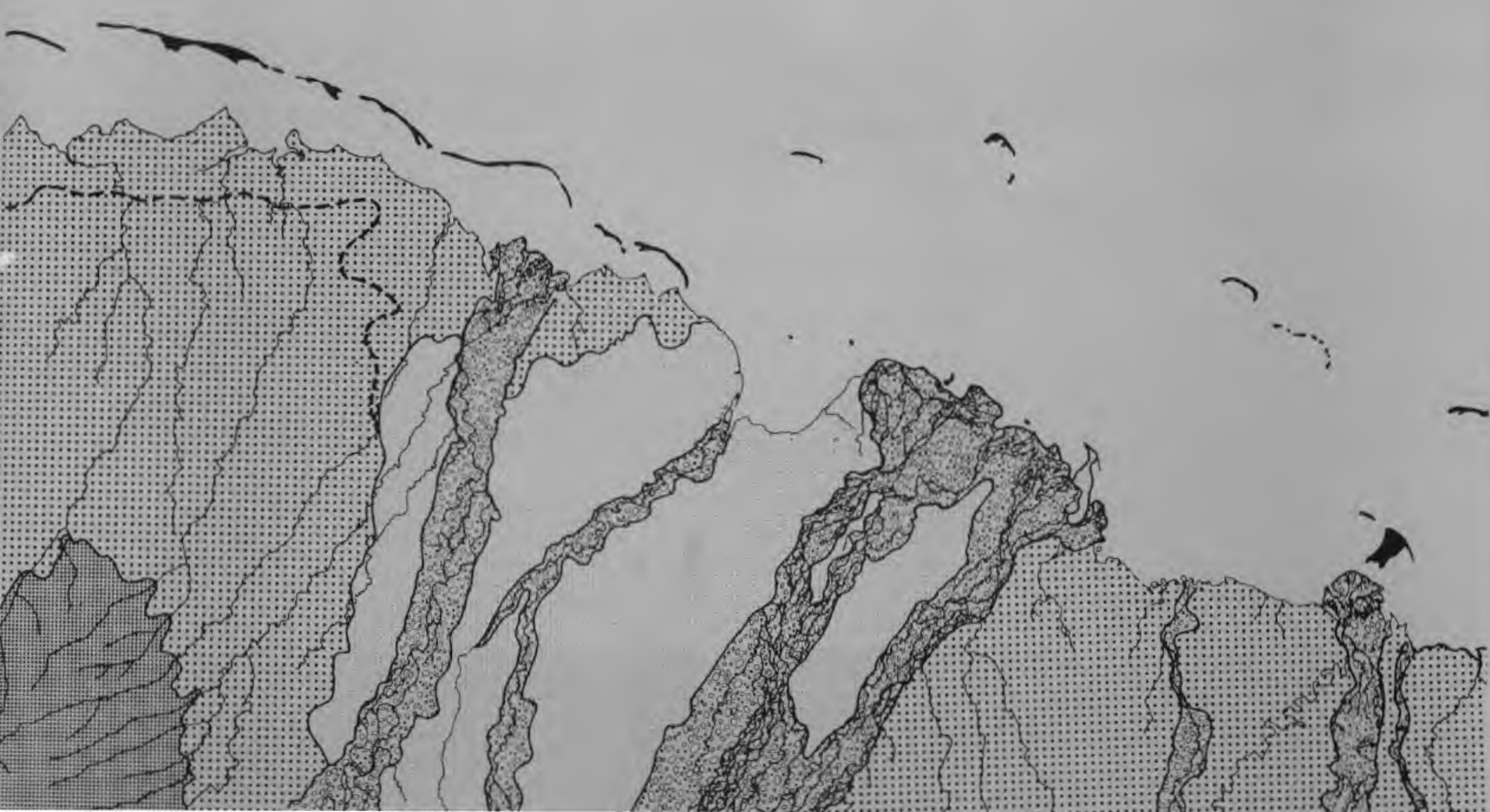
CRREL

# REPORT 87-5

US Army Corps of Engineers

Cold Regions Research & Engineering Laboratory

# *Vegetation and a Landsat-derived land cover map of the Beechey Point Quadrangle, Arctic Coastal Plain, Alaska*



CRREL Report 87-5

April 1987

# *Vegetation and a Landsat-derived land cover map of the Beechey Point Quadrangle, Arctic Coastal Plain, Alaska*

Donald A. Walker and William Acevedo

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

# REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188
Exp. Date Jun 30, 1986

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION<br>Unclassified | 1b. RESTRICTIVE MARKINGS |
| 2a. SECURITY CLASSIFICATION AUTHORITY<br>2b. DECLASSIFICATION / DOWNGRADING SCHEDULE | 3. DISTRIBUTION / AVAILABILITY OF REPORT<br>Approved for public release; distribution is unlimited. |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S) | 5. MONITORING ORGANIZATION REPORT NUMBER(S)<br>CRREL Report 87-5 |
| 6a. NAME OF PERFORMING ORGANIZATION<br>Institute of Arctic and Alpine Research<br>6b. OFFICE SYMBOL *(If applicable)* | 7a. NAME OF MONITORING ORGANIZATION<br>U.S. Army Cold Regions Research and Engineering Laboratory |
| 6c. ADDRESS *(City, State, and ZIP Code)*<br>University of Colorado<br>Boulder, Colorado | 7b. ADDRESS *(City, State, and ZIP Code)*<br>72 Lyme Road<br>Hanover, N.H. 03755-1290 |
| 8a. NAME OF FUNDING / SPONSORING ORGANIZATION<br>8b. OFFICE SYMBOL *(If applicable)* | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER<br>DACA89-81-K-0006 |
| 8c. ADDRESS *(City, State, and ZIP Code)* | 10. SOURCE OF FUNDING NUMBERS<br>PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO. |

11. TITLE *(Include Security Classification)*
VEGETATION AND A LANDSAT-DERIVED LAND COVER MAP OF THE BEECHEY POINT QUADRANGLE, ARCTIC COASTAL PLAIN, ALASKA

12. PERSONAL AUTHOR(S)
Walker, Donald A. and Acevedo, Wililam

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT *(Year, Month, Day)* | 15. PAGE COUNT |
|---|---|---|---|
| | FROM ______ TO ______ | April 1987 | 72 |

16. SUPPLEMENTARY NOTATION

| 17. COSATI CODES | | | 18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)* | |
|---|---|---|---|---|
| FIELD | GROUP | SUB-GROUP | Geobotanical mapping | Prudhoe Bay |
| | | | Landsat | Tundra |
| | | | Mapping | Vegetation classification |

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

This report presents a Landsat-derived land cover classification of the Beechey Point, Alaska, 1:250,000-scale quadrangle with descriptions of the major vegetation units. Eight Landsat-level units derived from multispectral scanner data, eleven photo-interpreted units, and eight common vegetation complexes are described and illustrated. Procedures of Landsat analysis, field methods, and cartographic methods are described. The region is divided into four landscape units: flat thaw-lake plains, gently rolling thaw-lake plains, hills, and flood plains. Area analysis of the quadrangle was done according to townships and nine small study areas. The map uses a modified version of the hierarchical tundra mapping classification of Walker (1983). Area-measurement data from geobotanical maps at eight study sites are compared with similar data from Landsat maps of the same sites. The results indicate that Landsat maps yield area measurements corresponding to broad geobotanical categories.

| | |
|---|---|
| 20. DISTRIBUTION / AVAILABILITY OF ABSTRACT<br>☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS | 21. ABSTRACT SECURITY CLASSIFICATION<br>Unclassified |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL<br>D.A. Walker | 22b. TELEPHONE *(Include Area Code)*<br>(303) 492-7303<br>22c. OFFICE SYMBOL |

**DD FORM 1473,** 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

## PREFACE

This report was prepared by Dr. Donald A. Walker, Plant Ecologist, Institute of Arctic and Alpine Research (INSTAAR), University of Colorado; and William Acevedo, Senior Data Analyst, Technicolor Government Services, NASA Ames Research Center. Numerous individuals helped considerably in this work. Dr. K.R. Everett, Professor, Institute of Polar Studies, The Ohio State University, accompanied the authors on most of the aerial surveys and helped with interpretation of the landscapes. Leonard Gaydos, Chief, Geographic Investigations Office, U.S. Geological Survey (USGS), NASA Ames Research Center, helped define the objectives of the work and secured funds for William Acevedo's participation. Dr. Patrick J. Webber, Professor and former Director of INSTAAR, University of Colorado, encouraged the strong link between Landsat and accurate reference data and obtained the INSTAAR funds necessary for this research. The project was supervised by Dr. Jerry Brown, formerly of CRREL.

James R. Wray, USGS, Reston, Virginia, was responsible for designing the Landsat cover map. Numerous individuals contributed to the field surveys, including Katie Palmer, Ken Bowman and Jane Westlye. Nan Lederer helped extensively during the data and manuscript preparation.

Primary support for this work came from CRREL under Contract No. DACA89-81-K-0006. This contract included support from the Department of Energy (DOE) and the U.S. Geological Survey National Petroleum Reserve–Alaska programs. Extensive use was made of the Image Processing Facility maintained by the Ecosystem Science and Technology Office at the NASA Ames Research Center. Part of the ground-reference data cited in this report was collected during vegetation mapping contracts to INSTAAR performed for SOHIO Alaska Petroleum Co. and ARCO Alaska, Inc. The authors thank all the individuals and companies in the Prudhoe Bay region who have helped with logistics and the field work. The North Slope Borough contributed with helicopter support and lodging space at Prudhoe Bay.

Reviewers of this manuscript were Dorothy K. Hall, Hydrological Science Branch, Goddard Space Flight Center; Stuart Rawlinson, Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys; Leslie Morrissey, Technicolor Government Services, NASA Ames Research Center; and Helene Wilson, Goddard Space Flight Center.

**CONTENTS**



**ILLUSTRATIONS**

Figure | Page

## TABLES

# Vegetation and A Landsat-Derived Land Cover Map of the Beechey Point Quadrangle, Arctic Coastal Plain, Alaska

DONALD A. WALKER AND WILLIAM ACEVEDO

## INTRODUCTION

Analyses of Landsat multispectral scanner (MSS) data are providing an economical means of mapping the large expanses of terrain in northern Alaska. This paper describes the vegetation of the Beechey Point Quadrangle and explains a comprehensive approach to making Landsat-derived vegetation maps of arctic tundra. The approach includes a rapid means of obtaining ground-reference data using helicopters. The method also uses a hierarchical classification scheme developed specifically for tundra vegetation. A major objective of this research was to examine the correspondence of areas of vegetation types on 1:6000-scale geobotanical maps with those on Landsat-derived maps of the same areas, and to modify the hierarchical scheme based on the results.

Landsat-derived land cover maps have numerous advantages for 1:250,000-scale mapping programs. For example, 1:250,000-scale maps produced by photointerpretation rarely have a resolution of less than 16 ha (40 acres). The 0.45-ha (1.1-acre) resolution of Landsat preserves much of the complexity of arctic tundra vegetation patterns. This is important for practical application of the maps to arctic land-use planning. Other advantages include continuous temporal coverage and moderate cost compared to photointerpretive approaches. The methods also allow consistent classification across broad regions based on spectral reflectance. These are advantages in rapidly developing regions such as Prudhoe Bay where new maps are continually required for planning new developments and monitoring environmental changes.

The Alaskan Arctic Coastal Plain has three characteristics that make it particularly suitable for using Landsat technology to map vegetation:

- The major vegetation types are related to environmental gradients that are predictable from the spectral information.
- The vegetation of the region is low-growing tundra with no trees; thus, the ground cover is readily visible by satellite sensors.
- The region is flat with few topographically produced shadows that could modify the spectral signatures of specific vegetation types.

Landsat-assisted mapping has been tried in several areas of northern Alaska (Lent and LaPerriere 1974, Belon et al. 1975, George et al. 1977, Nodler and LaPerriere 1977, Lyon and George 1979, Morrissey and Ennis 1981). Landsat applications in arctic Canada have been reviewed by Harvie et al. (1982) and Rubec (1983). Generally these efforts have been based on only small amounts of ground-reference data. The classification presented here was developed with the aid of an extensive terrain data base for the Prudhoe Bay region and a well-supported helicopter survey of remote areas of the Beechey Point Quadrangle.

This report is divided into two main sections. The first part is a description of the region, including detailed descriptions of the Landsat- and photointerpreted vegetation map units. The second section describes the methods of Landsat analysis, field procedures, and cartographic procedures. This section also compares vegetation area measurements from the Landsat- and photo-derived maps.

## GENERAL DESCRIPTION OF THE REGION

### Physiography

The terrain of the Beechey Point Quadrangle (Fig. 1) is for the most part a classic example of an oriented-thaw-lake landscape. Most of the area is part of the Teshekpuk Section of the Arctic Coastal Plain physiographic province (Wahrhaftig 1965) and is exceedingly flat and wet. Small areas in the southeast and southwest parts of the quadrangle are part of the White Hills Section (Wahrhaftig 1965) and are better drained. For purposes of this discussion, the quadrangle is divided into four major landscape units: flat thaw-lake plains, gently rolling thaw-lake plains, hills, and river flood plains (Fig. 2). Descriptions of the terrain within the Prudhoe Bay oil field can be found in Walker et al. (1980), Rawlinson (1984) and Walker (1985).

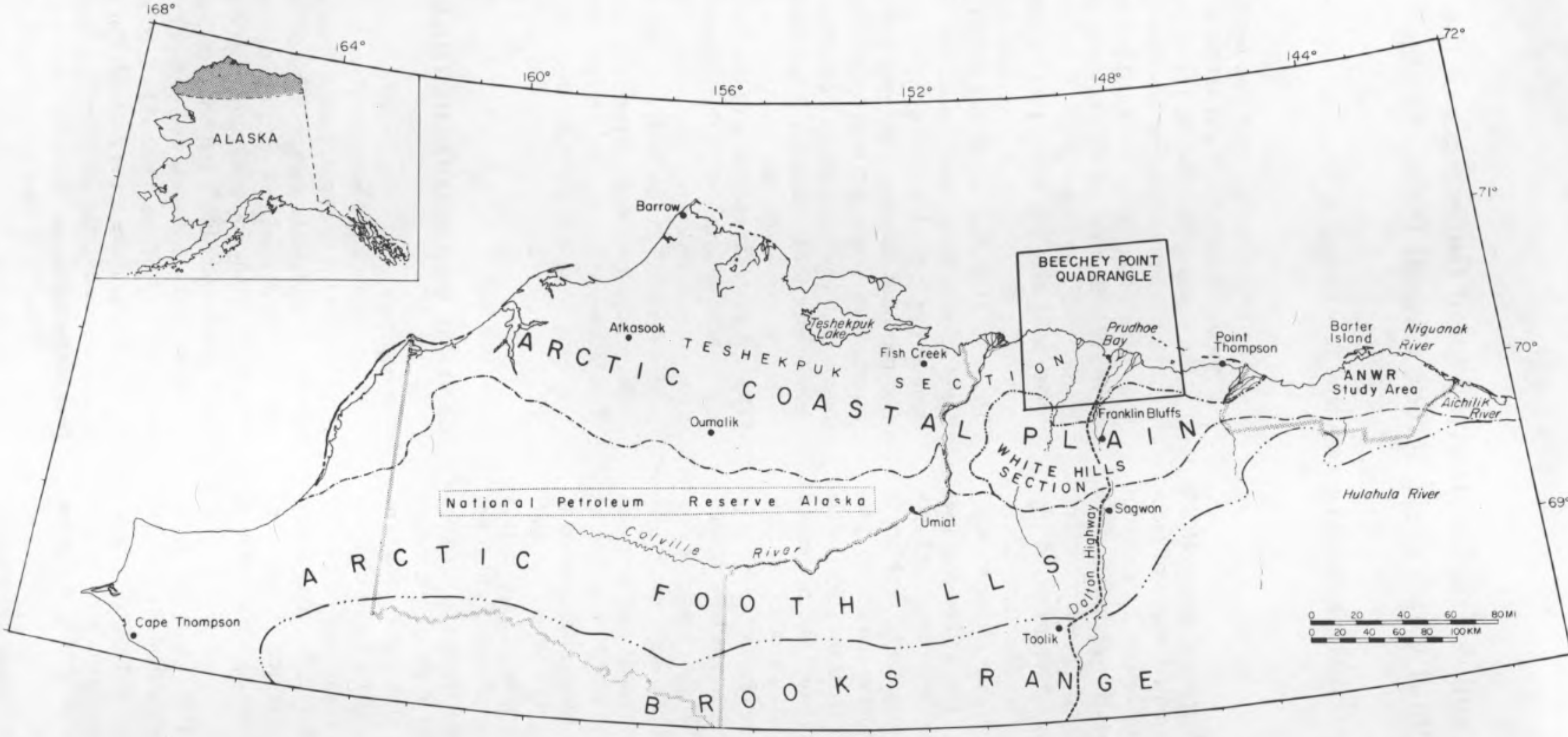



*Figure 1. Location of the Beechey Point Quadrangle. Boundaries of the physiographic provinces and sections follow Wahrhaftig (1965). Place names are those that appear in the text of this report.*

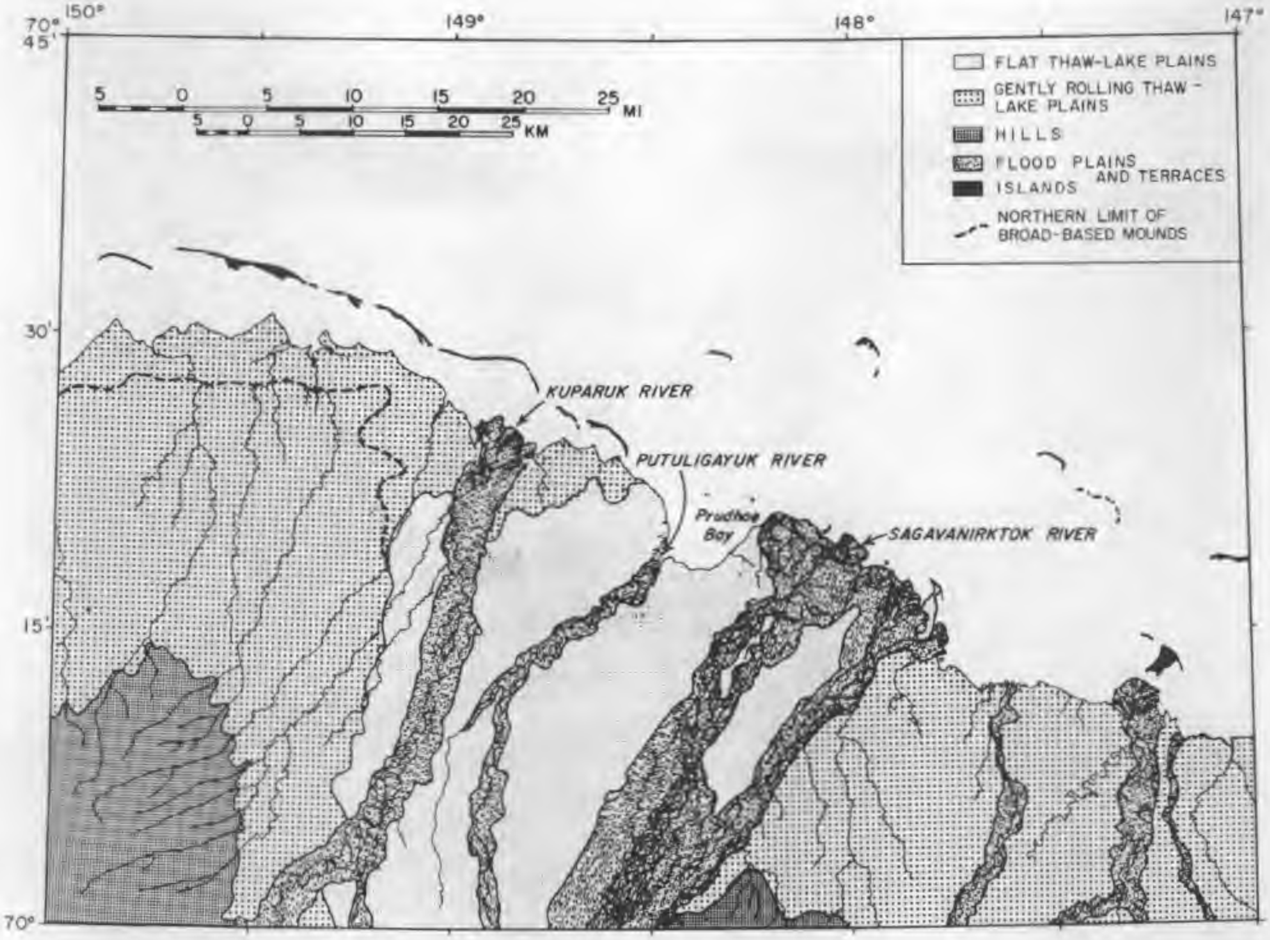



*Figure 2. Landscape units of the Beechey Point Quadrangle. Descriptions of the various units are given in the text.*

*Flat thaw-lake plains*

The flat thaw-lake plains are primarily old alluvial surfaces that are now covered by oriented thaw lakes and drained thaw-lake basins (Fig. 3). Areas between lakes are flat and generally wet with expanses of pond complexes, strangmoor and low-centered ice-wedge polygons. The shallow thaw (20–100 cm by late August) is responsible for much of the wetness of the landscape because there is little subsurface drainage. Surface relief over most of this area is less than 2 m, but local differences of 6–18 m are encountered at pingos and along some of the larger streams.

The flat thaw-lake plains occur primarily between the Sagavanirktok and Kuparuk rivers. This region is largely a glacio-fluvial outwash plain of the Sagavanirktok, Putuligayuk and Kuparuk rivers that likely formed during the period of high discharge that accompanied the sudden melting of the glaciers in the Brooks Range at the end of the last glaciation. Hamilton (1982) dates the deglaciation of the upper valleys of the central Brooks Range at about 11,800 years B.P. Several obscure low terraces of these rivers are visible on Landsat satellite images and aerial photographs of the region. Thaw lakes have probably been reworking the flat thaw-lake plain since shortly after the abandonment of the ancient river channels.

Many of these lakes are oriented along a N10°W axis (Cannon and Rawlinson 1979). This orientation has been attributed to prevailing winds that blow from the northeast at nearly right angles to the axis (Black and Barksdale 1949, Hopkins 1949, Carson and Hussey 1962). There are innumerable drained and partially drained lake basins that control surface runoff patterns. Drained lake basins often have complex microtopographies with ice-wedge polygons, systems of disjunct polygon rims, and small aligned hummocks. Numerous small tundra streams with poorly defined drainage systems meander between the lakes. Interlake areas are dominated by frost scars and ice-

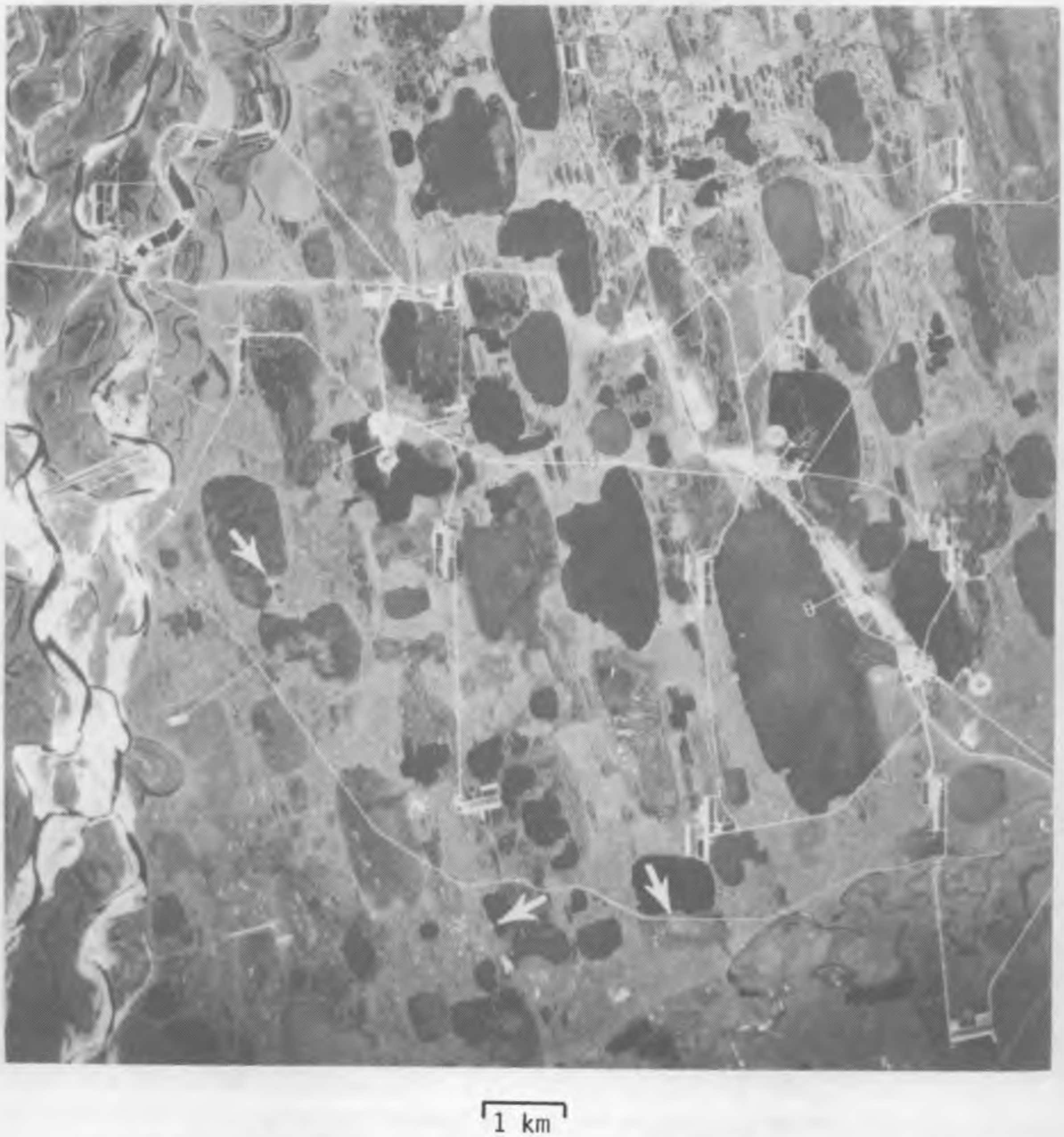



*Figure 3. Flat thaw-lake plains within the Prudhoe Bay oil field. Note the very wet landscape between thaw lakes and the complex terrain that forms in partially drained lake basins. Numerous steep-sided pingos (arrows) are also evident. Most of the roads lead to drill pads and oil field facilities. The Sohio base camp is on the large pad to the east of the largest lake. The Kuparuk River is the large braided river to the west, and the Putuligayuk River is the small stream cutting across the southeast corner of the photo. (NASA Flight 82-12, photo no. 9807.)*

wedge polygons of varying character (Everett 1980a).

*Gently rolling thaw-lake plains*

West of the Kuparuk River and east of the Sagavanirktok River the topography is slightly more rolling than in the flat thaw-lake areas (Fig. 4). The gentle hilly aspect is due mainly to many mounds, which cover a large percentage of the interlake areas. Recent drilling of these mounds indicates that at least some of the larger mounds contain massive ice and are thus pingos (Walker et al. 1985). The broad-based mounds are considerably larger and have gentler slopes than the steep-

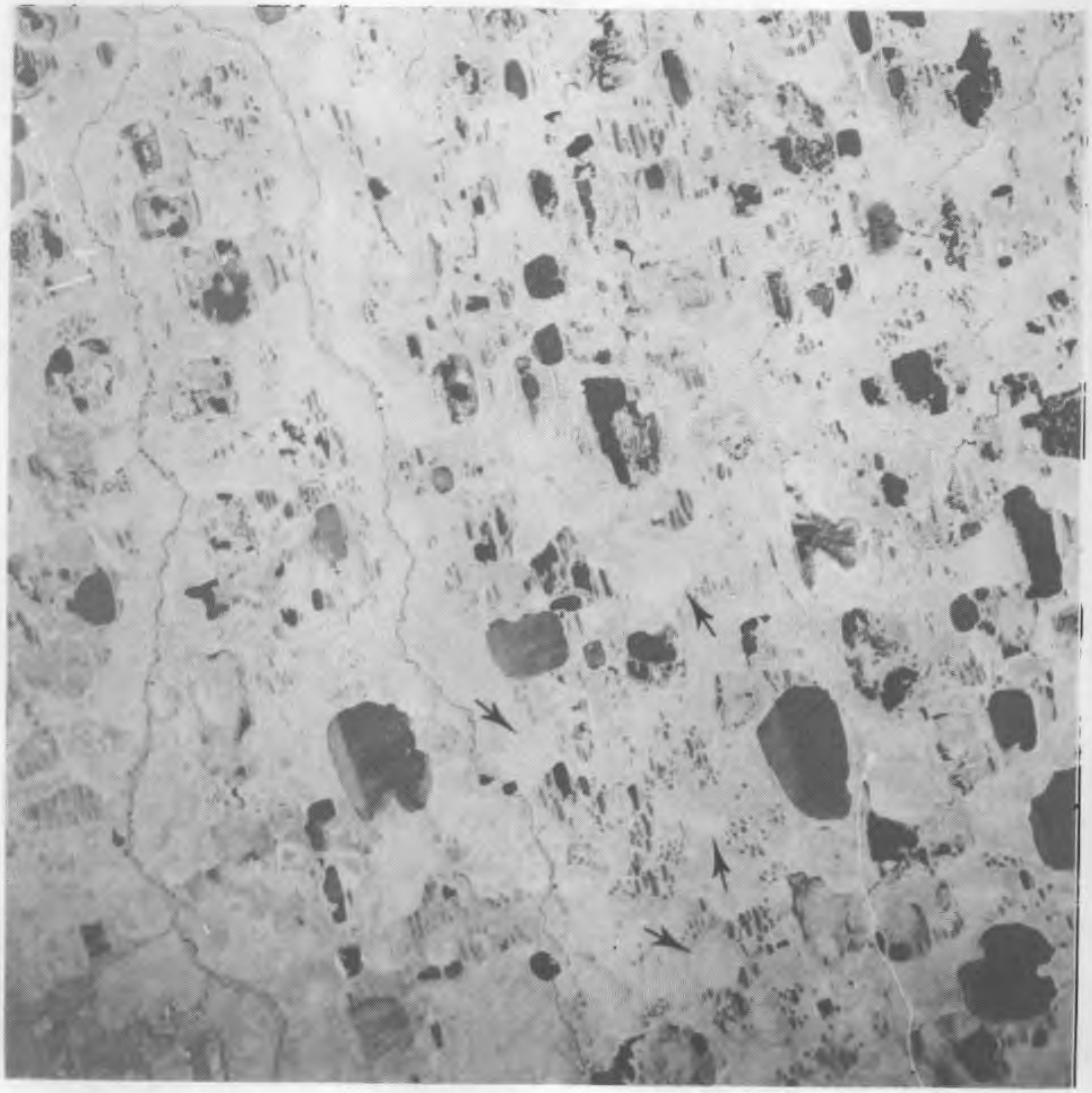



*Figure 4. Gently rolling thaw-lake plains west of the Kadleroshilik River. Note the well-drained surfaces associated with streams and numerous broad-based pingos (arrows). (NASA Flight 79-097, photo no. 2492.)*

sided pingos that are common across much of the coastal plain (for example, Carter and Galloway 1979). Figure 5 shows the distribution of steep-sided pingos and broad-based pingos with respect to the landscape units within the Beechey Point Quadrangle. The broad-based pingos can exceed 15 m high, but most are lower.

The broad-based mounds have a northern limit several kilometers south of the present-day coastline (Fig. 2); the boundary in part follows a marine terrace that is possibly of Flaxman age (Rawlinson, in press). Another possibility is that this boundary follows faults.* Near the coast the gently rolling character is even more subdued and approaches the flatness of the flat thaw-lake plains.

* Personal communication with S.E. Rawlinson, Alaska Dept. of Natural Resources, 1985.

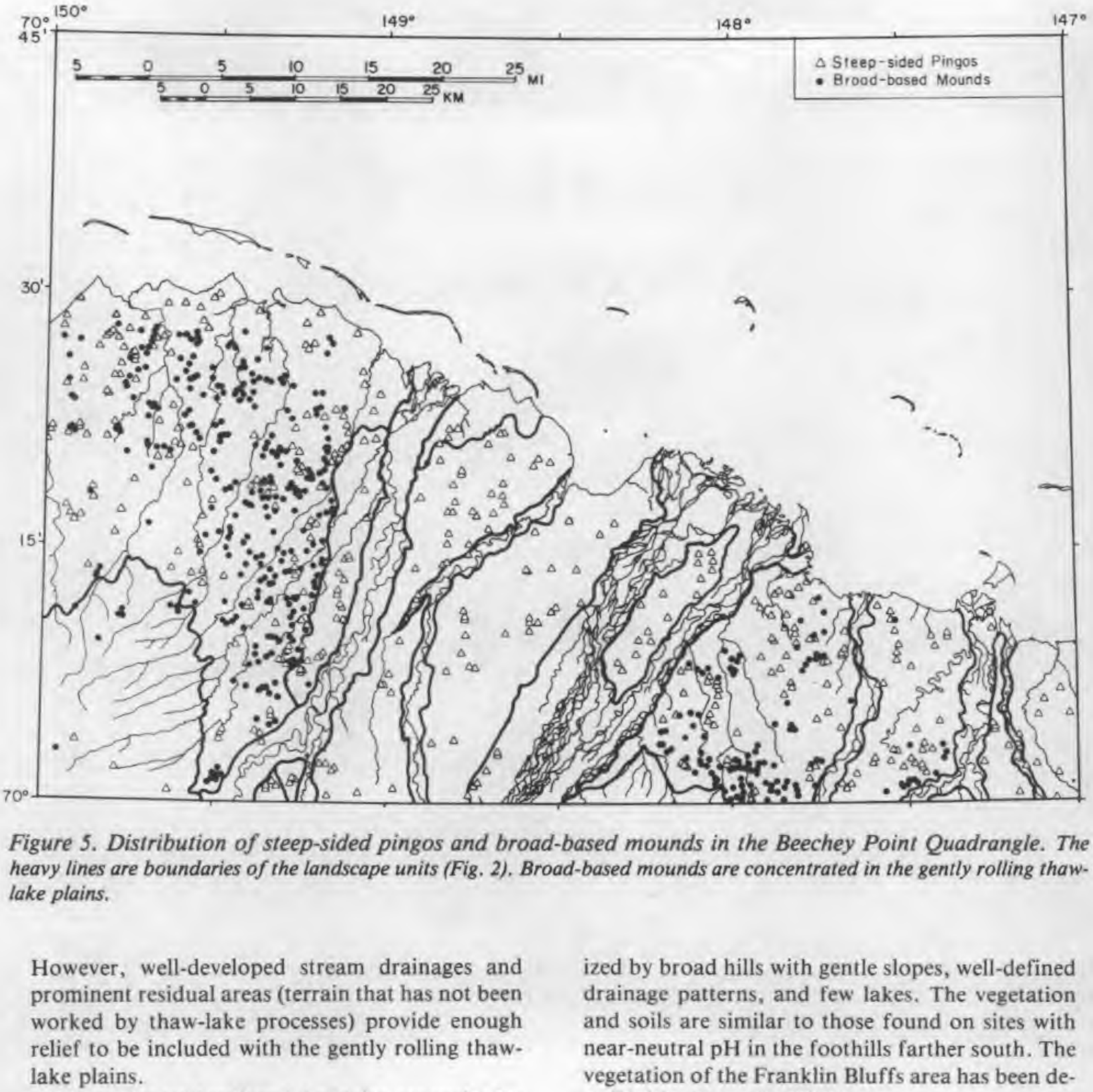



*Figure 5. Distribution of steep-sided pingos and broad-based mounds in the Beechey Point Quadrangle. The heavy lines are boundaries of the landscape units (Fig. 2). Broad-based mounds are concentrated in the gently rolling thaw-lake plains.*

However, well-developed stream drainages and prominent residual areas (terrain that has not been worked by thaw-lake processes) provide enough relief to be included with the gently rolling thaw-lake plains.

The gently rolling thaw lake plains are undoubtedly older than the flat thaw-lake plains. According to Rawlinson (in press) the surficial deposits of the gently rolling thaw-lake plains are covered with eolian sands deposited during the middle and late Wisconsinan.

*Hills*

Areas of hilly terrain occur in the southwest and southeast portions of the quadrangle (Fig. 2 and 6). The area to the southwest is a gently rolling outlier of the White Hills. The area to the southeast is associated with Franklin Bluffs and has more relief and better-drained tussock tundra than the area to the southwest. The terrain is characterized by broad hills with gentle slopes, well-defined drainage patterns, and few lakes. The vegetation and soils are similar to those found on sites with near-neutral pH in the foothills farther south. The vegetation of the Franklin Bluffs area has been described by Koranda (1960).

*Flood plains and terraces*

Flood plain and terrace terrain (Fig. 7) is associated with numerous streams and rivers that flow northward to the Beaufort Sea. The four largest rivers—the Sagavanirktok, Kuparuk, Kadleroshilik and Shaviovik—are extensively braided. The Sagavanirktok River is the largest and has a delta system that is about 20 km across at its mouth. Mud flats, island complexes and sand dunes are part of the delta. The Sagavanirktok River divides at the north end of the Franklin Bluffs and flows from there in two distinct channels. Numerous other streams have meandering unbraided chan-

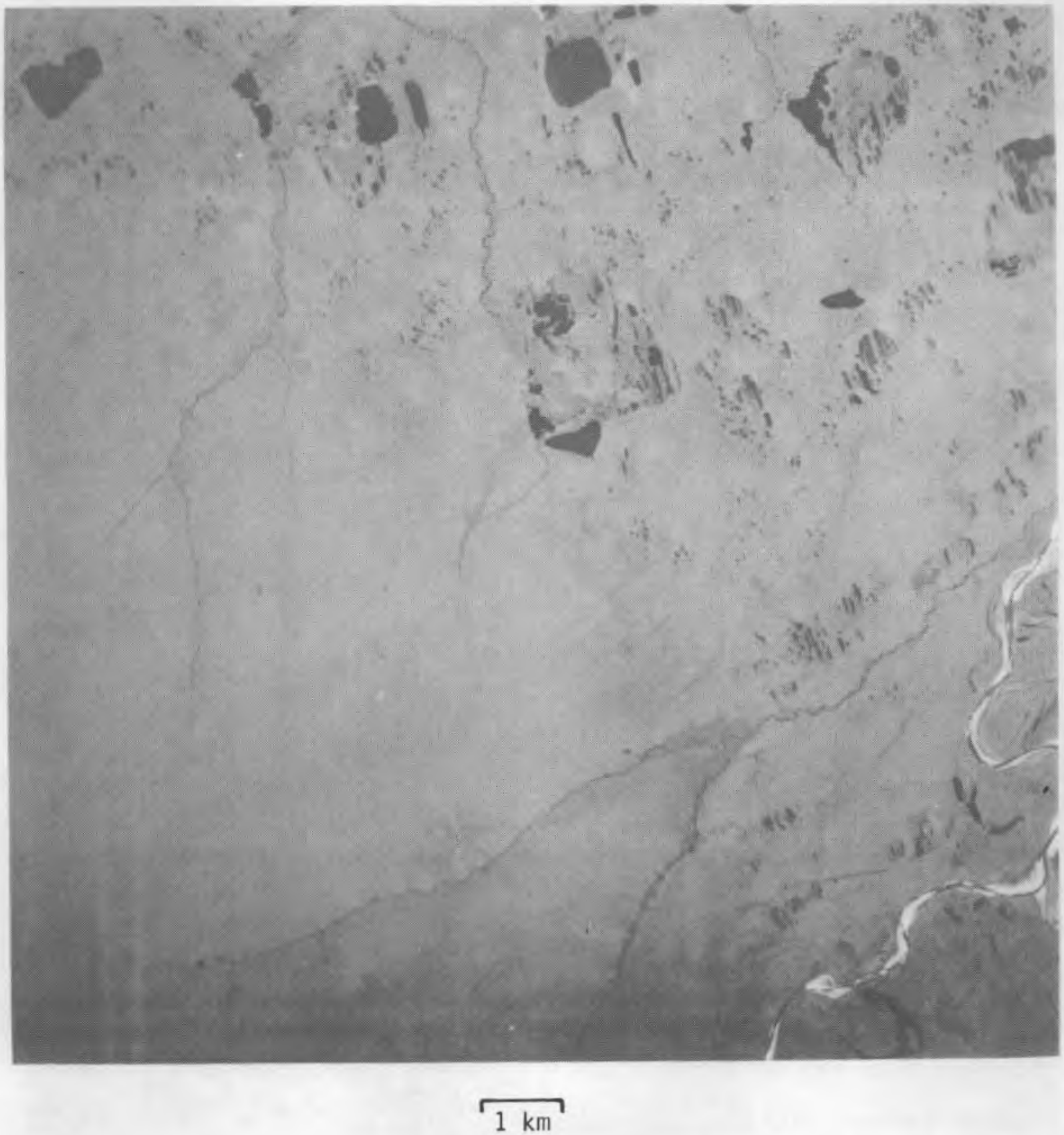




*Figure 6. Hills along the boundary between the White Hills section (Wahrhaftig 1965) and the gently rolling thaw-lake plains. This area is northeast of Franklin Bluffs. The stream on the right is the Kadleroshilik River. The better-drained surfaces are dominated by moist tussock-sedge, dwarf-shrub tundra. (NASA Flight 79-097, photo no. 2418.)*

nels. These include, from west to east, the Ugnuravik, Sakonowyak, Putuligayuk and several smaller unnamed creeks.

The flood plain and terrace landscape unit includes many abandoned channels that are associated with river systems. These channels, however, have braided channel patterns and other topography associated with fluvial systems. In contrast, the flat thaw-lake plains, which are also former river flood plains and terraces, are now covered by thaw lakes and ice-wedge polygons.

*Coast*

The coast in this region contains numerous

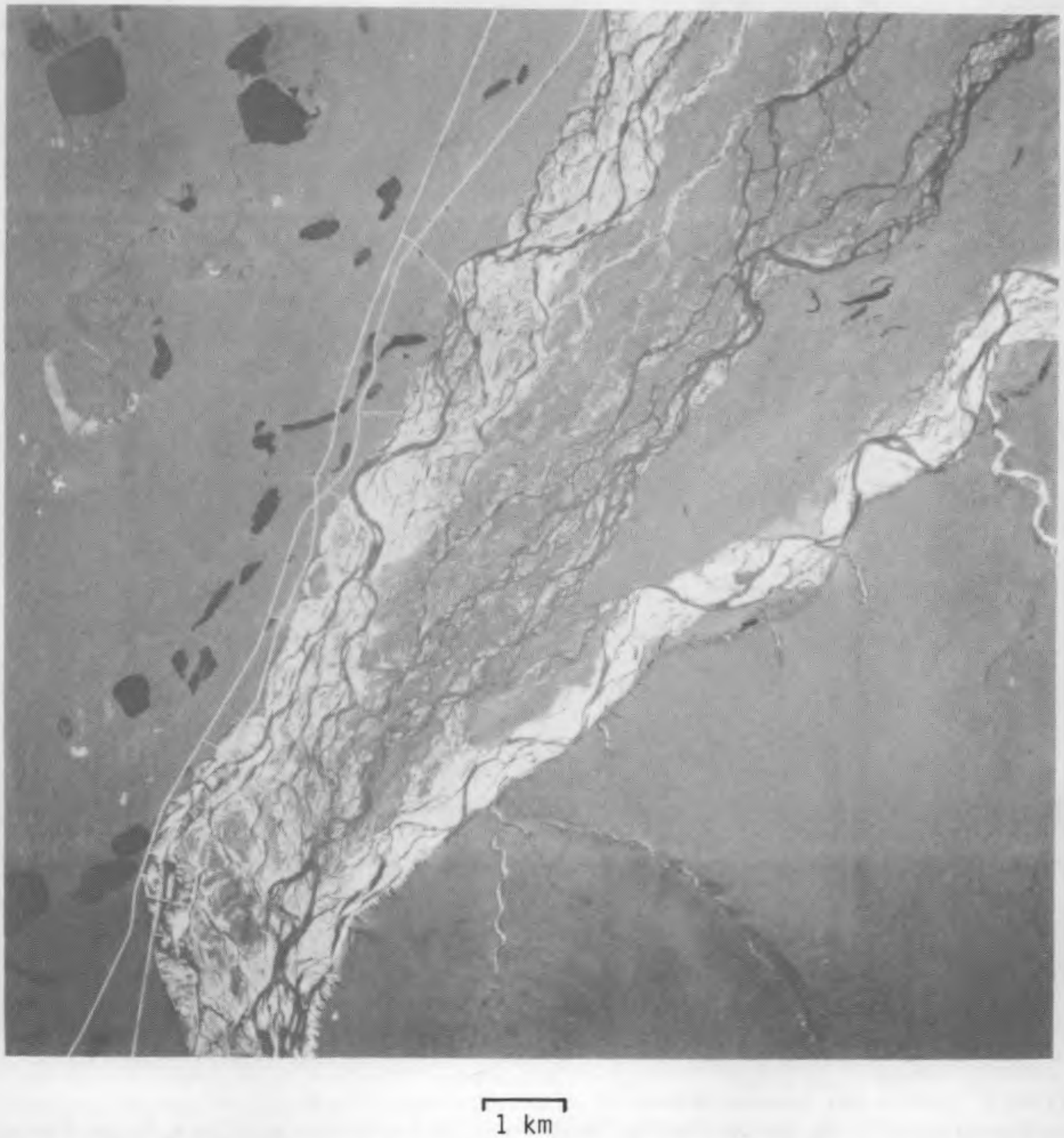




*Figure 7. Flood plains and terraces of the Sagavanirktok River at the junction of the east and west channels. Franklin Bluffs forms the right bank of the river at the bottom of the photograph. The area mapped as flood plain (Fig. 2) includes all the terraces between the channels and the oxbow lakes and flat area to the left of the braided channel. Flat thaw-lake plains appear in the upper left corner. Hilly terrain occurs on the east side of the river. (NASA Flight 79-097, photo no. 2422.)*


*Figure 8. Arctic coast in the vicinity of the West Dock (note coastal road and West Dock causeway). This area exhibits pointed promontories, curved spits and bays that are characteristic of much of the coast between the Putuligayuk and Colville rivers. Several areas of saline tundra are evident where storm surges have flooded low-lying coastal areas, particularly in drained lake basins (arrows). (NASA Flight 79-097, photo no. 3381.)*

points, which are formed by westerly near-shore sea currents (Fig. 8). Arcuate bays, curved spits and many barrier islands are also produced by this current (Short 1973, Barnes et al. 1977, Barnes and Minkler 1982). A chain of barrier islands is from 0.5 to 19 km offshore. Most of the barrier islands consist of barren sand and gravels, but a few (for example, Pingok, Bodfish, Cottle and Tigvariak islands) consist of ice-rich tundra and are remnants of a once-more-extensive coastal plain. Narrow beaches along the coast are either gravelly or sandy with low bluffs from 1 to 3 m high that are being rapidly eroded by melting. Occasional storm surges transport sediments that accumulate on the

**Table 1. Soils of the Prudhoe Bay region, Alaska. (Adapted from Everett 1980b.)**

| *Taxonomic name (subgroup level)* | *Identifying field characteristics* | *Typical microsite* |
|---|---|---|
| **Mollisols** | | |
| Pergelic Cryoboroll | A cold, more or less freely drained soil underlain by permafrost, with a dark, humus-rich, granular-textured surface horizon ≥ 18 cm thick; free carbonates throughout | Pingos, well-drained hummocky terrain, high-centered polygons, ridges |
| Pergelic Cryaquoll | A cold, dark-colored, moist to wet soil, prominently mottled in the lower part of the humus-rich, weakly granular surface horizon | Less well drained high-centered polygons |
| Pergelic-Ruptic-Aqueptic Cryaquoll | A cold soil of frost scar areas in which a Cryaquoll soil (above) is intimately associated with and interrupted by a cold, wet, gray and mottled mineral soil with a surface horizon < 25 cm and commonly < 10 cm, i.e. a Pergelic Cryaquept | Frost scar terrain |
| **Inceptisols** | | |
| Pergelic Cryaquept | A cold wet, gray and mottled mineral soil with no or only a shallow (< 25 cm thick) organic surface horizon | Wet sites with little accumulation of organic materials; wide variety of sites including areas with frost scars, flood plains, drained lake basins |
| Histic Pergelic Cryaquept | A cold, wet, gray mineral soil, commonly mottled, having a surface horizon ≥ 25 cm thick, composed of predominantly organic (peaty) material | Wet to very wet sites with moderate accumulation of organic materials; wide variety of wet microsites. Many otherwise organic soils that have been diluted with loess materials are classified here. |
| **Histosols** | | |
| Pergelic Cryosaprist | A cold, wet, dark-colored soil composed of highly decomposed organic material to depths > 40 cm | Moist sites with deep organic materials (e.g. polygon rims, some polygon centers, strangmoor, hummocks) |
| Pergelic Cryohemist | A cold, wet, dark-colored soil composed of moderately decomposed organic material to depths > 40 cm | Wet sites with deep organic materials (e.g. wet low-centered polygon centers and troughs); the most common organic soil of the region |
| Pergelic Cryofibrist | A cold, wet, dark-colored soil composed of little-decomposed fibrous organic material to depths > 40 cm | Very wet sites with deep organic materials (e.g. wet low-centered polygon centers, partially drained lake basins |
| **Entisols** | | |
| Pergelic Cryorthent | A cold, somewhat freely drained, usually gravelly soil lacking significant horizon development and generally free of organic material | River alluvium |
| Pergelic Cryopsamment | A cold, dark-grayish brown, more or less freely drained, sandy soil lacking significant horizon development and generally free of organic material | Stabilized sand dunes |

beaches and cause large blocks of sediment to fall into the sea (Harper 1978, Cannon and Rawlinson 1979).

Occasionally, large areas of tundra near the coast are flooded by seawater; a zone of barren, salt-killed tundra occurs in low areas and on bluffs near the shore. Low areas adjacent to the coast, such as estuaries, lagoons and drained lake basins, are often flooded with saltwater and support saline plant communities. Saline mud flats are common in the braided deltas of the Kuparuk and Sagavanirktok rivers.

**Climate**

Weather records have been kept at the Oliktok DEW Line station (Brower et al. 1977) and the airports at Deadhorse and the Arco camp (Walker 1980, Haugen and Brown 1980). The mean annual temperature at Deadhorse is -13 °C. Winters are extremely cold, with monthly means below -30 °C for January, February and March. The mean total snowfall amounts to about 130 mm of water equivalent, with a maximum April snowpack of 30-40 cm. Winter winds are primarily from the WSW or ENE. Calm, clear periods are common during the winter due to high pressure associated with a deep temperature inversion.

In summer the region is within a zone of strong coastal marine influence. Fog is common within a few kilometers of the coast. A steep summer temperature gradient is associated with the coast (Conover 1960, Haugen and Brown 1980, Walker 1980). The mean July temperature at the coast is normally less than 5 °C, and at the southern edge of the quadrangle it is near 8 °C. Most days in summer are windy. Drizzle, light rain and snow are common, but the total precipitation for June, July and August is normally less than 100 mm.

**Soils**

The study area is within the Coastal Plain Land Resources Region as defined by the Exploratory Soil Survey of Alaska (Rieger et al. 1979). Two major soil associations are recognized. The first is a Pergelic Cryaquoll-Histic Pergelic Cryaquept association with loamy-textured mineral components. These soils occur on flat and gently rolling thaw-lake plains. The second association is dominated by Pergelic Cryaquepts with gravelly mineral components. These soils are common on braided flood plains.

Everett (1980b) recognized ten distinct soils within the Prudhoe Bay region (Table 1). There is a high degree of correlation between surface forms, soil moisture, and soil type as demonstrated in numerous soils mapping efforts in northern Alaska (Drew 1957, Tedrow and Cantlon 1958, Tedrow et al. 1958, Brown 1962, Holowaychuk et al. 1966, Everett 1980b).

**Vegetation**

The general character of northern Alaska tundra vegetation has been described by Britton (1957), Spetzman (1959) and Wiggins and Thomas (1962). Detailed studies in wet tundra have been done at Barrow (Wiggins 1951, Britton 1957, Walker 1977), Fish Creek (Komárková and Webber 1978, Murray and Murray 1978), Atkasook (Komárková and Webber 1980), Point Storkerson (Bergman et al. 1977) and the Teshekpuk Lake vicinity (Derkson et al. 1981). Numerous shoreline vegetation studies have also been conducted (e.g. Jefferies 1977, Meyers 1981, Taylor 1981). The major ecosystems map of Alaska (scale 1:250,000, Joint Federal-State Land Use Planning Commission for Alaska 1973) portrays most of the quadrangle as wet tundra with small areas of moist tundra in the foothill sections.

Walker (1985) recognized 44 plant communities in a 250-km$^2$ area of the Prudhoe Bay oil field. Ten of these communities are related to the soil moisture and pH gradients. The rest are associated with microscale phenomena, such as frost scars, animal dens, pingos, snowbanks and strand lines, and are not distinguishable at small scales.

Microtopography associated with patterned ground is a major influence on the distribution of plant communities. Elevation differences of less than 0.5 m are associated with patterned ground and create distinct vegetation patterns (Wiggins 1951, Britton 1957, Cantlon 1961, Walker 1985). These patterns are particularly noticeable from the air. Vegetation succession in the thaw-lake plains is intimately linked to the thaw-lake cycle discussed elsewhere (Hopkins 1949, Britton 1957, Carson and Hussey 1962, Webber 1978, Billings and Peterson 1980, Everett 1980a).

Another important factor for the vegetation is alkaline silt (loess) that has been blown from the Sagavanirktok River flood plain (Drew 1957, Parkinson 1978, Walker and Webber 1979, Walker 1985). Areas downwind (WSW) from the river have alkaline substrates. Soil pH values generally decrease away from the river, except in local situations such as river alluvium, frost scars, beaches and wherever the alkaline parent material is near the surface. Wet sites outside the influence of windblown inputs usually have acidic soils.

The climate also varies southward across the Beechey Point Quadrangle, causing two distinct tundra zones. The steep coastal summer temperature gradient (Conover 1960, Haugen and Brown 1980) is responsible for a band of coastal vegetation that has few shrubs, limited cottongrass-tussock formation, reduced moss and lichen growth, and few species in the total flora (Cantlon 1961, Clebsch and Shanks 1968, Walker 1985). This band of coastal tundra lies north of the 7°C July mean isotherm. South of this isotherm is the region that Cantlon (1961) termed "typical tundra," which has more shrubs and a generally richer flora. This vegetation zone covers most of the Beechey Point Quadrangle. For a fuller discussion of the coastal plain vegetation in relation to various schemes of tundra zonation, see Walker (1985, pp. 114–117.)

## DESCRIPTIONS OF THE HIERARCHICAL VEGETATION AND LAND COVER UNITS

The legend for the Landsat-derived map uses a modified version of the hierarchical classification system of Walker (1983) (Table 2). The original hierarchical system is given in Appendix A. The modified system has three levels. Level A contains the eight Landsat land cover units. The nomenclature for Level A basically follows that recently adopted by the Alaska USGS Earth Resources Observation Systems (EROS) Field Office as a statewide interim land cover classification. The major exception is the addition of the moist herbaceous, mixed-shrub tundra category. In this classification scheme the term mixed-shrub is used specifically for tussock tundra with a mixture of dwarf (< 20 cm tall) and low (20–50 cm tall) deciduous shrubs (e.g. dwarf birch and low willows) and evergreen ericaceous shrubs.

Each Level A land cover unit contains several more-detailed Level B vegetation units that are spectrally similar. The Level B units can generally be interpreted from aerial photographs (scales 1:6,000 to 1:60,000) with adequate ground-reference data. The names of the Level B units basically follow the nomenclature system outlined in Walker (1983) (Appendix A). Level C contains representative plant communities that are determined by ground surveys (equivalent to Level D in Appendix A). The Level A and B units in Table 2 are most pertinent to this discussion.

Only those units that appear on the Beechey Point Quadrangle are described here. Noncomplex (i.e. homogeneous) units are described first, followed by common complex units (mosaics of vegetation in areas of complex surface topography). The units are arranged such that through Unit III they follow the moisture gradient from water to dry tundra, and then with increasing shrub cover through Unit V (shrubland). Areas of sparse vegetation, barrens and ice are last. Table 3 shows the approximate equivalents for the Level B units in the preliminary statewide Alaskan vegetation classification (Viereck et al. 1982). Several of the units contain comments regarding their appearance on Landsat imagery and some of the stratification procedures used in developing the final classification. Readers unfamiliar with these techniques should first read the overview of Landsat analysis methods and stratification procedures later in this report. The following descriptions should be read closely with Table 2 for the detailed species information. Plant nomenclature follows Hultén (1968) for vascular plants, Hale and Culberson (1975) for lichens, and Crum et al. (1973) for bryophytes. Common names are from Polunin (1959).

### I. Water

This unit depicts bodies of water that are greater than 0.4 ha, including ocean, lakes and rivers. It includes clear water, turbid water, water with aquatic grass tundra (*Arctophila fulva*), and some pond complexes with more than 40% open water. These areas have low spectral reflectance in all four Landsat spectral bands. Sea ice is included in this category because it is an ephemeral cover over seawater.

#### *Ia. Open water*

This unit includes all depths of water without vegetation or with very sparse cover of sedges or grasses. Many small ponds in the Prudhoe Bay region are quite shallow with light-colored marl-covered bottoms. In the computer cluster analysis (see Computer Classification, p. 35), these marl ponds cluster naturally with the barren land cover types, but they have been stratified out and placed in Unit I (see clusters 9, 46, 54 and 55 in Table 5).

#### *Ib. Aquatic grass marsh* (Fig. 9 and 10)

Emergent communities are common in partially drained lake basins and wherever there is perennial standing water less than 1 m deep. The primary taxon in water up to 1 m deep is pendant grass (*Arctophila fulva*). This community is distin-

*Figure 9. Aquatic grass marsh. The clones of vegetation along the margin of the lake are* Arctophila fulva.

*Figure 10.* Arctophila fulva *in a small pond of the Kuparuk oil field.*

**Table 2. Hierarchical vegetation mapping classification (Levels A and B of a three-level system) for the Alaskan Arctic Coastal Plain and Foothills. (After Walker 1983.)**

| *Level A (Landsat-derived map units)* | *Level B (Photointerpreted map units) (common noncomplex units only)* | *Description of Level B units* |
|---|---|---|
| I. Water | a. Open water* | Unvegetated water. |
| | b. Aquatic grass marsh* | Permanent water dominated by pendant grass (*Arctophila fulva*). Other vascular plants include common mare's-tail (*Hippuris vulgaris*), northern bur-reed (*Sparganium hyperboreum*), marsh marigold (*Caltha palustris*) and common bladderwort (*Utricularia vulgaris*). |
| | c. Aquatic forb marsh | Permanent water with forbs such as buckbean (*Menyanthes trifoliata*), northern burweed (*Sparganium hyperboreum*), marsh five-finger (*Potentilla palustris*), marsh marigold (*Caltha palustris*) and common mare's-tail (*Hippuris vulgaris*). |
| II. Wet herbaceous tundra | a. Aquatic sedge tundra* | Permanent water with sedges, mainly aquatic sedge (*Carex aquatilis*), common cottongrass (*Eriophorum angustifolium* ssp. *subarcticum*) and arctic cottongrass (*E. scheuchzeri*). Other common vascular plants include creeping sedge (*Carex chordorrhiza*), pallas buttercup (*Ranunculus pallasii*), marsh marigold (*Caltha palustris*), marsh five-finger (*Potentilla palustris*) and common bladderwort (*Utricularia vulgaris*). |
| | b. Wet sedge tundra* | Wet tundra that often floods in early summer but generally drains of excess water during dry periods and remains saturated throughout the summer. The primary taxa are aquatic sedge (*Carex aquatilis*), common cottongrass (*Eriophorum angustifolium*), cordroot sedge (*C. chordorrhiza*), rock sedge (*C. saxatilis*), sudetan lousewort (*Pedicularis sudetica* ssp. *albolabiata*), bog saxifrage (*Saxifraga hirculis*), nodding lychnis (*Melandrium apetalum*), marsh marigold (*Caltha palustris*) and marsh five-finger (*Potentilla palustris*). Fisher's dupontia (*Dupontia fisheri*) is common near the coast. Common mosses are *Drepanocladus* spp., *Scorpidium scorpioides, Campylium stellatum, Calliergon* spp. and *Sphagnum* spp. |
| | c. Wet sedge, dwarf-shrub, moss tundra | Wet acidic bogs mainly in foothill drainage basins. Sedges include *Carex rariflora, C. rotundata* and *Eriophorum scheuchzeri*. Dwarf (< 20 cm) or low (20-50 cm) shrubs are mainly *Salix pulchra, S. fuscescens* and bog birch (*Betula nana*). Mosses are mainly *Sphagnum* spp. |
| | d. Wet sedge tundra (saline areas)* | Coastal areas periodically inundated by saltwater. Primary taxa are Hoppner sedge (*Carex subspathacea*), creeping alkaligrass (*Puccinellia phryganodes*), bear sedge (*C. ursina*), low chickweed (*Stellaria humifusa*) and common scurvy grass (*Cochlearia officinalis*). |
| | e. Wet sedge, low-shrub tundra | Wet bogs, particularly in inland portions of the coastal plain with wet sedge tundra (see IIb) that has a large component of low willows (mainly *Salix lanata, S. pulchra, S. glauca*). |
| III. Moist or dry herbaceous, dwarf-shrub tundra | a. Moist non-tussock-sedge dwarf-shrub tundra* | Moist, well-drained sites near the coast, along streams and on alkaline or near-neutral unstable soils of upland areas. On moist alkaline sites of the coastal plain, the common sedges are Bigelow's sedge (*Carex bigelowii*), common cottongrass (*Eriophorum angustifolium* ssp. *triste*) and fragile sedge (*C. membranacea*). Dryas is usually an important component. Dwarf shrubs include arctic avens (*Dryas integrifolia*), net-veined willow (*Salix reticulata*), arctic willow (*S. arctica*) and woolly willow (*S. lanata*); forbs include woolly lousewort (*Pedicularis lanata*), bistort (*Polygonum bistorta*), long-stalked stitchwort (*Stellaria laeta*) and arctic senecio (*Senecio atropurpureus* ssp. *frigidus*). Common bryophytes are *Toment-* |

| Level A (Landsat-derived map units) | Level B (Photointerpreted map units) (common noncomplex units only) | Description of Level B units |
|---|---|---|
| | | *hypnum nitens, Hylocomium splendens, Aulacomnium turgidum, Ptilidium ciliare, Orthothecium chryseum, Ditrichum flexicaule* and *Distichium capillaceum*. The primary lichens are *Thamnolia subuliformis, Cetraria* spp. and *Dactylina arctica*. Alkaline upland sites of inland areas are likely to have scattered low (20–50 cm) willows (*Salix lanata* and *S. glauca*). Alkaline frost-scar areas on inland sites have similar vegetation with wide-leaved arctagrostis (*Arctagrostis latifolia*), arctic lupine (*Lupinus arcticus*), sweet coltsfoot (*Petasites frigidus*) and meadow horsetail (*Equisetum arvense*). *E. arvense* may be dominant on some hillside areas with unstable solifluction soil. Moist acidic coastal sites have rushes (*Luzula arctica, L. confusa*), sedges (*Carex aquatilis, C. bigelowii*), dwarf willows (*Salix pulchra, S. rotundifolia, S. arctica*) and moss hummocks (*Dicranum elongatum*) encrusted with lichens (*Ochrolechia frigida* and *Lecanora epibryon*). |
| | b. Moist tussock-sedge, dwarf-shrub tundra* | Moist tussock tundra on well-drained alkaline or near-neutral, relatively stable sites. The dominant sedge is tussock cottongrass (*Eriophorum vaginatum*). The vegetation is otherwise similar to the moist alkaline coastal plain areas described in IIIa. Some areas may have ericaceous shrubs (see IVa), particularly four-angled mountain heather (*Cassiope tetragona*) and willows (*Salix pulchra*), but the shrubs rarely exceed dwarf-shrub stature (20 cm). Common in the foothills on alkaline soils and well-drained coastal plain areas. |
| | c. Dry dwarf-shrub, crustose-lichen tundra* | Dry alkaline sites on pingos, ridges and river bluffs. Important taxa include a dwarf mat (< 5 cm tall) of arctic avens (*Dryas integrifolia*), with blackish oxytrope (*Oxytropis nigrescens*), rock sedge (*Carex rupestris*), moss campion (*Silene acaulis*), Lapland poppy (*Papaver lapponicum*), dwarf willows (*Salix reticulata, S. rotundifolia, S. phlebophylla*), arctic sandwort (*Cerastium beeringianum*), wooly lousewort (*Pedicularis lanata*), tundra milk vetch (*Astragalus umbellatus*), two-flowered cinquefoil (*Potentilla biflora*) and wormwood (*Artemisia borealis, A. glomerata, A. arctica*). These areas are often rather barren with a high percentage cover of bare soil and crustose soil lichens (e.g. *Lecanora epibryon, Ochrolechia frigida, Pertussaria* spp.). Other common lichens include *Thamnolia subuliformis, Cetraria* spp. (e.g. *C. islandica, C. cucullata, C. nivalis*) and *Dactylina arctica*. Mosses do not form a major component of the ground cover but include *Ditrichum flexicaule, Distichium capillaceum, Bryum* spp., *Encalypta* spp., *Dicranum elongatum, Thuidium abietinum, Rhytidium rugosum, Tortula ruralis, Drepanocladus uncinatus, Polytrichum juniperinum* and *Rhacomitrium lanuginosum*. |
| | d. Dry dwarf-shrub, fruticose-lichen tundra | Dry acidic tundra on moraines, kames and ridges. Includes many dwarf ericaceous shrubs (< 20 cm tall), for example, bearberry (*Arctostaphylos alpina, A. rubra*), crowberry (*Empetrum nigrum*), alpine azalea (*Loiseleuria procumbens*), lingonberry (*Vaccinium vitis-idaea*), bog blueberry (*V. uliginosum*) and four-angled mountain heather (*Cassiope tetragona*). Other dwarf shrubs include dryas (mainly *Dryas octopetala*), diapensia (*Diapensia lapponica*), dwarf willows (*Salix phlebophylla, S. rotundifolia*) and bog birch (*Betula nana*). Other vascular taxa include alpine holygrass (*Hierochloe alpina*), alpine pussytoes (*Antennaria friesiana*), arnica (*Arnica alpina, A. frigida*) and wormwood (*Artemisia arctica*). Lichens have a high percentage ground cover and include *Cladonia* spp., *Cetraria* spp., *Alectoria nigricans, A. ochroleuca, Dactylina arctica, Sphaerophorus globosus* and *Asahinea chrysantha*. Mosses are not a major component but include *Polytrichum juniperinum, P. piliferum, Dicranum elongatum, Rhacomitrium lanuginosum, Encalypta* spp. and *Bryum* spp. The most exposed ridges are dominated by an open dwarf mat of *Dryas octopetala* with most of the species mentioned above. |

*Common units on the beechey Point Quadrangle.

**Table 2 (cont'd). Hierarchical vegetation mapping classification (Levels A and B of a three-level system) for the Alaskan Arctic Coastal Plain and Foothills. (After Walker 1983.)**

| *Level A (Landsat-derived map units)* | *Level B (Photointerpreted map units) (common noncomplex units only)* | *Description of Level B units* |
|---|---|---|
| | e. Dry dwarf-shrub, forb, lichen tundra* | Dry river terraces with vegetation similar to IIIc but with many forbs commonly found near rivers. Forbs include oxytropes (*O. borealis, O. viscida, O. jordallii*), sweet vetch (*Hedysarum alpinum, H. mackenzii*), small-flowered anemone (*Anemone parviflora*), pale paintbrush (*Castilleja caudata*), boreal Jacobs-ladder (*Polemonium boreale*) and whorled lousewort (*Pedicularis verticillata*). Some areas may have an open canopy of scattered low willows (mainly *Salix lanata, S. alaxensis* and *S. glauca*). |
| IV. Moist herbaceous, mixed-shrub tundra | a. Moist tussock-sedge, mixed-shrub tundra | Moist tussock tundra on stable acidic soils. The dominant sedge is tussock cottongrass (*Eriophorum vaginatum*). Dwarf (5-20 cm) and low (20-50 cm) shrubs include numerous ericaceous species, such as bog blueberry (*Vaccinium uliginosum*), lingonberry (*V. vitis-idaea*), narrow-leafed Labrador tea (*Ledum palustre* ssp. *decumbens*), bearberry (*Arctostaphylos alpina, A. rubra*), crowberry (*Empetrum nigrum*) and four-angled mountain heather (*Cassiope tetragona*). Other deciduous shrubs include diamond-leafed willow (*Salix pulchra*) and dwarf birch (*Betula glandulosa* and *B. nana*). Other vascular taxa include bistort (*Polygonum bistorta*), Bigelow's sedge (*Carex bigelowii*), cloudberry (*Rubus chamaemorus*), lousewort (*Pedicularis labradorica, P. lapponica*) and sweet coltsfoot (*Petasites frigidus*). The main mosses are *Sphagnum* spp., *Hylocomium splendens, Aulacomnium* spp., *Polytrichum juniperinum* and *Dicranum* spp. Lichens are generally not abundant and are dominated by *Cladonia* spp. and *Cetraria* spp. |
| | b. Moist non-tussock sedge, mixed-shrub tundra | Moist nontussock tundra on relatively unstable acidic upland areas such as solifluction slopes. The dominant sedge is Bigelow's sedge (*Carex bigelowii*). The vegetation is otherwise similar to IVa. |
| | c. Moist sedge, mixed-shrub tundra with open tall shrubs | "Alder shrub savanna" in portions of the foothills with relatively high summer temperatures. Tall (>150 cm) alders (*Alnus crispa*) are scattered in tundra similar to IVa or IVb. Common near Umiat and the Colville River, extending onto the coastal plain on some river terraces of the Colville River. |
| V. Shrubland | a. Moist dwarf-shrub, moss tundra | Moist acidic tundra in bogs, common on high-centered polygons and palsas in the southern part of the coastal plain and in the foothills. Dominant dwarf shrub taxa are dwarf birch (*Betula nana*), narrow-leafed Labrador tea (*Ledum palustre* ssp. *decumbens*), cloudberry (*Rubus chamaemorus*), lousewort (*Pedicularis labradorica, P. lapponicum*), lingonberry (*Vaccinium vitis-idaea*) and bog rosemary (*Andromeda polifolia*). In relatively warm areas with adequate snow cover, the dwarf birch and a few ericaceous shrubs are likely to exceed 15 cm (hence, the vegetation is moist low-shrub, moss tundra). Dominant mosses are *Sphagnum* spp., *Aulacomnium turgidum, Hylocomium splendens* and *Polytrichum juniperinum*. Lichens are normally abundant and include mainly *Cladonia* spp. and *Cetraria* spp. |
| | b. Moist low-shrub tundra | Well-drained, often south-facing, slopes in the foothills. These sites are warm and often rocky with a wide variety of microsites, contributing to the high species diversity. Typical taxa include numerous species of willow (e.g. *Salix glauca, S. alaxensis, S. lanata, S. arbusculoides*), shrub birch (*Betula glandulosa*), mountain alder (*Alnus crispa*), arctic lupine (*Lupinus arcticus*), wormwood (*Artemisia arctica, A. tilesii*), delphinium-leafed monkshood (*Aconitum delphinifolium*), northern dwarf larkspur |

| Level A (Landsat-derived map units) | Level B (Photointerpreted map units) (common noncomplex units only) | Description of Level B units |
|---|---|---|
| | | (*Delphinium brachycentrum*), shrubby cinquefoil (*Potentilla fruticosa*), arctic brome-grass (*Bromus pumpellianus*), rough fescue (*Festuca altaica*), black-tipped groundsel (*Senecio lugens*), pale paintbrush (*Castilleja caudata*), small-bristled sedge (*Carex microchaeta*), arnica (*Arnica alpina. A. frigida*), sweet coltsfoot (*Petasites frigidus*), three-toothed saxifrage (*Saxifraga tricuspidata*), Siberian aster (*Aster sibirica*), bog blueberry (*Vaccinium uliginosum*), lingonberry (*V. vitis-idaea*), narrow-leafed Labrador tea (*Ledum palustre* ssp. *decumbens*) and crowberry (*Empetrum nigrum*). |
| | c. Wet low-shrub tundra | Wet areas in the foothills, particularly water tracks and drainages, dominated by diamond-leafed willow (*Salix pulchra*) and/or dwarf birch (*Betula nana*). Other common taxa include common cottongrass (*Eriophorum angustifolium* ssp. *subarcticum*), sweet coltsfoot (*Petasites frigidus*), blue Jacobs-ladder (*Polemonium acutiflorum*), capitate valerian (*Valeriana capitata*), cloudberry (*Rubus chamaemorus*) and brook saxifrage (*Saxifraga punctata*). Mosses include *Drepanocladus uncinatus, Sphagnum* spp., *Calliergon* spp. and *Dicranum* spp. |
| | d. Moist low shrubland* | Generally dense, low (20–150 cm) willow communities along streams. Dominant willows are *S. alaxensis, S. glauca, S. lanata* and *S. niphoclada*. Understories include sweet vetch (*Hedysarum alpinum, H. mackenzii*), bearberry (*Arctostaphylos alpina, A. rubra*), oxytrope (*Oxytropis campestris, O. maydelliana, O. borealis, O. viscida*), alpine milk-vetch (*Astragalus alpinus*), grass of Parnassus (*Parnassia kotzebuei, P. palustris*), small-flowered anemone (*Anemone parviflora*), pale paintbrush (*Castilleja caudata*) and horsetails (*Equisetum arvense, E. variegatum*). |
| | e. Dry low-shrub, fruticose-lichen tundra | Dry river terraces with birch (*Betula glandulosa*) or willows (*Salix alaxensis, S. lanata*) and an understory of lichens (mainly *Cladonia* spp., *Stereocaulon* spp., *Cetraria* spp.) and dwarf ericaceous shrubs (*Ledum palustre* ssp. *decumbens, Empetrum nigrum, Vaccinium uliginosum, V. vitis-idaea*). |
| VI. Sparse vegetation | Wide variety of Level B units, but most are complexes | These areas normally have over 30% barren mineral or peat substrate. Such sites can occur in a wide variety of areas, including coastal beaches, sand dunes, mud flats, river bars, rocklands and mountainous areas. Vegetation appearing in these areas is often similar to that described above, particularly IId, IIIc, IIIe and Vd. |
| VII. Barren | Includes true barrens and a wide variety of very sparsely vegetated Level B complexes | These areas normally have over 60% barren mineral or peat substrate. Common barren areas include sand dunes, barrier islands, coastal beaches, river bars, mud flats and unvegetated rocklands such as scree slopes and steep rock faces. Some areas classed as barrens along rivers and ridge tops have sparse but rich floras similar to those described for IIIc and IIIe. |
| VIII. Ice | Ice | No vegetation |

*Common units on the Beechey point Quadrangle.

**Table 3. Level A and B units with approximate corresponding Viereck et al. (1982) Level IV units.**

| *Level A (Landsat land cover units)* | *Level B (Photointerpreted units)* | *Corresponding Viereck et al. (1982) Level IV units* |
|---|---|---|
| I. Water | Ia. Water | |
| | Ib. Aquatic grass marsh | 3.A(3)e Fresh grass marsh |
| | Ic. Aquatic forb marsh | 3.B(3)a Fresh herb marsh |
| II. Wet herbaceous tundra | IIa. Aquatic sedge tundra | 3.A(3)a Wet sedge meadow tundra |
| | IIb. Wet sedge tundra | 3.A(3)a Wet sedge meadow tundra |
| | IIc. Wet sedge, dwarf-shrub, moss tundra | 3.A(3)b Wet sedge-grass meadow tundra<br>3.A(3)c Wet sedge-herb tundra<br>Probably included within 3.A(3)a Wet sedge meadow tundra |
| | IId. Wet sedge tundra (saline areas) | 3.A(3)j Halophytic grass wet meadow<br>3.A(3)k Halophytic sedge wet meadow |
| | IIe. Wet sedge, low-shrub tundra | 2.C(2)m Willow-sedge fen<br>2.C(2)r Willow-sedge tundra |
| III. Moist or dry herbaceous, dwarf-shrub tundra | IIIa. Moist non-tussock-sedge, dwarf-shrub tundra | 3.A(2)g Mesic grass-herb meadow tundra<br>3.A(2)h Sedge willow-tundra<br>3.A(2)j Sedge-dryas tundra<br>Also includes sedge-willow-forb types (no Viereck equivalent) |
| | IIIb. Moist tussock-sedge, dwarf-shrub tundra | None. (Suggest addition of sedge tussock-dryas tundra.) Also includes sedge-tussock dryas tundra with widely spaced low willows (mainly *Salix lanata* and *S. glauca*). |
| | IIIc. Dry dwarf-shrub, crustose-lichen tundra | 2.D(2)b Dryas-lichen tundra<br>2.D(2)c Dryas-herb tundra<br>2.C(1)a Mat and cushion-sedge tundra |
| | IIId. Dry dwarf-shrub, fruticose-lichen tundra | 2.D(2)a Snowbed<br>2.D(1)d Cassiope tundra<br>2.D(1)g Low ericaceous shrub tundra |
| | IIIe. Dry dwarf-shrub, forb, lichen tundra | 2.D(2)c Dryas-herb tundra |
| IV. Moist herbaceous, mixed-shrub tundra | IVa. Moist tussock-sedge, mixed-shrub tundra | 3.A(2)d Sedge tussock-mixed shrub tundra |
| | IVb. Moist non-tussock-sedge, mixed-shrub tundra | Included in 3.A(2)d Sedge tussock-mixed shrub tundra |
| | IVc. Moist sedge, mixed-shrub tundra with open tall shrubs | 2.B(2)b Tall alder (open shrub canopy) |
| V. Shrubland | Va. Moist dwarf-shrub, moss tundra | 2.C(2)h Dwarf shrub-ericaceous shrub-Sphagnum bog |
| | Vb. Moist low-shrub tundra | 2.B(2)3 Alder-birch-willow (open shrub canopy)<br>2.C(1)a Dwarf birch (closed shrub canopy)<br>2.C(1)b Low willow (closed shrub canopy)<br>2.C(2)a Dwarf birch (open shrub canopy)<br>2.C(2)t Birch-ericaceous shrub tundra (open shrub canopy)<br>2.C(2)u Mixed shrub tundra (open shrub canopy) |
| | Vc. Wet low-shrub tundra | 2.C(1)b Low willow (closed shrub canopy) |
| | Vd. Moist shrubland | 2.B(1)a Tall willow (closed shrub canopy)<br>2.B(1)d Alder-willow (closed shrub canopy)<br>2.B(1)e Shrub birch-willow (closed shrub canopy)<br>2.C(1)a Dwarf birch (closed shrub canopy)<br>2.C(1)b Low willow (closed shrub canopy)<br>2.C(1)c Dwarf birch-willow (closed shrub canopy) |
| | Ve. Dry low-shrub, fruticose-lichen tundra | 2.C(2)a Dwarf birch (open shrub canopy)<br>2.C(2)e Low alder-willow (open shrub canopy)<br>2.C(2)t Birch and ericaceous shrub tundra (open shrub canopy) |
| VI. Sparse vegetation | | Viereck et al. (1982) do not have a unit for sparsely vegetated areas. |
| VII. Barrens | | In Viereck et al. (1982) areas are considered barren if they have less than 2% vegetation. With Landsat it is not practical to define barrens with this little vegetation; areas with less than 30% cover of plants cannot be reliably separated from purely barren areas. |
| VIII. Ice | VIII. Ice | |

guished on natural-color aerial photographs by its dark reddish color.

**II. Wet herbaceous tundra**

These areas have shallow water (10–30 cm deep) all summer or water that evaporates or drains by midsummer, leaving saturated soil. Patterned-ground features are common, especially hummocks, disjunct polygons, low-centered ice-wedge polygons and strangmoor. This unit includes numerous complexes that may have high percentages of water or other tundra types, but wet sedge tundra (Unit IIb) is usually dominant.

*IIa. Aquatic sedge tundra* (Fig. 11 and 12)

Emergent communities in shallow water (10–30 cm deep) are usually dominated by aquatic sedge (*Carex aquatilis*), with other sedges including

*Figure 11. Aquatic sedge tundra. This photo illustrates a common successional sequence with circular clones of* Carex aquatilis *growing within and replacing* Arctophila fulva *in areas of shallow water.*

*Figure 12.* Carex aquatilis *and* Eriophorum scheuchzeri *(white inflorescences) in about 15 cm of water.*

*Figure 13. A large, recently drained thaw lake (foreground) with noncomplex wet sedge tundra. The darker areas in the basin are somewhat wetter with aquatic grass marsh.*

*Figure 14. Wet sedge tundra with low productivity. This is the wet end of the spectrum for this type. The level C name is wet* Carex aquatilis, Scorpidium scorpioides *sedge tundra.*

*Figure 15. Wet sedge tundra with high productivity. The Level C name is wet* Carex aquatilis, Eriophorum angustifolium, Saxifraga hirculus, Melandrium apetalum, Drepanocladus brevifolius *sedge, forb tundra.*

*Figure 16. A very productive* Carex aquatilis *community bordering a small stream.*

*Figure 17. Wet saline tundra on alluvium in the Sagavanirktok River delta.*

*Figure 18. Wet saline tundra in a portion of the area shown in Figure 17. The community is an almost pure stand of* Carex subspathacea.

common cottongrass (*Eriophorum angustifolium*) and arctic cotton grass (*E. scheuchzeri*). This unit has a dark spectral signature on aerial photographs and is sometimes difficult to distinguish from unvegetated water.

*IIb. Wet sedge tundra* (Fig. 13–16)

This unit occurs in broad flat areas with few well-drained microsites, such as strangs, small hummocks and disjunct ice-wedge polygon rims. These well-drained features normally cover less than 20% of the area. Large areas of noncomplex wet sedge tundra occur in the deltas of large rivers and in recently drained lake basins.

*IId. Wet sedge tundra (saline areas)* (Fig. 17 and 18)

This unit occurs in coastal lagoons, estuaries and saline mud flats. Most saline areas have numerous ponds and barren areas or both and thus are likely to be classed as either water (Unit I) or sparse vegetation (Unit VI).

## Table 4. Comparison of the character and composition of major Level B moist upland tundra types.

| | Unit | | | | |
|---|---|---|---|---|---|
| | *IIIa* Moist non-tussock-sedge, dwarf-shrub tundra | *IIIb* Moist tussock-sedge, dwarf-shrub tundra | *IVa* Moist tussock-sedge, mixed-shrub tundra | *IVb* Moist non-tussock-sedge, mixed-shrub tundra | *Vb* Moist low-shrub tundra |
| **Character** | | | | | |
| Soil pH | Neutral to alkaline | Slightly alkaline to slightly acidic | Acidic | Acidic | Acidic |
| Cryoturbation | Generally high | Moderate | Moderate to low | Low to moderate | Low |
| Soil flow (solifluction) | Low to moderate | Low | Low | Moderate | Low to moderate |
| Occurrence near coast (north of 7°C July mean isotherm) | Common on mesic sites | Occasional on stable sites | Rare | Absent | Absent |
| Occurrence inland | Mesic stream banks and frost-active slopes | Moderately frost-active slopes | Abundant on all mesic acidic substrates and stable sites | Slopes with moderate solifluction | South-facing slopes and stable warm upland sites |
| **Composition** (partial list of important species): | | | | | |
| Low shrubs (0.2–1.5 m): | | | | | |
| *Alnus crispa* | 0* | 0 | 0 | 0 | 0–4 |
| *Betula nana* spp. *exilis* | 0 | 0 | 3 | 3 | 3–4 |
| *Ledum palustre* spp. *decumbens* | 0 | 0–2 | 3 | 3 | 3 |
| *Salix glauca* | 0 | 0–2 | 1 | 1 | 3 |
| *S. lanata* ssp. *richardsonii* | 0–2 | 0–2 | 1 | 1 | 2 |
| *S. pulchra*† | 0 | 0 | 3 | 3 | 3–4 |
| *Vaccinium uliginosum* | 0 | 0–2 | 3 | 3 | 3 |
| Dwarf shrubs (< 0.2 m): | | | | | |
| *Dryas integrifolia* | 3 | 3 | 1 | 1 | 2 |
| *Rubus chamaemorus* | 0 | 0 | 2–3 | 2–3 | 2–3 |
| *Salix arctica* | 3 | 3 | 1 | 1 | 2 |
| *S. pulchra*† | 0–3 | 2 | 3 | 3 | 3 |
| *S. reticulata* | 3 | 3 | 1 | 1 | 3 |
| *Vaccinium vitis-idaea* | 0 | 1 | 3 | 3 | 3 |
| Graminoids: | | | | | |
| *Arctagrostis latifolia* | 2 | 2 | 1 | 1 | 1 |
| *Carex aquatilis* | 0–3 | 1 | 0 | 0 | 0 |
| *C. bigelowii* | 3 | 3 | 3 | 3–4 | 2 |
| *Eriophorum angustifolium* | 3–4 | 3 | 0–3 | 0–2 | 2 |
| *E. vaginatum* | 1 | 3–4 | 3–4 | 0–2 | 2 |
| Bryophytes: | | | | | |
| *Aulacomnium palustre* | 2–3 | 2–3 | 3 | 3 | 3 |
| *Dicranum* spp. | 0–3 | 0–2 | 3 | 3 | 0–3 |
| *Ditrichum flexicaule* | 0–3 | 0–2 | 1 | 1 | 1 |
| *Hylocomium splendens* | 0–3 | 3–4 | 3–4 | 3–4 | 3–4 |
| *Polytrichum juniperinum* | 0–3 | 0–2 | 3 | 0–3 | 3 |
| *Ptilidium ciliare* | 0–2 | 0–3 | 0–3 | 0–3 | 0–3 |
| *Sphagnum* spp. | 1 | 1 | 2–4 | 2–4 | 2–4 |
| *Tomenthypnum nitens* | 2–4 | 2–4 | 2 | 0–3 | 1 |
| Lichens: | | | | | |
| *Cetraria cucullata* | 3 | 3 | 3 | 3 | 2–3 |
| *C. islandica* | 3 | 3 | 3 | 3 | 2–3 |
| *Cladina arbuscula* | 0 | 0–2 | 2–3 | 2–3 | 2–3 |
| *C. rangiferina* | 0 | 0–2 | 2–3 | 2–3 | 2–3 |
| *Dactylina arctica* | 3 | 3 | 3 | 3 | 2–3 |
| *Peltigera aphthosa* | 2 | 2 | 2–3 | 2–3 | 3 |
| *Thamnolia subuliformis* | 3 | 2–3 | 0–2 | 0–2 | 0–2 |

* 0 = absent; 1 = rare; 2 = occasional; 3 = frequent to abundant; 4 = dominant within the respective canopy layer.

† *S. pulchra* is listed as a dwarf shrub and a low shrub; near the coast it is prostrate; inland it grows up to 2 m tall.

**III. Moist or dry herbaceous, dwarf-shrub tundra**

This unit is common on relatively large, moderately well drained surfaces. It is a highly varied unit that encompasses much of the moist to dry end of the moisture gradient. In the Beechey Point Quadrangle this unit includes five main Level B noncomplex types; three of these are moist tundra types, and two are dry tundra. These types have somewhat higher reflectance in the visible bands (bands 4 and 5) than wet tundra (Unit II) or the more shrubby units (Units IV and V). This is due to high percentages of erect dead sedge vegetation in moist tundra types, and light-colored crustose lichens, bare gravel and dry dead vegetation in the dry tundra types. *Dryas integrifolia* is an important component of most vegetation types in this unit. Table 4 accompanies the following descriptions and provides a comparison of the major moist upland-tundra types.

*IIIa. Moist non-tussock-sedge, dwarf-shrub tundra* (Fig. 19 and 20)

This unit is most common on moderately well drained sites near the coast where there is poor tussock-tundra development. These areas commonly have less than 20% cover of cottongrass tussocks (*Eriophorum vaginatum*). Typical surface forms include flat-centered polygons and gentle slopes along drainages. Wetter facies near streams are likely to have no tussocks and higher percentages of dwarf willows.

*Figure 19. Well-drained terrain along the Kuparuk River with moist sedge, dwarf-shrub tundra.*

Near the coast a variant of this type occurs on moist sites on ice-wedge polygon rims and high-centered ice-wedge polygons (Fig. 21). This is a sparse community with considerable ground cover of *Dicranum* moss hummocks that are encrusted with lichens.

***Figure 20. Moist tundra in the Kuparuk oil field. The Level C name is moist*** **Carex bigelowii, Dryas integrifolia, Salix reticulata, Tomenthypnum nitens** ***sedge, dwarf-shrub tundra.***

***Figure 21. Coastal tundra near the West Dock at Prudhoe Bay. The Level C name is moist*** **Salix rotundifolia, Poa arctica, Dicranum elongatum, Ochrolechia frigida** ***graminoid, dwarf-shrub, crustose-lichen tundra.***

*IIIb. Moist tussock-sedge, dwarf-shrub tundra* (Fig. 22 and 23)

Tussock tundra can be divided into two broad categories on the basis of the shrub portion of the plant canopy (Table 3). The first category (Unit IIIb) includes types that have a large component of arctic avens (*Dryas integrifolia*), a dwarf evergreen shrub. The second type (Unit IVa) has a large component of low deciduous shrubs (20–50 cm tall), primarily diamond-leafed willow (*Salix pulchra*) and dwarf birch (*Betula nana* ssp. *exilis*). Unit IIIb occurs primarily in moist coastal areas where there are relatively few shrubs in the plant canopy; it is also the most common tussock-tundra type in areas with alkaline or near-neutral soils. Unit IVa occurs mainly on acidic soils. Unit IIIb is the most common tussock-tundra type in the Beechey Point Quadrangle. The main characteristics that distinguish Unit IIIb from Unit IVa are as follows:

1. Although both units are dominated by cottongrass tussocks (*Eriophorum vaginatum*), the shrub component in Unit IIIb consists mainly of

*Figure 22. Moist tussock-sedge, dwarf-shrub tundra (coastal type) in the Kuparuk oil field.*

*Figure 23. Detail of Figure 22. The Level C name is moist* Eriophorum vaginatum, Dryas integrifolia, Salix arctica, Cassiope tetragona, Tomenthypnum nitens, Thamnolia subuliformis *tussock-sedge, dwarf-shrub tundra.*

dwarf shrubs (<20 cm tall), including arctic avens (*Dryas integrifolia*), diamond-leafed willow (*S. pulchra*), net-veined willow (*Salix reticulata*) and arctic willow (*S. arctica*). Low shrubs (20–50 cm tall) are mainly scattered and include woolly willow (*Salix lanata* ssp. *richardsonii*) and northern willow (*S. glauca*). In Unit IVa, shrubs are more varied and often taller than in Unit IIIb; there is a higher percentage of deciduous shrubs, mainly diamond-leafed willow, dwarf birch (*Betula nana* ssp. *exilis*) and a variety of ericaceous shrubs, including bog blueberry (*Vaccinium uliginosum*), mountain cranberry (*V. vitis-idaea*) and narrow-leafed Labrador tea (*Ledum palustre* spp. *decumbens*).

2. The moss canopy in Unit IIIb is dominated by *Tomenthypnum nitens*, and that in Unit IVa is dominated by *Sphagnum* or *Hylocomium splendens* or both.

3. The principal lichens in Unit IIIb are *Thamnolia subuliformis, Dactylina arctica* and numerous species of *Cetraria*. The main lichens in Unit IV are of the family Cladoniaceae but also include *Cetraria* spp. and *Dactylina arctica*.

*IIIc. Dry dwarf-shrub, crustose-lichen tundra* (Fig. 24 and 25).

This unit occurs on very well drained sites such as pingos, river bluffs, well-developed high-centered polygons, and other sites that are dry and exposed to wind during the winter. These areas are often rather barren with high percentages of bare soil and crustose soil lichens. The white crustose lichens give these areas a light tone on aerial photographs. The dominant vascular taxon is invariably arctic avens (*Dryas integrifolia*). The driest, most-exposed sites on mineral soil generally are dominated by crustose lichens, arctic avens, rock sedge (*Carex rupestris*) and blackish oxytrope (*Oxytropis nigrescens*). Less-exposed sites have a few more dicotyledons and sedges. Purple mountain saxifrage (*Saxifraga oppositifolia*) is particularly common on dry unstable soils, such as those subject to cryoturbation.

*IIIe. Dry dwarf-shrub, forb, lichen tundra*

This unit occurs on dry river terraces, especially of large braided rivers such as the Sagavanirktok and rivers to the east of the Beechey Point Quadrangle. The vegetation is similar to Unit IIIc except there are numerous forbs typically found in association with riparian habitats. Near the coast these sites have no low shrubs, but inland, canopies of open low willows are common.

**IV. Moist herbaceous, mixed-shrub tundra** (Fig. 26)

This unit occurs on upland areas with acidic

*Figure 24. High-centered ice-wedge polygon complex with dry dwarf-shrub, crustose-lichen tundra on the polygon tops. Polygon tops are approximately 5–7 m in diameter.*

*Figure 25. Dry tundra near the Putuligayuk River. The Level C name is* Dryas integrifolia, Carex rupestris, Saxifraga oppositifolia, Lecanora epibryon *dwarf-shrub, crustose-lichen tundra.*

*Figure 26. Moist tussock-sedge, mixed-shrub tundra south of the Beechey Point Quadrangle. This vegetation type is rare in the map area. Note the high percentage cover of low shrubs (15–50 cm tall). The Level C name is moist* Eriophorum vaginatum, Betula nana *spp.* exilis, Salix pulchra, Vaccinium vitis-idaea, Ledum palustre *spp. decumbens, Sphagnum sp. tussock-sedge, low-shrub tundra.*

soils and accumulations of *Sphagnum* or *Hylocomium* peat. The soils, although somewhat better drained than in Unit II, are often wet. Although it is the dominant type in many foothill areas, it is uncommon on the Beechey Point Quadrangle. It does occur in small areas west of the Kuparuk River and along a small drainage between the Shaviovik and Kadleroshilik rivers.

The two Level B categories both have high percentages of dwarf and low shrubs. The main difference between Unit IVa and IVb is the dominant sedge. In moist tussock-sedge, mixed-shrub tundra the dominant sedge is sheathed cottongrass (*Eriophorum vaginatum*); in moist non-tussock-sedge, mixed-shrub tundra the dominant sedge is Bigelow's sedge (*Carex bigelowii*). The reader should contrast this type with moist tussock-sedge, dwarf-shrub tundra (Unit IIIb) described above and in Table 3.

**V. Shrubland**

Dense deciduous shrubs dominate this unit. The shrubs cause high reflectance in Bands 6 and 7 of the Landsat data. Riparian shrublands occur in the Beechey Point Quadrangle, but other shrub tundra communities, including moist shrub tundra (common in the foothills on warm, south-facing slopes) and wet shrub tundra (common in water tracks), do not occur.

*Vd. Moist low shrubland*
*(closed riparian shrubland)* (Fig. 27 and 28)

Willow communities are found on stable river bars along the larger rivers. The main shrubs are feltleaf willow (*Salix alaxensis*), woolly willow (*S. lanata* ssp. *richardsonii*), tongue-leafed willow (*S. niphoclada*), and northern willow (*S. glauca*). Willow stands are among the most floristically rich communities in the region. Dwarf willows often grow along some of the smaller tundra streams in fairly dense stands with aquatic sedge (*Carex aquatilis*). Taller riparian shrubs occur along the Kuparuk River and the larger streams, but generally they are not extensive. In the Beechey Point Quadrangle, most willow stands have open canopies and are classed as sparse vegetation (Unit VI).

**VI. Sparse vegetation**

This unit includes a wide variety of areas that have sparse vegetation, such as river bars, beaches, dunes and deltas. Many of these areas consist of complexes of various vegetation types with large barren areas. The percentage cover of vegetation in this unit depends on the dominant plant growth form but normally is only 30–60% of a given pixel. The high percentage of bare gravel or sand gives these types high reflectance in the visible bands. The presence of many forbs, grasses and shrubs also gives partially vegetated areas

*Figure 27. Riparian shrubland along the Kuparuk River just south of the Prudhoe Bay oil field. The gravel bar is dominated by willows up to 50 cm tall.*

*Figure 28. Willow community shown in Figure 27. The Level C name is moist* Salix lanata, S. alaxensis, Lupinus arcticus, Equisetum arvense, Astragalus alpinus *low-shrub tundra.*

moderately high reflectance in the near-infrared bands.

**VII. Barrens**

This unit includes areas such as river gravels (Fig. 29), tidal flats (Fig. 30), spits, dunes, roads, pads, runways and dark-colored peat that are totally barren or have less than 30% total vegetation cover. Some dunes and riparian sites are among the most floristically rich areas in the region. Totally barren areas on river bars and beaches could not be consistently separated from areas with sparse cover of plants because of the overwhelming brightness of the light-colored gravel.

*Figure 29. Barren gravel bars along the Kuparuk River.*

*Figure 30. Barren silt and sand in the delta of the Sagavanirktok River.*

**VIII. Ice**

This unit includes glaciers and aufeis, neither of which occur in the Beechey Point Quadrangle. Sea ice is classed as water.

**Complex land-cover units**

Patterned ground associated with features such as ice-wedge polygons and frost scars is particularly abundant in northern Alaska. The vegetation mosaics associated with patterned ground generally consist of elements that are less than 0.4 ha and are thus below the minimum resolution of the satellite sensors. Spectral signatures are therefore averages of reflectance values from the various elements within a given pixel. Many combinations of vegetation types can and do occur in vegetation complexes, and it is not possible to describe all of the known combinations here. However, a few complexes that are particularly common are described below.

*Water and tundra complex (pond complex)* (Fig. 31)

Very wet tundra often has numerous small bodies of water mixed with areas of wet and moist tundra. These pond complexes are particularly common in drained lake basins and usually have features such as strangmoor and disjunct polygon rims. Water-covered surfaces are dominant, but relatively well drained tundra of varying character may cover up to 40% of the unit. Low-centered polygon complexes with standing water or aquatic vegetation in their centers are often included in this unit. Such areas are usually classed as water (Unit I). Pixels on the margins of lakes often appear as cluster no. 4 (see Fig. 40 and Table 5). These border pixels cause a problem that is difficult to solve satisfactorily in highly dissected wetland terrain. In this classification, cluster 4 (which also includes areas of shallow water, aquatic tundra and pond complexes) was placed in the water category (Unit I).

*Figure 31. Pond complex in an area of well-developed low-centered polygons in the Kuparuk River delta. This complex has aquatic grass marsh and aquatic sedge tundra in the polygon basins and moist sedge, dwarf-shrub tundra on the polygon rims.*

*Figure 32. Low-centered ice-wedge polygon terrain in the Prudhoe Bay region. The Level B classification is wet sedge tundra and moist sedge, dwarf-shrub tundra complex. Wet sedge tundra is in the polygon basin.*

*Figure 33. Low-centered polygon complex near Deadhorse with vegetation similar to that shown in Figure 32.*

*Figure 34. Moist sedge, dwarf-shrub tundra and wet sedge tundra complex. This area is less wet than that shown in Figure 33.*

*Tundra and water complex*

The tundra component of this complex is dominant, but water or aquatic vegetation may cover up to 50% of a given pixel. Low-centered polygon complexes or areas with extensive thermokarst pits are common in this subunit. Nonaquatic portions of the complex may be tundra of varying character, including moist non-tussock-sedge, dwarf-shrub tundra; moist tussock-sedge, dwarf-shrub tundra; dry dwarf-shrub, crustose-lichen tundra; and wet sedge tundra. This complex is usually classed as wet herbaceous tundra (Unit III).

*Wet sedge tundra and moist, non-tussock-sedge, dwarf-shrub tundra complex* (Fig. 32 and 33).

This common unit occurs in a) low-centered polygon complexes with well-developed polygon rims, b) areas with mixed high- and low-centered polygons, and c) string bogs with closely spaced ridges of moist vegetation. Wet tundra is dominant, but moist tundra may cover up to 40% of a given area. It is classed as wet herbaceous tundra (Unit III).

*Moist sedge, dwarf-shrub tundra and wet sedge tundra complex* (Fig. 34)

This common unit is intermediate between wet sedge tundra and moist sedge, dwarf-shrub tundra complex and moist sedge, dwarf-shrub tundra. It occurs particularly in areas with mixtures of high- and low-centered polygons. Moist tundra (Units IIIa, IIIb and IVa) is usually dominant, but there may be up to 40% cover of wet sedge tundra in polygon basins, troughs, thermokarst pits and interhummock areas in strangmoor. Spectral signatures of these areas vary depending on the percentage of moist tundra, the season and the summer rainfall. Moist areas may have cottongrass tussocks, especially in inland areas and areas with non-frost-active soils.

*Moist sedge, dwarf-shrub tundra and barren complex (frost-scar complex)* (Fig. 35 and 36)

This unit occurs primarily on well-drained surfaces with 30–90% cover of frost scars. These features may be barren or may have sparse vegetation consisting of such taxa as wide-leafed arctagrostis (*Arctagrostis latifolia*), sweet coltsfoot (*Petasites frigidus*), arctic avens (*Dryas integrifolia*), entire-leafed chrysanthemum (*Chrysanthemum integrifolium*) and purple mountain saxifrage (*Saxifraga oppositifolia*). Common mosses include *Rhacomitrium lanuginosum*, *Bryum spp.*, *Distichium capillaceum* and *Drepanocladus uncinatus*. On tundra near the coast, areas between frost scars are usually Unit IIIa. Inland, frost-scar tundra occurs mainly on slopes and ridge tops and commonly has scattered woolly willows (*Salix lanata* ssp. *richardsonii*) or northern willows (*S. glauca*) up to 40 cm tall, and other taxa typical of unstable tundra, such as common horsetail (*Equisetum arvense*) and wide-leafed arctagrostis (*Arctagrostis latifolia*).

*Dry barren and low shrubland complex (open riparian shrubland)*

This unit is similar to Unit Vd, except that it is more open, with barren gravel and scattered mixed forbs, grasses and small shrubs. Barrens or poorly vegetated areas cover 40–70% of the unit. This complex is usually classed as sparse vegetation (Unit VI).

*Dry barren and dwarf-shrub, forb, grass tundra complex (forb-rich river bars)* (Fig. 37)

This unit occurs along streams in less-stable sites than riparian shrubland (Unit Vd). Erect wil-

*Figure 35. Frost-scar tundra in the Kuparuk oil field. Light-colored speckles are frost scars with crustose lichens. (Air Photo Tech. 1973, photo no. 28-025, scale 1:6000).*

*Figure 36. Moist sedge, dwarf-shrub tundra with frost scars. White flowers are entire-leafed chrysanthemum (*Chrysanthemum integrifolia*).*

*Figure 37. A forb-rich gravel bar on the Kuparuk River near the arctic coast. The Level C name is dry* Bromus pumpellianus, Festuca rubra, Astragalus alpinus, Androsace chamaejasme, Salix ovalifolia *grass, forb, dwarf-shrub tundra. When this type occurs as a complex with barren gravels, it is classed as sparse vegetation (Unit VI).*

lows are scattered or absent. Common taxa include numerous grasses, for example, arctic brome grass (*Bromus pumpellianus*), red fescue (*Festuca rubra*), spiked trisetum (*Trisetum spicatum*) and tufted hairgrass (*Deschampsia caespitosa*). Forbs include river beauty (*Epilobium latifolium*), wormwood (*Artemisia arctica*, *A. borealis* and *A. glomerata*), pale paintbrush (*Castilleja caudata*), hedysarum (*Hedysarum alpinum* and *H. mackenzii*), bearberry (*Arctostaphylos rubra*), yellow oxytrope (*Oxytropis campestris*), small flowered anemone (*Anemone parviflora*), common horsetail (*Equisetum arvense*) and alpine milk-vetch (*Astragalus alpinus*). This complex is usually classed as sparse vegetation (Unit VI).

*Barren and wet sedge tundra complex (barren and saline tundra complex)*

This unit occurs along the coast on tidal flats, estuaries and lagoons. The primary vegetation is the same as that described in Unit IId, but there are also large barren areas. This complex is often classed as sparse vegetation (Unit VI).

## LANDSAT ANALYSIS METHODS

### Overview

Methods used to produce the land-cover classification were developed by researchers at the USGS Western Mapping Center's Geographic Investigations Office at NASA Ames Research Center, Moffett Field, California. This office is responsible for conducting remote sensing research and developing techniques for digital map production.

Landsat multispectral scanner (MSS) data consist of spectral information from four sensors aboard the satellite. Each sensor records the reflectance from the earth in discrete spectral bands: Band 4 (green, 0.5–0.6 $\mu$m), Band 5 (red, 0.6–0.7 $\mu$m), Band 6 (photographic infrared, 0.7–0.8 $\mu$m) and Band 7 (near infrared, 0.8–1.1 $\mu$m). A single scene contains four images, one from each spectral band. Each image contains over six million picture elements, or pixels. Each pixel contains the brightness level from 1.12 acres (0.45 ha). The entire scene, or any portion of it, can be viewed and analyzed using image-processing systems, which are now available at many remote sensing centers.

The MSS data were processed at Ames Research Center employing various algorithms that statistically quantify the different land cover units. The analysis followed the steps shown in Figure 38, which include Landsat and ground-reference data acquisition, cluster analysis, computer classification and final map production. Several computer systems were used for this analysis. The ERTS Data Interpreter and TENEX Operations Recorder (EDITOR) software package was the primary image-analysis system. Other computer systems that were used because of their unique processing capabilities included the ILLIAC IV parallel processor, the IBM 360/67, the CDC-7600 and the HP-3000, all based at the Ames Research Center. The Advanced Research Projects Agency Network linked the Ames Computers and TENEX computer systems at Bolt Beranek and Newman Inc. in Boston.

### Data preparation

*Data acquisition*

Landsat data acquisition began with an initial computer search of the Earth Resources Observation Systems (EROS) data bank for all available Landsat imagery covering the Prudhoe Bay region. Scene 21635-21044 acquired on 15 July 1979 (Fig. 39) was eventually selected for analysis. This was the only available cloud-free scene that covered the entire Beechey Point Quadrangle during the peak vegetative growing season. Computer compatible tapes (CCTs) for the scene were obtained from the EROS Data Center in band interleaved by line (BIL) format (Holkenbrink 1978). False color composites at various scales were also ordered at this time. The raw data were preprocessed by the EROS Data Center Digital Image Processing System (EDIPS) and included radiometric and geometric corrections, contrast stretch and atmospheric effects correction. The scene was also reformatted into the standard EDITOR format used on the TENEX system.

*Data compression*

Compression of the original four-channel data was necessary for processing efficiency. A Landsat frame contains over 40 million bytes of information. For this analysis the study area was reduced by eliminating the offshore pack ice from the data set; ice covered half of the Landsat frame. Although reduced to five million pixels, the final working data set was still too large for statistical clustering on the available computer systems. To reduce this data set further, a data-compression algorithm was used before clustering. The algorithm scans the data for duplicates of four-channel spectral values. Pixel-value dupli-

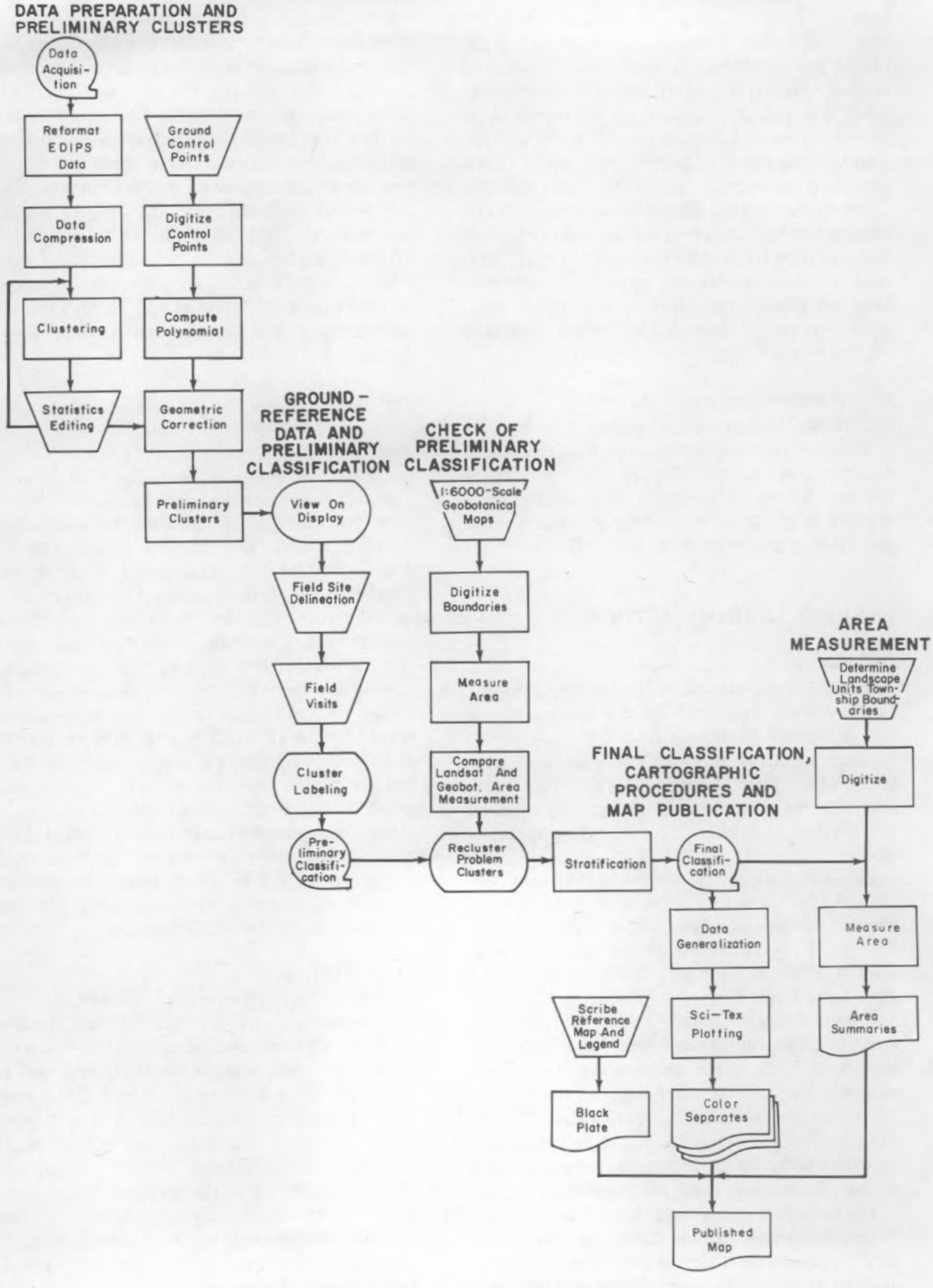



*Figure 38. Flow chart of the Landsat data analysis methods.*

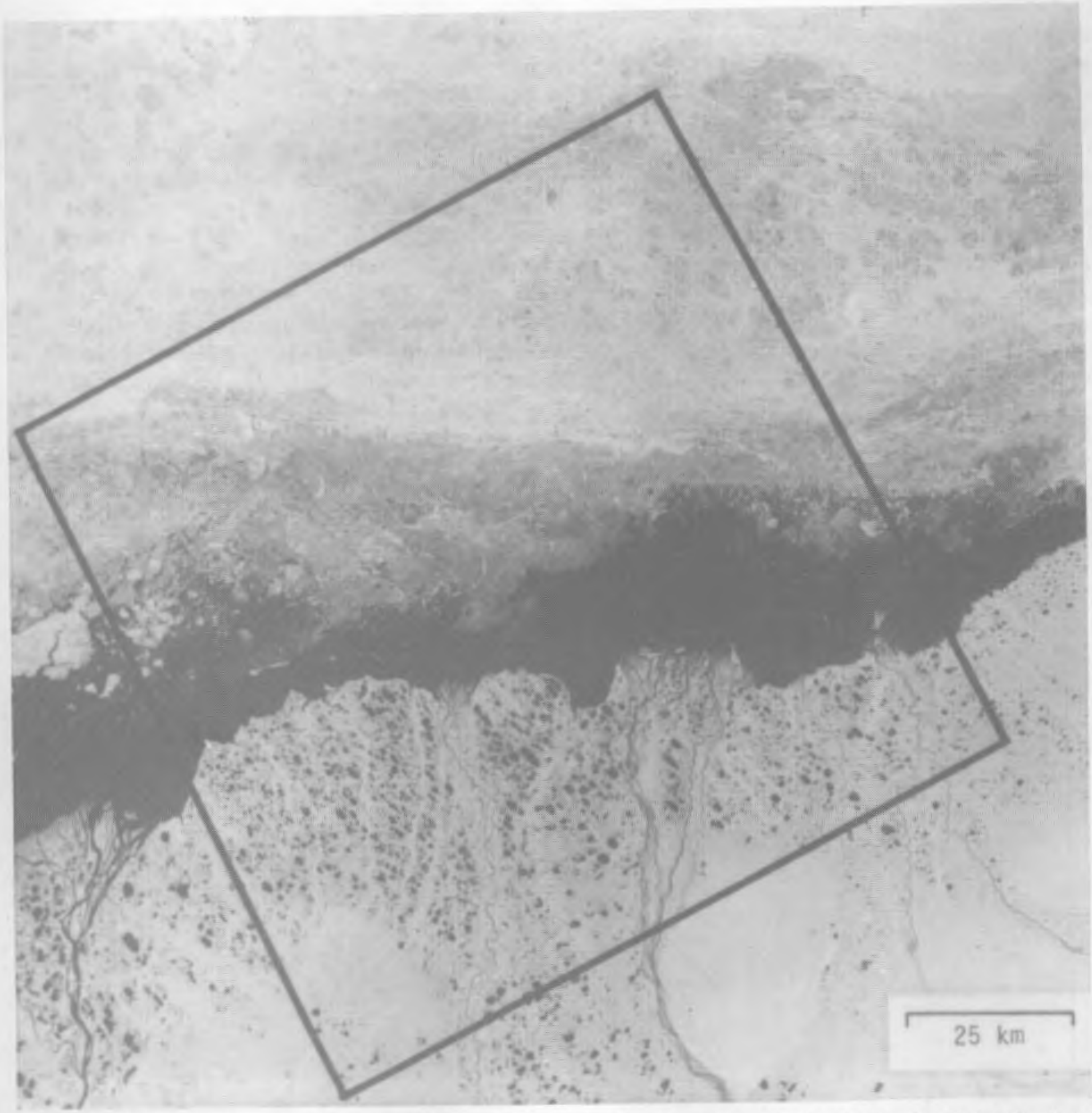



*Figure 39. NASA Landsat scene 21635-21044. This scene was taken on 15 July 1979. The Beechey Point Quadrangle is delineated by the rectangle. The scene covers the Colville River delta to the west, Franklin Bluffs at the bottom center, and Flaxman Island to the east.*

cates are stored only once with a multiplier that is equal to the number of occurrences. If, for example, there were 235 occurrences of the same pixel value, it need only be stored once along with its multiplier rather than 235 separate times.

Due to hardware limitations and the nature of the data, this program still did not successfully compress half the frame. The program limitation of 67,000 unique pixel values was reached after processing only 5% of the data. At this point a cycle was invoked which deleted single-occurrence pixel values. After experimentation the best results were obtained by sampling every fifth line and second column (10% of the original data). This increment ensured that each of the satellite's six detectors was sampled equally.

**Computer classification**

*Clustering*

A clustering algorithm, first developed at Purdue University (Swain 1972), was used to define discrete groups of pixels on the basis of their reflectance in the four Landsat spectral bands. For each cluster the algorithm generates statistics describing a) the mean value of the pixel reflectance from each band and b) a covariance matrix, which is a measure of the size and shape of the cluster.

The first clustering iteration was done on the ILLIAC-IV computer using compressed data from the Landsat scene. Histograms were generated that displayed the proportional distribution of spectral intensities in the four spectral bands. The histograms aided the analyst in deciding how many cluster centers were necessary to statistically describe the data. With the Beechey Point Quadrangle data, three unsupervised clustering jobs were run for 25, 36 and 40 cluster centers.

*Statistics editing*

Spectral plots and statistical listings were generated for each of the clustered data sets. The statistical listings describe each cluster in terms of means, variances and intercluster separability. Clusters from upland and lowland sites were examined together, and the analyst decided which clusters to keep, delete or merge before using them in the classification process. These decisions were made on the basis of an analysis of the spectral statistics, especially cluster separability and variances. In general, clusters were used that resulted in the least conflict in terms of spectral overlap. The composite statistics file was then generated. It contained 41 spectral classes and was the basis for determining the preliminary classification (Fig. 40).

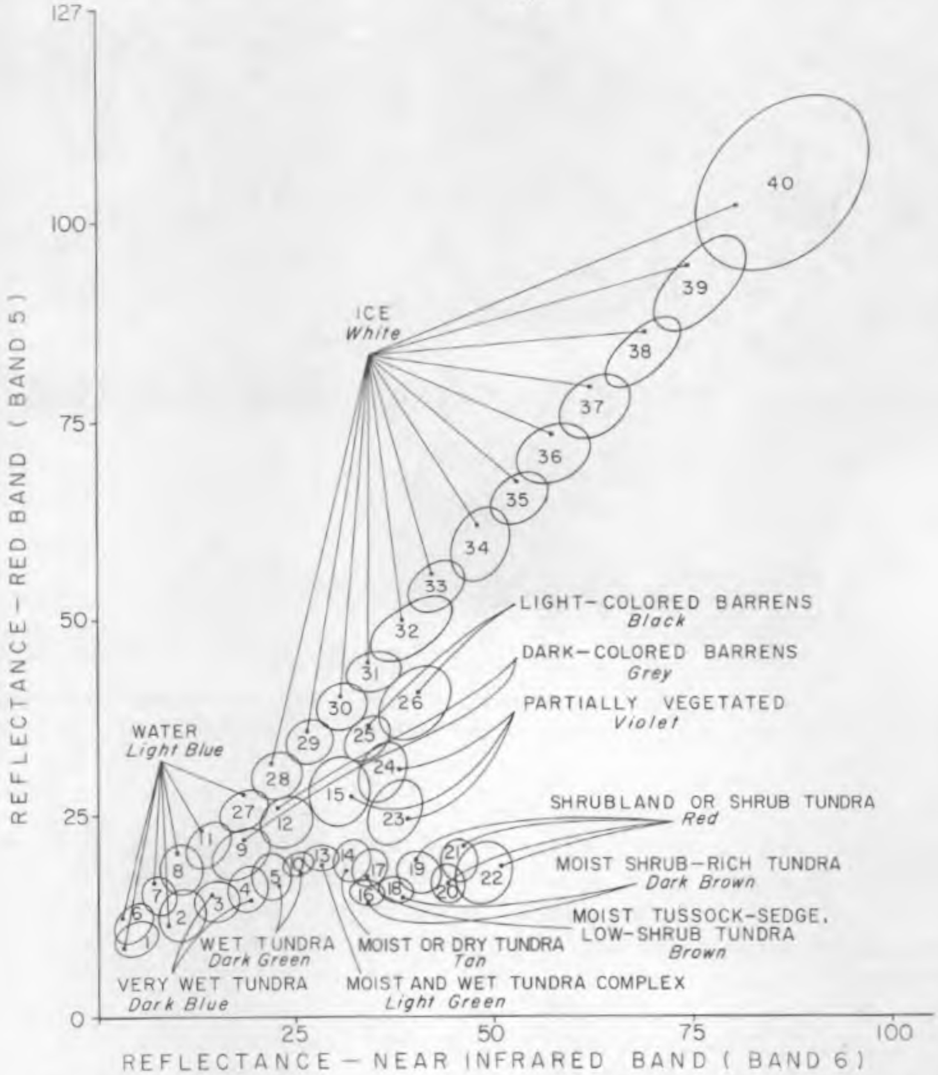



*Figure 40. Preliminary cluster diagram for scene 21635-21044, Bands 5 and 6. Each ellipse encloses 80% of the pixels assigned to the respective cluster. The land cover designations indicate how the clusters were grouped in the preliminary investigation.*

*Maximum likelihood classification*

Once a set of statistics was defined, a Gaussian maximum likelihood classification was performed. This algorithm evaluates a probability density for each pixel and assigns each pixel to the cluster for which the probability is greatest (Gaydos and Newland 1978). In this way all pixels were separated into spectral classes defined by the cluster statistics. This classification process was performed on the CDC-7600 computer.

*Cluster labeling*

A preliminary cluster labeling was performed by visual interpretation of the classified image as viewed on a color monitor. Using the Interactive Digital Manipulation System (IDIMS), the selected portions of the Landsat scene were viewed and each spectral class (cluster) was assigned a distinctive color, while the vegetation was identified from high-resolution aerial photographs, cluster plots and color-composite Landsat images. This step was repeated after the field visits when photo-interpretation keys were developed for more accurate identification of land cover types. Field notes aided this interpretation.

Following the field work (see next section) each cluster was interpreted and identified as to the land cover unit it represented. Table 5 summarizes the cluster identifications. Several clusters often defined a single land cover unit, and some clusters included more than one land cover unit. Twelve land cover units were established as a result of numerous iterations in attempting to describe the vegetation with as many distinct and valid vegetation types as possible. These twelve units were later reduced to eight on the basis of area information from geobotanical maps that became available after the original set of units was defined.

**Ground-reference data**

*Background*

This work began in 1978 when Komárková and Webber (1980) made a detailed map of the Atkasook, Alaska, region and related their findings to a Landsat classification of the National Petroleum Reserve in Alaska (Morrissey and Ennis 1981). The study pointed out the need for extensive ground-reference data in making maps of tundra. Since then the authors have collected detailed ground data from numerous areas across northern Alaska with the goal of eventually making Landsat-derived land cover maps for all of northern Alaska. Observations on the Arctic Coastal Plain include most of the region from Barrow to the Niguanak River southeast of Barter Island. In 1982 a Landsat-derived land cover map of the coastal plain portion of the Arctic National Wildlife Refuge (ANWR) was published (Acevedo et al. 1982) as part of a baseline study by the U.S. Fish and Wildlife Service (USFWS) for the proposed oil and gas exploration within the ANWR (USFWS 1982, Walker et al. 1982). The area where most ground-reference data have been collected is the Prudhoe Bay region, which was a study site for the International Biological Program (IBP) Tundra Biome (Brown et al. 1980). The vegetation, soils and landforms of much of the region were described and mapped at the 1:6000 scale as part of the IBP studies and other CRREL- and local-industry-supported projects (Walker et al. 1980, Everett et al. 1981, Walker et al. 1982). In addition, ground-reference data were collected from the Dalton Highway and Trans-Alaska Pipeline System (TAPS) corridor (Webber et al. 1978).

*Cluster label verification*

Surveys for the Beechey Point Quadrangle were concentrated in 20 frames of 1:60,000-scale color-infrared (CIR) photographs that represent the major terrain types within the study area. This information was supplemented with extensive ground-reference data from the Prudhoe Bay region gathered during the past several years (Fig. 41).

Prior to field work, numerous areas for ground checking were delineated on the CIR photographs (Fig. 42). The most satisfactory method of choosing these areas used the IDIMS image analysis system at Ames. With this system, areas represented by an individual spectral category or cluster could be displayed. The first step was to display the area corresponding to a given CIR frame. All pixels of a given spectral cluster (Fig. 40) were then displayed in red against a black background, sometimes with water bodies displayed in blue to assist in locating the areas on the photographs.

Next, several areas (polygons) that had homogeneous spectral signatures of the cluster corresponding to the areas displayed on the IDIMS screen were located on the aerial photograph. Normally, large homogeneous areas were selected, but other considerations included sites that represented a variety of terrain features or distinctive areas that covered only a small portion of the photograph. For each polygon the cluster numbers and a preliminary interpretation of the vegetation according to Walker (1983) Level B units were

**Table 5. Cluster classification for the Beechey Point Quadrangle spectral data. The first 41 clusters apply to the preliminary classification (Fig. 40). The remaining 16 clusters are stratified clusters and others generated for the final classification (Fig. 43–46).**

| *Cluster no.** | *Description of land cover* |
|---|---|
| 1 | Deep, clear water, mainly lakes |
| 2 | Turbid water (inc. sewage ponds), lake margins, flooded areas near road, pond complexes with > 80% open water |
| 3 | Pond complexes with 50-80% water, low-centered polygons with > 60% water, some aquatic tundra, mostly small areas |
| 4 | Pond complexes with 40-65% water, aquatic tundra, lake margins, *Arctophila fulva* areas |
| 5 | Wet tundra (wetter facies with *Scorpidium scorpioides*), some pond complexes with up to 30% water |
| 6 | Water, mostly ocean, slightly turbid water |
| 7 | Turbid lakes and ocean water in delta areas, water on dirty ice |
| 8 | Muddy water, Colville River |
| 9 | Barren wet mud, wet darker gravels, marl-bottomed lakes (stratified out and classed as pond complex), shallow water over mud, salt-killed areas along coast, barrier islands (stratified out and classed as barrens) |
| 10 | Wet tundra, saturated soils but no open water, some emergent *Carex aquatilis* |
| 11 | Turbid water |
| 12 | Wet gravel, darker-colored roads, pads, barren peat, beach gravel, < 30% vegetated |
| 13† | Moist/wet tundra complex, moist tundra without cottongrass tussocks, moist tundra with cottongrass tussocks and *Dryas integrifolia* (low foothills north of the White Hills), moist tundra along streams, moist frost-scar tundra, *Dryas* tussock tundra with up to 20% wet tundra, river complexes with 40–80% *Dryas* river terraces |
| 14 | Dry tundra, moist tundra with high albedo (drier facies of moist tundra), *Dryas* river terraces along the Sagavanirktok River, *Dryas* tussock tundra, foothills north of Franklin Bluffs, moist tundra along streams (north-facing slopes), frost-scar tundra, Kuparuk River terraces near coast, coastal terraces, moist tundra near coast with up to 20% sedge, dwarf-shrub, crustose-lichen tundra |
| 15** | Sparse vegetation, dunes, poorly vegetated coastal bluffs with frost scars |
| 16 | Low-shrub, tussock-sedge tundra south of Franklin Bluffs; riparian scrub with 50-cm-high willows, willow-rich water track complexes, birch tundra, dwarf willow communities along streams, forb, grass river terraces |
| 17 | Tussock-sedge, low-shrub tundra on hills east of Franklin Bluffs; areas along beaded streams with dense sedges and dwarf willows; some forbs, grass, willow, *Dryas* communities along Kuparuk River; frost-scar tundra on Franklin Bluffs |
| 18 | Low-shrub, tussock-sedge tundra, low shrubs along rivers, water-track complexes with low shrubs |
| 19 | Open riparian shrubs, shrub tundra on south side of Franklin Bluffs, some dwarf-shrub, forb communities along streams, water tracks without dense shrubs |
| 20 | Riparian shrubs, somewhat denser than Cluster 19, shrub tundra |
| 21 | Dense riparian shrubs |
| 22 | Dense tall riparian shrubs (only a few very small areas along Kuparuk River), very dense shrub tundra in water tracks |
| 23 | Sparse vegetation, drained lake basins with rich sedges (stratified out and classed as wet tundra), sewage-fertilized tundra (stratified out and classed as wet tundra), stabilized dunes, sparsely vegetated river terraces and coastal bluffs, 20–50% barren, dry open dwarf-shrub tundra in delta of Sagavanirktok River with up to 50% bare soil, sparsely vegetated areas with high percentage of dry dwarf-shrub tundra |
| 24 | Sparse vegetation areas, 30–70% barren |
| 25 | Sparse vegetation, mostly gravel (up to 90%) |
| 26 | Bright gravel, pads, east channel of Sagavanirktok River |
| 27 | Water on ice |

| | |
|---|---|
| 28 | Dirty ice (all sea ice has been classed as water) |
| 29 | Dirty ice (all sea ice has been classed as water), bright roof tops in Prudhoe Bay oil field |
| 30 | Dirty ice (all sea ice has been classed as water), bright roof tops in Prudhoe Bay oil field |
| 31 | Dirty ice (all sea ice has been classed as water), bright roof tops in Prudhoe Bay oil field |
| 32 | Dirty ice (all sea ice has been classed as water), bright roof tops in Prudhoe Bay oil field |
| 33 | Dirty ice (all sea ice has been classed as water), bright roof tops in Prudhoe Bay oil field |
| 34 | Ice (all sea ice has been classed as water), bright roof tops in Prudhoe Bay oil field |
| 35 | Ice (all sea ice has been classed as water) |
| 36 | Ice (all sea ice has been classed as water) |
| 37 | Ice (all sea ice has been classed as water) |
| 38 | Ice (all sea ice has been classed as water) |
| 39 | Clean ice (all sea ice has been classed as water) |
| 40 | Clean ice (all sea ice has been classed as water) |
| 41 | Clean ice (all sea ice has been classed as water) |
| 42 | Stratification cluster, dirty ice misclassified as vegetation, now classed as water |
| 43 | Barrens on barrier islands |
| 44 | Stratification cluster, dirty ice misclassified as vegetation, now classed as water |
| 45 | Stratification cluster, dirty ice misclassified as vegetation, now classed as water |
| 46 | Stratification cluster, marl-bottomed lakes misclassified as barrens, now classed as water |
| 47 | Stratification cluster, lush drained lake basins misclassified as shrublands, now classed as wet herbaceous tundra |
| 48 | Unused stratification cluster |
| 49 | Moist sedge, dwarf-shrub tundra; moist tundra with frost scars; well-drained lake margins; moist/wet tundra complexes with up to 50% wet tundra; moist tussock-sedge, dwarf-shrub tundra with up to 30% barren frost scars; moist tundra with up to 20% water |
| 50 | Wet sedge tundra; wet sedge/moist sedge, dwarf-shrub tundra complex with up to 20% wet tundra; dry dwarf-shrub, crustose-lichen/wet sedge tundra complexes on old braided terraces of the Sagavanirktok River; moist sedge, dwarf-shrub/water complexes with up to 20% water; margins of some lakes (mostly margins between water and moist tundra) |
| 51 | Moist tussock-sedge, dwarf-shrub/wet sedge tundra complex in the White Hills vicinity of the Kuparuk Field; moist/wet tundra complexes with up to 50% wet tundra; moist tundra complexes with up to 20% water or aquatic tundra; narrow strips of moist and wet complexes with up to 50% water or wet tundra; wet sedge/moist sedge, dwarf-shrub with up to 60% wet tundra; moist terraces of the Putuligayuk River with less than 10–20% wet tundra |
| 52 | Sparsely vegetated gravel bars with less than 30% cover, drained lake basin at Pump Station 1, very sparsely vegetated dunes in Sagavanirktok River delta, dry sparsely vegetated tundra on Sagavanirktok River bars and islands |
| 53 | Barrens, bare white gravel |
| 54†† | Much of road network and gravel areas that border tundra, dry tundra on Sagavanirktok River gravel bars, sparsely vegetated areas (many pixels are on boundaries between barrens and tundra areas), some pond complexes with marl-bottomed lakes, coastal bluffs with salt kill and dry tundra, coastal beaches with some vegetation |
| 55 | Dry tundra on Sagavanirktok River bars, scattered pixels of sparse vegetation, some pond complexes with marl-bottomed lakes, coastal bluffs with salt kill, coastal beaches with some vegetation |
| 56 | Barrens (mostly roads) |
| 57 | Barrens (mostly roads) |

* Refer to Figure 46.

† Reclustered into clusters 49, 50 and 51; see Figure 43.

** Reclustered into clusters 52, 53 and 54; see Figure 44.

†† Reclustered into clusters 55, 56 and 57; see Figure 45.

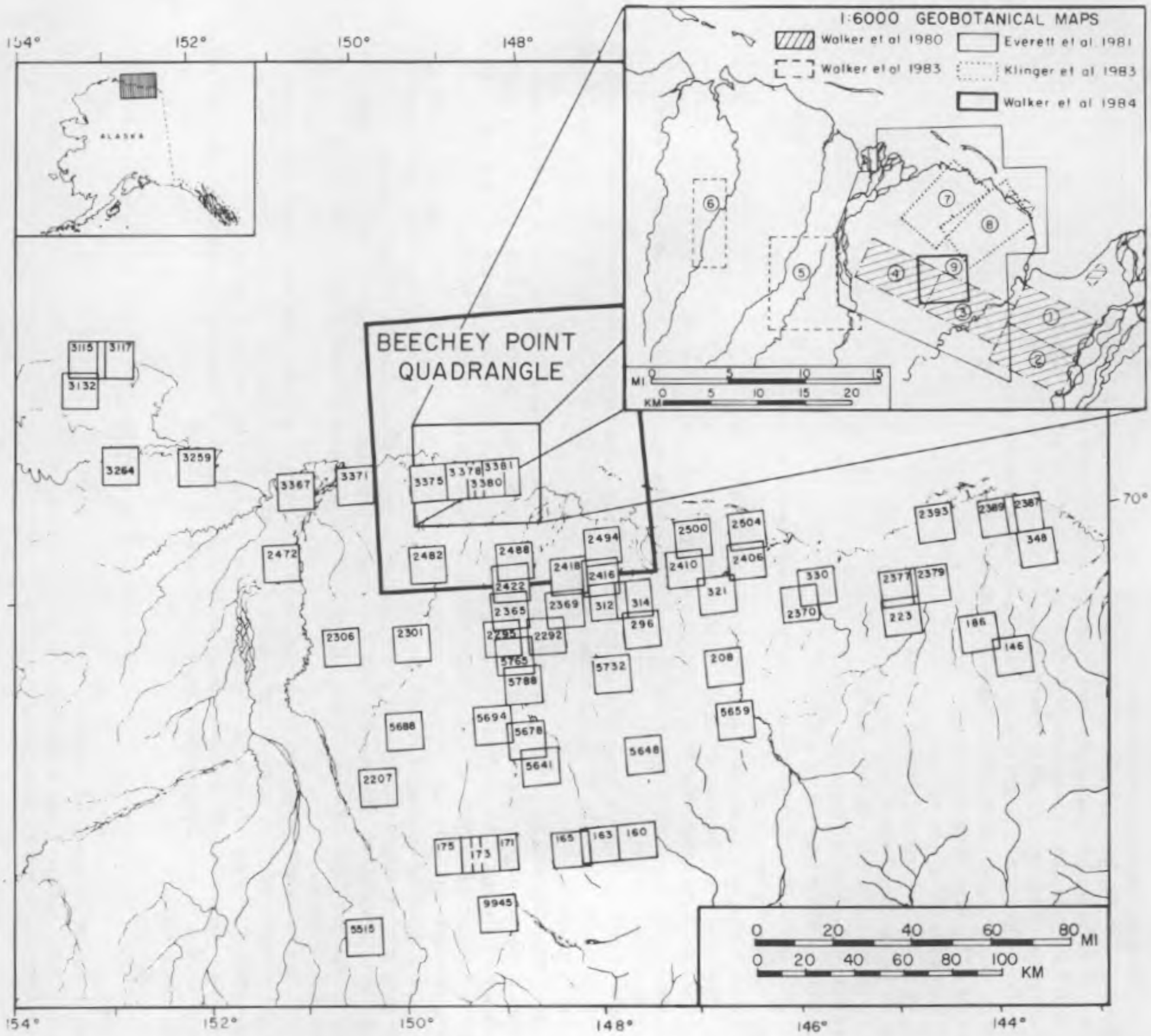


*Figure 41. Ground-reference data for the eastern portion of the Arctic Coastal Plain and Foothills. Each square represents a 1:60,000-scale CIR photograph. NASA frame numbers are shown for each photo. Photos are from five different NASA flights (74-104, 78-084, 78-015, 79-006 and 79-097). The inset map is a detail of the Prudhoe Bay region showing the location of 1:6000-scale geobotanical maps. The numbered 1:6000-scale areas are the sites used for the area measurement check.*

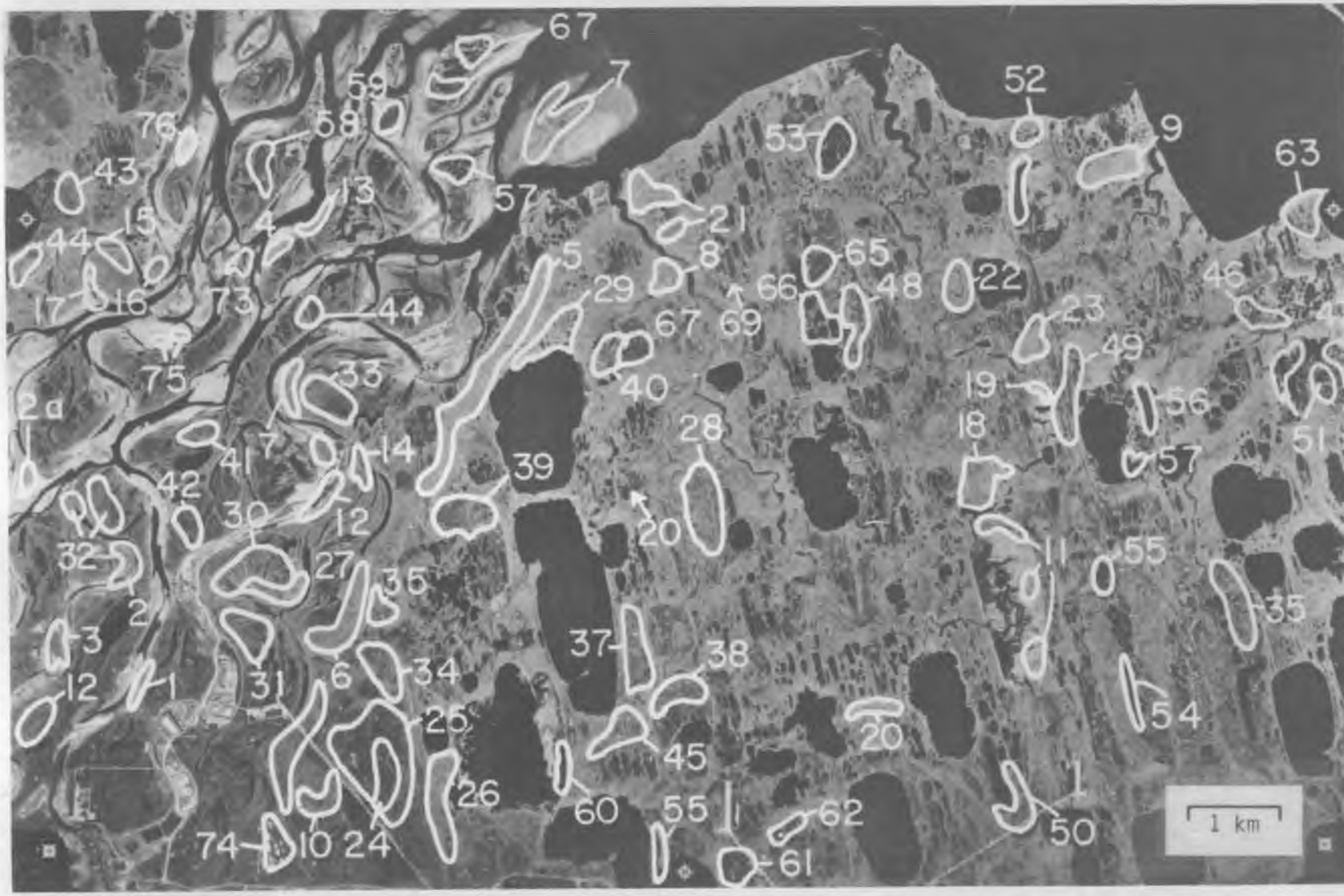



*Figure 42. Example of a color-infrared photograph on which areas of homogeneous spectral reflectance have been delineated. Each numbered area represents a group of pixels from a single cluster (Fig. 40). All pixels from a given cluster were assigned a color and displayed on the IDIMS monitor independent of all other pixels. Large areas of the given category were then delineated on the CIR photograph and a preliminary identification was made (Table 6). This was done for all clusters appearing on the photograph. The photograph was then taken into the field, and each polygon was visited and the vegetation and landforms were described (Table 6).*

## Table 6. Sample field data from ground-reference surveys.

Landsat Classification Ground Reference Data

USGS quadrangle: Beechey Point    CIR frame no: 3380    Observers: Walker and Acevedo    Page 3 / 5

Date of preliminary classification analysis 7/4/81    Date of ground reference data: 7/17/82

Location: Point Storkersen and Kuparuk Delta

| | Preliminary Classification | | Ground Reference Data - Percent Cover of Vegetation Types (Walker 1983 Level C Types) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. Polygon no. | 2. Statistical Cluster #'s | 3. Est. Veg. cover Walker Level C | 4. Dominant Type | 5. Secondary Type | 6. Tertiary Type | 7. Others | 8. Surface form | 9. Shrub Ht. | 10. General Description and Notes |
| 44 | 10 | 90% wt sdg; 10% mst sdg, dwf shrb | 50% wt sdg | 30% mst sdg dwf hrb | 20% aq sdg | | disjunct LC polygons | — | wt sdg / mst sdg dwf shrb tndr cmplx |
| 45 | 10 | 70% wt sdg; 20% mst sdg dwf shrb; 5% $H_2O$ | 60% wt sdg | 30% mst sdg, dwf shrb | 5% $H_2O$ | 5% dwf shrb crst lchn | L.C. polys w/ strangs | — | wt sdg / mst sdg, dwf shrb tndr cmplx |
| 46 | 5 | 70% wt sdg; (possibly saline); 30% $H_2O$ | 40% wt sdg (saline) | 30% $H_2O$ | 15% brm | 15% mst sdg dwf shrb | pond complex | — | saline wt sdg / $H_2O$ cmplx |
| 47 | 5 | 40% aq. sdg; 40% $H_2O$ 20% mst sdg, dwf shrb | (poly gon missed during field check) | | | | | | |
| 48 | 5 | 40% aq sdg; 30% wt sdg 20% $H_2O$, 10% mst sdg dwf shrb | 50% $H_2O$ | 20% aq sdg | 20% mst sdg, dwf shrb | 10% wt sdg | pond complex w/ strangs | — | $H_2O$ / mst sdg, dwf shrb Tndr cmplx |
| 49 | 5 | 50% aq sdg, 30% $H_2O$ 20% mst sdg, dwf shrb | 50% $H_2O$ | 20% mst sdg, dwf shrb | 15% wt sdg | 15% dry dwf shrb, crst lchn | pond complex | — | $H_2O$ / mst sdg, dwf shrb Tndr cmplx |
| 50 | 5 | 90% aq sdg; 5% $H_2O$ 5% mst sdg | 80% aq sdg | 10% $H_2O$ | 5% mst sdg dwf shrb | 5% dry dwf shrb, crst lchn | strangmoor | — | aq sdg tndr |
| 51 | 1 | 80% $H_2O$; 20% islands | 70% $H_2O$ | 20% wt sdg | 10% aq sdg | 2% mst sdg dwf shrb | pond complex | — | $H_2O$ |
| 52 | 1 | 70% $H_2O$; 20% islands 10% aq grs | 80% $H_2O$ | 10% aq. sdg | 10% aq grs | | pond complex | — | $H_2O$ |
| 53 | 1 | 40% $H_2O$; 40% aq sdg 20% aq grs | 75% $H_2O$ | 20% aq sdg | 5% wt sdg | + mst sdg dwf shrb | pond complex | — | $H_2O$/aq sdg tndr cmplx |

entered on a data sheet (Table 6, col. 1–3). At this point Walker's (1983) classification system was used. (This was later modified after problems were noted when the area measurement data were compared with detailed geobotanical maps.) This was done systematically for all 41 spectral clusters.

*Field work*

Each of the areas delineated on the CIR photographs was then examined in the field. For most areas the procedure involved circling the field site with a helicopter at about 150 m altitude and estimating the percentage cover of the dominant vegetation types (Table 6, col. 4–7). Also noted were the dominant surface form, the height of shrubs, and a general description of the area (Table 6, col. 8–10). If there was doubt about the vegetation or if the area represented an unfamiliar vegetation type, a ground check was made and detailed notes were taken regarding species composition and soil type. Ground checks were made frequently to verify that interpretations from the air were correct. At 150 m altitude it was often difficult to determine growth forms in the vegetation canopy. This was particularly true with tussock sedges; for example, earth hummocks were sometimes interpreted as cottongrass tussocks (*Eriophorum vaginatum*), and it took much experience before these determinations could be consistently made from the air.

*Check of preliminary classification*

Eight detailed 1:6000-scale geobotanical maps of portions of the Prudhoe Bay oil field were available from our previous work for checking the classification (areas 1–8 in Fig. 41, also appendix figures D1–D16). Area-measurement data from these maps were used to test the reliability of the preliminary Landsat-derived classification (Fig. 40). Boundaries of the maps were digitized, and the areas of the land cover units were measured with a counting algorithm from the EDITOR software package.

Table 7 summarizes area data from the geobotanical maps and corresponding data from preliminary Landsat maps of the same areas. The table also has ratios of the Landsat and geobotanical area values. A ratio of 1.0 indicates identical area measurements on the Landsat and geobotanical maps. The ratios indicate that overall there was not good correspondence for any of the categories except wet tundra. Water and moist tundra were underrepresented; very wet tundra and moist and wet tundra complex were overrepresented. Values for the partially vegetated and barren classes were difficult to judge because of limited data and different dates of the various maps. Extensive road and pad construction had occurred in most of the map areas between the date of the photos used for geobotanical mapping and the date of the Landsat scene. Several other basic differences were evident between the geobotanical and Landsat maps. For example, road-caused flooding had increased the amount of open water and very wet tundra between 1973 (date of the photos used for Walker et al. [1980]) and 1979 (date of the Landsat scene) and again between 1979 and 1981 (date of photos used for Walker et al. [1983] and Klinger et al. [1983]). Only sites 6 and 7 were basically the same on both the geobotanical and the Landsat-derived maps.

The results of this check indicated that the original classification needed to be revised. The major problem class was the moist and wet tundra complex (cluster no. 13 in Fig. 40). This single cluster of pixels covered 11.4% of the map area, the highest value for any terrestrial unit. This cluster initially was thought to define complexes of moist tundra and wet tundra, but closer examination of the data showed that it also included a large amount of moist tundra, particularly in the gently rolling thaw-lake plains and the low hills in the southwest corner of the quadrangle. There was no way to retain the class and keep it consistent across the entire map.

This problem was resolved by reclustering clusters 13 and 15. All pixels in cluster 13 and 15 were extracted from the raw multispectral image and placed in a new output image file. The resulting image contained the four-channel spectral reflectance values for all pixels that the classifier had earlier assigned to clusters 13 and 15. This image contained no geometric information since the data were packed without regard to spatial relationships. From these new data sets the IDIMS clustering algorithm ISOCLS defined three spectral classes for each data set (Fig. 43 and 44). With this method, clusters 13 and 15 were each reclustered to form new clusters 49–54. Pixels in the new clusters were then viewed on the video display to determine how they should be combined in the remaining land-cover classes. The determinations are recorded in Table 5. Clusters 49 and 51 were determined to be moist tundra or moist tundra complexes; cluster 50 was wet tundra and wet tundra complexes; clusters 52 and 53 were barrens. Cluster 54 presented a problem because it still included many barrens (mainly roads) and areas

**Table 7. Summary of area-measurement data for eight geobotanical maps and corresponding data for six land cover units appearing on the Landsat-derived maps. The data from the geobotanical maps have been grouped into equivalent classes to correspond to the land cover units. The ratios are the Landsat data values divided by the geobotanical data values.**

| | *Land cover unit* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Open water* | | *Very wet tundra* | | *Wet tundra* | | *Moist/wet tundra* | | *Moist or dry tundra* | | *Partially vegetated and Barren* | |
| | *% area* | *Ratio* | *% area* | *Ratio* | *% area* | *Ratio* | *% area* | *Ratio* | *% area* | *Ratio* | *% area* | *Ratio* |
| **Site no. 1** (Walker et al. 1980) | | | | | | | | | | | | |
| Landsat | 16.37 | | 13.10 | | 41.68 | | 9.59 | | 0.99 | | 18.13 | |
| Geobotanical | 22.63 | 0.69 | 6.76 | 1.90 | 45.73 | 0.91 | NCD* | | 18.81 | 0.05 | 10.22 | 1.77 |
| **Site no. 2** (Walker et al. 1980) | | | | | | | | | | | | |
| Landsat | 23.27 | | 10.99 | | 42.16 | | 4.80 | | 0.54 | | 18.83 | |
| Geobotanical | 27.73 | 0.84 | 3.72 | 2.95 | 45.89 | 0.92 | NCD | | 16.50 | 0.03 | 8.99 | 2.02 |
| **Site no. 3** (Walker et al. 1980) | | | | | | | | | | | | |
| Landsat | 21.85 | | 10.69 | | 35.51 | | 13.52 | | 0.79 | | 17.54 | |
| Geobotanical | 27.75 | 0.79 | 1.86 | 5.75 | 41.20 | 0.86 | NCD | | 25.63 | 0.03 | 9.53 | 1.84 |
| **Site no. 4** (Walker et al. 1980) | | | | | | | | | | | | |
| Landsat | 24.13 | | 15.80 | | 30.80 | | 14.17 | | 2.16 | | 12.80 | |
| Geobotanical | 31.63 | 0.76 | 3.68 | 4.29 | 39.02 | 0.79 | NCD | | 21.29 | 0.10 | 5.26 | 2.43 |
| **Site no. 5** (Walker et al. 1983) | | | | | | | | | | | | |
| Landsat | 10.52 | | 11.22 | | 39.86 | | 28.05 | | 5.64 | | 4.46 | |
| Geobotanical | 22.29 | 0.47 | 0.78 | 14.38 | 46.12 | 0.86 | 9.60 | 2.92 | 17.55 | 0.32 | 3.77 | 1.18 |
| **Site no. 6** (Walker et al. 1983) | | | | | | | | | | | | |
| Landsat | 13.13 | | 9.79 | | 28.90 | | 27.80 | | 19.16 | | 0.89 | |
| Geobotanical | 23.76 | 0.55 | 1.55 | 6.32 | 36.35 | 0.80 | 9.08 | 3.06 | 27.92 | 0.69 | 1.52 | 0.58 |
| **Site no. 7** (Klinger et al. 1983) | | | | | | | | | | | | |
| Landsat | 12.16 | | 13.34 | | 36.67 | | 27.07 | | 9.96 | | 0.76 | |
| Geobotanical | 21.49 | 0.57 | 3.79 | 3.52 | 48.58 | 0.75 | 3.39 | 7.98 | 21.06 | 0.47 | 1.29 | 0.59 |
| **Site no. 8** (Klinger et al. 1983) | | | | | | | | | | | | |
| Landsat | 26.80 | | 14.74 | | 35.83 | | 16.90 | | 3.13 | | 2.57 | |
| Geobotanical | 35.42 | 0.76 | 3.94 | 3.74 | 39.72 | 0.90 | 1.72 | 8.08 | 16.19 | 0.19 | 2.12 | 1.21 |

* NCD = no comparable data.

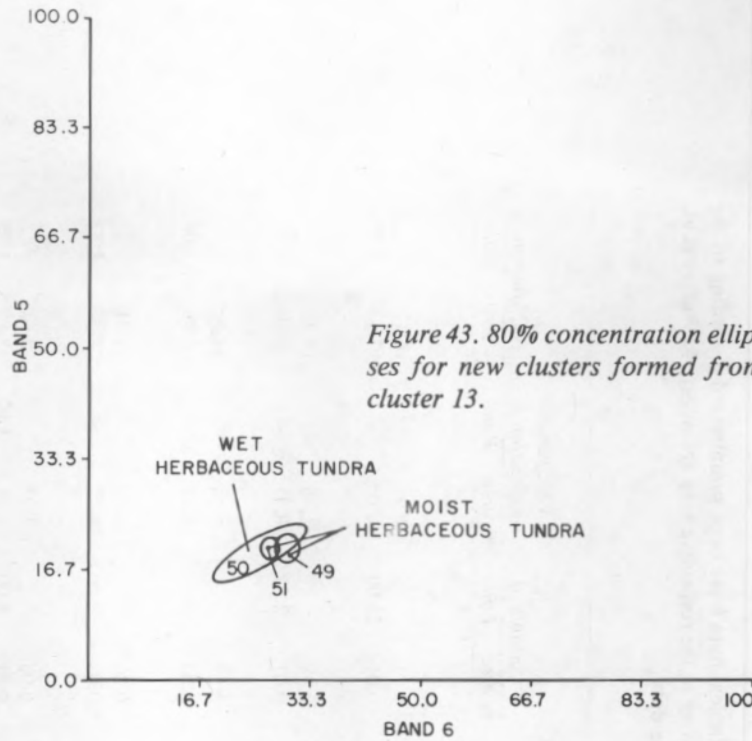



*Figure 43. 80% concentration ellipses for new clusters formed from cluster 13.*

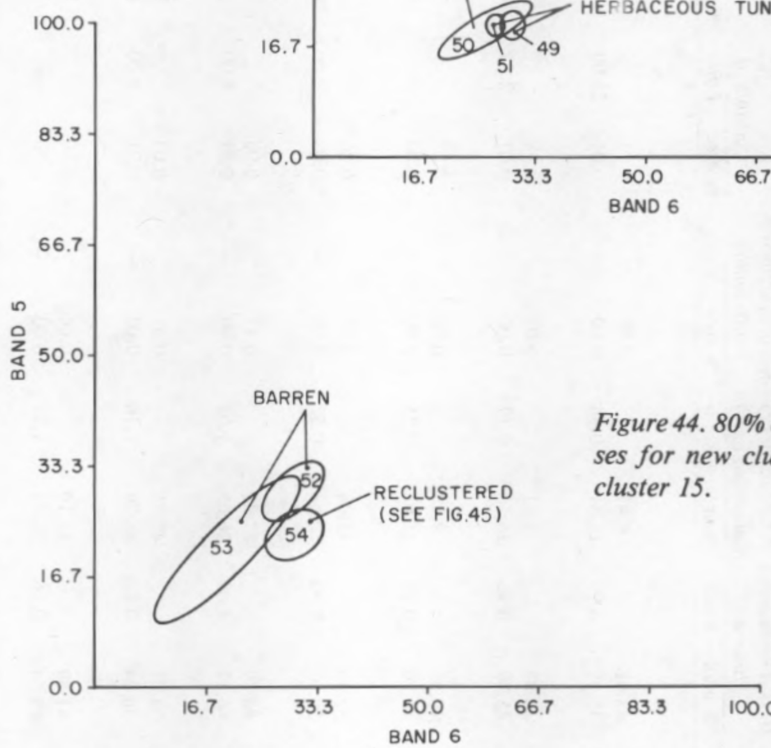



*Figure 44. 80% concentration ellipses for new clusters formed from cluster 15.*

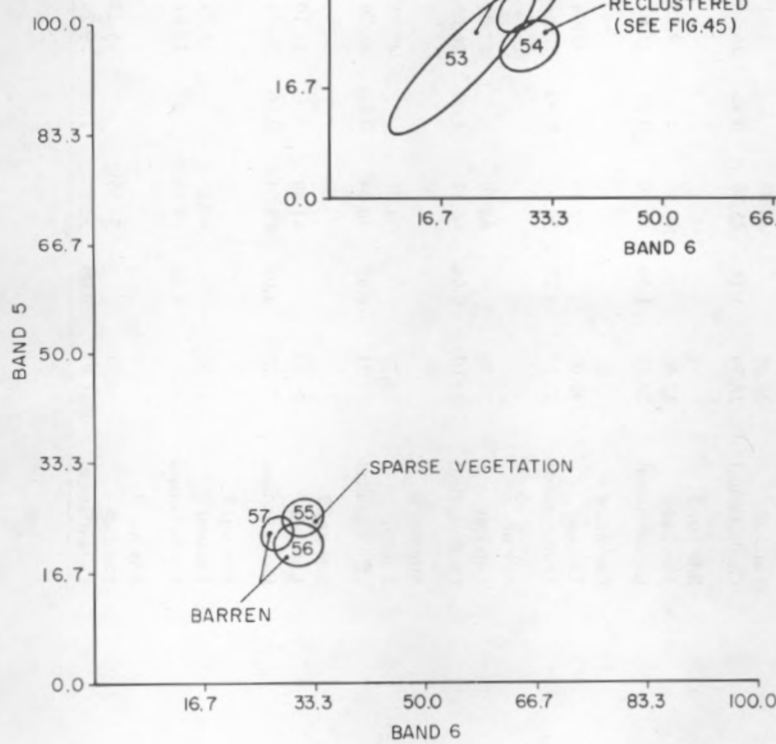



*Figure 45. 80% concentration ellipses for new clusters formed from cluster 54.*

**Table 8. Summary of area-measurement data after reclustering. The geobotanical data have been summarized according to the equivalent modified Walker et al. (1983) Level B units. Area values are percentage cover in the respective map areas. Site 9 (Walker et al. 1984) was mapped after the initial analysis and provided an additional check of the data.**

| | *Land cover unit* | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *I. Water* | | *II. Wet herbaceous tundra* | | *III. Moist or dry herbaceous tundra* | | *IV. Moist herbaceous, mixed-shrub tundra* | | *V. Shrubland* | | *VI. Sparse vegetation* | | *VII. Barren* | |
| | *% area* | *Ratio* | *% area* | *Ratio* | *% area* | *Ratio* | *% area* | *Ratio* | *% area* | *Ratio* | *% area* | *Ratio* | *% area* | *Ratio* |
| **Site no. 1** | | | | | | | | | | | | | | |
| Landsat | 29.62 | | 45.61 | | 6.41 | | 0.00 | | 0.23 | | 1.96 | | 16.17 | |
| Geobotanical | 27.96 | 1.06 | 45.91 | 0.99 | 18.81 | 0.34 | 0.00 | — | 0.01 | 23.00 | NCD* | — | 7.32 | 2.20 |
| **Site no. 2** | | | | | | | | | | | | | | |
| Landsat | 34.26 | | 44.47 | | 2.81 | | 0.06 | | 0.18 | | 1.76 | | 16.46 | |
| Geobotanical | 28.94 | 1.18 | 45.89 | 0.96 | 16.50 | 0.17 | 0.00 | — | 0.07 | 2.57 | NCD | — | 8.60 | 1.91 |
| **Site no. 3** | | | | | | | | | | | | | | |
| Landsat | 32.60 | | 40.55 | | 9.27 | | 0.00 | | 0.03 | | 2.28 | | 15.27 | |
| Geobotanical | 28.19 | 1.16 | 41.20 | 0.98 | 25.63 | 0.35 | 0.00 | — | 0.00 | — | NCD | — | 4.98 | 3.06 |
| **Site no. 4** | | | | | | | | | | | | | | |
| Landsat | 40.00 | | 35.10 | | 12.04 | | 0.07 | | 0.00 | | 1.79 | | 11.01 | |
| Geobotanical | 32.27 | 1.24 | 39.02 | 0.90 | 20.63 | 0.58 | 0.00 | — | 0.03 | 0.00 | NCD | — | 8.04 | 1.37 |
| **Site no. 5** | | | | | | | | | | | | | | |
| Landsat | 21.74 | | 46.30 | | 27.25 | | 0.17 | | 0.08 | | 1.03 | | 3.43 | |
| Geobotanical | 23.07 | 0.94 | 46.12 | 1.00 | 26.65 | 1.02 | 0.00 | — | 0.01 | 8.00 | 1.01 | 1.02 | 3.15 | 1.09 |
| **Site no. 6** | | | | | | | | | | | | | | |
| Landsat | 22.28 | | 33.25 | | 42.71 | | 0.51 | | 0.03 | | 0.74 | | 0.48 | |
| Geobotanical | 25.31 | 0.88 | 36.24 | 0.92 | 36.79 | 1.16 | 0.00 | — | 0.01 | 3.00 | 1.46 | 0.51 | 0.18 | 2.67 |
| **Site no. 7** | | | | | | | | | | | | | | |
| Landsat | 25.49 | | 41.89 | | 31.19 | | 0.66 | | 0.00 | | 0.18 | | 0.59 | |
| Geobotanical | 25.25 | 1.01 | 48.64 | 0.86 | 24.45 | 1.27 | 0.00 | — | 0.00 | — | 1.34 | 0.53 | 1.32 | 0.45 |
| **Site no. 8** | | | | | | | | | | | | | | |
| Landsat | 41.55 | | 40.23 | | 15.38 | | 0.27 | | 0.00 | | 0.21 | | 2.36 | |
| Geobotanical | 39.35 | 1.06 | 39.65 | 1.01 | 17.91 | 0.86 | 0.00 | — | 0.00 | — | 0.07 | 3.00 | 3.08 | 0.77 |
| **Site no. 9** | | | | | | | | | | | | | | |
| Landsat | 46.37 | | 34.55 | | 5.25 | | 0.07 | | 0.00 | | 0.86 | | 12.88 | |
| Geobotanical | 46.92 | 0.99 | 32.97 | 1.05 | 9.26 | 0.57 | 0.00 | — | 0.00 | — | 0.67 | 1.28 | 10.18 | 1.27 |

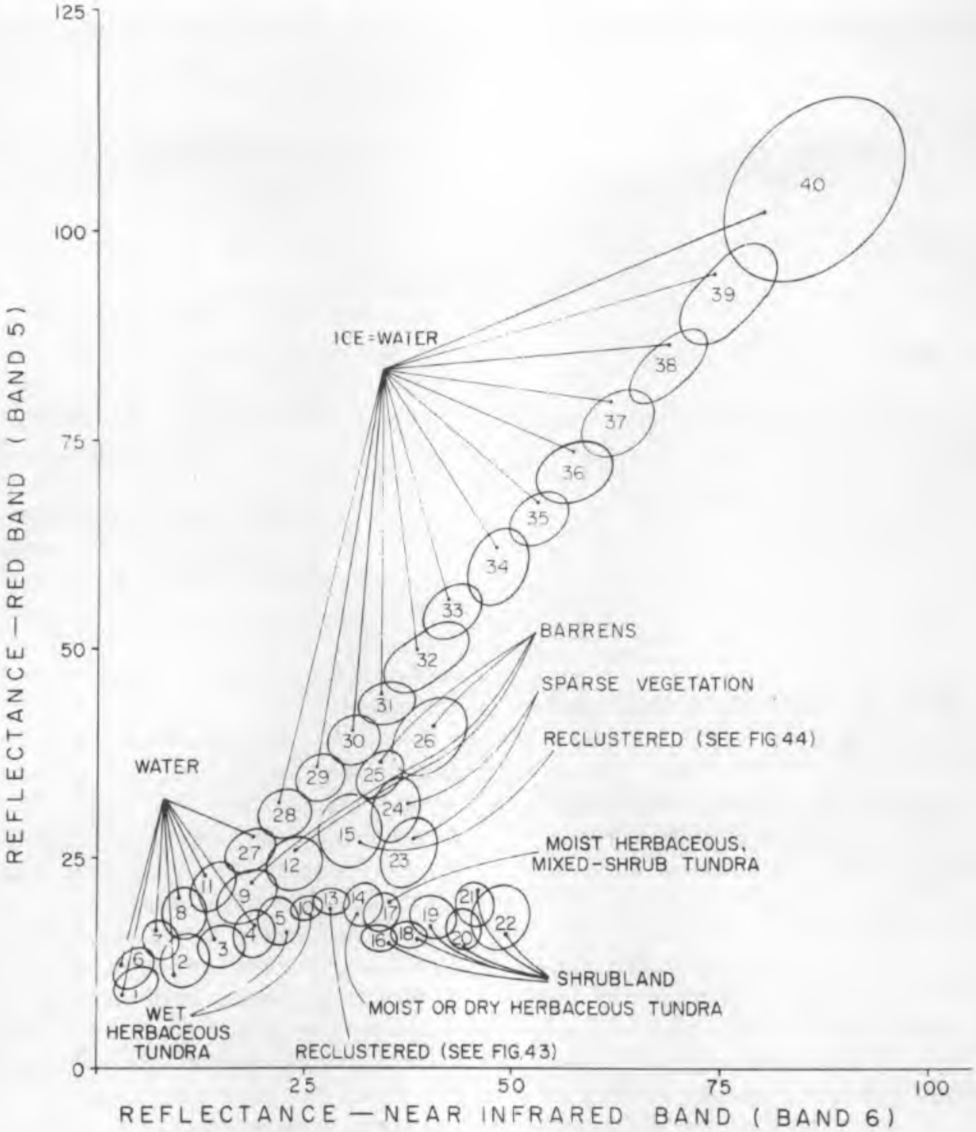



*Figure 46. Final cluster labeling for the Beechey Point classification.*

with sparse vegetation. Hence, cluster 54 was reclustered to form clusters 55–57 (Fig. 45). The primary objective was to ensure that roads were classed as barrens and not as sparse vegetation. In the final classification, clusters 56 and 57 were identified mainly as roads and placed in the barren category.

Cluster 14 includes a wide variety of moist and dry tundra types. Reclustering of this cluster was attempted to separate dry tundra, particularly extensive *Dryas*-covered river terraces, as a separate land cover type. In this case, reclustering did not work; clusters that contained dry tundra also included large areas of moist tundra.

Another problem was that the wet tundra class was too large and the water class too small. To solve this, the water and very wet tundra classes were combined into a single category called water. The area measurement for this unit was very close to the total for water and aquatic tundra. Unfortunately areas of emergent tundra, particularly *Arctophila fulva* communities, could not be consistently mapped on this scene.

Separating light- and dark-colored barrens also did not contribute much meaningful information to the map. These two classes were combined into a single category called barren.

Newly classified pixels were then reinserted into the classified Landsat data. Area data for the Landsat and geobotanical maps were then again compared (Table 8), with a substantial improvement in the comparative ratios. Figure 46 shows the relabeled cluster diagram for the final classification. Table 9 presents the final cluster aggregations.

At this point an additional geobotanical map

**Table 9. Cluster aggregations for the final classification.**

| *Land cover category* | *Cluster numbers* |
|---|---|
| Water | 1,2,3,4,6,7,8,11,27,42, 44,45,46 |
| Wet herbaceous tundra | 5,10,47,50 |
| Moist or dry herbaceous, dwarf-shrub tundra | 14,49,51 |
| Moist herbaceous, mixed-shrub tundra | 17 |
| Shrubland | 16,18,19,20,21,22 |
| Sparse vegetation | 23,24,55,56 |
| Barren | 9,12,25,26,43,52,53,57 |
| Ice | 28 to 40 |
| Background | 41 |

area was available for which the Landsat data could be compared (area 9 in Fig. 41, also see appendix figures B1, B2, D17, D18). Area 9 is a geobotanical and historical disturbance map (Walker et al. 1984). From this map the amount of roads, pads, flooding and other disturbances could be calculated for 1979, the same year as the classified Landsat scene. Table 10 shows geobotanical area-measurement data for area 9. The table lists combinations of vegetation codes, interpreted from 1949 predisturbance aerial photographs, and 1979 disturbance codes. The footnote in Table 10 shows how the geobotanical and historical disturbance code combinations were combined for comparison with the Landsat-derived land cover units. The geobotanical map from Area 9 is better for comparison with Landsat data than the other eight geobotanical map areas because it gives area data for the same year as the classified Landsat scene, and it is the only one of the geobotanical maps that utilized the modified hierarchical vegetation legend (Table 2) during the map-making process.

The results of the comparison indicate that the Landsat classification accurately portrays water and wet herbaceous tundra. The area of water on the Landsat classifications is within 12% of the values on all the geobotanical maps except on the maps where there was a major increase in flooding between the date of the map and the date of the Landsat scene (areas 1–4). Landsat values of wet herbaceous tundra are within 10% of the geobotanical values on all nine maps. However, the moist or dry herbaceous tundra unit has distinctly different ratios in the flat thaw-lake plains (areas 1, 2, 3, 4, 8 and 9) and the gently rolling thaw-lake plains (areas 5, 6 and 7). The ratios are less than 1.0 for all the flat thaw-lake plain areas, indicating that the Landsat classification is underrepresenting the moist or dry herbaceous tundra in this landscape unit; in the gently rolling thaw-lake plains, the ratios are greater than 1.0. A possible explanation for this is that the moist herbaceous tundra has distinctly different distribution patterns in the two landscape units. On the gently rolling thaw-lake plains, moist herbaceous tundra covers large broad units and is usually not complexed with wet tundra. On the flat thaw-lake plains, large noncomplex areas of moist tundra are infrequent, and a common situation is moist sedge, dwarf-shrub tundra complexed with wet sedge tundra in areas of ice-wedge polygons. Some complexes are predominantly moist herbaceous tundra, in which case they should be included with the moist herbaceous tundra land cover unit. The predominantly wet complexes should be mapped as wet herbaceous tundra.

Secondary vegetation codes are available for the geobotanical map of area 9, so it is possible to determine the area covered by vegetation complexes. Moist sedge, dwarf-shrub/wet sedge tundra complexes (vegetation code 9, 5) covers 3.66% of area 9. If these complexes were misclassified on the Landsat-based map as wet herbaceous tundra instead of moist herbaceous tundra, the ratios in Table 8 would change to those shown in Table 11, which are quite close to the ideal ratios of 1.0. Another possibility is that many of the moist-wet complexes should have been mapped as wet-moist complexes (vegetation code 5, 9 rather than 9, 5) on the geobotanical map. A spot check of several aerial photographs indicated that the latter is the most likely cause of the problem.

The area values for sparse vegetation on the Landsat-based classification are reasonable considering the small areas involved and the difficulty of photointerpreting sparse vegetation complexes. The value for barrens is also reasonable. Both the sparse vegetation and barren classes are possibly underrepresented on the geobotanical map because areas of disturbance adjacent to roads and pads may be larger than portrayed on the geobotanical map.

*Classification stratification*

Occasionally a single spectral class represented more than one mapping unit. When this occurred in geographically separated areas involving obviously misclassified regions, a post-classification stratification step was used. Misclassified areas

**Table 10. Summary of area-measurement data for area 9.**

| *Vegetation** | *Disturbance*† | *Corresponding Landsat classification unit*** | *Percent area* | *Vegetation* | *Disturbance*† | *Corresponding Landsat classification unit*** | *Percent area* |
|---|---|---|---|---|---|---|---|
| 1 | 0 | I | 37.20 | 5 | 8 | I | 0.03 |
| 1 | 1 | I | 0.16 | 5 | 10 | VII | 0.13 |
| 1 | 3 | I | 0.51 | 5 | 11 | VII | 0.72 |
| 2 | 0 | I | 1.67 | 5 | 12 | II | 0.16 |
| 2 | 1 | VII | 0.01 | 9 | 0 | III | 8.61 |
| 2 | 3 | VII | 0.02 | 9 | 1 | VII | 0.61 |
| 3 | 0 | II | 15.76 | 9 | 3 | VII | 1.71 |
| 3 | 1 | VII | 0.61 | 9 | 4 | I | 0.33 |
| 3 | 3 | VII | 0.68 | 9 | 5 | I | 0.54 |
| 3 | 4 | III | 1.04 | 9 | 6 | I | 0.37 |
| 3 | 5 | III | 3.44 | 9 | 7 | VI | 0.03 |
| 3 | 6 | III | 0.03 | 9 | 8 | VI | 0.12 |
| 3 | 8 | VI | 0.17 | 9 | 10 | VII | 0.42 |
| 3 | 10 | VII | 0.14 | 9 | 11 | VII | 0.54 |
| 3 | 11 | VII | 0.34 | 10 | 0 | III | 0.23 |
| 3 | 12 | II | 0.13 | 10 | 11 | VII | 0.01 |
| 5 | 0 | II | 17.21 | 13 | 0 | III | 0.02 |
| 5 | 1 | VII | 0.74 | 19 | 0 | III | 0.40 |
| 5 | 3 | VII | 2.50 | 19 | 1 | VII | 0.05 |
| 5 | 4 | I | 0.46 | 19 | 3 | VII | 0.24 |
| 5 | 5 | I | 1.29 | 19 | 4 | I | 0.04 |
| 5 | 6 | I | 0.49 | 19 | 5 | I | 0.02 |
| 5 | 7 | VI | 0.03 | 28 | 0 | VII | 0.04 |
| | | | | Total | | | 100.00 |

* Predisturbance vegetation (interpreted from U.S. Navy 1949 1:20,000-scale aerial photographs)

1. Water
2. Aquatic grass marsh
3. Aquatic sedge tundra
5. Wet sedge tundra
9. Moist sedge, dwarf-shrub tundra
10. Moist tussock-sedge, dwarf-shrub tundra
13. Dry dwarf-shrub, fruticose-lichen tundra
19. Dry dwarf-shrub, crustose-lichen tundra
28. Barren

† Disturbance (interpreted from 1979 1:18,000-scale photographs)

0. No disturbance
1. Roads
3. Pads
4. Continuous flooding (> 75% cover)
5. Discontinuous flooding (< 75% cover)
6. Human-induced thermokarst
7. Vehicle tracks, deeply rutted
8. Vehicle tracks, not deeply rutted
10. Gravel and debris (> 75% cover)
11. Gravel and debris (< 75% cover)
12. Heavy dust

** Final Landsat classification unit corresponding to geobotanical and historical disturbance code combinations.

were identified and outlined with a cursor using the Classified Image Editor (CIE) on the SEL 32/77 computer at Ames. All pixels of the specified class within outlined polygons were changed by the program to a class specified by the analyst.

This procedure was used to correct the classifications of some marl-bottomed lakes that had been originally classified as barrens. Also, some recently drained lake basins with chlorophyll-rich wet herbaceous tundra originally classed as shrublands because of their high reflectance in the infrared bands were changed to wet herbaceous tundra. Finally sea ice was reclassified as water for the final map. In general the areas selected for reclassification were isolated and easily recognizable on the CIR imagery, but it is possible that some small areas, particularly small marl-bottomed lakes, remain misclassified on the map.

*Final land cover unit names*

The names of the units on the final map were modified to conform to the interim land cover classification for the State of Alaska. The only unit not present in the statewide classification is

**Table 11. Possible solution to the problem of low Landsat/geobotanical ratios for moist or dry herbaceous tundra in the flat thaw-lake plains.** This solution assumes that moist and wet complexes (code 9,5) were either mistakenly included in the wet herbaceous tundra land cover unit or that they were misclassified on the geobotanical map.

| | | *Area 9* | |
|---|---|---|---|
| *Land cover unit* | *Data source* | *% area* | *Ratio* |
| Water | Landsat | 46.37 | 0.99 |
| | Geobotanical | 46.92 | |
| Wet herbaceous tundra | Landsat | 34.55 | |
| | Geobotanical | 32.97 + 3.66* | 0.94 |
| Moist or dry herbaceous, dwarf-shrub tundra | Landsat | 5.25 | |
| | Geobotanical | 9.26 − 3.66 | 0.94 |

* 3.66% is the area of 9,5 (complex of moist sedge, dwarf-shrub tundra and wet sedge tundra) vegetation complexes on the geobotanical map (Walker et al. 1984).

the moist herbaceous, mixed-shrub tundra category. This unit includes tussock-sedge, mixed-shrub tundra, which, while not important in the Beechey Point Quadrangle, does cover large expanses of the foothills. Changes to the classification resulted in a much simplified map with only seven classes. There is good correspondence between the area data from the geobotanical maps and the Landsat-derived map.

*Areal acreage summaries*

Measurements were made of areas occupied by the land cover units for the entire quadrangle, regional landscape units, and townships. These were produced by digitizing boundaries of each, registering the boundaries to the Landsat classification, and running a counting algorithm. The area summaries are in Appendix C.

Area-measurement data from the landscape units are particularly useful for contrasting and characterizing large landscape units. For example, open water covers approximately 34% of the flat thaw-lake plains, 20% of the gently rolling thaw-lake plains and only 2% of the hills. Conversely, moist or dry herbaceous tundra covers 12% of the flat thaw-lake plains (the actual value may be as much as 4% greater due to the possible exclusion of moist and wet herbaceous tundra complexes), 40% of the gently rolling thaw-lake plains and 84% of the hills.

## Cartographic procedures

*Geometric correction*

Once a final classification was generated for the scene, geometric correction of the data was performed. The data were corrected by selecting corresponding locations on the Landsat scene and on topographic maps. Precision correction was a multi-phase process that resulted in the calculation of transformation coefficients necessary to perform a registration of the digital data to a Universal Transverse Mercator (UTM) projection. Transformation coefficients were calculated from the precision calibration polynomial created during geographic referencing. In registering to the UTM coordinate system, a nearest-neighbor rule was used to resample original Landsat pixels to new pixels measuring 50 m on a side.

*Map publication*

Map publication involved the coordinated efforts of various groups within the National Mapping Division of the USGS. The vegetation and landcover map of the Beechey Point 1:250,000-scale quadrangle will be part of the USGS Land Use Series.

A Scitex laser plotter was used to generate four color-separation plates (yellow, cyan, magenta and black) from the Landsat data at 1:250,000 scale. A distinctive color was selected for each land cover unit. Each pixel was reproduced as a matrix of 16 black-and-white dots for each separation plate. Each matrix (pixel) was plotted at 200 μm spot size to achieve the 1:250,000 scale. A second black plate was made that contained the map legend and descriptive information. The color-separation plates were registered to the base map and used to lithograph the map using yellow, cyan, magenta and black in a color additive process. The final map, Vegetation and Land Cover, Beechey Point Quadrangle, Alaska, 1984, is included in the back of this report and is also available from the USGS as Map L-0211.

## CONCLUSION

Comparison of area-measurement data between Landsat and detailed 1:6000-scale geobotanical maps shows that the Landsat maps do give corresponding data for most of the map categories. Correspondence was best with area 9, which was a geobotanical map that used the modified hierarchical vegetation classification system and had data that was directly comparable for 1979, the year that the classified Landsat scene was taken. This temporal correspondence is important because of the rapid oil-field development that has changed large areas of the map. Water and wet herbaceous tundra classes correspond very well on all the maps. The moist or dry herbaceous tundra category properly classifies expanses of noncomplex moist tundra but appears to misclassify some complex areas dominated by moist tundra. This problem could be due to an overly large wet herbaceous tundra Landsat category or to improperly mapped complexes of moist and wet tundra on the geobotanical maps.

The method of reclustering problem clusters was useful in this classification. It helped create a better fit with our conceptual vegetation units and improved the hierarchical link to photointerpreted geobotanical maps.

The present Landsat-level categories of the hierarchical classification are broader than hoped for, but they are useful because acreage summaries for even the broadest land cover categories have not been previously available for the Prudhoe Bay region. Area comparisons of the Landsat classification with 1:6000-scale geobotanical maps are encouraging and indicate that it is possible to produce Landsat-derived maps on which the areas of the land cover units can be directly related to the area values obtained from more detailed geobotanical maps.

While Landsat maps are not expected to satisfy all needs for vegetation maps, they can be a key element in a multi-stage mapping program. Landsat data could also be effectively used for annual monitoring of some aspects of cumulative impact, particularly road-related impoundments and gravel placement. When a hierarchical vegetation classification scheme is used, there are strong connections between maps produced by Landsat and photointerpretive methods, thereby increasing the usefulness of the maps.

## LITERATURE CITED

**Acevedo, W., D.A. Walker, L. Gaydos and J. Wray** (1982) Vegetation and land cover, Arctic National Wildlife Refuge, Coastal Plain, Alaska. Colored, 1:250,000-scale map. U.S. Geological Survey, Map I-1443.

**Barnes, P.W. and P.W. Minkler** (1982) Sedimentation in the vicinity of a causeway groin—Beaufort Sea, Alaska. U.S. Geological Survey, Open-File Report 82-615.

**Barnes, P.W., E. Reimnitz, G. Smith and J. Melchior** (1977) Bathymetric and shoreline changes—northwestern Prudhoe Bay, Alaska. U.S. Geological Survey, Open-File Report 77-161.

**Belon, A.E., J.M. Miller and W.J. Stringer** (1975) Environmental assessment of resource development in the Alaskan coastal zone based on LANDSAT imagery. NOAA/OCS Project Office, Geophysical Institute, University of Alaska, Fairbanks, Alaska. Arctic Project Bulletin No. 7.

**Bergman, R.D., R.L. Howard, K.F. Abraham and M.W. Weller** (1977) Waterbirds and their wetland resources in relation to oil development at Storkersen Point, Alaska. U.S. Fish and Wildlife Service, Resource Publication 129.

**Billings, W.D. and K.M. Peterson** (1980) Vegetational change and ice-wedge polygons through the thaw-lake cycle in arctic Alaska. *Arctic and Alpine Research*, **12:** 413–432.

**Black, R.F. and W.L. Barksdale** (1949) Oriented lakes of northern Alaska. *Journal of Geology*, **57:** 105–118.

**Britton, M.E.** (1957) Vegetation of the arctic tundra. In *Arctic Biology* (P. Hansen, Ed.). Corvallis: Oregon State University Press.

**Brower, W.A., H.F. Diaz, A.S. Prechtel, H.W. Searby and J.L. Wise** (1977) *Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska*, Vol. III. *Chukchi–Beaufort Sea.* Arctic Environmental Information and Data Center, University of Alaska, Anchorage, Alaska.

**Brown, J.** (1962) Soils of the northern Brooks Range, Alaska. Ph.D. thesis, Rutgers University, New Jersey.

**Brown, J., P.C. Miller, L.L. Tieszen and F.L. Bunnell (Ed.)** (1980) *An Arctic Ecosystem: The Coastal Tundra at Barrow, Alaska.* Stroudsburg, Pennsylvania: Dowden, Hutchinson and Ross.

**Cannon, P.J. and S.E. Rawlinson** (1979) The environmental geology and geomorphology of the barrier island-lagoon system along the Beaufort Sea coastal plain from Prudhoe Bay to the Colville River. In *Environmental Assessment of the Alaskan Continental Shelf,* Annual Reports of Principal Investigators, March 1979. NOAA, Outer Continental Shelf Environmental Assessment Program, Boulder, Co., **10**: 209-248.

**Cantlon, J.E.** (1961) Plant cover in relation to macro-, meso- and microrelief. Final Report, Office of Naval Research, Grants No. ONR-208 and 216.

**Carson, C.D. and K.M. Hussey** (1962) The oriented lakes of arctic Alaska. *Journal of Geology,* **70**: 417–439.

**Carter, L.D. and J.P. Galloway** (1979) Arctic coastal plain pingos in National Petroleum Reserve in Alaska. In *The United States Geological Survey in Alaska: Accomplishments during 1978* (K.M. Johnson and J.R. Williams, Ed.). U.S. Geological Survey, Circular 804-B, pp. B33–B35.

**Clebsch, E.E.C. and R.E. Shanks** (1968) Summer climatic gradients and vegetation near Barrow, Alaska. *Arctic,* **21**: 161-171.

**Conover, J.H.** (1960) Macro- and micro-climate of the Arctic Slope of Alaska. Quartermaster Research and Engineering Center, Natick, Massachusetts, Technical Report EP-139.

**Crum, H.A., W.C. Steere and L.E. Anderson** (1973) A new list of mosses of North America north of Mexico. *The Bryologist,* **76**(1): 85-130.

**Derkson, D.V., T.C. Rothe and W.D. Eldridge** (1981) Use of wetland habitats by birds in the National Petroleum Reserve-Alaska. U.S. Fish and Wildlife Service, Resource Publication 141.

**Drew, J.V.** (1957) A pedologic study of Arctic Coastal Plain soils near Point Barrow, Alaska. Ph.D. thesis, Rutgers University, New Jersey.

**Everett, K.R.** (1980a) Landforms. In *Geobotanical Atlas of the Prudhoe Bay Region, Alaska* (D.A. Walker, K.R. Everett, P.J. Webber and J. Brown, Ed.). USA Cold Regions Research and Engineering Laboratory, CRREL Report 80-14, pp. 14–19.

**Everett, K.R.** (1980b) Soils. In *Geobotanical Atlas of the Prudhoe Bay Region, Alaska* (D.A. Walker, K.R. Everett, P.J. Webber and J. Brown, Ed.). USA Cold Regions Research and Engineering Laboratory, CRREL Report 80-14, pp. 20–23.

**Everett, K.R., D.A. Walker and P.J. Webber** (1981) Prudhoe Bay oilfield geobotanical master map. 23 map sheets, scale 1:6000. SOHIO Alaska Petroleum Colorado.

**Gaydos, L. and W.L. Newland** (1978) Inventory of land use and land cover of the Puget Sound region using Landsat digital data. *Journal of Research, U.S. Geological Survey,* **6**: 807–814.

**George, T.H., W.J. Stringer and J.N. Baldridge** (1977) Reindeer range inventory of western Alaska from computer-aided digital classification of Landsat data. In *Proceedings of the 11th International Symposium on Remote Sensing of Environment,* Ann Arbor, Michigan. Environmental Research Institute of Michigan, vol. 1, pp. 677–682.

**Hale, M.E., Jr. and W.L. Culberson** (1975) A fourth checklist of the lichens of the continental United States and Canada. *The Bryologist,* **73**(3): 499–543.

**Hamilton, T.D.** (1982) A late Pleistocene glacial chronology for the southern Brooks Range—Stratigraphic record and regional significance. *Geological Society of America Bulletin,* **93**: 700–716.

**Harper, J.R.** (1978) Coastal erosion rates along the Chukchi Sea coast near Barrow, Alaska. *Arctic,* **31**: 428–433.

**Harvie, J.M., J. Cihlar and C. Goodfellow** (1982) Surface cover mapping in the Arctic through satellite remote sensing. Canada Centre for Remote Sensing, Department of Energy, Mines and Resources, Ottawa, User's Manual 82-1.

**Haugen, R.K. and J. Brown** (1980) Coastal-inland distributions of summer air temperature and precipitation in northern Alaska. *Arctic and Alpine Research,* **12**: 403–412.

**Holkenbrink, P.E.** (1978) Manual on characteristics of Landsat computer-compatible tapes produced by the EROS Data Center Digital Image Processing System. U.S. Geological Survey, Washington, D.C.

**Holowaychuck, N., J. Petro, H.R. Finney, R.S. Farnham and P.L. Gersper** (1966) Soils of Ogotoruk Creek Watershed. In *Environment of the Cape Thompson Region, Alaska* (N.J. Wilimovsky and J.N. Wolfe, Ed.). U.S. Atomic Energy Commission, Oak Ridge, Tennessee, pp. 221–273.

**Hopkins, D.M.** (1949) Thaw lakes and thaw sinks in the Imuruk Lake area, Seward Peninsula, Alaska. *Journal of Geology,* **57**: 119-131.

**Hultén, E.** (1968) *Flora of Alaska and Neighboring Territories. A Manual of the Vascular Plants.* Stanford: Stanford University Press.

**Jefferies, R.L.** (1977) The vegetation of salt marshes at some coastal sites in arctic North America. *Journal of Ecology,* **65:** 661–672.

**Joint Federal-State Land Use Planning Commission for Alaska** (1973) Major ecosystems of Alaska. Fold-out map.

**Klinger, L.F., D.A. Walker and P.J. Webber** (1983) The effects of gravel roads on Alaskan Arctic Coastal Plain tundra. In *Permafrost: Fourth International Conference, Proceedings,* 17–22 July 1983, University of Alaska, Fairbanks. Washington, D.C.: National Academy Press, pp. 628–633.

**Komárková, V. and P.J. Webber** (1978) Geobotanical mapping, vegetation disturbance and recovery. In *Tundra Disturbances and Recovery Following the 1949 Exploratory Drilling, Fish Creek, Northern Alaska* (D.E. Lawson, J. Brown, K.R. Everett, A.W. Johnson, V. Komárková, B.M. Murray, D.F. Murray and P.J. Webber, Ed.). USA Cold Regions Research and Engineering Laboratory, CRREL Report 78-28, pp. 41–51.

**Komárková, V. and P.J. Webber** (1980) Two Low Arctic vegetation maps near Atkasook, Alaska. *Arctic and Alpine Research,* **12:** 447–472.

**Koranda, J.J.** (1960) The plant ecology of the Franklin Bluffs area, Alaska. Ph.D. thesis, University of Tennessee.

**Lent, P.C. and A.J. LaPerriere** (1974) Application of ERTS imagery to study of caribou movements and winter habitat. Final report to NASA, Goddard Space Flight Center. Alaska Cooperative Wildlife Research Unit.

**Lyon, J.G. and T.L. George** (1979) Vegetation mapping in the Gates of the Arctic National Park. In *Proceedings of the 45th Annual Meeting of the American Society of Photogrammetry,* 22 March 1979, Washington, D.C., pp. 483–497.

**Mackay, J.R.** (1979) Pingos of the Tuktoyaktuk Peninsula area, Northwest Territories. *Geographie Physique et Quaternaire,* **33:** 3–61.

**Meyers, C.R.** (1981) Provisional checklist of the vascular flora of the Beaufort Lagoon coastal environment, Arctic National Wildlife Refuge. University of Alaska Museum, Fairbanks.

**Morrissey, L.A. and R.A. Ennis** (1981) Vegetation mapping of the National Petroleum Reserve in Alaska using LANDSAT digital data. U.S. Geological Survey, Open-File Report 81-315.

**Murray, B.M. and D.F. Murray** (1978) Checklists of vascular plants, bryophytes, and lichens for the Alaskan U.S. IBP Tundra Biome study areas—Barrow, Prudhoe Bay, Eagle Summit. In *Vegetation and Production Ecology of an Alaskan Arctic Tundra* (L.L. Tieszen, Ed.). New York: Springer-Verlag, pp. 647–677.

**Nodler, F.A. and A.J. Laperrier** (1977) Landsat mapping—North Slope Arctic National Wildlife Refuge. Reprint in U.S. Fish and Wildlife Service files, Fairbanks, Ak.

**Parkinson, R.J.** (1978) Genesis and classification of Arctic Coastal Plain soils, Prudhoe Bay, Alaska. Institute of Polar Studies, Ohio State University, Columbus, Ohio, Report No. 68.

**Polunin, N.** (1959) *Circumpolar Arctic Flora.* Oxford: Clarendon Press.

**Rawlinson, S.E.** (1984) Guidebook to permafrost and related features, Prudhoe Bay, Alaska. Guidebook 5, Fourth International Conference on Permafrost, 18–22 July 1983, Fairbanks, Alaska. Fairbanks: Alaska Division of Geological and Geophysical Surveys.

**Rawlinson, S.E.** (In press) Late Cenozoic geology of the Arctic Coastal Plain between the Colville and Canning rivers. Submitted to the Geological Survey of Canada.

**Rieger, S., D.B. Schoephorster and C.E. Furbush** (1979) Exploratory soil survey of Alaska. U.S. Soil Conservation Service.

**Rubec, C.D.A.** (1983) Applications of remote sensing in ecological land survey in Canada. *Canadian Journal of Remote Sensing,* **9:** 19–30.

**Short, A.D.** (1973) Beach dynamics and nearshore morphology of the Alaska arctic coast. Ph.D. dissertation, Louisiana State University, Baton Rouge, Louisiana.

**Spetzman, L.A.** (1959) Vegetation of the Arctic Slope of Alaska. U.S. Geological Survey, Professional Paper 302-B, pp. 19–58.

**Swain, P.H.** (1972) Pattern recognition—A basis for remote sensing data analysis. Purdue University Laboratory for Applications of Remote Sensing, LARS Information Note 111572. Purdue University, West Lafayette, Indiana.

**Taylor, R.J.** (1981) Shoreline vegetation of the arctic Alaska coast. *Arctic,* **34:** 37–42.

**Tedrow, J.C.F. and J.E. Cantlon** (1958) Concepts of soil formation and classification in arctic regions. *Arctic,* **11:** 166179.

**Tedrow, J.C.F., J.V. Drew, D.E. Hill and L.A. Douglas** (1958) Major genetic soils of the Arctic Slope of Alaska. *Journal of the Soil Science Society of the Philippines,* **9:** 33–45.

**U.S. Fish and Wildlife Service** (1982) Proposed oil and gas exploration within the coastal plain of the Arctic National Wildlife Refuge. Draft Environmental Impact Statement and Draft Regulations. U.S. Department of the Interior.

**Viereck, L.A., C.T. Dyrness and A.R. Batten** (1982) 1982 revision of preliminary classification for vegetation of Alaska. Preliminary draft.

**Wahrhaftig, C.** (1965) Physiographic divisions of Alaska. U.S. Geological Survey, Professional Paper 482.

**Walker, D.A.** (1977) The analysis of the effectiveness of a television scanning densitometer for indicating geobotanical features in an ice-wedge polygon complex at Barrow, Alaska. M.A. thesis, University of Colorado, Boulder, Colorado.

**Walker, D.A.** (1980) Climate. In *Geobotanical Atlas of the Prudhoe Bay Region, Alaska* (D.A. Walker, K.R. Everett, P.J. Webber and J. Brown, Ed.). USA Cold Regions Research and Engineering Laboratory, CRREL Report 80-14, pp. 10–13.

**Walker, D.A.** (1983) A hierarchical tundra vegetation classification especially designed for mapping in northern Alaska. In *Permafrost: Fourth International Conference, Proceedings,* 17-22 July 1983, University of Alaska, Fairbanks. Washington, D.C.: National Academy Press, pp. 1332–1337.

**Walker, D.A.** (1985) The vegetation and environmental gradients of the Prudhoe Bay region, Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 85-14.

**Walker, D.A. and P.J. Webber** (1979) Relationships of soil acidity and air temperature to the wind and vegetation at Prudhoe Bay, Alaska. *Arctic,* **32:** 224–236.

**Walker, D.A., K.R. Everett, P.J. Webber and J. Brown** (1980) Geobotanical atlas of the Prudhoe Bay region, Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 80-14.

**Walker, D.A., S.K. Short, J.T. Andrews and P.J. Webber** (1981) Late Holocene pollen and present-day vegetation, Prudhoe Bay and Atigun River, Alaskan North Slope. *Arctic and Alpine Research,* **13:** 153–172.

**Walker, D.A., K.R. Everett, W. Acevedo, L. Gaydos, J. Brown and P.J. Webber** (1982) Landsat-assisted environmental mapping in the Arctic National Wildlife Refuge, Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 82-27.

**Walker, D.A., K.R. Everett and P.J. Webber** (1983) Geobotany. In *Prudhoe Bay Unit—Eileen West End Environmental Studies Program, Summer 1982* (D.M. Troy, Ed.). Prepared by LGL Alaska Research Associates, Inc., Fairbanks, Alaska, for Sohio Alaska Petroleum Co., Anchorage, Alaska., pp. 2-1 to 2-77.

**Walker, D.A., M.D. Walker, N.D. Lederer and P.J. Webber** (1984) The use of geobotanical maps and automated mapping techniques to study the historical changes in the Prudhoe Bay oil field, Alaska. Final report to U.S. Fish and Wildlife Service, Habitat Resources Section, Anchorage, Alaska.

**Walker, D.A., M.D. Walker, K.R. Everett and P.J. Webber** (1985) Pingos of the Prudhoe Bay region, Alaska. *Arctic and Alpine Research,* **17:** 321–336.

**Webber, P.J.** (1978) Spatial and temporal variation of the vegetation and its productivity, Barrow, Alaska. In *Vegetation and Production Ecology of an Alaskan Arctic Tundra* (L.L. Tieszen, Ed.). New York: Springer-Verlag, pp. 37–112.

**Webber, P.M., V. Komárková, D.A. Walker and E. Werbe** (1978) Vegetation mapping and response to disturbance along the Yukon River–Prudhoe Bay Haul Road. Progress report to USA Cold Regions Research and Engineering Laboratory, Contract Agreement No. DACA 89-77-6-063.

**Wiggins, I.L.** (1951) The distribution of vascular plants on polygonal ground near Point Barrow, Alaska. *Contributions, Dudley Herbarium, Stanford University,* **4:** 41–56.

**Wiggins, I.L. and J.H. Thomas** (1962) A flora of the Alaskan Arctic Slope. Arctic Institute of North America Special Publication No. 4. Toronto: University of Toronto Press.

# APPENDIX A: A HIERARCHICAL TUNDRA VEGETATION CLASSIFICATION ESPECIALLY DESIGNED FOR MAPPING IN NORTHERN ALASKA

This paper originally appeared in *Proceedings of the Fourth International Conference on Permafrost* (July 1983, University of Alaska, Fairbanks. Washington, D.C.: National Academy Press, pp. 1332–1337).

## A HIERARCHICAL TUNDRA VEGETATION CLASSIFICATION ESPECIALLY DESIGNED FOR MAPPING IN NORTHERN ALASKA

Donald A. Walker

Institute of Arctic and Alpine Research
University of Colorado, Boulder, Colorado 80309 USA

This paper presents a tundra vegetation classification scheme that is designed for describing vegetation at four levels: (1) very-small-scale maps, (2) LANDSAT-derived maps, (3) photo-interpreted maps, and (4) plant community descriptions. A system of nomenclature is described that links the four levels.

### INTRODUCTION

Land-use planning in tundra regions utilizes knowledge of vegetation more than any other terrain factor. The vegetation gives insight to a host of environmental variables, many of which are related to permafrost, including soil properties, depth of the active layer, temperature regime and snow regime. There are three primary methods of interpreting vegetation: (1) plant community descriptions at ground level, (2) aerial photographs, and (3) multi-spectral satellite data. Currently there is no classification system that relates the map units from one method to those of the other two. Viereck and Dyrness (1980) developed a hierarchical method of vegetation classification for Alaska, but it is not specifically designed for mapping and is particularly difficult to apply to LANDSAT-dervived classifications. The classification scheme presented here (Table 1) meets three basic criteria:

- At the LANDSAT level, the land cover units are based on those characteristics of the vegetation that can be classified consistently from LANDSAT data.
- At lower levels, the classification system is consistent yet flexible enough to describe the great variety of tundra communities. At the community level, the system is open-ended so that units that do not accurately describe the vegetation of a given area need not be used.
- The lower level units can be grouped within the higher level units with a minimum of overlap so that there is clear compatibility between levels.

The highest classification level, Level A, is very general and useful for very-small-scale vegetation maps of Alaska. Level B consists of LANDSAT-level land cover units that can be interpreted using digital multi-spectral satellite data. Level C consists of vegetation subunits that can be interpreted from aerial photographs if supplemented with adequate ground truth. Level D consists of individual plant communities, determined by ground surveys. The following discussion presents the classification system "from the ground up," starting with level D.

### LEVEL D--PLANT COMMUNITY NAMES AND UNITS FOR VERY-LARGE-SCALE MAPS

Level D units describe specific vegetation classes that correspond approximately to the stand types of Marr (1967) the associations of Daubenmire (1952) or Braun-Blanquet (1932), and the plant community or community type of Whittacker (1967). At this level there are many units and the system is open, such that any newly described vegetation community can be easily added. The nomenclature used for describing vegetation at this level always follows fixed guidelines. The following discussion explains the nomenclature system for plant communities and noncomplex map units and then for complex map units. Complex map units contain two or more distinct vegetation communities, and each community covers at least 30% of the map unit. Level D is appropriate for very-large-scale maps of small areas (e.g. a 1:1,000-scale map of a 5 acre ecology study site).

#### Noncomplex Units

Plant community names have four parts that are always arranged in the following sequence: (1) a site moisture term, (2) the dominant plant taxa, (3) the dominant plant growth forms, and (4) an overall physiognomic descriptor. The site moisture term can be dry, moist, wet or aquatic. These are subjective terms based on the soil moisture at the end of the growing season. The site moisture term is followed by the names of the dominant plant taxa, one or more from each of the representative shrub, herb, and cryptogam layers of the canopy. The number of taxa is kept to the minimum required to adequately distinguish the community from others on the map; the total normally does not exceed six.

The dominant growth forms follow next and can be any of the following: (1) tall shrub (>1.5 m), (2) low shrub (0.2 to 1.5 m), (3) dwarf shrub (<0.2 m), (4) sedge, (5) grass, (6) rush, (7) tussock sedge, (8) forb, (9) moss, (10) crustose lichen, and (11) fruticose lichen. The term graminoid is used when two or more of the dominant

TABLE 1 Hierarchical Classification Scheme for Tundra on the Arctic Coastal Plain and Foothills of Northern Alaska.

| Level A<br>VERY SMALL SCALE UNITS | Level B<br>LANDSAT LAND COVER UNITS (suggested map colors) | Level C<br>PHOTO-INTERPRETED MAP UNITS | Level D<br>TYPICAL PLANT COMMUNITIES |
|---|---|---|---|
| A. Water | I. Water (light blue) | Ia. Water | No vegetation |
| B. Wet Tundra | II. Very Wet Tundra (dark blue) | IIa. Shallow Water (pond margins) | No vegetation |
| | | Noncomplex subunits:<br>IIb. Aquatic Graminoid Tundra | Aquatic Arctophila fulva Grass Tundra<br>Aquatic Carex aquatilis Sedge Tundra |
| | | IIc. Aquatic Forb Tundra | Aquatic Hippuris vulgaris, Caltha palustris, Menyanthes trifoliata Forb Tundra (aquatic tundra, inland areas) |
| | | Common complex subunits:<br>IId. Water/ Tundra Complex: (pond complex) | Typical communities listed under Ia, IIa, IIIa, IIIb, and Va |
| | III. Wet Tundra (dark green) | Noncomplex subunits:<br>IIIa. Wet Sedge Tundra | Wet Carex aquatilis, Scorpidium scorpioides Sedge Tundra (wettest facies of wet alkaline tundra)<br>Wet Carex chordorrhiza, Eriophorum scheuchzeri, Potentilla palustris Sedge Tundra (wet acidic tundra - inland areas)<br>Wet Carex aquatilis, Eriophorum angustifolium, Pedicularis sudetica ssp. albolabiata, Drepanocladus brevifolius Sedge Tundra (wet alkaline tundra)<br>Wet Eriophorum angustifolium, Dupontia fisheri, Campylium stellatum Graminoid Tundra (wet acidic tundra, coastal areas) |
| | | IIIb. Wet Graminoid Tundra (wet saline Tundra) | Wet Carex subspathacea, Puccinellina phryganodes, Stellaria humifusa, Cochlearia officinalis Sedge Tundra |
| | | Common Complex Subunits:<br>IIIc. Wet Sedge Tundra/ Water Complex (pond complex) | Typical communities listed under Ia, IIa and IIIa |
| | | IIId. Wet Sedge/ Moist Sedge, Dwarf Shrub Tundra Complex (wet patterned-ground complex) | Typical communities listed under IIIa and Va |
| C. Moist Tundra | IV. Moist/ Wet Tundra Complex (light green) | Common Complex Subunits:<br>IVa. Moist Sedge, Dwarf Shrub/ Wet Graminoid Tundra Complex (moist patterned-ground complex) | Typical communities listed under Va and IIIa |
| | V. Moist or Dry Tundra (tan) | Noncomplex Subunits:<br>Va. Moist Sedge, Dwarf Shrub Tundra | Moist Carex bigelowii, Eriophorum angustifolium ssp. triste, Dryas integrifolia, Salix reticulata, Tomenthypnum nitens, Thamnolia subuliformis Sedge, Dwarf Shrub Tundra (moist alkaline tundra)<br>Moist Luzula arctica, Poa arctica, Saxifraga cernua, Salix planifolia ssp. pulchra, Dicranum elongatum, Ochrolechia frigida Graminoid, Dwarf Shrub, Crustose Lichen Tundra (moist coastal acidic tundra)<br>Moist Carex aquatilis, Eriophorum angustifolium ssp. triste, Salix planifolia ssp. pulchra, Campylium stellatum Sedge, Dwarf Shrub Tundra (moist acidic tundra, wetter facies)<br>Moist Carex bigelowii, Dryas integrifolia, Lupinus arcticus, Salix lanata ssp. richardsonii, Arctagrostis latifolia, Equistetum arvense, Tomenthypnum nitens, Sedge, Dwarf shrub, Forb Tundra (moist non-tussock alkaline tundra) |
| | | Vb. Moist Tussock Sedge, Dwarf Shrub Tundra | Moist Eriophorum vaginatum, Dryas integrifolia, Salix reticulata, S. arctica, Tomenthypnum nitens, Thamnolia subuliformis, Tussock Sedge, Dwarf Shrub Tundra (alkaline tussock tundra)<br>Moist Eriophorum vaginatum, Dryas integrifolium, Salix planifolia ssp. pulchra, Salix reticulata, Hylocomium splendens, Ptilidium ciliare, Cetraria cucullata Tussock Sedge, Dwarf Shrub Tundra (neutral to slightly acidic tussock tundra) |
| | | Vc. Dry Dwarf Shrub, Crustose Lichen Tundra (Dryas tundra) | Dry Dryas integrifolia, Carex rupestris, Oxytropis nigrescens, Salix reticulata, Ditrichum flexicaule, Lecanora epibryon Dwarf Shrub, Forb, Crustose Lichen Tundra (Dryas river terraces)<br>Dry Dryas integrifolia, Astragalus alpinus, Oxytropis borealis, Salix reticulata, Distichium capillaceum, Lecanora epibryon Dwarf Shrub, Forb, Crustose Lichen Tundra (Dryas river terraces) |
| | | Vd. Dry Dwarf Shrub, Fruticose Lichen Tundra (Dry acidic tundra) | Dry Dryas octopetala, Arctostaphylos alpina, Empetrum nigrum Salix phlebophylla, Rhytidium rugosum, Alectoria nigricans Dwarf Shrub, Fruticose Lichen Tundra (dry acidic tundra on kames and moraines in foothills)<br>Dry Salix rotundifolia, Pedicularis kanei, Luzula arctica, Polytrichum sp. Alectoria nigricans, Cetraria islandica Dwarf Shrub, Fruticose Lichen Tundra (dry acidic tundra near coast) |

TABLE 1 (Continued)

| Level A<br>VERY SMALL SCALE UNITS | Level B<br>LANDSAT LAND COVER UNITS (suggested map colors) | Level C<br>PHOTO-INTERPRETED MAP UNITS | Level D<br>TYPICAL PLANT COMMUNITIES |
|---|---|---|---|
| | | Common Complex Subunit:<br>Ve. Moist Graminoid, Dwarf Shrub Tundra/ Barren Complex (frost-scar complex) | Typical communities listed under Va and Vb plus either completely barren, frost-scars or communities such as: Dry Saxifraga oppositifolia, Dryas integrifolia, Chrysanthemum integrifolium, Juncus biglumis, Arctagrostis latifolia, Ochrolechia frigida Barren (alkaline frost scars) |
| | VI. Moist Tussock Sedge, Low Shrub Tundra (brown) | Noncomplex Subunit:<br>VIa. Moist Tussock Sedge, Low Shrub Tundra (acidic tussock tundra) | Moist Eriophorum vaginatum, Salix planifolia ssp. pulchra, Betula nana ssp. exilis, Ledum palustre ssp. decumbens, Vaccinium spp., Sphagnum spp., Cladonia spp. Tussock Sedge, Low Shrub Tundra |
| | | Complex Subunits:<br>VIb. Moist Tussock Sedge, Low Shrub Tundra/ Tall Shrub Complex (alder tundra savanna) | Typical communities listed under Vb and VIa plus widely spaced Alnus crispa |
| | | VIc. Moist Tussock Sedge, Low Shrub/ Wet Low Shrub Tundra Complex (water track complex) Note: This complex may appear as sub-unit of VI or VII depending on the density of water tracks. | Typical communities listed under VIa and VIIIa |
| | VII. Moist Shrub-rich Tundra (dark brown) | Noncomlex Subunits:<br>VIIa. Moist Low Shrub, Tussock Sedge Tundra (shrubby tussock tundra) | Moist Salix planifolia ssp. pulchra, Betula nana ssp. exilis, Eriophorum vaginatum, Ledum palustre ssp. decumbens, Vaccinium spp., Sphagnum spp. Low Shrub, Tussock Sedge Tundra |
| | | VIIb. Moist Dwarf Shrub, Moss Tundra (Sphagnum-rich dwarf shrub tundra) | Moist Rubus chamaemorus, Ledum palustre spp. decumbens, Betula nana, spp. exilis, Vaccinium spp., Sphagnum spp., Cladonia spp. Dwarf Shrub, Moss Tundra |
| | | Complex Subunit:<br>VIIc. Moist Tussock Sedge, Low Shrub/ Wet Low Shrub Tundra Complex (water track complex -- see note under VIc.) | Typical communities listed under VIa and VIIa |
| D. Shrubland | VIII. Shrubland or Shrub Tundra (red) | VIIIa. Wet Low Shrub Tundra | Wet Salix planifolia pulchra, Betula nana ssp. exilis, Sphagnum spp. Low Shrub Tundra (wet willow tundra)<br>Wet Betula nana ssp. exilis, Sphagnum spp. Low Shrub Tundra (wet birch tundra) |
| | | VIIIb. Moist Low Shrub Tundra | Moist Betula nana spp. exilis, Ledum palustre ssp. decumbens, Salix planifolia ssp. pulchra, Vaccinium spp., Cladonia spp. Low Shrub Tundra (moist birch tundra)<br>Moist Betula nana ssp. exilis, Vaccinium uliginosum, Potentilla fruticosa, Shepherdia canadensis, Salix spp., Festuca altaica Low Shrub Tundra (south facing shrub tundra in foothills)<br>Moist Alnus crispa, Betula nana ssp. exilis, Salix spp. Low Shrub Tundra (alder shrub tundra) |
| | | VIIIc. Moist Shrubland (closed riparian shrubland) | Moist Salix alaxensis, Salix spp. Tall Shrubland (willow riparian shrubland)<br>Moist Betula nana ssp. exilis, Betula glandulosa Low Shrubland (birch riparian shrubland) |
| E. Partially Vegetated and Barren | IX. Partially Vegetated (violet) | Riparian areas:<br>IXa. Dry, Barren/ Low Shrub Complex (open riparian shrubland) | Typical communities and ground cover listed under VIIIc and Xa. |
| | | IXb. Dry Barren/ Dwarf Shrub, Forb Grass Complex (forb-rich river bars) | Typical communities listed under Vc, Xa, also mixed forb grass and dwarf shrub communities such as:<br>Dry Bromus pumpellianus, Festuca rubra, Astragalus alpinus, Androsace chamaejasme, Salix ovalifolia Grass, Forb, Dwarf Shrub Tundra (forb-rich river bars)<br>Dry Dryas integrifolia, Artemisia borealis, A. glomerata, Salix ovalifolia, Androsace chamaejasme Dwarf Shrub, Forb Tundra (Dryas river bars near arctic coast) |
| | | IXc. Dry Barren/ Forb Complex | Dry Epilobium latifolium, Artemisia arctica, Wilhelmsia physodes Forb Barren (active river channels) |
| | | IXd. Dry Barren/ Low Shrub Forb Complex (open riparian shrubland) | Dry Salix alaxensis, Salix spp. Hedysarum spp. Astragalus alpinus, Equisetum arvense, Oxytropis campestris, O. borealis, Anemone parviflora Low Shrub, Forb Tundra (river bars inland) |
| | | Sand Dunes:<br>IXe. Dry Barren/ Grass Complex (sand dune grassland) | Dry Elymus arenarius Grass Tundra (sand dune grassland) |
| | | IXf. Dry Barren/ Dwarf Shrub, Grass Complex (sand dune steppe) | Dry Artemesia borealis, A. glomerata, Deschampsia caespitosa Trisetum spicatum Dwarf Shrub, Grass Tundra (sand dune steppe) |
| | | IXg. Dry Barren/ Low Shrub Complex (sand dune scrub) | Dry Salix alaxensis, S. glauca, Elymus arenarius, Carex obtusata, Dryas integrifolia Low Shrub, Tundra (sand dune scrub) |

TABLE 1 (Continued)

| Level A<br>VERY SMALL SCALE UNITS | Level B<br>LANDSAT LAND COVER UNITS (suggested map colors) | Level C<br>PHOTO-INTERPRETED MAP UNITS | Level D<br>TYPICAL PLANT COMMUNITIES |
|---|---|---|---|
| | | Beaches, river deltas, and estuaries:<br>IXh. Wet Barren/ Wet Sedge Tundra Complex (barren/ saline tundra complex) | Typical ground cover listed under IIIb |
| | | IXi. Dry Barren/ Forb, Graminoid Complex (coastal barrens) | Dry Cochlearia officinalis, Stellaria humifusa, Puccinellia phryganodes, P. andersonii, Salix ovalifolia, Potentilla pulchella Forb, Graminoid Tundra (coastal saline barrens) |
| | | Mountainous areas:<br>IXj. Dry Barren/ Dwarf Shrub, Graminoid Tundra Complex (dry alpine tundra) | Typical ground cover listed under Xd, Vc, or the following, among many others:<br>Dry Dryas octopetala, Salix phlebophylla, Carex microchaeta, Kobresia myosuroides, Saxifraga bronchialis, Hierochloe alpina, Potentilla hyparctica, Minuartia arctica Dwarf Shrub, Graminoid Tundra (dry alpine tundra) |
| | | IXk. Moist Barren/ Moss, Forb, Dwarf Shrub Tundra (moist alpine tundra) | Moist Hylocomium splendens, Saxifraga bronchialis, Saxifraga tricuspidata, Salix phlebophylla, S. chamissonis, Cladonia spp., Moss, Forb, Dwarf Shrub Tundra |
| | X. Light-colored Barrens (Note: Most areas classed as barrens are likely to have some vegetation but ground cover is less than 30% (black) | Xa. River gravels | Completely barren or with typical communities listed under IXb, IXc, IXd |
| | | Xb. Sand dunes | Typical communities listed under IXe, IXf, IXg |
| | | Xc. Barren gravel outcrops | Typical communities listed under Vd or the following, among many others:<br>Dry Dryas octopetala, Lupinus arcticus, Potentilla biflora, Smelowski calycina, Saxifraga tricuspidata, Salix phlebophylla, Silene acaulis Dwarf Shrub, Forb Barren (gravel outcrops) |
| | | Xd. Talus slopes and blockfields | Dry Rhizocarpon spp., Lecidea spp., Umbilicaria spp., Cetraria spp. Crustose Lichen Barren (blockfields and talus) |
| | | Xe. Gravel roads and pads | Completely barren |
| | XI. Dark Colored Barrens (gray) | XIa. Wet mud | Completely barren or with communities listed under IIIb |
| | | XIb. Wet or dark-colored gravels | Completely barren |
| | | XIc. Bare peat | Mostly barren areas along the coast caused by storm surges or man-made disturbances, communities listed under IIIb |
| | | XId. Talus slopes and block fields | Same as Xd |
| F. Ice | XII. Ice (white) | XII. Ice | Completely barren |

grass-like plants are in different families. Only the growth forms contributing at least 30% of the readily visible ground cover are included in the community name.

The last portion of the community name is the physiognomic descriptor, which is a term that applies to the appearance of the general vegetation landscape. The term tundra is used for most arctic and alpine nonforested areas with generally continuous ground cover. The term barren is used in areas where there is less than 30% ground cover. The term shrubland applies only to shrub-covered areas that are traditionally not considered tundra, such as dense riparian shrubs along large rivers. Shrub dominated vegetation in water tracks that are common in the foothills are generally considered shrub tundra, as are shrub-dominated units on mountain slopes and on open flat terrain. Examples of community names can be found in the right hand column of Table 1.

## Complex Units

Complexes of vegetation are particularly common in the Arctic, where patterned ground is prevalent. Areas where complexes are mapped include ice-wedge polygons, sorted block fields, strangmoor, water tracks, frost-scar areas, and solifluction stripes and lobes. Often one community is consistently associated with a particular element of the surface form, such as polygon rims, while another community is consistently found on another element, such as the polygon basins and troughs. A consistent method of describing complexes utilizes the basic community nomenclature described above. For example, the following description is for a map unit in a foothill area with water tracks.

Water-track complex:

a) Interfluves and upland areas: Moist Eriphorum vaginatum, Salix planifolia ssp. pulchra, Ledum palustre ssp. decumbens, Sphagnum sp., Cladina arbuscula Tussock Sedge, Low Shrub Tundra.

b) Water tracks: Wet Salix planifolia ssp. pulchra, Betula nana ssp. exilis, Carex aquatilis, Sphagnum sp. Low Shrub Tundra.

Note that the community names follow descriptions of the microsites on which they occur, and the complex is named according to the dominant patterned-ground feature or landform. The unit description includes only those plant communities that are associated with distinctive patterned-ground elements (e.g. polygon rims, water tracks, polygon troughs etc.) and that cover more than 30% of a map unit.

## LEVEL C--PHOTO-INTERPRETED MAP UNITS

Level C can be used for photo-interpreted maps at scales from 1:6,000 to 1:63,360. On aerial photographs there are two main characters that are useful for identifying tundra vegetation. The first is color or a gray tone. The darkness of tone is often indicative of the moisture status of the site. Darker areas are normally wet, and lighter areas tend to be moist or dry due to an abundance of erect dead graminoid vegetation and/or crustose lichens. There are, of course, exceptions to this. Sometimes dry areas will also be dark due to barren peat or an abundance of dark-colored fruticose lichens, such as Alectoria nigricans and Cornicularia divergens, or wet areas may be light-toned due to marl on pond bottoms. On color-infrared photographs, color is important. For example, red tones are indicative of deciduous shrubs and are important in interpreting categories of tussock tundra vegetation with varying amounts of shrub cover.

The second useful character is texture. Many textures are indicative of surface forms and thus are useful for recognizing vegetation complexes. The presence of ice-wedge polygons, frost boils, solifluction lobes, strangmoor, blockfields, talus, and rugged rocky terrain can be recognized on the basis of texture. On very-large-scale photographs, texture can also be helpful in identifying shrub vegetation and cottongrass tussocks.

Photo interpretation of tundra vegetation is difficult because nearly all the communities are low growing and the clues for distinguishing units are frequently quite subtle. It should be stressed that the critical element for accurate vegetation maps is extensive ground reference data. With adequate ground experience, site moisture regime and dominant plant growth forms can normally be interpreted.

### Noncomplex Units

The species composition of tundra vegetation can very rarely be reliably interpreted from aerial photographs. Thus at Level C, the nomenclature drops the plant taxa names and consistently uses the remaining parts of the nomenclature outlined for Level D, i.e., the site moisture term, the dominant plant growth forms, and the physiognomic descriptor. An example of a Level C unit is Moist Tussock Sedge, Low Shrub Tundra. Other examples may be found in Table 1.

### Complex Units

Complex units are treated in a similar fashion with the term complex attached to the end of the unit name and the components of the complex separated by a slash (/). An example for a low-centered ice-wedge polygon complex is Wet Sedge/Moist Sedge, Dwarf Shrub Tundra Complex. The physiognomic term tundra is included only for the last portion of the complex. The physiognomic term for the first portion of the complex is included only if it is different from the last. The first part of the complex name is the dominant portion. The Level C equivalent of the water track complex mentioned in the previous section is Moist Tussock Sedge, Low Shrub/Wet Low Shrub Tundra Complex. The term water track complex could be used as a shorter synonym in general discussion. For the formal map unit titles, however, every attempt should be made to use the complete names since this increases the amount of information available on the map and makes all the units comparable.

## LEVEL B--LANDSAT-INTERPRETED MAP UNITS

LANDSAT methods have certain advantages over photo interpretation. These include the digital format of the data, and the speed with which maps of large areas can be made. The minimum LANDSAT mapping area is one pixel or picture element that corresponds to a ground area of 0.44 ha (1.1 acre). This is considerably smaller than minimum map unit size at all but the very largest photo-interpreted map scales.

The big disadvantage of LANDSAT methods is that the final map units are based solely on surface reflectance. Promising methods that may aid in interpretation of tundra vegetation from LANDSAT data include: 1) using multiple LANDSAT scenes from several seasons, and 2) use of digitized landform and terrain data from geographic information systems. The combination of spectral reflectance and terrain information can be used to produce computer models that are capable of interpreting more vegetation units than can be mapped with spectral data alone. There have been some attempts to use digital elevation data from topographic maps to help model problem categories on the basis of slope aspect and elevation (for example, Justice et al. 1981). These methods have not, however, been used extensively on the Arctic Slope due largely to the very flat landscape where interpolation of elevation values from widely spaced topographic contours can produce inaccurate interpretations.

A classification for LANDSAT-derived maps should recognize the limitations of the data. There are two primary characters of the northern Alaskan vegetation that affect its spectral reflectance and are most important with regards to LANDSAT-derived vegetation classifications. These are the amount of water on the surface and the percentage of deciduous shrubs in the vegetation canopy. Numerous other factors, such as the total percentage of plant cover, the amount of erect dead graminoid vegetation, the color of the substrate, the amount of lichen cover, and the nutrient status of the site, also affect the reflectance. Figure 1 is a cluster diagram for a typical LANDSAT scene from northern Alaska illustrating the spectral signatures in two bands for the major Level B classes. The 12 Level B units are based primarily on moisture status, the amount of shrubs in the canopy, and, in the case of the partially vegetated and barren units, the total percentage of plant cover. A full discussion of the units can be found in Walker et al. (in press).

## LEVEL A--VERY-SMALL-SCALE MAP UNITS

Level A consists of only six units that are useful for very general vegetation maps of Alaska. The units are Water, Wet Tundra, Moist Tundra, Shrubland, Partially Vegetated and Barren, and Ice. These units are comparable to the classes used for the major ecosystem map of Alaska (Joint Federal-State Land Use Planning Commission 1973) and the USGS land cover classification

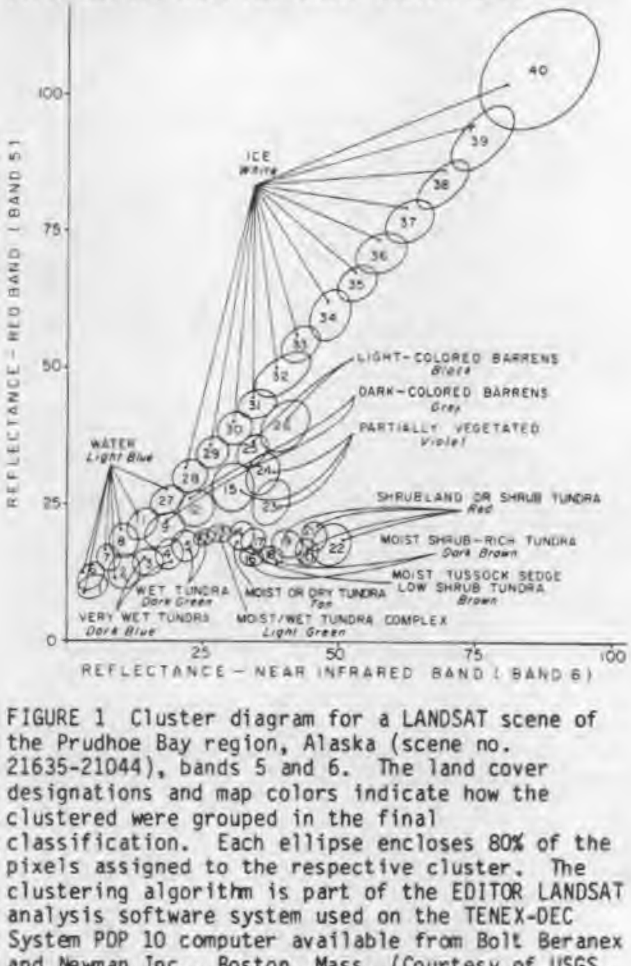



FIGURE 1 Cluster diagram for a LANDSAT scene of the Prudhoe Bay region, Alaska (scene no. 21635-21044), bands 5 and 6. The land cover designations and map colors indicate how the clustered were grouped in the final classification. Each ellipse encloses 80% of the pixels assigned to the respective cluster. The clustering algorithm is part of the EDITOR LANDSAT analysis software system used on the TENEX-DEC System PDP 10 computer available from Bolt Beranex and Newman Inc., Boston, Mass. (Courtesy of USGS Geography Branch, Moffet Field, California.)

system for remote sensor data (Anderson et al. 1976).

## CONCLUSION

The hierarchical classification scheme presented here offers a first approximation at a link between two methods of vegetation mapping that are being widely used in northern Alaska--one based on LANDSAT technology and the other based on photo interpretation. It ties both of these methods to a comprehensive means of describing tundra vegetation on the ground. It is presently a flexible system that will undoubtedly continue to evolve as more experience is gained in mapping tundra vegetation.


## ACKNOWLEDGMENTS

This work was sponsored by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). The classification system was developed during contracts with CRREL, the Sohio Alaska Petroleum Co., and ARCO Alaska, Inc. The U.S. Fish and Wildlife Service (USFWS), the U.S. Geological Survey (USGS), and the North Slope Borough have provided extensive logistical support and funds. The USGS Geography Branch at Moffet Field, Calif., and Reston, Va., was responsible for the technical expertise required for the LANDSAT classifications. Patrick J. Webber, Director of INSTAAR and others too numerous to mention here have helped me in developing this classification.


## REFERENCES


Anderson, J. R., Hardy, E. E., Roach, R. E. and Witmer, R. E., 1976, A land cover classification system for use with remote sensor data: USGS Professional Paper 969, 28 pp.

Braun-Blanquet, J., 1932, Plant Sociology: the study of plant communities (English translation): McGraw-Hill, New York, 439 p.

Daubenmire, R., 1951, Forest vegetation of northern Idaho and adjacent Washington and its bearing on concepts of vegetation classification: Ecological Monographs vol. 22, p. 301-330.

Joint Federal-State Land Use Commission for Alaska, 1973, Major ecosystems of Alaska. Fold-out map. (Scale 1:2,500,000).

Justice, C. O., Wharton, S. W., and Holdben, B. N., 1981, Application of digital terrain data to quantify and reduce the topographic effect of Landsat data: International Journal of Remote Sensing, vol. 2, p. 213-230.

Marr, J. W., 1967, Ecosystems of the east slope of the Front Range in Colorado: University of Colorado Studies, Series in Biology, No. 8, 134 p.

Viereck, L. A. and Dyrness, C. T., 1980, A preliminary classification system for vegetation of Alaska. U.S. Department of Agriculture, Forest Service, Pacific Northwest Range and Experimental Station, General Technical Report PNW 206. 38 p.

Walker, D. A., Acevedo, W., Everett, K. R., Gaydos, L., Brown, J. and Webber, P. J., 1982, Landsat-assisted environmental mapping in the Arctic National Wildlife Refuge, Alaska: U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H. 03755, CRREL Report 82-37, 59 p.

Walker, D. A., Acevedo, W., Everett, K. R., Gaydos, L., and Webber, P. J., (in prep.), Landsat-derived vegetation map of the Beechey Point Quadrangle, Arctic Coastal Plain, Alaska.

Whittacker, R. H., 1967, Gradient analysis of vegetation: Biological review, vol. 42, p. 207-264.

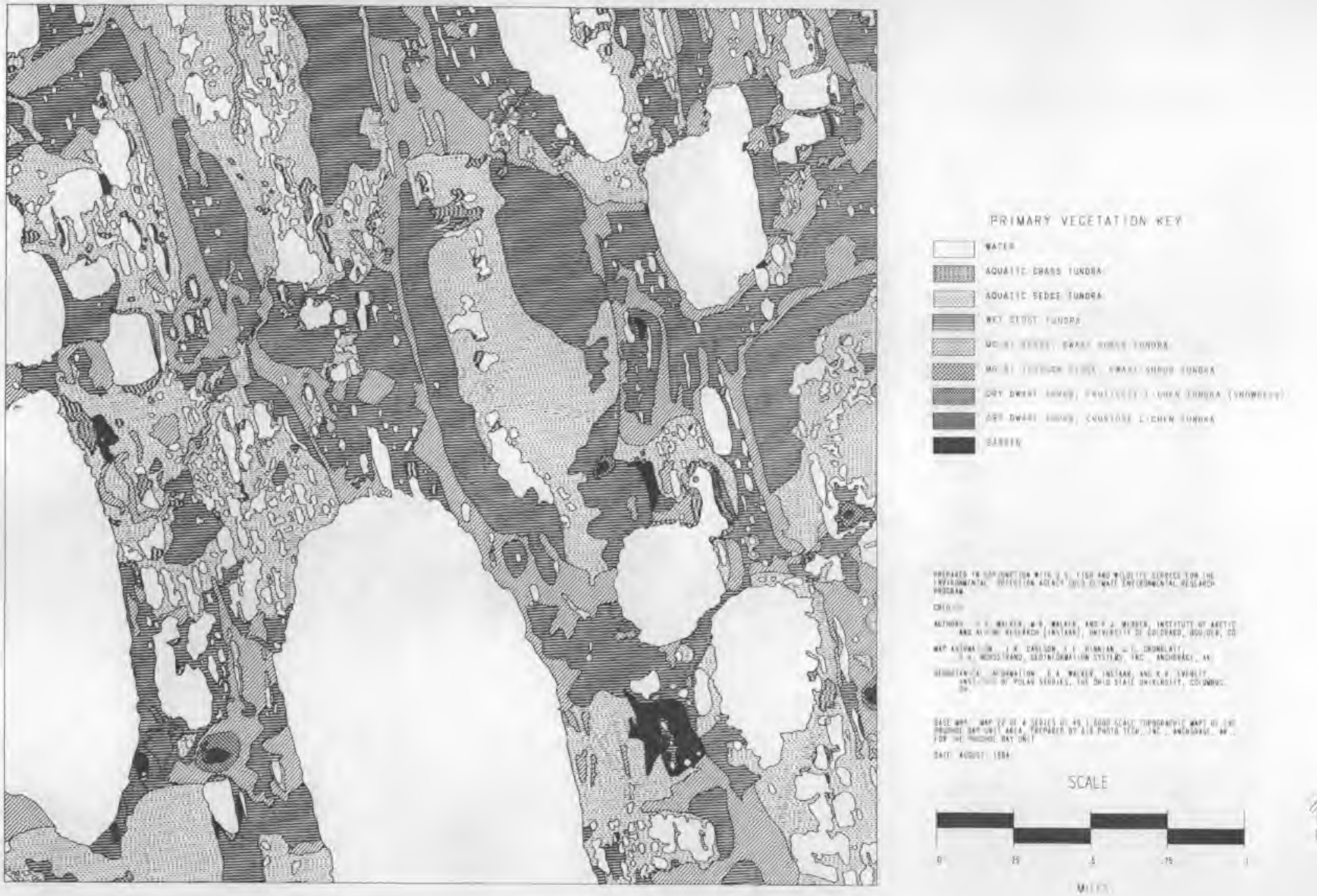



*Figure B1. Vegetation map of Area 9.*

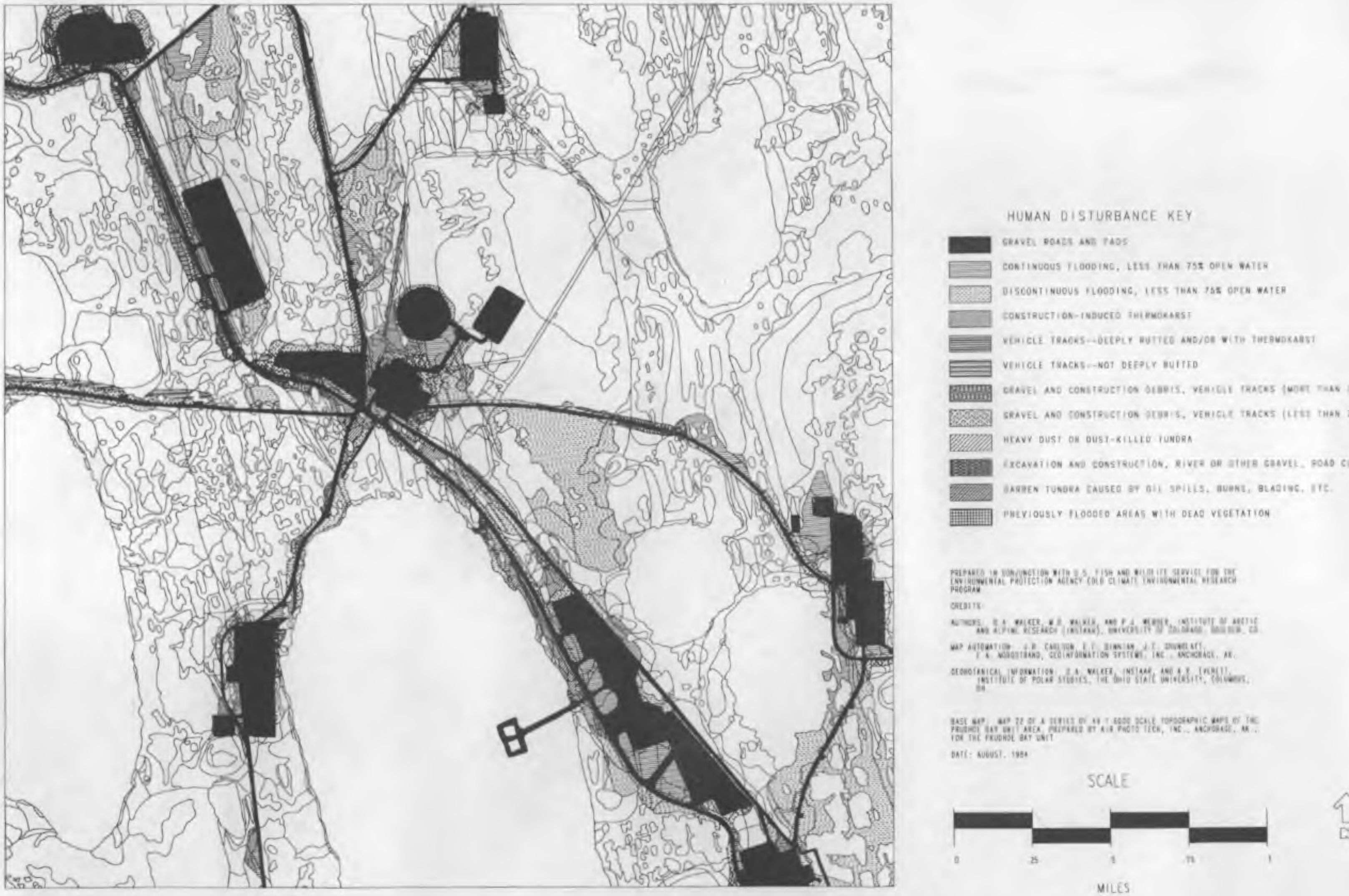



*Figure B2. Anthropogenic disturbance map of Area 9 in 1979.*

| Site | Vegetation units: Water | | Wet herbaceous tundra | | Moist or dry herbaceous tundra | | Moist herbaceous mixed-shrub tundra | | Shrubland | | Sparse vegetation | | Barren | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area (ha) | % of site | Area (ha) | % of site | Area (ha) | % of site | Area (ha) | % of site | Area (ha) | % of site | Area (ha) | % of site | Area (ha) | % of site | Area (ha) | % of site |
| Flat thaw-lake plains | 37,613 | 33.70 | 54,198 | 48.55 | 13,956 | 12.50 | 23 | 0.02 | 6 | 0.01 | 813 | 0.73 | 5,013 | 4.49 | 111,622 | 100.00 |
| Gently rolling thaw-lake plains | 45,777 | 20.54 | 83,765 | 37.58 | 89,231 | 40.04 | 1,766 | 0.79 | 240 | 0.11 | 490 | 0.22 | 1,603 | 0.72 | 222,872 | 100.00 |
| Hills | 915 | 2.07 | 5,663 | 12.81 | 37,180 | 84.11 | 327 | 0.74 | 24 | 0.05 | 64 | 0.14 | 32 | 0.07 | 44,205 | 99.99 |
| Flood plains and terraces | 10,835 | 12.06 | 20,197 | 22.49 | 29,252 | 32.57 | 752 | 0.84 | 647 | 0.72 | 3,950 | 4.40 | 24,176 | 26.92 | 89,809 | 100.00 |
| Islands | 0 | 0.00 | 235 | 31.24 | 78 | 10.32 | 0 | 0.05 | 0 | 0.00 | 5 | 0.65 | 435 | 57.74 | 748 | 100.00 |
| Entire map | 877,622 | 70.18 | 163,622 | 13.08 | 169,209 | 13.53 | 2,849 | 0.23 | 896 | 0.07 | 6,337 | 0.51 | 30,047 | 2.40 | 1,250,582 | 100.00 |
| Area 1 | 1,045 | 29.61 | 1,617 | 45.85 | 226 | 6.41 | 0 | 0.00 | 0 | 0.00 | 69 | 1.96 | 570 | 16.17 | 3,527 | 100.00 |
| Area 2 | 1,212 | 34.26 | 1,582 | 44.70 | 100 | 2.81 | 0 | 0.00 | 0 | 0.00 | 62 | 1.76 | 582 | 16.46 | 3,538 | 100.00 |
| Area 3 | 1,139 | 32.60 | 1,416 | 40.55 | 324 | 9.27 | 0 | 0.00 | 1 | 0.03 | 80 | 2.28 | 533 | 15.27 | 3,493 | 100.00 |
| Area 4 | 1,384 | 40.00 | 1,214 | 35.10 | 415 | 12.04 | 2 | 0.07 | 0 | 0.00 | 62 | 1.79 | 381 | 11.01 | 3,459 | 100.01 |
| Area 5 | 1,565 | 21.74 | 3,333 | 46.30 | 1,962 | 27.25 | 13 | 0.17 | 6 | 0.08 | 74 | 1.03 | 247 | 3.42 | 7,200 | 100.00 |
| Area 6 | 692 | 22.28 | 1,042 | 33.52 | 1,327 | 42.71 | 7 | 0.23 | 1 | 0.03 | 23 | 0.74 | 15 | 0.48 | 3,107 | 99.99 |
| Area 7 | 989 | 25.49 | 1,651 | 42.54 | 1,210 | 31.19 | 0 | 0.01 | 0 | 0.00 | 7 | 0.18 | 23 | 0.59 | 3,880 | 100.00 |
| Area 8 | 1,584 | 41.55 | 1,544 | 40.50 | 586 | 15.38 | 0 | 0.00 | 0 | 0.00 | 8 | 0.21 | 90 | 2.35 | 3,812 | 100.00 |
| Area 9 | 1,004 | 46.37 | 748 | 34.55 | 114 | 5.25 | 2 | 0.07 | 0 | 0.00 | 19 | 0.86 | 279 | 12.88 | 2,166 | 99.98 |

CRREL Report 87-5—USGS Map L-0211

ERRATA

| | |
|---|---|
| Map legend, line 8 | "moist herbaceous tundra" should read "moist herbaceous, dwarf-shrub tundra" |
| Map legend, line 12 | Same change |
| Map legend, line 13 | "*Eriphorum*" should read "*Eriophorum*" |
| Map legend, line 22 | Same change |
| Map legend, line 24 | "*Vaccanium*" should read "*Vaccinium*" |