observed.
  - 1—some breakage observed (1 to 10% of plants affected).
  - 2—moderate breakage observed (11 to 50% of plants affected).
  - 3—severe breakage observed (more than 50% of plants affected).
5. *Deposition*—refers to accumulation of mud and moss to sides of track.
  - 0—no mud or moss accumulation at sides of track.
  - 1—few shallow patches of mud or moss.
  - 2—many shallow patches of mud or moss.
  - 3—continuous thick deposit of mud or moss.

**Overall Impact**

- Observed*  
 Rated subjectively on the basis of observed impact scores (numerators) in the five categories above:  
 0—no observable impact.  
 1—slight impact.  
 2—moderate impact.  
 3—severe impact.
- Predicted*  
 Rated subjectively on the basis of predicted impact scores (denominators) in the five categories above. The scale is the same as for overall observed impact.

Low sensitivity	Moderate sensitivity	High sensitivity
U3 Trough	U3 Rim	B3 Frost boil
B2 Ridge	M2 Low center or flat area	M4 Low center or flat area
U3 Low center	U4 Rim or hummock	M4 Trough
B1 Ridge or high center		
U4 Low center		
U4 Upland		
U4 Trough		



**Figure 101. Rolligon sensitivity.**



## Summary

THE MAPPING PROGRAM IN THE PRUDHOE BAY region has yielded an abundance of information and several techniques for depicting the data. The development of the master landscape maps and the further demonstration of the intimate relationship of the landforms, soils and vegetation in Arctic Coastal Plain ecosystems have practical importance for land-use planning and management in the Arctic. Detailed master landscape maps of a 145-km<sup>2</sup> area were prepared and an additional 5 km<sup>2</sup> of vegetation mapped in the sand dunes and on the coast.

The soils and vegetation studies conducted in conjunction with the mapping programs yielded a large data base for a previously unstudied type of Alaskan arctic tundra, i.e. an alkaline peaty coastal tundra. Forty-two vegetation communities were described; many of these had not been previously reported in Alaska. Thirteen major landform types were characterized, and eight soils were described. One of these, the Pergelic Cryoboroll, represents a previously undescribed soil of calcium-rich portions of the coastal plain.

The climatic studies characterized the temperature gradient inland from the Beaufort Sea coast and demonstrated the regional importance of the gradient to vegetation. Future studies along the temperature gradient will undoubtedly yield much valuable information regarding growth response to variations in summer warmth of individual taxa and entire plant communities. The studies also demonstrated the important role of wind and loess in maintaining the wet alkaline tundra environment of the Prudhoe Bay region.

Field trials conducted in conjunction with the mapping program yielded approaches to solving some of the potential environmental problems associated with oilfield development. In particular, maps of summer off-road vehicle sensitivity and oil spill sensitivity were produced for small areas, and can be expanded as required. Special purpose maps of bird densities during breeding, lichen distribution, plant growth-forms, and water and wet terrain were prepared, as were other maps useful for engineering purposes, including peat thickness, snow depth, and active layer thickness.

Many applications can be foreseen for the maps within the Prudhoe Bay region, and they should aid in future land-use decisions within this and other oilfields. One example is the extension of the mapping approach to the classification and delineation of, and potential impacts on, wetlands. The mapping methods also lend themselves well to computerized systems for producing detailed derived maps.

The master landscape map approach should prove useful for other future industrial and community developments and also areas of intensive scientific research. Mapping programs such as this should be encouraged at least two years prior to development. This would ensure that development proceeds with full knowledge of sensitive areas and that scientific activities are focused on areas of primary importance. Maps of this type provide a framework for unifying all information gathered. The importance of large-scale (at least 1:6000) aerial photographic coverage and the focusing of a

large portion of a program on thorough ground-truth coverage cannot be overemphasized. True color or color-infrared photography greatly aids air photographic interpretation. The use of satellite imagery to produce vegetation maps of large regions of the Alaskan Arctic will benefit from detailed maps such as those presented in this atlas.

The Prudhoe Bay road system offers access to several pingos and tundra streams that should be conserved to the extent possible. Included are the Little Putuligayuk River, the Putuligayuk River south of the main spine road, and several drainages associated with the Kuparuk River. Of special interest on the Kuparuk River terraces is the plant *Thlaspi arcticum*, known from only one other site in Alaska (Murray and Murray 1975). The pingos within the present road net most worthy of preservation are Michelle, Angel, the IBP Pingo, and two pingos between Pad F and Frontier Camp.

The changes caused by a major industrial development in what was once a remote wilderness are of obvious historical interest. Analysis of the large quantity of data gathered during our field investigations will continue (Walker, in prep.). It will expand further the knowledge of the Prudhoe Bay region and provide a valuable reference point for future scientific work that is taking place in the area and westward in the Kuparuk field, and which is likely to take place along the transportation corridor to the south. The large data base plus the easy access to a variety of tundra habitats should ensure that the area will attract investigators for many years to come.



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## Appendix A: Master Maps

The four master maps (Fig. A2 and A6-A8) cover 145 km<sup>2</sup> (22%) of the coastal tundra within the Prudhoe Bay oilfield as it was in 1973. The size of the individual maps and their position within the field was governed by available photography and a desire to include as much of the field and facilities on either side of the main road as possible at a meaningful mapping scale.

The master maps were constructed according to procedures presented on pages 35 and 36. Figures 87-89 show that it is possible to view separately the spatial distribution of a single map component, e.g. landforms, soils or vegetation. Using the master map and the appropriate code symbols such geobotanical maps can be produced quickly with a set of colored felt pens. Figures A3, A4 and A5 are such colored geobotanical maps developed from the master map for area 3 (Fig. A2). This area was chosen because it included the vast majority of landform, soils and vegetation units within the oilfield and a wide variety of oilfield facilities. The area also included the map and test sites for the special purpose maps as well as the original IBP strip map (Fig. 2) (Everett 1975, Webber and Walker 1975). Printing costs prohibited the production of such single component maps for the other three areas.

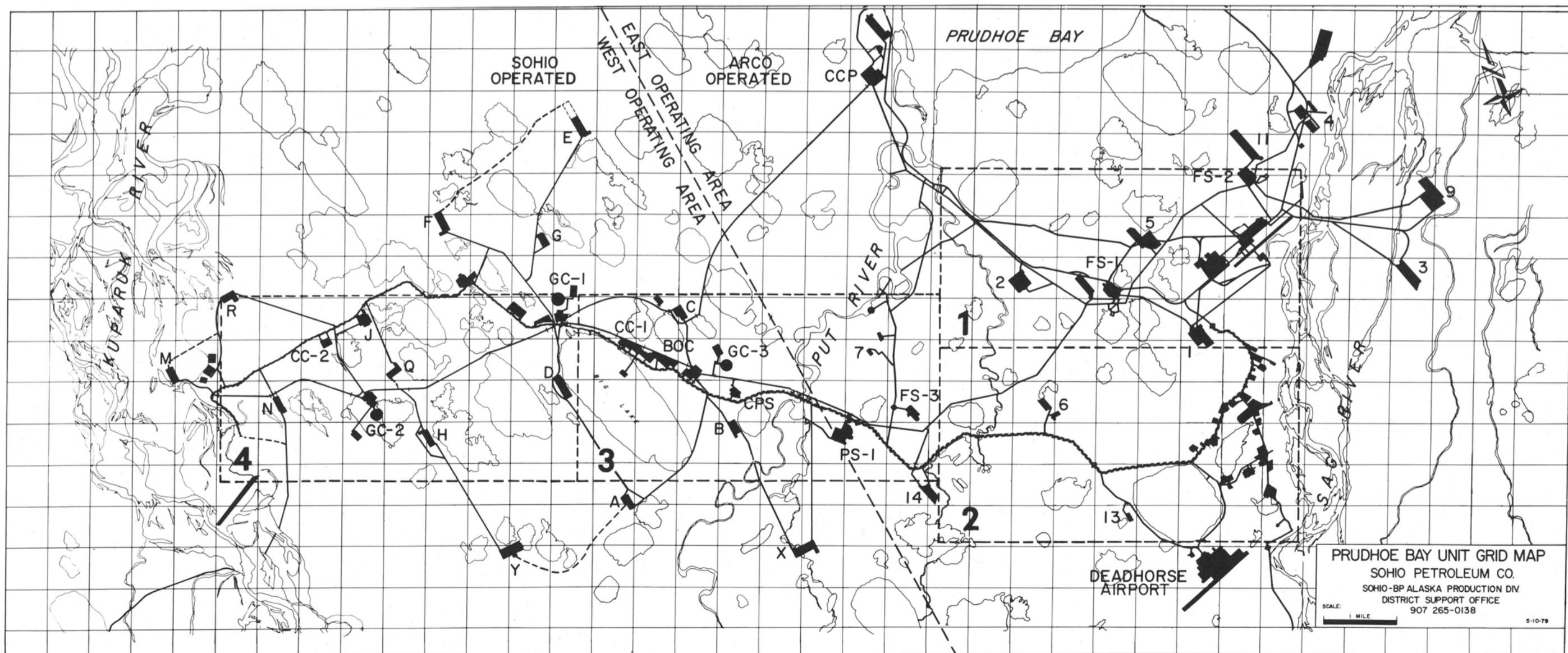
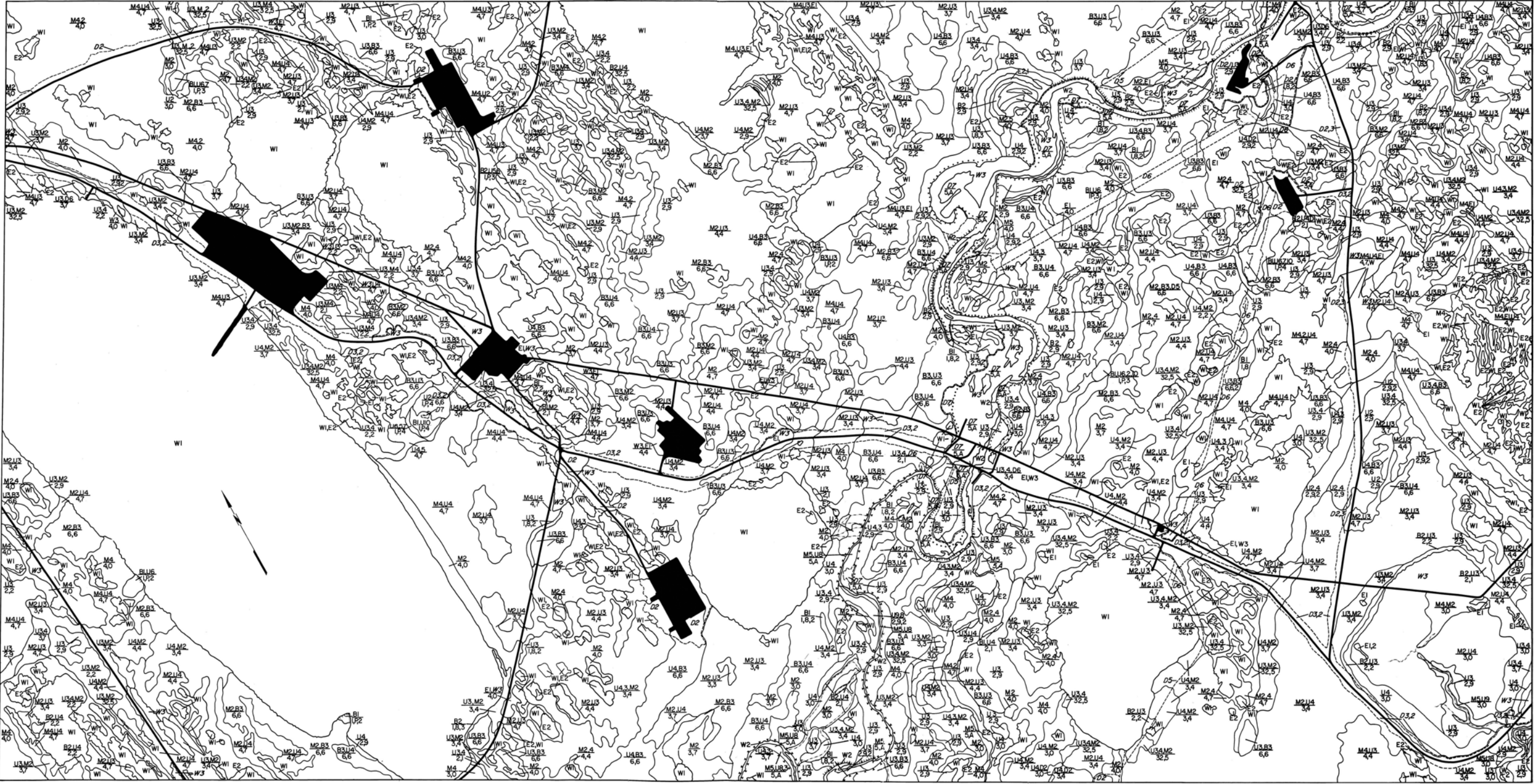


Figure A1. Index map showing areas covered by the maps in Appendix A. The road network and drill sites are shown as of 1979.





0 250 500 750 1000  
meters



Figure A2

# Master Map: Prudhoe Bay Region, Alaska, Area 3

by K.R. Everett, D.A. Walker, and P.J. Webber

Information is coded in fraction form:  $\frac{\text{Vegetation Stand Type(s)}}{\text{Soil Unit, Landform Unit, Slope}}$

## Numerator: Vegetation

Stand type no.	Community	Characteristic microsite
<b>B—Dry sites</b>		
B1	DRY <i>Dryas integrifolia</i> , <i>Oxytropis nigrescens</i> , <i>Lecanora epibryon</i> PROSTRATE SCRUB	Pingos, ridges, high polygon centers
B2	DRY <i>Dryas integrifolia</i> , <i>Saxifraga oppositifolia</i> , <i>Lecanora epibryon</i> PROSTRATE SCRUB	Similar to Stand Type B1, but less exposed to wind
B3	DRY <i>Saxifraga oppositifolia</i> , <i>Juncus biglumis</i> FROST-BOIL BARREN	Frost boils
B4	DRY <i>Epilobium latifolium</i> , <i>Artemisia arctica</i> RIVER-BAR BARREN	River gravel bars
B5	DRY <i>Dryas integrifolia</i> , <i>Salix ovalifolia</i> , <i>Artemisia borealis</i> SANDY FLATS BARREN	Sandy river terraces, stabilized sand dunes
B6	DRY <i>Dryas integrifolia</i> , <i>Astragalus alpinus</i> RIVER BAR PROSTRATE SCRUB	River banks
B7	DRY <i>Braya purpurascens</i> , <i>Anemone parviflora</i> , <i>Arctagrostis latifolia</i> SLUMPING RIVER BLUFF COMPLEX	Slumping river bluffs
B14	DRY <i>Dryas integrifolia</i> , <i>Salix reticulata</i> , <i>Cetraria richardsonii</i> SNOW PATCH PROSTRATE SCRUB	Dry, early-thawing snow patch areas with hummocky terrain
G	BARREN GRAVEL	
<b>U—Moist sites</b>		
U1	MOIST <i>Carex aquatilis</i> , <i>Ochrolechia frigida</i> GRAMINOID MEADOW	Polygon rims and aligned hummocks in acidic tundra region
U2	MOIST <i>Eriophorum vaginatum</i> , <i>Dryas integrifolia</i> , <i>Tomenthypnum nitens</i> , <i>Thamnia vermicularis</i> TUSsock GRAMINOID MEADOW	Well-drained upland sites
U3	MOIST <i>Eriophorum angustifolium</i> , <i>Dryas integrifolia</i> , <i>Tomenthypnum nitens</i> , <i>Thamnia vermicularis</i> GRAMINOID MEADOW	Well-drained upland sites, polygon rims, aligned hummocks
U4	MOIST <i>Carex aquatilis</i> , <i>Dryas integrifolia</i> , <i>Salix arctica</i> , <i>Tomenthypnum nitens</i> GRAMINOID MEADOW	Moister upland sites, basins of drier low-centered polygons, polygon rims, aligned hummocks
U6	DRY <i>Dryas integrifolia</i> , <i>Cassiope tetragona</i> SNOW PATCH DWARF SCRUB	Well-drained snow patch areas
U7	MOIST <i>Salix rotundifolia</i> SNOW PATCH PROSTRATE SCRUB	Late-thawing snow patch areas
U8	MOIST <i>Salix lanata</i> , <i>Carex aquatilis</i> STREAM BANK DWARF SCRUB	Stream banks, lake margins
U9	MOIST <i>Dryas integrifolia</i> , <i>Eriophorum angustifolium</i> , <i>Tomenthypnum nitens</i> , <i>Didymodon asperifolius</i> STREAM BANK GRAMINOID MEADOW	Upland stream banks that are swept by the spring flood
U10	MOIST <i>Festuca bafinensis</i> , <i>Papaver macounii</i> GRAMINOID MEADOW	Pingo tops, bird mounds and animal dens

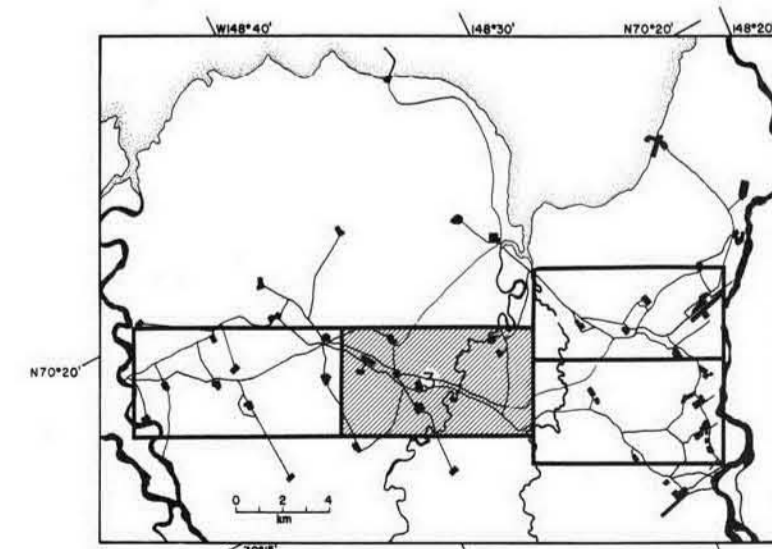
Stand type no.	Community	Characteristic microsite
<b>M—Wet sites</b>		
M1	WET <i>Carex aquatilis</i> , <i>Saxifraga foliolosa</i> GRAMINOID MEADOW	Wet microsities in acidic tundra areas, primarily associated with aligned hummocks.
M2	WET <i>Carex aquatilis</i> , <i>Drepanocladus brevifolius</i> GRAMINOID MEADOW	Wet polygon centers and troughs, lake margins
M3	WET <i>Carex aquatilis</i> , <i>Dupontia fisheri</i> , <i>Calliergon richardsonii</i> GRAMINOID MEADOW	Wet polygon centers in sand dunes region and along Kuparuk River
M4	VERY WET <i>Carex aquatilis</i> , <i>Scorpidium scorpioides</i> GRAMINOID MEADOW	Low wet sites, polygon centers, drained lakes, lake margins
M5	WET <i>Carex aquatilis</i> , <i>Salix rotundifolia</i> STREAM BANK GRAMINOID MEADOW	Moist stream banks
<b>E—Emergent sites</b>		
E1	VERY WET <i>Carex aquatilis</i> GRAMINOID MEADOW	Water to about 30 cm
E2	VERY WET <i>Arctophila fulva</i> GRAMINOID MEADOW	Water to about 100 cm
E3	VERY WET <i>Scorpidium scorpioides</i> AQUATIC MOSS MEADOW	Water to about 100 cm in sand dunes region
<b>W—Open water</b>		
W1	None	Lakes and ponds
W2	None	Streams and rivers
W3	Varies	Flooded areas caused by roads or pads
<b>D—Disturbed sites</b>		
Type of disturbance		
D1	Bare earth with pioneering species, DRY <i>Braya purpurascens</i> , <i>Leptobryum pyriforme</i> , <i>Marchantia polymorpha</i> DISTURBANCE COMPLEX	
D2	Foreign gravel or construction debris	
D3	Dust-covered areas adjacent to roads	
D4	Vehicle tracks—deeply rutted	
D5	Vehicle tracks—not deeply rutted	
D6	Winter road	
D7	Excavated areas primarily in river gravels	
W3	Flooded areas caused by roads or pads	
---	Boundary of disturbance	

## Denominator: Soils, Landforms and Slope

Unit (1st no.)	Soil	Identifying field characteristics
1	Pergelic Cryoboroll	A cold, more or less freely drained soil, underlain by permafrost (Pergelic) with a dark, humus-rich, granular textured surface horizon >18 cm thick
2	Pergelic Cryaquoll	A cold, dark-colored, wet soil, prominently mottled in the lower part of the humus-rich, weakly granular surface horizon
3	Complex of: 1) Histic Pergelic Cryaquept 2) Pergelic Cryohemist 3) Pergelic Cryosaprist	1) A cold, wet, gray mineral soil, commonly mottled, having a surface horizon >25 cm thick, composed of predominantly organic (peaty) material 2) A cold, wet, dark-colored soil consisting of moderately decomposed organic materials to depths >40 cm 3) A cold, wet, dark soil consisting of well-decomposed organic materials to depths >40 cm
32	None	A complex in which Pergelic Cryaquolls (Unit 2) and soils of Unit 3 are in nearly equal amounts
4	Complex of: 1) Histic Pergelic Cryaquept 2) Pergelic Cryofibrist	1) As above 2) A cold, wet, reddish to yellowish soil consisting of little-decomposed fibrous organic materials to depths >40 cm
5	Pergelic Cryorthent	A cold, somewhat freely drained gravelly soil lacking significant horizon development and generally free of organic matter
6	Pergelic-Ruptic-Aqueptic Cryaquoll	The cold soil of frost boil areas in which a Cryaquoll soil (Unit 2) is intimately associated with and interrupted by a cold, wet, gray and mottled mineral soil lacking any significant organic surface horizon—a Pergelic Cryaquept

Unit (2nd no.)	Landform	Code (3rd no.)	Slope range (%)
1	High-centered polygons, center-trough contrast >0.5 m	None	0 to 2
2	High-centered polygons, center-trough contrast ≤0.5 m	2	>2 to 6
3	Low-centered polygons, rim-center contrast >0.5 m	3	>6 to 12
4	Low-centered polygons, rim-center contrast ≤0.5 m	4	>12 to 20
5	Mixed high- and low-centered polygons in an intricate pattern	5	>20
6	Frost boil tundra		
7	Strangmoor and/or large diameter, commonly discontinuous low-centered polygon pattern; little or no microrelief contrast		
8	Hummocky terrain associated with steep slopes		
9	Reticulate patterned ground—slightly convex polygons with hummocky microrelief, hummock-interhummock relief contrast ≤15 cm		
0	Non-patterned ground or with patterned ground occupying <20%		
P	Pingo		
A	Floodplain		
▲▲▲	Steep embankment		
▬▬▬▬▬	Undercut river bank		
●●●●●	Excavated		
----	Stream		

■ Roads and Pads



Location of Area 3

Base map prepared by the Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado. Lake boundaries and areal control from topographic map (1.4 m contour interval) provided by Prudhoe Bay Environmental Subcommittee, Alaska Oil and Gas Association. Interpretation based on 1:6000 black and white aerial photography by Air Photo Tech Inc., 1973.



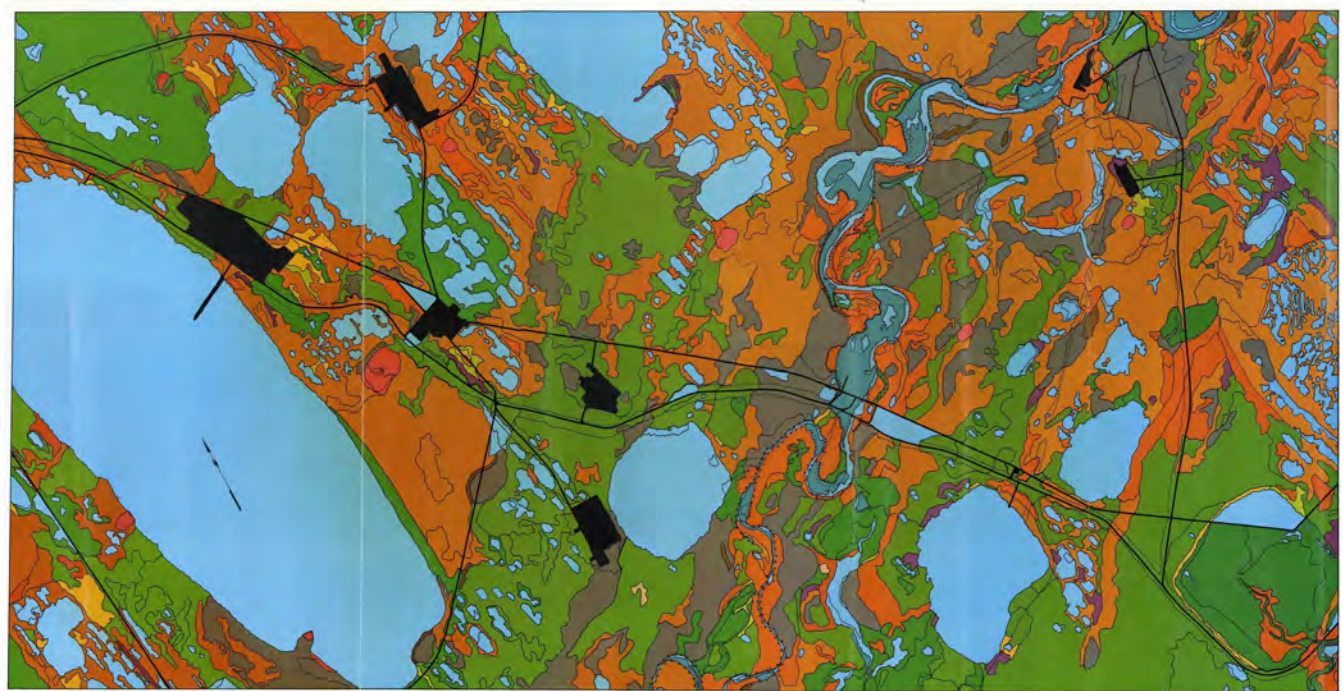
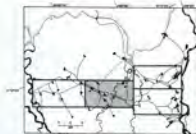
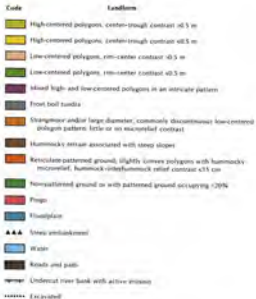




Figure A3

## Landforms: Prudhoe Bay Region, Alaska, Area 3

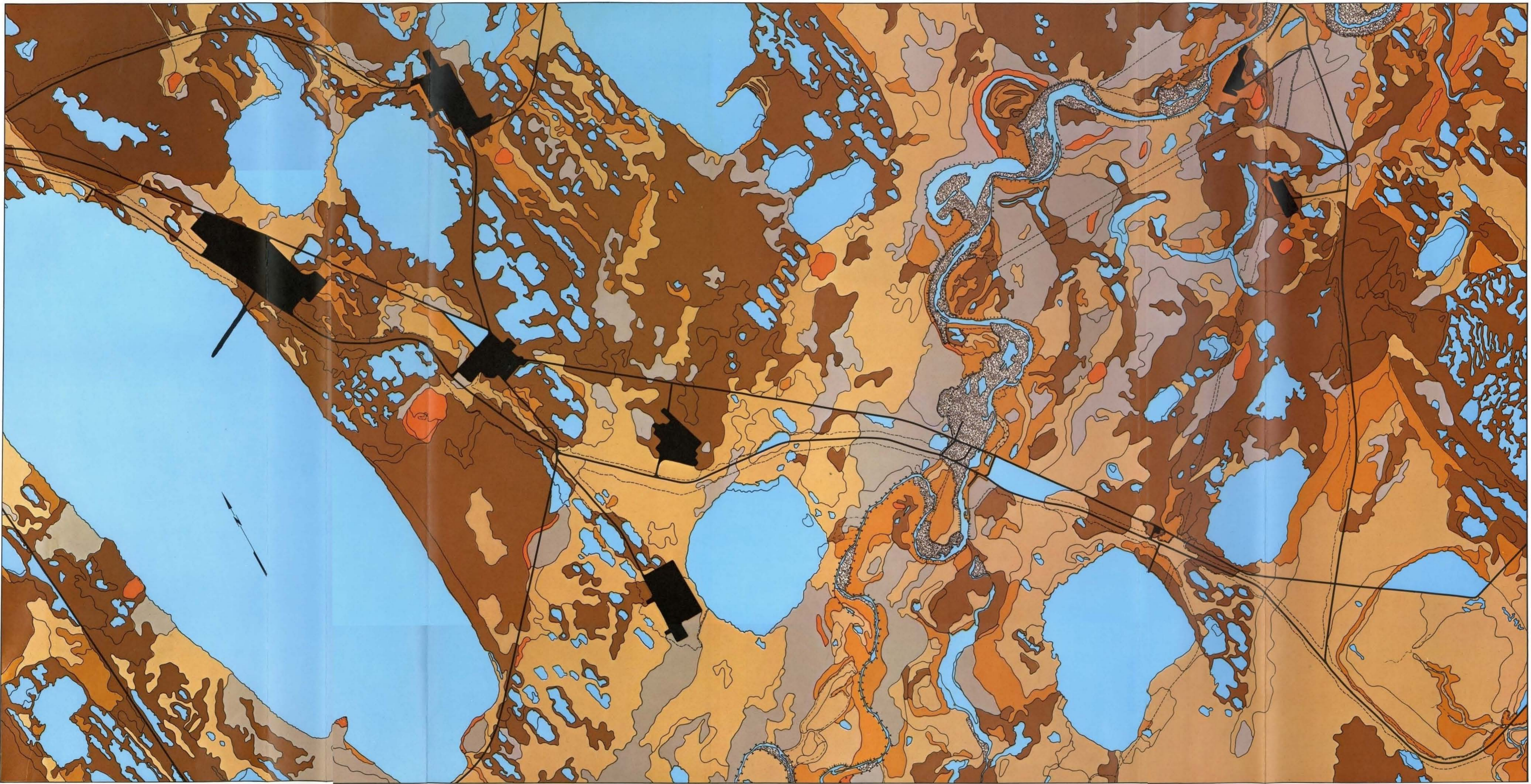
by R.R. Everett



Location of Area 3

Raster map prepared by the Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado. Lake boundaries and area contrast from topographic map (3.4 m contour interval) provided by Prudhoe Bay Environmental Subcommittee, Alaska Oil and Gas Association. Color cartography by V. Dow. Interpretation based on 1:6000 black and white aerial photography by Air Photo Tech Inc., 1973.













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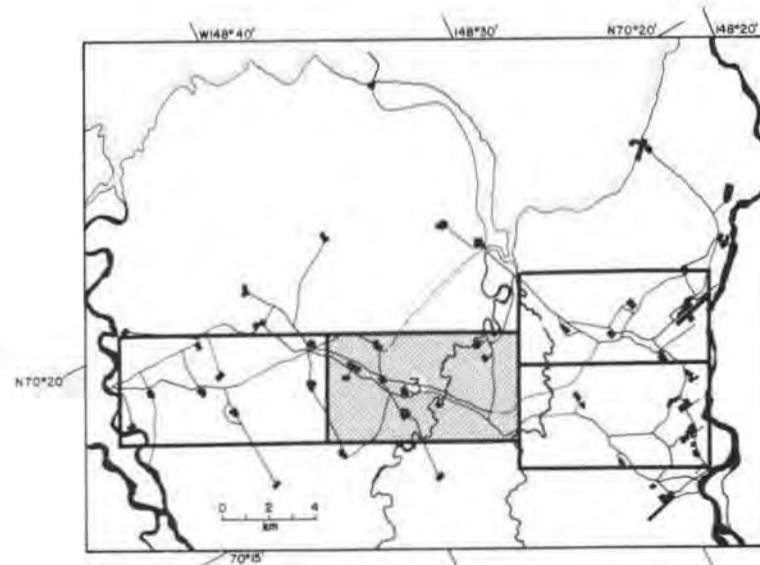


Figure A4

## Soils: Prudhoe Bay Region, Alaska, Area 3

by K.R. Everett

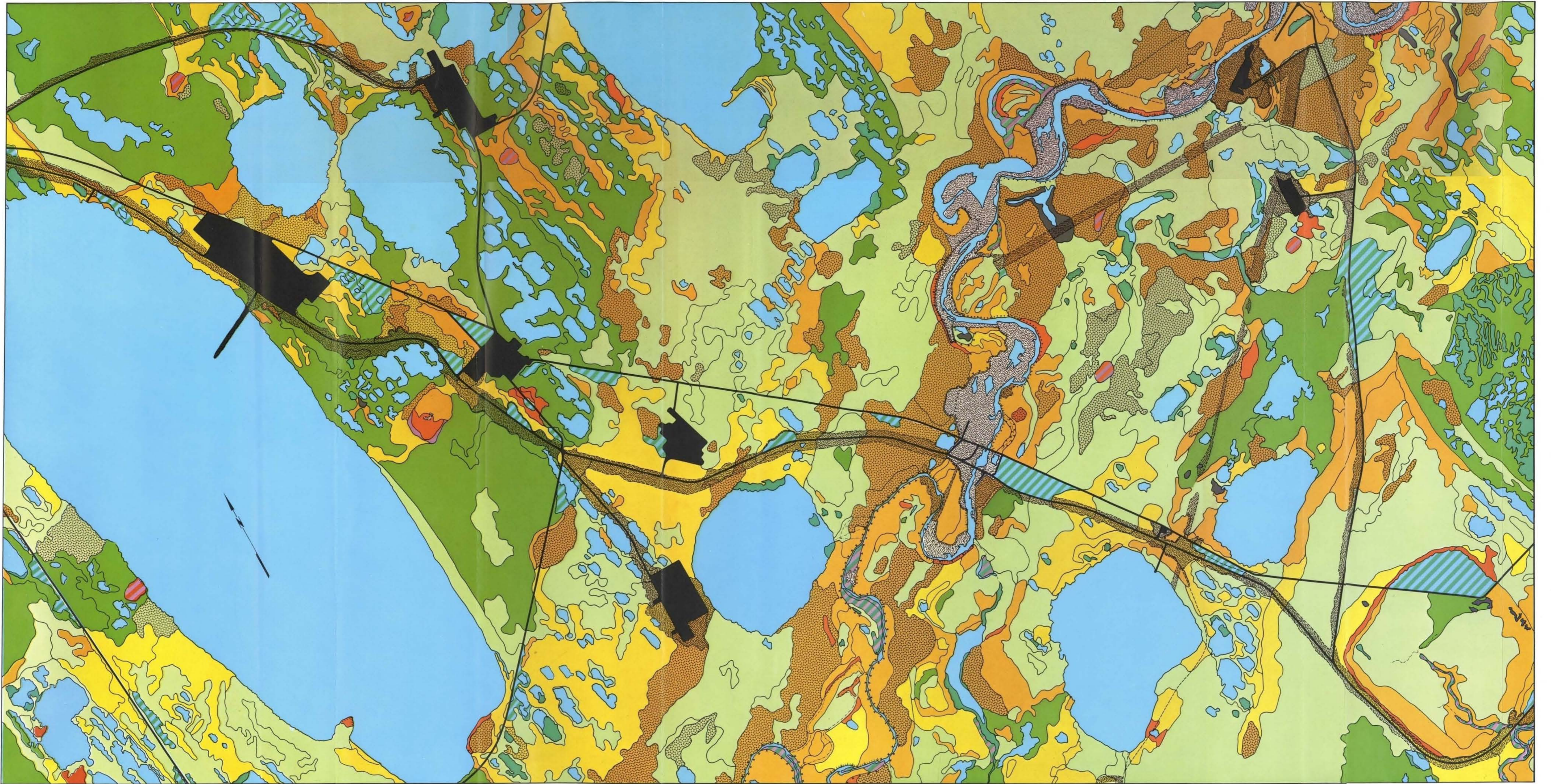
Code	Taxonomic name	Identifying field characteristics
	Pergelic Cryoboroll	A cold, more or less freely drained soil, underlain by permafrost (pergelic) with a dark, humus-rich, granular textured surface horizon >18 cm thick
	Pergelic Cryaquoll	A cold, dark, wet soil, prominently mottled in the lower part of the humus-rich, weakly granular surface horizon
	Complex of:	
	1.Histic Pergelic Cryaquept	1.A cold, wet, gray mineral soil, commonly mottled, having a surface horizon >25 cm thick, composed of predominantly organic (peaty) material
	2.Pergelic Cryohemist	2.A cold, wet, dark soil consisting of moderately decomposed organic materials to depths >40 cm
	3.Pergelic Cryosaprist	3.A cold, wet, dark soil consisting of well-decomposed organic materials to depths >40 cm
	Also includes Soil Unit 32, which is similar to the above complex except that Pergelic Cryaquolls may cover as much as 50%	
	Complex of:	
	1.Histic Pergelic Cryaquept	1.As above
	2.Pergelic Cryofibrist	2.A cold, wet, reddish to yellowish soil consisting of little-decomposed fibrous organic materials to depths >40 cm
	Pergelic Cryorthent	A cold, somewhat freely drained gravelly soil lacking significant horizon development and generally free of organic matter
	Pergelic-Ruptic-Aqueptic Cryaquoll	The cold soil of frost-boil areas in which a Cryaquoll soil is intimately associated with and interrupted by a cold, wet, gray and mottled mineral soil lacking any significant organic surface horizon—a Pergelic Cryaquept
	Water	Ponds, lakes, streams
	Roads and pads	



Location of Area 3

Base map prepared by the Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado. Lake boundaries and areal control from topographic map (1.4 m contour interval) provided by Prudhoe Bay Environmental Subcommittee, Alaska Oil and Gas Association. Color cartography by V. Dow. Interpretation based on 1:6000 black and white aerial photography by Air Photo Tech Inc., 1973.





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meters

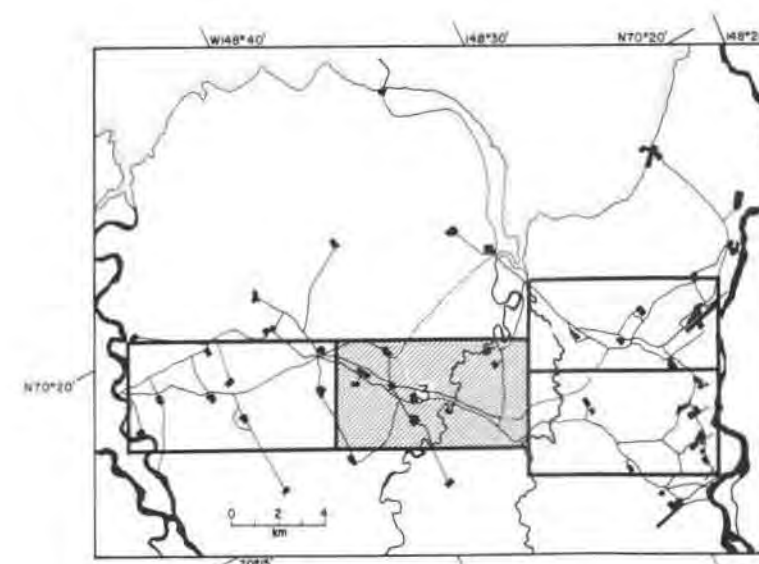


Code	Map unit	Microsite	Stand types	Principal species
	1. Dry Tundra	a. Ridge tops, river bluffs, high polygon centers b. Polygon troughs	a. B1 or B2 b. U3 or U4	a. <i>Dryas integrifolia</i> , <i>Oxytropis nigrescens</i> , <i>Carex rupestris</i> , <i>Salix reticulata</i> , <i>Saxifraga oppositifolia</i> , <i>Distichium capillaceum</i> , <i>Ditrichum flexicaule</i> , <i>Lecanora epibryon</i> , <i>Thamnia vermicularis</i> b. <i>Eriophorum angustifolium</i> , <i>Dryas integrifolia</i> , <i>Tomenthypnum nitens</i> , <i>Thamnia vermicularis</i> , <i>Cetraria islandica</i>
	2. Pingo Vegetation Complex	a. Dry pingo sides b. Pingo top and animal den areas c. Snow patches	a. B1 or B2 b. U10 c. B14, U6, or U7	a. Same as map unit 1a. b. <i>Dryas integrifolia</i> , <i>Ranunculus pedatifidus</i> , <i>Papaver macounii</i> , <i>Arctagrostis latifolia</i> , <i>Polemonium boreale</i> , <i>Festuca</i> spp., <i>Thuidium abietinum</i> , <i>Drepanocladus uncinatus</i> , <i>Bryum</i> spp. c. Same as 6a and b.
	3. Frost-Boil Vegetation Complex	a. Frost-boils b. Inter-frost-boil	a. B3 b. Variable, indicated by background color	a. <i>Saxifraga oppositifolia</i> , <i>Dryas integrifolia</i> , <i>Juncus biglumis</i> , <i>Eriophorum angustifolium</i> , <i>Bryum wrightii</i> , <i>Distichium capillaceum</i> , <i>Lecanora epibryon</i> , <i>Thamnia vermicularis</i> b. Variable.
	4. Moist Tundra	Upland areas, flat and slightly high-centered polygons	U2, U3, or U4	<i>Eriophorum angustifolium</i> , <i>E. vaginatum</i> , <i>Carex bigelowii</i> , <i>C. membranacea</i> , <i>Dryas integrifolia</i> , <i>Salix reticulata</i> , <i>S. arctica</i> , <i>S. lanata</i> ssp. <i>richardsonii</i> , <i>Polygonum viviparum</i> , <i>Tomenthypnum nitens</i> , <i>Ditrichum flexicaule</i> , <i>Thamnia vermicularis</i> , <i>Cetraria</i> spp., <i>Dactylina arctica</i>
	5. Moist Tundra Vegetation Complex	a. Tops of flat-centered polygons and drier low-centered polygons, polygon rims, hummocks b. Polygon troughs, depressions between hummocks	a. U2, U3, or U4 b. M2	a. Same as 4. b. <i>Carex aquatilis</i> , <i>Eriophorum angustifolium</i> , <i>Pedicularis sudetica</i> , <i>Drepanocladus brevifolius</i>
	6. Snow Patch Vegetation Complex	a. Upper part of snow patch area b. Lower part of snow patch area	a. B14 and/or U6 b. U7	a. <i>Dryas integrifolia</i> , <i>Cassiope tetragona</i> , <i>Salix reticulata</i> , <i>Astragalus umbellatus</i> , <i>Pedicularis capitata</i> , <i>Carex scirpoidea</i> , <i>Silene acaulis</i> , <i>Tomenthypnum nitens</i> , <i>Drepanocladus uncinatus</i> , <i>Ditrichum flexicaule</i> , <i>Thuidium abietinum</i> , <i>Cetraria richardsonii</i> , <i>C. nivalis</i> , <i>C. islandica</i> , <i>C. cucullata</i> , <i>Peltigera canina</i> b. <i>Salix rotundifolia</i> , <i>Carex aquatilis</i> , <i>Senecio atropurpureus</i> , <i>Equisetum variegatum</i> , <i>Eriophorum angustifolium</i> , <i>Distichium capillaceum</i> , <i>Ditrichum flexicaule</i>
	7. Wet Tundra (alkaline facies)	a. Wet polygon basins, lake margins, wet meadows, low areas between hummocks, polygon troughs b. Polygon rims, aligned hummocks, hummocks	a. M2 b. U3 or U4	a. <i>Carex aquatilis</i> , <i>Eriophorum angustifolium</i> , <i>Pedicularis sudetica</i> , <i>Drepanocladus brevifolius</i> , <i>Catascopium nigrum</i> , <i>Cinclidium arcticum</i> , <i>Meesia triquetra</i> b. <i>Eriophorum angustifolium</i> , <i>Carex aquatilis</i> , <i>C. bigelowii</i> , <i>C. atrofusca</i> , <i>C. rotundata</i> , <i>Dryas integrifolia</i> , <i>Salix reticulata</i> , <i>S. arctica</i> , <i>S. lanata</i> ssp. <i>richardsonii</i> , <i>Polygonum viviparum</i> , <i>Tomenthypnum nitens</i> , <i>Ditrichum flexicaule</i> , <i>Thamnia vermicularis</i> , <i>Cetraria</i> spp., <i>Dactylina arctica</i>
	8. Very Wet Tundra (alkaline facies)	a. Low polygon centers, lake margins, very wet meadows, depressions between hummocks, polygon troughs b. Polygon rims, aligned hummocks, hummocks	a. M4 b. U4 or U3	a. <i>Carex aquatilis</i> , <i>C. saxatilis</i> ssp. <i>laxa</i> , <i>Eriophorum angustifolium</i> , <i>Pedicularis sudetica</i> , <i>Scorpidium scorpioides</i> b. Same as 7b.
	9. Emergent Tundra (shallow water, <30 cm)	Lake margins, ponds	E1	<i>Carex aquatilis</i> , <i>Eriophorum angustifolium</i> , <i>Caltha palustris</i> , <i>Ranunculus pallasii</i>
	10. Emergent Tundra (deep water, 30 to 100 cm)	Lake margins, ponds	E2	<i>Arctophila fulva</i>
	11. Open Water	Lakes and streams	W1 or W2	None
	12. Tundra Stream Vegetation Complex	a. Stream waters b. Moist stream margins c. River gravels and sands d. Snow patches e. Slumping bluffs f. Dry sandy terraces g. Upland areas within the high spring flood line	a. W2, E1 or E2 b. M5 or U8 c. B4 d. B14, U6 or U7 e. B7 f. B6 g. U9	a. <i>Carex aquatilis</i> , <i>Arctophila fulva</i> , <i>Calliergon giganteum</i> , <i>Hippuris vulgaris</i> , <i>Caltha palustris</i> b. <i>Carex aquatilis</i> , <i>Eriophorum angustifolium</i> , <i>Equisetum variegatum</i> , <i>Salix lanata</i> ssp. <i>richardsonii</i> , <i>S. rotundifolia</i> , <i>S. arctica</i> , <i>Pedicularis sudetica</i> , <i>Thalictrum alpinum</i> , <i>Cardamine hyperborea</i> c. <i>Epilobium latifolium</i> , <i>Artemisia arctica</i> , <i>A. borealis</i> , <i>A. glomerata</i> , <i>Wilhelmsia physodes</i> , <i>Astragalus alpinus</i> , <i>Salix ovalifolia</i> , <i>Trisetum spicatum</i> , <i>Elymus arenarius</i> ssp. <i>mollis</i> , <i>Anemone parviflora</i> d. Same as 6a and b. e. <i>Braya purpurascens</i> , <i>Anemone parviflora</i> , <i>Dryas integrifolia</i> , <i>Senecio reseditolius</i> , <i>Oxyria digyna</i> , <i>Parnassia kotzebuei</i> , <i>Erigeron humilis</i> , <i>Arctagrostis latifolia</i> , <i>Festuca</i> spp., <i>Epilobium latifolium</i> , <i>Lloydia serotina</i> , <i>Aster sibiricus</i> f. <i>Dryas integrifolia</i> , <i>Astragalus alpinus</i> , <i>A. umbellatus</i> , <i>Carex scirpoidea</i> , <i>Kobresia myosuroides</i> , <i>Carex rupestris</i> , <i>Androsace chamaejasme</i> , <i>Silene acaulis</i> , <i>Anemone richardsonii</i> , <i>Distichium capillaceum</i> , <i>Ditrichum flexicaule</i> g. <i>Dryas integrifolia</i> , <i>Salix rotundifolia</i> , <i>S. reticulata</i> , <i>Eriophorum angustifolium</i> , <i>Astragalus umbellatus</i> , <i>Parrya nudicaulis</i> , <i>Carex scirpoidea</i> , <i>Saxifraga oppositifolia</i> , <i>Tomenthypnum nitens</i> , <i>Ditrichum flexicaule</i> , <i>Didymodon asperifolius</i> , <i>Tortula ruralis</i>
	13. Flooding disturbance caused by roads or pads	Generally low sites as in drained lake basins	W3	Variable.
	14. Disturbed areas	Variable	D1-D7	Variable.
	15. Roads and pads			

Figure A5

## Vegetation: Prudhoe Bay Region, Alaska, Area 3

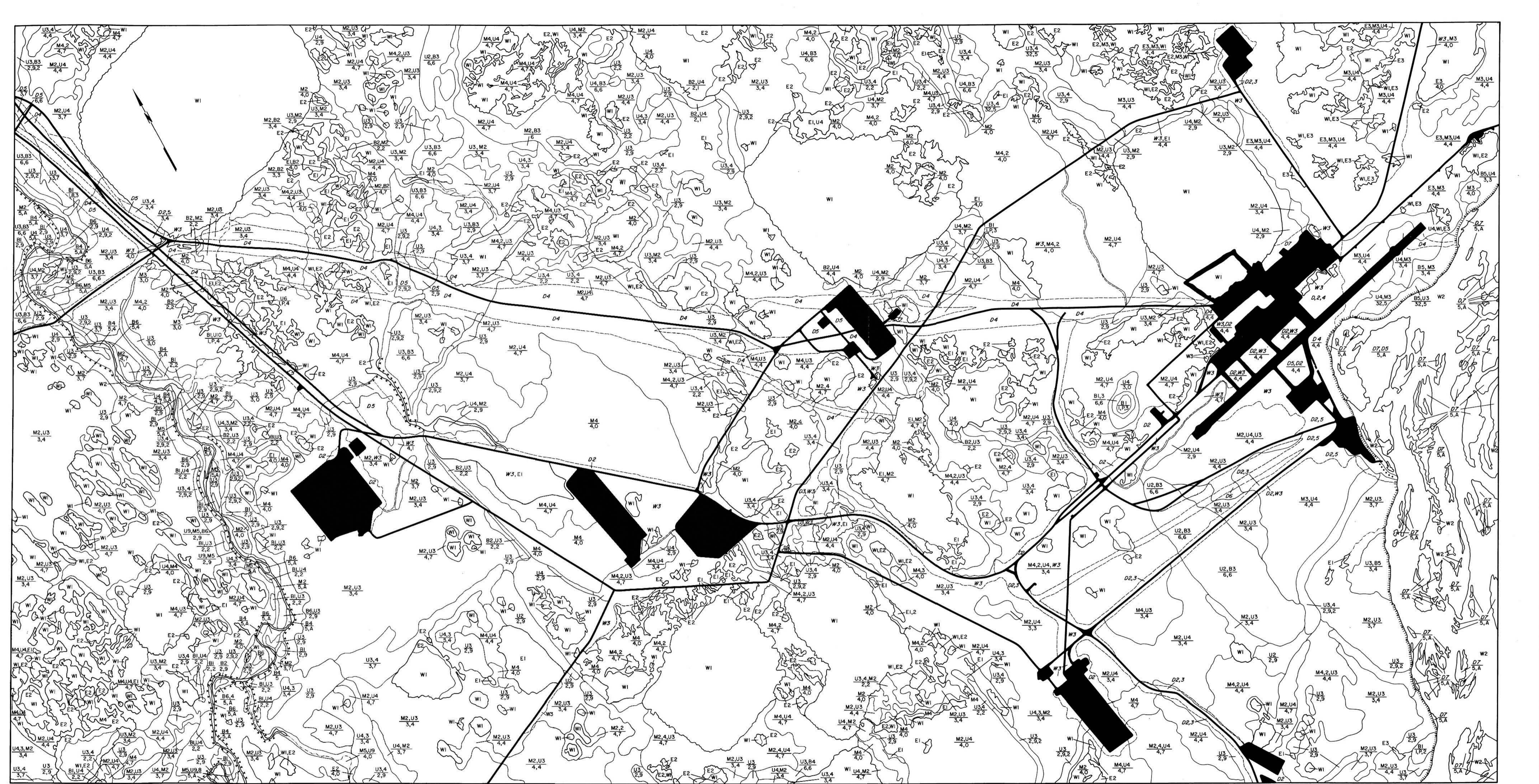
by D.A. Walker and P.J. Webber



Location of Area 3

Base map prepared by the Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado. Lake boundaries and areal control from topographic map (1.4 m contour interval) provided by Prudhoe Bay Environmental Subcommittee, Alaska Oil and Gas Association. Color cartography by V. Dow. Interpretation based on 1:6000 black and white aerial photography by Air Photo Tech Inc., 1973.





0 250 500 750 1000  
meters



Figure A6

# Master Map: Prudhoe Bay Region, Alaska, Area 1

by K.R. Everett, D.A. Walker, and P.J. Webber

Information is coded in fraction form:  $\frac{\text{Vegetation Stand Type(s)}}{\text{Soil Unit, Landform Unit, Slope}}$

## Numerator: Vegetation

Stand type no.	Community	Characteristic microsite
<b>B—Dry sites</b>		
B1	DRY <i>Dryas integrifolia</i> , <i>Oxytropis nigrescens</i> , <i>Lecanora epibryon</i> PROSTRATE SCRUB	Pingos, ridges, high polygon centers
B2	DRY <i>Dryas integrifolia</i> , <i>Saxifraga oppositifolia</i> , <i>Lecanora epibryon</i> PROSTRATE SCRUB	Similar to Stand Type B1, but less exposed to wind
B3	DRY <i>Saxifraga oppositifolia</i> , <i>Juncus biglumis</i> FROST-BOIL BARREN	Frost boils
B4	DRY <i>Epilobium latifolium</i> , <i>Artemisia arctica</i> RIVER-BAR BARREN	River gravel bars
B5	DRY <i>Dryas integrifolia</i> , <i>Salix ovalifolia</i> , <i>Artemisia borealis</i> SANDY FLATS BARREN	Sandy river terraces, stabilized sand dunes
B6	DRY <i>Dryas integrifolia</i> , <i>Astragalus alpinus</i> RIVER BAR PROSTRATE SCRUB	River banks
B7	DRY <i>Braya purpurascens</i> , <i>Anemone parviflora</i> , <i>Arctagrostis latifolia</i> SLUMPING RIVER BLUFF COMPLEX	Slumping river bluffs
B14	DRY <i>Dryas integrifolia</i> , <i>Salix reticulata</i> , <i>Cetraria richardsonii</i> SNOW PATCH PROSTRATE SCRUB	Dry, early-thawing snow patch areas with hummocky terrain
G	BARREN GRAVEL	
<b>U—Moist sites</b>		
U1	MOIST <i>Carex aquatilis</i> , <i>Ochrolechia frigida</i> GRAMINOID MEADOW	Polygon rims and aligned hummocks in acidic tundra region
U2	MOIST <i>Eriophorum vaginatum</i> , <i>Dryas integrifolia</i> , <i>Tomenthypnum nitens</i> , <i>Thamnia vermicularis</i> TUSsock GRAMINOID MEADOW	Well-drained upland sites
U3	MOIST <i>Eriophorum angustifolium</i> , <i>Dryas integrifolia</i> , <i>Tomenthypnum nitens</i> , <i>Thamnia vermicularis</i> GRAMINOID MEADOW	Well-drained upland sites, polygon rims, aligned hummocks
U4	MOIST <i>Carex aquatilis</i> , <i>Dryas integrifolia</i> , <i>Salix arctica</i> , <i>Tomenthypnum nitens</i> GRAMINOID MEADOW	Moister upland sites, basins of drier low-centered polygons, polygon rims, aligned hummocks
U6	DRY <i>Dryas integrifolia</i> , <i>Cassiope tetragona</i> SNOW PATCH DWARF SCRUB	Well-drained snow patch areas
U7	MOIST <i>Salix rotundifolia</i> SNOW PATCH PROSTRATE SCRUB	Late-thawing snow patch areas
U8	MOIST <i>Salix lanata</i> , <i>Carex aquatilis</i> STREAM BANK DWARF SCRUB	Stream banks, lake margins
U9	MOIST <i>Dryas integrifolia</i> , <i>Eriophorum angustifolium</i> , <i>Tomenthypnum nitens</i> , <i>Didymodon asperifolius</i> STREAM BANK GRAMINOID MEADOW	Upland stream banks that are swept by the spring flood
U10	MOIST <i>Festuca balfinensis</i> , <i>Papaver macounii</i> GRAMINOID MEADOW	Pingo tops, bird mounds and animal dens

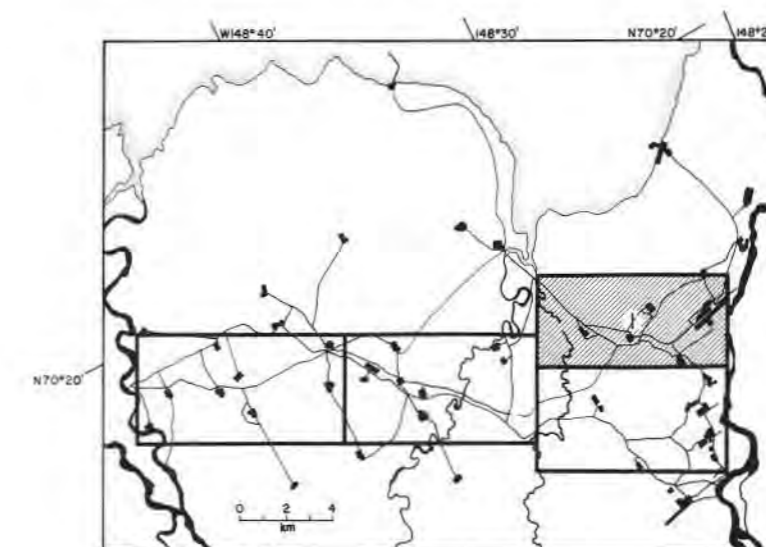
Stand type no.	Community	Characteristic microsite
<b>M—Wet sites</b>		
M1	WET <i>Carex aquatilis</i> , <i>Saxifraga foliolosa</i> GRAMINOID MEADOW	Wet microsites in acidic tundra areas, primarily associated with aligned hummocks.
M2	WET <i>Carex aquatilis</i> , <i>Drepanocladus brevifolius</i> GRAMINOID MEADOW	Wet polygon centers and troughs, lake margins
M3	WET <i>Carex aquatilis</i> , <i>Dupontia fisheri</i> , <i>Calliergon richardsonii</i> GRAMINOID MEADOW	Wet polygon centers in sand dunes region and along Kuparuk River
M4	VERY WET <i>Carex aquatilis</i> , <i>Scorpidium scorpioides</i> GRAMINOID MEADOW	Low wet sites, polygon centers, drained lakes, lake margins
M5	WET <i>Carex aquatilis</i> , <i>Salix rotundifolia</i> STREAM BANK GRAMINOID MEADOW	Moist stream banks
<b>E—Emergent sites</b>		
E1	VERY WET <i>Carex aquatilis</i> GRAMINOID MEADOW	Water to about 30 cm
E2	VERY WET <i>Arctophila tulva</i> GRAMINOID MEADOW	Water to about 100 cm
E3	VERY WET <i>Scorpidium scorpioides</i> AQUATIC MOSS MEADOW	Water to about 100 cm in sand dunes region
<b>W—Open water</b>		
W1	None	Lakes and ponds
W2	None	Streams and rivers
W3	Varies	Flooded areas caused by roads or pads
<b>D—Disturbed sites</b>		
	Type of disturbance	
D1	Bare earth with pioneering species, DRY <i>Braya purpurascens</i> , <i>Leptobryum pyriforme</i> , <i>Marchantia polymorpha</i> DISTURBANCE COMPLEX	
D2	Foreign gravel or construction debris	
D3	Dust-covered areas adjacent to roads	
D4	Vehicle tracks—deeply rutted	
D5	Vehicle tracks—not deeply rutted	
D6	Winter road	
D7	Excavated areas primarily in river gravels	
W3	Flooded areas caused by roads or pads	
---	Boundary of disturbance	

## Denominator: Soils, Landforms and Slope

Unit (1st no.)	Soil	Identifying field characteristics
1	Pergelic Cryoboroll	A cold, more or less freely drained soil, underlain by permafrost (Pergelic) with a dark, humus-rich, granular textured surface horizon >18 cm thick
2	Pergelic Cryaquoll	A cold, dark-colored, wet soil, prominently mottled in the lower part of the humus-rich, weakly granular surface horizon
3	Complex of: 1) Histic Pergelic Cryaquept 2) Pergelic Cryohemist 3) Pergelic Cryosaprist	1) A cold, wet, gray mineral soil, commonly mottled, having a surface horizon >25 cm thick, composed of predominantly organic (peaty) material 2) A cold, wet, dark-colored soil consisting of moderately decomposed organic materials to depths >40 cm 3) A cold, wet, dark soil consisting of well-decomposed organic materials to depths >40 cm
32	None	A complex in which Pergelic Cryaquolls (Unit 2) and soils of Unit 3 are in nearly equal amounts
4	Complex of: 1) Histic Pergelic Cryaquept 2) Pergelic Cryofibril	1) As above 2) A cold, wet, reddish to yellowish soil consisting of little-decomposed fibrous organic materials to depths >40 cm
5	Pergelic Cryorthent	A cold, somewhat freely drained gravelly soil lacking significant horizon development and generally free of organic matter
6	Pergelic-Ruptic-Aqueptic Cryaquoll	The cold soil of frost boil areas in which a Cryaquoll soil (Unit 2) is intimately associated with and interrupted by a cold, wet, gray and mottled mineral soil lacking any significant organic surface horizon—a Pergelic Cryaquept

Unit (2nd no.)	Landform	Code (3rd no.)	Slope range (%)
1	High-centered polygons, center-trough contrast >0.5 m	None	0 to 2
2	High-centered polygons, center-trough contrast ≤0.5 m	2	>2 to 6
3	Low-centered polygons, rim-center contrast >0.5 m	3	>6 to 12
4	Low-centered polygons, rim-center contrast ≤0.5 m	4	>12 to 20
5	Mixed high- and low-centered polygons in an intricate pattern	5	>20
6	Frost boil tundra		
7	Strangmoor and/or large diameter, commonly discontinuous low-centered polygon pattern; little or no microrelief contrast		
8	Hummocky terrain associated with steep slopes		
9	Reticulate patterned ground—slightly convex polygons with hummocky microrelief, hummock-interhummock relief contrast ≤15 cm		
0	Non-patterned ground or with patterned ground occupying <20%		
P	Pingo		
A	Floodplain		
▲▲▲	Steep embankment		
	Undercut river bank		
●●●●●	Excavated		
-----	Stream		

■ Roads and Pads



Location of Area 1

Base map prepared by the Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado. Lake boundaries and areal control from topographic map (1.4 m contour interval) provided by Prudhoe Bay Environmental Subcommittee, Alaska Oil and Gas Association. Interpretation based on 1:6000 black and white aerial photography by Air Photo Tech Inc., 1973.



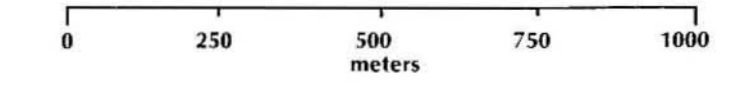




Figure A7

# Master Map: Prudhoe Bay Region, Alaska, Area 2

by K.R. Everett, D.A. Walker, and P.J. Webber

Information is coded in fraction form:  $\frac{\text{Vegetation Stand Type(s)}}{\text{Soil Unit, Landform Unit, Slope}}$

## Numerator: Vegetation

Stand type no.	Community	Characteristic microsite
<b>B—Dry sites</b>		
B1	DRY <i>Dryas integrifolia</i> , <i>Oxytropis nigrescens</i> , <i>Lecanora epibryon</i> PROSTRATE SCRUB	Pingos, ridges, high polygon centers
B2	DRY <i>Dryas integrifolia</i> , <i>Saxifraga oppositifolia</i> , <i>Lecanora epibryon</i> PROSTRATE SCRUB	Similar to Stand Type B1, but less exposed to wind
B3	DRY <i>Saxifraga oppositifolia</i> , <i>Juncus biglumis</i> FROST-BOIL BARREN	Frost boils
B4	DRY <i>Epilobium latifolium</i> , <i>Artemisia arctica</i> RIVER-BAR BARREN	River gravel bars
B5	DRY <i>Dryas integrifolia</i> , <i>Salix ovalifolia</i> , <i>Artemisia borealis</i> SANDY FLATS BARREN	Sandy river terraces, stabilized sand dunes
B6	DRY <i>Dryas integrifolia</i> , <i>Astragalus alpinus</i> RIVER BAR PROSTRATE SCRUB	River banks
B7	DRY <i>Braya purpurascens</i> , <i>Anemone parviflora</i> , <i>Arctagrostis latifolia</i> SLUMPING RIVER BLUFF COMPLEX	Slumping river bluffs
B14	DRY <i>Dryas integrifolia</i> , <i>Salix reticulata</i> , <i>Cetraria richardsonii</i> SNOW PATCH PROSTRATE SCRUB	Dry, early-thawing snow patch areas with hummocky terrain
G	BARREN GRAVEL	
<b>U—Moist sites</b>		
U1	MOIST <i>Carex aquatilis</i> , <i>Ochrolechia frigida</i> GRAMINOID MEADOW	Polygon rims and aligned hummocks in acidic tundra region
U2	MOIST <i>Eriophorum vaginatum</i> , <i>Dryas integrifolia</i> , <i>Tomenthypnum nitens</i> , <i>Thamnia vermicularis</i> TUSSOCK GRAMINOID MEADOW	Well-drained upland sites
U3	MOIST <i>Eriophorum angustifolium</i> , <i>Dryas integrifolia</i> , <i>Tomenthypnum nitens</i> , <i>Thamnia vermicularis</i> GRAMINOID MEADOW	Well-drained upland sites, polygon rims, aligned hummocks
U4	MOIST <i>Carex aquatilis</i> , <i>Dryas integrifolia</i> , <i>Salix arctica</i> , <i>Tomenthypnum nitens</i> GRAMINOID MEADOW	Moister upland sites, basins of drier low-centered polygons, polygon rims, aligned hummocks
U6	DRY <i>Dryas integrifolia</i> , <i>Cassiope tetragona</i> SNOW PATCH DWARF SCRUB	Well-drained snow patch areas
U7	MOIST <i>Salix rotundifolia</i> SNOW PATCH PROSTRATE SCRUB	Late-thawing snow patch areas
U8	MOIST <i>Salix lanata</i> , <i>Carex aquatilis</i> STREAM BANK DWARF SCRUB	Stream banks, lake margins
U9	MOIST <i>Dryas integrifolia</i> , <i>Eriophorum angustifolium</i> , <i>Tomenthypnum nitens</i> , <i>Didymodon asperifolius</i> STREAM BANK GRAMINOID MEADOW	Upland stream banks that are swept by the spring flood
U10	MOIST <i>Festuca baffinensis</i> , <i>Papaver macounii</i> GRAMINOID MEADOW	Pingo tops, bird mounds and animal dens

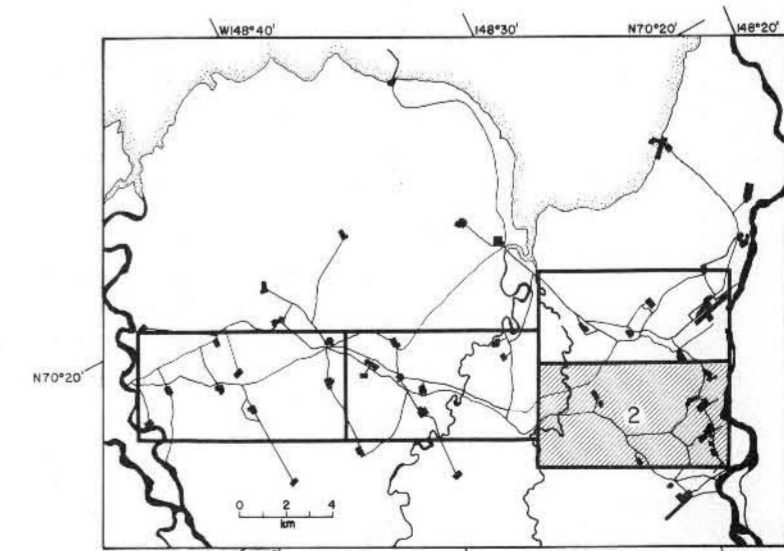
Stand type no.	Community	Characteristic microsite
<b>M—Wet sites</b>		
M1	WET <i>Carex aquatilis</i> , <i>Saxifraga foliolosa</i> GRAMINOID MEADOW	Wet microsities in acidic tundra areas, primarily associated with aligned hummocks.
M2	WET <i>Carex aquatilis</i> , <i>Drepanocladus brevifolius</i> GRAMINOID MEADOW	Wet polygon centers and troughs, lake margins
M3	WET <i>Carex aquatilis</i> , <i>Dupontia fisheri</i> , <i>Calliergon richardsonii</i> GRAMINOID MEADOW	Wet polygon centers in sand dunes region and along Kuparuk River
M4	VERY WET <i>Carex aquatilis</i> , <i>Scorpidium scorpioides</i> GRAMINOID MEADOW	Low wet sites, polygon centers, drained lakes, lake margins
M5	WET <i>Carex aquatilis</i> , <i>Salix rotundifolia</i> STREAM BANK GRAMINOID MEADOW	Moist stream banks
<b>E—Emergent sites</b>		
E1	VERY WET <i>Carex aquatilis</i> GRAMINOID MEADOW	Water to about 30 cm
E2	VERY WET <i>Arctophila fulva</i> GRAMINOID MEADOW	Water to about 100 cm
E3	VERY WET <i>Scorpidium scorpioides</i> AQUATIC MOSS MEADOW	Water to about 100 cm in sand dunes region
<b>W—Open water</b>		
W1	None	Lakes and ponds
W2	None	Streams and rivers
W3	Varies	Flooded areas caused by roads or pads
<b>D—Disturbed sites</b>		
Type of disturbance		
D1	Bare earth with pioneering species, DRY <i>Braya purpurascens</i> , <i>Leptobryum pyriforme</i> , <i>Marchantia polymorpha</i> DISTURBANCE COMPLEX	
D2	Foreign gravel or construction debris	
D3	Dust-covered areas adjacent to roads	
D4	Vehicle tracks—deeply rutted	
D5	Vehicle tracks—not deeply rutted	
D6	Winter road	
D7	Excavated areas primarily in river gravels	
W3	Flooded areas caused by roads or pads	
---	Boundary of disturbance	

## Denominator: Soils, Landforms and Slope

Unit (1st no.)	Soil	Identifying field characteristics
1	Pergelic Cryoboroll	A cold, more or less freely drained soil, underlain by permafrost (Pergelic) with a dark, humus-rich, granular textured surface horizon >18 cm thick
2	Pergelic Cryaquoll	A cold, dark-colored, wet soil, prominently mottled in the lower part of the humus-rich, weakly granular surface horizon
3	Complex of: 1) Histic Pergelic Cryaquept 2) Pergelic Cryohemist 3) Pergelic Cryosaprist	1) A cold, wet, gray mineral soil, commonly mottled, having a surface horizon >25 cm thick, composed of predominantly organic (peaty) material 2) A cold, wet, dark-colored soil consisting of moderately decomposed organic materials to depths >40 cm 3) A cold, wet, dark soil consisting of well-decomposed organic materials to depths >40 cm
32	None	A complex in which Pergelic Cryaquolls (Unit 2) and soils of Unit 3 are in nearly equal amounts
4	Complex of: 1) Histic Pergelic Cryaquept 2) Pergelic Cryofibril	1) As above 2) A cold, wet, reddish to yellowish soil consisting of little-decomposed fibrous organic materials to depths >40 cm
5	Pergelic Cryorthent	A cold, somewhat freely drained gravelly soil lacking significant horizon development and generally free of organic matter
6	Pergelic-Ruptic-Aqueptic Cryaquoll	The cold soil of frost boil areas in which a Cryaquoll soil (Unit 2) is intimately associated with and interrupted by a cold, wet, gray and mottled mineral soil lacking any significant organic surface horizon—a Pergelic Cryaquept

Unit (2nd no.)	Landform	Code (3rd no.)	Slope range (%)
1	High-centered polygons, center-trough contrast >0.5 m	None	0 to 2
2	High-centered polygons, center-trough contrast ≤0.5 m	2	>2 to 6
3	Low-centered polygons, rim-center contrast >0.5 m	3	>6 to 12
4	Low-centered polygons, rim-center contrast ≤0.5 m	4	>12 to 20
5	Mixed high- and low-centered polygons in an intricate pattern	5	>20
6	Frost boil tundra		
7	Strangmoor and/or large diameter, commonly discontinuous low-centered polygon pattern; little or no microrelief contrast		
8	Hummocky terrain associated with steep slopes		
9	Reticulate patterned ground—slightly convex polygons with hummocky microrelief, hummock-interhummock relief contrast ≤15 cm		
0	Non-patterned ground or with patterned ground occupying <20%		
P	Pingo		
A	Floodplain		
▲▲▲	Steep embankment		
	Undercut river bank		
●●●●●	Excavated		
-----	Stream		

Roads and Pads



Location of Area 2

Base map prepared by the Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado. Lake boundaries and areal control from topographic map (1.4 m contour interval) provided by Prudhoe Bay Environmental Subcommittee, Alaska Oil and Gas Association. Interpretation based on 1:6000 black and white aerial photography by Air Photo Tech Inc., 1973.



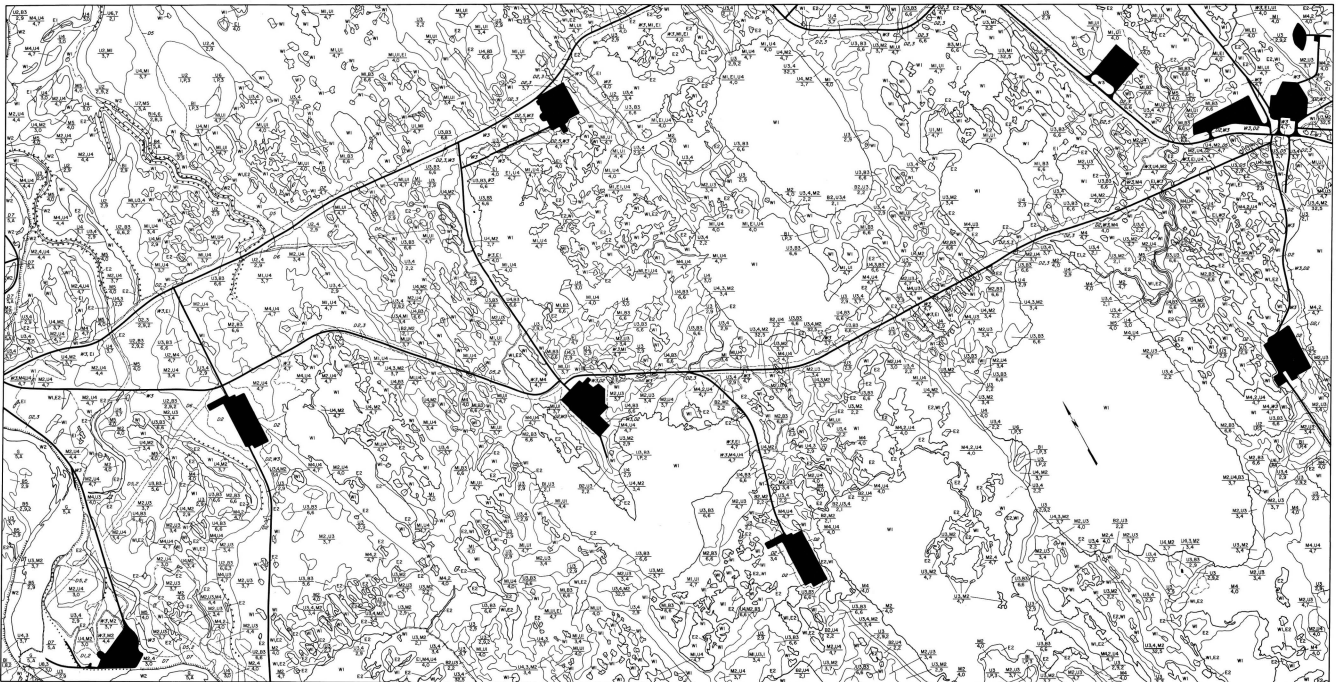




Figure A8

## Master Map: Prudhoe Bay Region, Alaska, Area 4

by K.R. Everett, D.A. Walker, and P.J. Webber

Information is coded in fraction form:  $\frac{\text{Vegetation Stand Type}(i)}{\text{Soil Unit, Landform Unit, Slope}}$ 

## Numerator: Vegetation

Stand type no.	Community	Characteristic microsite
<b>B—Dry sites</b>		
B1	DRY Dryas integrifolia, Chytrium nigrescens, Lecanora ephryon PROSTRATE SCRUB	Frings, ridges, high polygon centers
B2	DRY Dryas integrifolia, Sauregha oppositifolia, Lecanora ephryon PROSTRATE SCRUB	Similar to Stand Type B1, but less exposed to wind
B3	DRY Sauregha oppositifolia, Juncus hughesii FROST-BLIND BARREN	Free beds
B4	DRY Epilobium latifolium, Artemisia arctica RIVER-BANK BARREN	River gravel bars
B5	DRY Dryas integrifolia, Salix ovalifolia, Artemisia biennis SANDY FLATS BARREN	Sandy river terraces, stabilized sand dunes
B6	DRY Dryas integrifolia, Astragalus alpinus RIVER BANK PROSTRATE SCRUB	River banks
B7	DRY Briza pappostachya, Anemone parviflora, Antergastion luteum SLUICING RIVER BILET COMPLEX	Sluicing river blets
B14	DRY Dryas integrifolia, Salix reticulata, Comarostaphylis richardsonii SNOW	Dry, early-spring snow patch areas with hummocky terrain
<b>C—BARREN GRAVEL</b>		
<b>U—Moist sites</b>		
U1	MOIST Carex aquatilis, Ochrolechia frigida GRAMINOID MEADOW	Polygon sites and aligned hummocks in acidic tundra region
U2	MOIST Eriophorum vaginatum, Dryas integrifolia, Tomentophyllum nitens, Phacelia verticillata TESSERAC GRAMINOID MEADOW	Well-drained upland sites
U3	MOIST Eriophorum vaginatum, Dryas integrifolia, Tomentophyllum nitens, Phacelia verticillata GRAMINOID MEADOW	Well-drained upland sites, polygon rims, aligned hummocks
U4	MOIST Carex aquatilis, Dryas integrifolia, Salix arctica, Tomentophyllum nitens GRAMINOID MEADOW	Moister upland sites, basins of drier low-centered polygons, polygon rims, aligned hummocks
U6	DRY Dryas integrifolia, Cassiope tetragona SNOW PATCH DWARF SCRUB	Well-drained snow patch areas
U7	MOIST Salix rotundifolia SNOW PATCH PROSTRATE SCRUB	Late-thawing snow patch areas
U8	MOIST Salix laricina, Carex aquatilis STREAM BANK DWARF SCRUB	Stream banks, lake margins
U9	MOIST Dryas integrifolia, Eriophorum angustifolium, Tomentophyllum nitens, Diphysaema asperifolium STREAM BANK GRAMINOID MEADOW	Upland stream banks that are swept by the spring flood
U10	MOIST Festuca hillebrandii, Papaver maculatum GRAMINOID MEADOW	Frings tops, bird mounds and animal dens

## Denominator: Soils, Landforms and Slope

Unit (Unit no.)	Soil	Identifying field characteristics
1	Pergelic Cryoborol	A cold, more or less freely drained soil, gleyfaded by permafrost (Pergelic) with a dark, hummock, general trilateral surface horizon ~16 cm thick
2	Pergelic Cryosol	A cold, dark-colored, wet soil, prominently mottled in the lower part of the hummock, usually granular surface horizon
3	Complex of: 1) Hectic Pergelic Cryoscept 2) Pergelic Cryohemist 3) Pergelic Cryoscept	1) A cold, wet, gray mineral soil, commonly mottled, having a surface horizon 25+ cm thick, composed of predominantly organic (sawto) material 2) A cold, wet, dark-colored soil consisting of moderately decomposed organic materials to depths ~40 cm 3) A cold, wet, dark soil consisting of well-decomposed organic materials to depths ~40 cm
32	None	A complex in which Pergelic Cryoscept (Unit 2) and soils of Unit 3 are in nearly equal amounts
4	Complex of: 1) Hectic Pergelic Cryoscept 2) Pergelic Cryohemist	1) As above 2) A cold, wet, reddish to yellowish soil consisting of little-decomposed fibrous organic materials to depths ~40 cm
5	Pergelic Cryoscept	A cold, somewhat freely drained gravelly soil lacking significant horizon development and generally free of organic matter
6	Pergelic-Bogusic Asceptic Cryoscept	The cold soil of frost heaf areas in which a Cryoscept soil (Unit 2) is intimately associated with and interrupted by a cold, wet, gray and mottled mineral soil lacking any significant organic surface horizon—a Pergelic Cryoscept

Stand type no.	Community	Characteristic microsite
<b>M—Wet sites</b>		
M1	WET Carex aquatilis, Sauregha foliolosa GRAMINOID MEADOW	Wet microsites in acidic tundra areas, primarily associated with aligned hummocks.
M2	WET Carex aquatilis, Drepanocladus brevifolius GRAMINOID MEADOW	Wet polygon centers and troughs, lake margins
M3	WET Carex aquatilis, Diponele fisheri, Calligonum richardsonii GRAMINOID MEADOW	Wet polygon centers in sand dunes region and along Kupuk River
M4	VERY WET Carex aquatilis, Scirpium scopioides GRAMINOID MEADOW	Low wet sites, polygon centers, drained lakes, lake margins
M5	WET Carex aquatilis, Salix rotundifolia STREAM BANK GRAMINOID MEADOW	Moist stream banks
<b>E—Emergent sites</b>		
E1	VERY WET Carex aquatilis GRAMINOID MEADOW	Water to about 30 cm
E2	VERY WET Arctophila fulva GRAMINOID MEADOW	Water to about 300 cm
E3	VERY WET Scirpium scopioides AQUATIC MOSS MEADOW	Water to about 300 cm in sand dunes region
<b>W—Open water</b>		
W1	None	Lakes and ponds
W2	None	Streams and rivers
W3	Varies	Flooded areas caused by roads or pads
<b>D—Disturbed sites</b>		
D1	TYPE of disturbance Bare earth with pioneering species, DRY Briza pappostachya, Legitimium purpureum, Marchantia polymorpha DISTURBANCE COMPLEX	
D2	Foreign gravel or construction debris	
D3	Dust-covered areas adjacent to roads	
D4	Vehicle tracks—deeply rutted	
D5	Vehicle tracks—not deeply rutted	
D6	Winter road	
D7	Excavated areas primarily in river gravels	
W3	Flooded areas caused by roads or pads	
---	Boundary of disturbance	

## Unit (Unit no.)

(Unit no.)

## Landform

Landform

## Code (Unit no.)

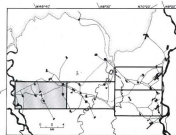
Code (Unit no.)

## Slope range (%)

Slope range (%)

1	High-centered polygons, center-innug contrast <0.5 m	None	0 to 2
2	High-centered polygons, center-innug contrast <0.5 m	1	<2 to 6
3	Low-centered polygons, rim-center contrast <0.5 m	2	>6 to 12
4	Low-centered polygons, rim-center contrast <0.5 m	3	>12 to 20
5	Mixed high- and low-centered polygons in an intricate pattern	4	>20
6	Free bed banks	5	>20
7	Streamgrou and/or large diameter, commonly discontinuous low-centered polygon pattern, little or no microrelief contrast	6	
8	Hummocky terrain associated with steep slopes	7	
9	Heterotaxic patterned ground—slightly convex polygons with hummocky microrelief, hummock-interhummock relief contrast <15 cm	8	
0	Non-patterned ground or with patterned ground covering <20%	9	
P	Frings	0	
A	Hummock	1	
AAA	Slope embankment	2	
*****	Underlain river bank	3	
-----	Excavated	4	
-----	Stream	5	

Roads and Pads



Location of Area 4



## Appendix B: Profiles of the Major Soils

The soil profiles and accompanying chemical analyses which compose this Appendix were selected, usually from many tens of similar profiles, to represent each of the major soils encountered not only within the mapped areas but the Prudhoe Bay region generally (Parkinson 1978). Figure B1 shows the locations of the soil profiles and vegetation plots (Walker, in prep.). It is from such morphological and chemical information that special purpose maps, e.g. peat thickness (Fig. 90), can be developed.

The alphanumeric combinations appearing under the strata in each profile description designate that strata or horizon as follows. Horizons designated O are composed of organic materials. The lower case character indicates the degree of decomposition: O<sub>i</sub> little-decomposed, O<sub>e</sub> partly decomposed, O<sub>a</sub> nearly completely decomposed.

The letter A indicates that the horizon consists of less than 20% organic materials. When it is followed by the number 1 (A1 or A11) the implication is that the organic component is undergoing decomposition to form humus. An underlying A12 horizon is

similar to the A11, but may differ in one or more secondary characters. B horizons are mineral horizons, normally below A horizons, into which clays, humus, iron or aluminum have moved from the A horizon. The B2 horizons of Prudhoe Bay soils are transitional either to overlying A horizons or underlying C horizons. The C horizons represent mineral materials little altered by weathering or biological activity. When the B or C horizons are followed by a subscript (g) it indicates that reducing (gley) conditions occur throughout much or all of the year. Mottles of reddish or yellowish colors are commonly associated. Roman numerals preceding B or C horizons indicate a significant textural change from the overlying horizon. Horizon designations followed by a lower case (f) were frozen at the time of description and sampling.

In site 2, A11 and A12 horizons are followed by (ca), indicating that free carbonates are present in excess of 5% of the volume of the horizon.

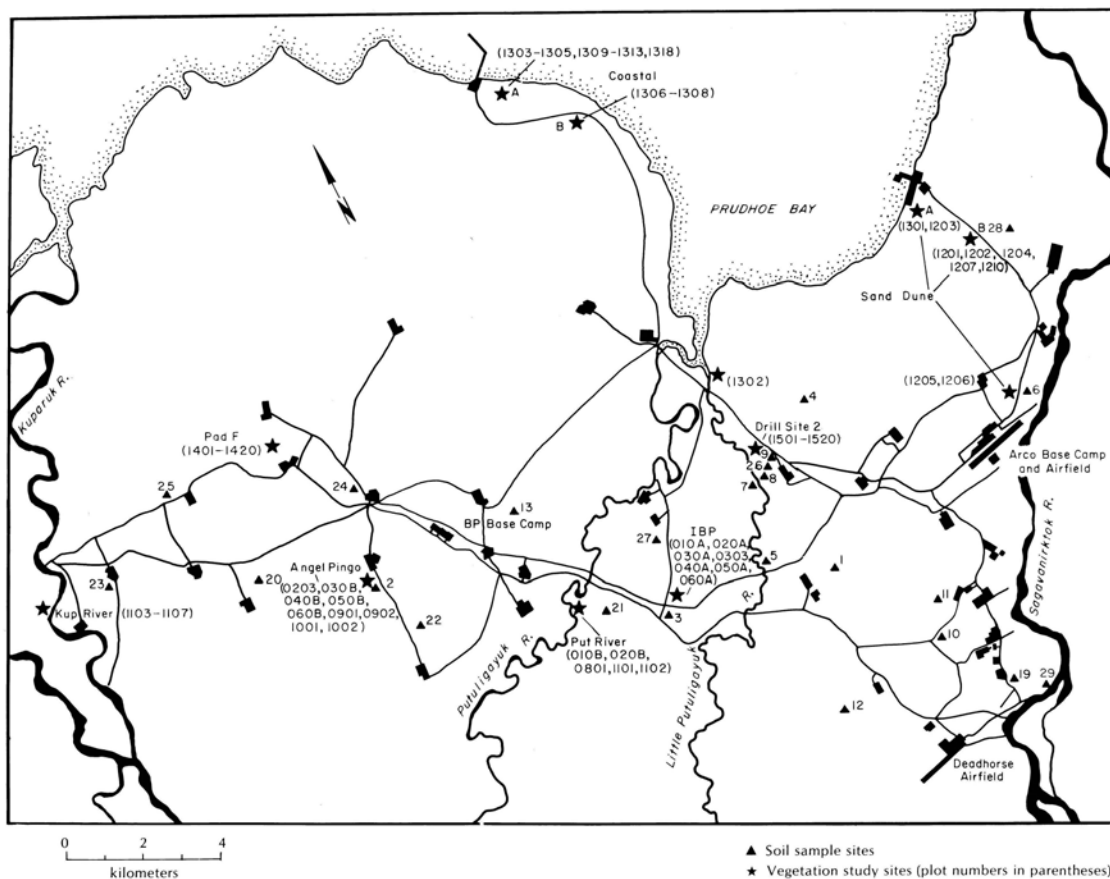


Figure B1. Location of soil and vegetation study sites. Soil profiles are shown on the following pages.



## Site: 2

Location: NW ¼, SE ¼, Sec. 23, T. 11N., R. 13E.

Classification: Pergelic Cryoboroll, sandy-skeletal mixed (calcareous)

Landform: Nonsorted net (earth hummock) on a pingo

Element: Hummock

Parent Material: Organic-rich lacustrine sediment overlying Gubik formation sediment

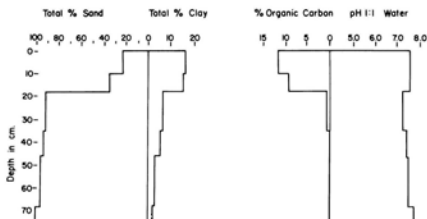
Relief: Macro = 15 m; micro = 10 cm

Slope: 14%

Vegetation: *Dryas integrifolia*, *Cladonia* spp., *Thamnia vermicularis*, *Saxifraga* spp.

Notes: Pit located on shoulder of Angel Pingo summit where differences in microtopographic relief were somewhat depressed due to erosion; permafrost table at 61 cm on 12 July 1974; permafrost table at 104 cm on 2 September 1974.

Horizon	Depth (cm)	Description
A11ca	0-10	Very dusky red (2.5YR 2/2) organic-rich silt loam; moderate coarse granular structure; very friable; white (10YR 8/2) carbonate filaments, occupying about 8% of total volume; thin patchy white (10YR 8/2) carbonate coatings on undersides of gravel; moderately alkaline; slight effervescence; est. 10% gravel; common roots; clear wavy boundary.
A12ca	10-18	Dark brown (7.5YR 3/2) silt loam; moderate fine granular structure; very friable; thin patchy white (10YR 8/2) carbonate coatings on undersides of gravel; mildly alkaline; slight effervescence; est. 14% gravel; few roots; abrupt wavy boundary.
IIC1	18-35	Grayish brown (2.5Y 5/2) sand; single grain; loose; thin patchy dark grayish brown (2.5Y 4/2) silt coatings on upper sides of gravel; thin patchy white (10YR 8/2) carbonate coatings on undersides of gravel; moderately alkaline; slight effervescence; est. 5% gravel; no roots; clear smooth boundary.
IIC2ca	35-46	Grayish brown (2.5Y 5/2) gravelly fine sand; single grain; loose; thin patchy dark grayish brown (2.5Y 4/2) silt coatings on upper sides of gravel; thin patchy white (10YR 8/2) carbonate coatings on undersides of gravel; moderately alkaline; strong effervescence; est. 35% gravel; clear smooth boundary.
IIC3ca	46-61	Grayish brown (2.5Y 5/2) very gravelly sand; single grain; loose; thin patchy dark grayish brown (2.5Y 4/2) silt coatings on the upper sides of gravel; thick patchy white (10YR 8/2) carbonate coatings on the undersides of gravel; moderately alkaline; strong effervescence; est. 80% gravel; abrupt smooth boundary.
IIC4	61-68	Grayish brown (2.5Y 5/2) very gravelly coarse sand; single grain; loose; thin very patchy dark grayish brown (2.5Y 4/2) silt coatings on upper sides of gravel; thin patchy white (10YR 8/2) carbonate coatings on the undersides of gravel; moderately alkaline; slight effervescence; est. 85% gravel; abrupt smooth boundary.
IIC5	68-94	Yellowish brown (10YR 5/4) gravelly coarse sand; single grain; loose; thin patchy white (10YR 8/2) carbonate coatings on undersides of some gravel; strongly alkaline; strong effervescence; est. 35% gravel.



## Site: 5

Location: SE ¼, NW ¼, Sec. 2, T. 10 N., R. 14 E.

Classification: Pergelic Cryaquoll, loamy, mixed (calcareous)

Landform: Slightly convex polygon

Element: Hummock

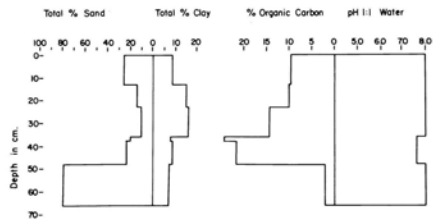
Parent Material: Degraded mineral-rich histice epipedon overlying organic-rich lacustrine sediment

Relief: Macro &lt; 1 m; micro = 13 cm

Slope: 1%

Vegetation: Vascular Plants: *Eriophorum angustifolium*, *Salix reticulata*, *Saxifraga oppositifolia*, *Dryas integrifolia*, *Salix arctica*, *Cassiope tetragona*, *Pedicularis kaneli*, *Mnauaria arctica*, *Chrysanthemum integrifolium*, *Carex aquatilis*, *Carex scirpoides*. Mosses: *Drepanocladus uncinatus*, *Tomenhyphnum nitens*, *Ditrichum flexicaule*, *Ditrichum capillaceum*, *Hypnum pteridium* spp. Lichens: *Thamnia vermicularis*, *Dactylina arctica*, *Lecanora epibryon*, *Cetraria richardsonii*, *Cetraria islandica*, *Rimodina* sp.Notes:  $T_{10\text{ cm}} = 4^\circ\text{C}$ ; Polygon area = 63 m<sup>2</sup>; Center element = 57 m<sup>2</sup> (90%); Trough element = 6 m<sup>2</sup> (10%).

Horizon	Depth (cm)	Description
A11	0-13	Dark brown (7.5YR 3/2) silt loam; moderate very fine granular structure; friable; moderately alkaline; strong effervescence; roots common; clear smooth boundary.
A12	13-23	Dark brown (7.5YR 3/2) silt loam; common fine prominent dark red (2.5YR 3/6) mottles and few fine prominent red (2.5YR 4/8) mottles along root channels; weak medium and coarse platy structure parting to moderate fine granular; friable; moderately alkaline; slight effervescence; roots common; clear smooth boundary.
I1021	23-36	Dark reddish brown (5YR 2/2) finely divided organic matter; moderate medium and coarse platy structure parting to strong medium granular; friable; moderately alkaline; slight effervescence; 2% gravel; roots common; abrupt smooth boundary.
I1022	36-38	Black (10YR 2/1) finely divided organic matter; weak fine platy parting to weak fine granular structure; slightly sticky; mildly alkaline; slight effervescence; abrupt smooth boundary.
I1023f	38-48	Black (10YR 2/1) (wet, thawed); finely divided organic matter; mildly alkaline; slight effervescence; frozen; abrupt wavy boundary.
I11Cf	48-68	Dark gray (5Y 4/1) loamy sand; single grain; moderately alkaline; strong effervescence; est. 10% gravel; frozen, 19 August 1974 est. 40% ice crystals.



## Site: 4

Location: SE ¼, NE ¼, Sec. 25, T. 11N., R. 14E.

Classification: Pergelic Ruptic Aqueptic Cryaquoll, loamy mixed (calcareous)

Landform: Frost bolt tundra

Element: Hummock

Parent Material: Organic-rich lacustrine sediment

Relief: Macro &lt; 1 m; micro = 13 cm

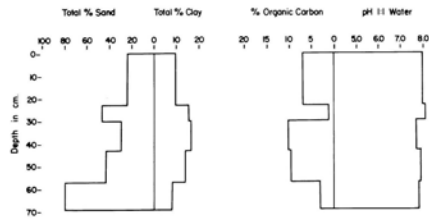
Slope: 1%

Vegetation: *Eriophorum vaginatum*, *Thamnia vermicularis*, *Dryas integrifolia*, moss.

Notes: Permafrost depth ranged from 36 cm to 43 cm in a 23-cm-46-cm pit; permafrost depth was inversely proportional to the thickness of the mollie epipedon; this site located 1.52 m from the frost bolt element. Taxon not currently established. Soils currently recognized as Pergelic Cryaquoll-Pergelic Cryaqueptic complex.

## Part I—Hummock Element

Horizon	Depth (cm)	Description
A1	0-23	Very dark grayish brown (10YR 3/2) (broken face and rubbed) silt loam; few fine prominent yellowish red (5YR 4/6) and few fine distinct strong brown (7.5YR 5/6) mottles along root channels; moderate fine granular structure; friable; moderately alkaline; strong effervescence; common roots; abrupt wavy boundary.
B2g	23-30	Dark grayish brown (2.5Y 4/2) loam; weak medium platy structure; firm; moderately alkaline; strong effervescence; few roots; clear wavy boundary.
IIC1	30-43	Black (10YR 2/1) silt loam; moderate fine granular structure; friable; mildly alkaline; strong effervescence; est. 3% gravel; few roots; abrupt wavy boundary.
IIC2f	43-57	Dark brown (7.5YR 3/2) loam; moderately alkaline; strong effervescence; est. 3% gravel; frozen; abrupt wavy boundary.
IIC3f	57-69	Gray (5Y 5/1) loamy fine sand; mildly alkaline; strong effervescence; est. 3% gravel; frozen, 16 August 1974.

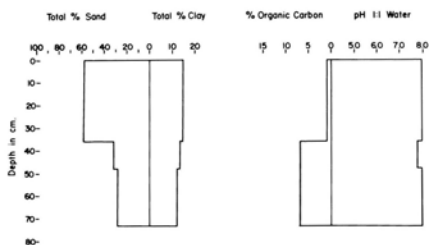




**Site:** 4  
**Location:** SE ¼, NE ¼, Sec. 25, T. 11N., R. 14E.  
**Classification:** Pergelic Ruptic Aqueptic Cryaquoll, loamy mixed (calcareous)  
**Landform:** Frost boil tundra  
**Element:** Frost boil  
**Parent Material:** Organic-rich lacustrine sediment  
**Relief:** Macro < 1 m; micro = 13 cm  
**Slope:** 1%  
**Vegetation:** *Saxifraga oppositifolia*, *Thamnochloa vermicularis*, *Dryas integrifolia*, moss  
**Notes:** Permafrost depth ranged from 48 cm to 56 cm in the 30-cm x 40-cm pit, and was inversely proportional to the thickness of the overlying vegetative mat; (mat thickness ranged from 2 to 6 cm); pit located 1.52 m from the hummock element; taxon not currently established. Soils currently recognized as Pergelic Cryaquoll-Pergelic Cryaquept complex.

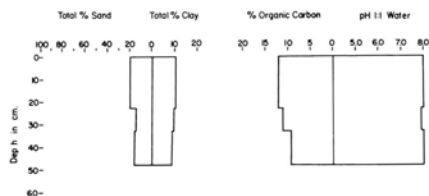
## Part II—Frost Boil Element

Horizon	Depth (cm)	Description
A1	2-0	Very dark brown (10YR 2/2) (broken face) intermediately decomposed plant material; black (10YR 2/1) (rubbed and pressed); massive; friable; moderately alkaline; strong effervescence; abrupt wavy boundary
B2g	0-36	Olive gray (5Y 4/2) loam; common fine distinct yellowish brown (10YR 5/4) and dark gray (5Y 4/1) mottles; weak medium platy structure; firm; yellowish red (5YR 5/6) mottles along root channels from 0 to 8 cm; moderately alkaline; strong effervescence; few roots; abrupt wavy boundary.
IIC1	36-48	Black (10YR 2/1) silt loam; moderate fine granular structure; friable; mildly alkaline; strong effervescence; few roots; abrupt smooth boundary.
IIC2f	48-73	Very dark grayish brown (10YR 3/2) silt loam; moderately alkaline; strong effervescence; est. 3% gravel; frozen, 16 August 1974.



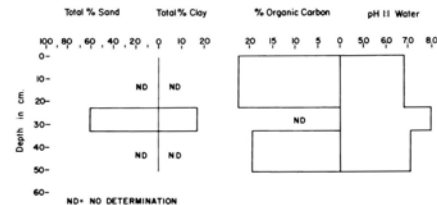
**Site:** 1  
**Location:** SW ¼, SW ¼, Sec. 1, T. 10N., R. 14E.  
**Classification:** Histlic Pergelic Cryaquept, loamy mixed (calcareous)  
**Landform:** Low-centered polygon  
**Element:** Center  
**Parent Material:** Organic mat overlying organic rich lacustrine sediment  
**Relief:** Macro < 1 m; micro = 18 cm  
**Slope:** 1%  
**Vegetation:** *Carex aquatilis*, *Drepanocladus* sp.  
**Notes:** Polygon area = 120 m<sup>2</sup>; Rims = 24 m<sup>2</sup> (20%); Troughs = 12 m<sup>2</sup> (10%); Center = 84 m<sup>2</sup> (70%);  $T_{air}$  = 2°C;  $T_{10\text{ cm}}$  = 2°C.

Horizon	Depth (cm)	Description
O1	0-23	Very dark brown (10YR 2/2) (broken face and rubbed and pressed) moderately decomposed organic material (est. 60% fiber broken, 40% fiber, rubbed); weak medium platy structure, nonsticky; moderately alkaline; strong effervescence; many roots; abrupt smooth boundary.
IIC1	23-33	Very dark gray (10YR 3/1) silt loam; weak coarse platy structure; slightly sticky; moderately alkaline; slight effervescence; few roots; abrupt smooth boundary.
IIC2f	33-48	Very dark gray (10YR 3/1) silt loam; moderately alkaline; strong effervescence; frozen, 19 August 1974.



**Site:** 24  
**Location:** SW ¼, NW ¼, Sec. 13, T. 11N., R. 13E.  
**Classification:** Pergelic Cryofibrist, euic  
**Landform:** Aligned hummock terrain  
**Parent Material:** Organic material overlying lacustrine sediment  
**Relief:** Macro < 1 m; micro = 15 cm  
**Slope:** 0%  
**Vegetation:** *Scorpidium scorpioides*, *Carex aquatilis* and scattered *Pedicularis* spp.  
**Notes:**  $T_{air}$  = 6°C;  $T_{10\text{ cm}}$  = 4°C; Water table at surface.

Horizon	Depth (cm)	Description
O1i	0-23	Dark yellowish brown (10YR 3/4) unrubbed, very dark grayish brown (10YR 3/2) rubbed fibric material composed of sedge; about 85% fibers, 80% after rubbing; weak, coarse platy structure (6 mm thick); nonsticky; neutral; slight effervescence at surface; many roots; abrupt smooth boundary.
IIC1	23-33	Dark gray (7.5YR N 4/ ) fine sandy loam; weak, coarse platy structure; slightly sticky; moderately alkaline; strong effervescence; est. 7% gravel; few roots; abrupt smooth boundary.
IIC2f	33-51	Very dark grayish brown (10YR 3/2) fibric material composed of sedge; about 80% fibers, 75% after rubbing; sand lenses at lower depths; neutral; slight effervescence; est. 1% gravel; frozen.





## Site: 29

Location: SW¼, SW¼, Sec. 20, T. 10N., R. 15E.

Classification: Pergelic Cryorthent, sandy-skeletal, mixed (calcareous)

Landform: Floodplain—Sagavanirktok River

Parent Material: Alluvium

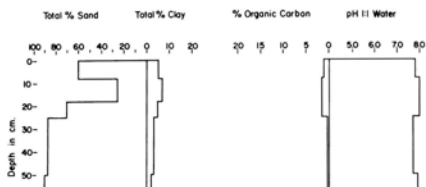
Relief: Less than 1 m

Slope: Less than 1%

Notes: Floodplain was being extensively mined for construction aggregate; pedon located in a slightly concave position.

 $T_{air} = 5^{\circ}\text{C}$ ;  $T_{10\text{ cm}} = 4^{\circ}\text{C}$ ; No free water in pit.

Horizon	Depth (cm)	Description
C1	0-8	Dark grayish brown (2.5Y 4/2) very fine sandy loam interbedded with lenses of fine and medium sand; depositional platy structure; common medium distinct yellowish red (5YR 5/8) mottles and few fine distinct yellowish brown (10YR 5/4) mottles; very friable; mildly alkaline; strong effervescence; est. 2% gravel; common roots; abrupt smooth boundary.
C2	8-18	Dark grayish brown (2.5Y 4/2) silt loam; moderate medium platy depositional structure; few fine distinct strong brown (7.5YR 5/6) mottles; discontinuous very dark brown (10YR 2/2) bands of organic residue (3 mm thick) occurring at 6-mm depth intervals; friable; moderately alkaline; strong effervescence; few roots; abrupt smooth boundary.
IIC3	18-25	Dark grayish brown (2.5Y 4/2) fine sandy loam; weak, coarse platy depositional structure; very friable; moderately alkaline; strong effervescence; est. 3% gravel; few roots; abrupt smooth boundary.
IIIC4	25-50	Dark grayish brown (10YR 4/2) very gravelly coarse sand; single grain; loose; mildly alkaline; strong effervescence; est. 55% gravel; abrupt smooth boundary.
IIIC5f	50-75	Dark grayish brown (10YR 4/2) very gravelly coarse sand; moderately alkaline; strong effervescence; est. 55% gravel; frozen, 3 August 1975.



## Site: 22

Location: SW¼, SW¼, Sec. 25, T. 11N., R. 15E.

Classification: Pergelic Cryohemist, euc

Landform: Low-centered polygon

Element: Center

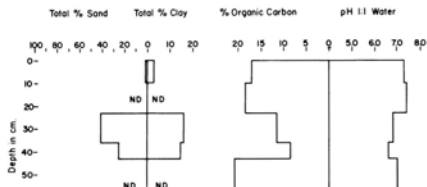
Parent Material: Organic (sedge) overlying organic-rich lacustrine sediment

Relief: Macro &lt; 1 m; micro = 25 cm

Slope: 1%

Notes: Polygon area = 236 m<sup>2</sup>; Center element = 129 m<sup>2</sup> (55%).

Horizon	Depth (cm)	Description
Oe1	0-10	Very dark grayish brown (10YR 3/2) hemic material composed of sedge; about 60% fibers, 35% after rubbing; weak medium platy structure (4 mm thick); light gray (10YR 7/2) band of carbonates at surface and grayish brown (10YR 5/2) band of carbonate at 10 cm; appreciable silt content; neutral; slight effervescence; many roots; clear smooth boundary.
Oe2	10-23	Very dark grayish brown (10YR 3/2) hemic material composed of sedge; about 55% fibers, 30% after rubbing; moderate medium platy structure (5 mm thick); appreciable silt content; mildly alkaline; slight effervescence; many roots, abrupt smooth boundary.
IIC1	23-36	Very dark grayish brown (10YR 3/2) organic-rich loam; weak, very coarse platy structure; slightly sticky; neutral; est. 5% gravel; few roots; abrupt smooth boundary.
IIC2f	36-43	Very dark grayish brown (10YR 3/2) silt loam; neutral; est. 3% gravel; frozen.
Oa1f	43-61	Very dark brown (10YR 2/2) sapric material; less than 10% fibers and a trace after rubbing; neutral; est. 2% gravel; frozen, 8 August 1975.



## Site: 7

Location: NE¼, NE¼, Sec. 35, T. 11N., R. 14E.

Classification: Pergelic Cryosaprist, euc

Landform: Low-centered polygon

Element: Rim

Parent Material: Sedge peat overlying organic-rich lacustrine sediments

Relief: Macro &lt; 1 m; micro = 23 cm

Slope: 1%

Notes: Polygon area = 273 m<sup>2</sup>; Rim area = 122 m<sup>2</sup> (44%).

Horizon	Depth (cm)	Description
Oa1	0-5	Very dark brown (10YR 2/2) unrubbed and rubbed and pressed sapric material; 60% fiber, 8% rubbed; weak, fine platy structure; friable; mildly alkaline; strongly effervescent; many roots; abrupt smooth boundary.
Oa2	5-8	Very dark brown (10YR 2/2) sapric material; weak, very fine granular structure; friable; mildly alkaline; strongly effervescent; roots common; abrupt wavy boundary.
IIC1	8-11	Dark gray (5Y 4/1) fine sandy loam; weak, coarse platy structure; very friable; mildly alkaline; strongly effervescent; few roots; clear wavy boundary.
Oe1	11-18	Very dark grayish brown (10YR 3/2) hemic material composed of moss parts; weak medium platy structure; very friable; mildly alkaline; strongly effervescent; abrupt wavy boundary.
Oa3	18-28	Black (10YR 2/1) sapric material; weak, coarse platy structure; friable; appreciable silt loam content; neutral; slightly effervescent; abrupt smooth boundary.
Oa4f	28-53	Very dark brown (10YR 2/2) sapric material; neutral; slightly effervescent; est. 3% gravel; frozen, 16 July 1975.

